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Restorative Potential and Working Memory Capacity of Exposure to Vegetation in Indoor Built Environments

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RESTORATIVE POTENTIAL AND

WORKING MEMORY CAPACITY OF EXPOSURE TO

VEGETATION IN INDOOR BUILT ENVIRONMENTS

by

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ABSTRACT

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by

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This research seeks to understand how natural elements – specifically, vegetation in the indoor environment - influence people's ability to restore attention and working memory capacity. Previous research demonstrates the benefits of nature on human beings in various ways. For instance, numerous studies show the positive effects of nature on stress reduction (Hartig, Mang, & Evans, 1991; Ulrich et al., 1991) and attention restoration (Staats, Kieviet, & Hartig, 2003). However, most of these studies focus on the effect of nature in outdoor settings. Relatively few studies focus on the presence of natural elements indoors. This is an important gap in the literature because people spend most of their time indoors. A few studies on indoor environments have focused on the benefits of vegetation (Kiyota, 2009; Raanaas, Patil, & Hartig, 2010; Shibata & Suzuki, 2001, 2002, 2004); however, they emphasized the effects of the vegetation and did not delve into the impact of the amount of vegetation on these effects.

In response, this research explores how people perceive and are influenced by vegetation, the built environment, and vegetation within the built environment. To this end it employs surveys, tasks, and electroencephalography (EEG). EEG has been widely used to investigate people's attention and restoration. The increased and extreme changes of alpha and theta activity measured by EEG (Aftanas & Golocheikine, 2001; Basar et al., 2001; Chen et al., 2020; Grassini et al., 2019;

Jacobs & Friedman, 2004) are widely accepted as a neurophysiological indicator of attention and restoration. During the experiments in this study, participants were seated in designated spaces for EEG recordings, and then presented with a series of photos of various built environments with nature elements. After each EEG recording, they were asked to answer a survey (PRS-11; Pasini et al, 2014) about the spaces and images that they observed, and then perform a cognitive task (the backward digit span task).

The results revealed that indirect and symbolic visual contact with vegetation had a significant association with restorative potential and working memory capacity. Furthermore, varied levels of exposure to vegetation showed significant quantitative impact on peoples' restoration and attention. Qualitative findings from perceived restorativeness scores (PRS-11), backward digit span task scores, and EEG alpha and theta relative power spectrum density (PSD) suggest that indoor vegetation can benefit peoples' well-being and productivity, by increasing restoration and working memory capacity. We discovered that when there is 12% or more vegetation in an indoor space, the restorative potential was closely equivalent to full nature. Also, we found that working memory capacity is most effective in the range of 24 - 36% vegetation in indoor built environment settings. Lastly, in situ environment (indirect visual contact with vegetation) showed stronger beta relative PSD compared to image viewing (symbolic visual contact with vegetation).

This dissertation seeks to establish guidelines for reference by the designers and decision-makers of urban built environments to achieve the maximum positive benefits of biophilic design, and more specifically, to promote the physical and mental health benefits of vegetation for dwellers.

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1. Introduction

1.1. Problem Statement

Biophilia is the passionate love of life and of all that is alive; it is the wish to further growth, whether in a person, a plant, an idea or a social group (Fromm, 1973, p.366).

Since 2007, a majority of the world's population has lived in the mega-polis and its metropolitan vicinities. As of 2017, the number stands at 4.1 billion people living in urban areas (United Nations Department of Economic and Social Affairs, 2019).[1] And yet, 'everyday city life' describes only a small portion of our 300,000 to 450,000-year history. The first permanent human settlements, after all, were established by the Sumerian city of Uruks sometime between 4,000 and 3,000 B.C, and large-scale urbanization driven by modern economic development has only occurred in the last two hundred years. For the majority of human existence, the environments we inhabited were dominated by the nature. Our primitive ancestors needed to successfully negotiate and biologically adapt to the natural elements. While city living has increased dramatically in

[1] Throughout this dissertation, the term "urban" environment is used as an antipode term to "rural" environment. It does not specify large geographical settings as opposed to architectural or indoor settings.

recent centuries, this legacy of negotiation and adaptation has by no means gone away, and in fact, it can provide crucial insights for architectural studies.

This is due to the fact that our overall health still depends on contact with natural elements. The interconnectedness between people and nature is an indispensable constituent in fostering human health and well-being (Kellert, 2008; Wilson, 1984). For example, we can turn to a famous study comparing two architecturally similar housing complexes, one with a green courtyard, and the other with grey pavement. This study demonstrated that the life of the two sets of residents, especially the children, differed significantly based on their proximity to natural elements. The residents of the green courtyard housing complex were physically and psychologically healthier, and maintained more supportive social interactions, than those in the grey pavement housing complex (Coley, Kuo, and Sullivan, 1997). Other studies have shown that the children in the green courtyard housing complex spent more time in spaces with trees and grass and played more creatively (Taylor, Wiley, Kuo, & Sullivan, 1998), and also that increases in vegetation[2] in public spaces can significantly reduce neighborhood crime (Kondo, Hohl, Han, &Branas, 2016). In general, across such studies, residents who have access to vegetation typically sustain stronger

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[2] Vegetation means "Plants considered collectively, especially those found in a particular area or habitat" (Oxford, 2020b). Broadly, vegetation includes areas such as forests, grass lands, and etc. However, in this dissertation, vegetation refers to living plants and trees, including trees, bushes, shrubs, plants, flowers, grass, and etc.

social ties with their neighbors and experience more of a sense of community than residents with less access to vegetation.

Today, most of the global population dwells in urban areas, while rural areas continue to decline (Farmer et al., 2006). This trend will only increase with ongoing urbanization, as innovative construction materials and technologies have allowed this new and growing urban population to more completely segregate from nature by modifying environmental qualities like air temperatures, humidity levels, light levels, and etc. In fact, North Americans spend more than 90% of their time indoors throughout the year and up to 98% of their time indoors during the winter season (Leech, Burnett, Nelson, Aaron, & Raizenne, 2000). They spend the majority of their time, that is, inside a built environment, and this phenomenon massively increased all around the globe in the year 2020 in response to the COVID-19 pandemic. This matters a great deal because dense urbanized environments are related to lower subjective well-being and life-satisfactory levels (Winters & Li, 2016). Research also shows that the limited contact with nature associated with dwelling in urbanized environments may cause frequent mental and physical illness, and increase stress levels (Grinde & Patil, 2009; Gullone, 2000). Modern urbanized spaces, in other words, are more denaturalized than ever before, with all the attendant potential problems.

In response, some pioneering work has strongly suggested bringing natural elements back into the everyday built environments (Senosiain, 2003). Planners and designers have attempted to include more vegetation and nature into the urban landscape. For example, the Ford Foundation Center for Social Justice in New York City (Figure 1.1), designed by Kevin Roche John Dinkeloo Associates in 1967, is an early example of a vertical indoor botanical garden in the center of one of the most crowded urban cities in the world. The 1/3-acre (0.13ha) and 125 feet (38m) tall atrium

landscapes includes a pool, 37 trees, 148 vines, 999 shrubs, and 22,000 plants. It provides an oasis in the city not only to office workers, but also to pedestrians passing 42nd street (Roberts, 1967).

While the building and the atrium were renovated in 2018 by Gensler, for a more recent example, we can turn to the Boeri Studio's (2014) were internationally renowned for planting 800 trees, 5,000 shrubs, and 11,000 perennials within the two dense high-rise residential buildings of the Bosco Verticale in Milan (Xie, 2017; Figure 1.2). We can also look to the Danish architectural firm Bjarke Ingels Group (BIG)'s office building construction project "the Spiral" in New York City, anticipated to be completed in 2022. This project includes a half mile landscaped terraces with trees and vegetation wrapped around the 65-story skyscraper. Its prime design concept is offering outdoor atmosphere and light to every floor of the tower to maximize quality for the people that occupy the building (Walsh, 2019). Also, on a larger scale, the High Line in New York City deserves mention. The High Line was a collaborative project between James Corner Field Operations (landscape architect), Diller Scofidio + Renfro (architect), and Piet Oudolf (garden designer), and it is now the city's most beloved tourist attraction with an estimated 8 million annual visitors (Mathews, 2019).

Along with office and public spaces, some hospitals are actively incorporating healing gardens and indoor landscaping in their hospital designs to draw on the therapeutic benefits of nature. For example, the Khoo Teck Puat Hospital in Singapore (Figure 1.3), which opened in 2010, is well-known example of biophilic design hospital which won the Stephen R. Kellert Biophilic Design Award in 2017. It was designed by CPG Consultants in collaboration with RMJM, and achieved a remarkable green plot ratio of 3.92, which means the total surface area of horizontal

Figure 1.1

The Replanted Garden of the Ford Foundation Center for Social Justice (Photo by Simon Luethi, Kimmelman, 2018)

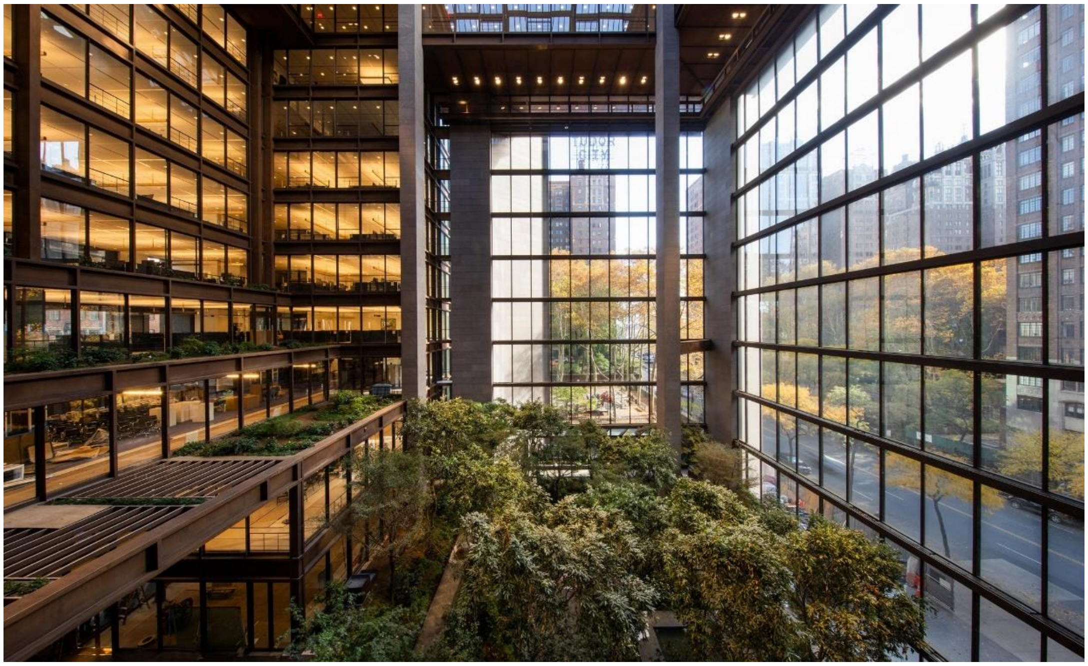

Figure 1.2

Aerial Photography of the Bosco Verticale (Stefano Boeri Architetti, n.d.)

and vertical greenery of the building is nearly four times larger than that of the hospital site. The hospital's rooftop farm has 100 species of fruit trees, 50 species of vegetables, and 50 species of herbs (International Building Future Institute, n.d.). Also, the Maggie's Leeds Centre (Figure 1.4), a small annex of St. James's University Hospital in Leeds that provides free practical and emotional support to people with cancer, is covered with 23,000 bulbs and 17,000 plants and created a rooftop gardens (Pintos, 2020). It is designed by Heatherwick Studio, co-designer of Google's new Mountain View headquarters which also includes indoor trees and landscaping throughout the greenhouse-inspired campus.

Such efforts to create spaces that promote the health and well-being of users are based on biophilic design, which reconsiders the relationship between built environments, natural elements, and human well-being. In terms of architecture studies, this trend deserves significant attention: the application of biophilic design is slowly spreading throughout health care facilities, schools, offices, hospitality venues, communities, and some cases even airports and manufacturing facilities (Salingaros, 2015). But how, exactly, do the natural elements found in urban, built environments influence the people who use the space? How does our contact with nature in the spaces we live, work, and rest affect our health and well-being? Could the influence of nature extend to our emotions and cognitive performance, according to the degree of nature found within the built environment? Considering the growing ubiquity of biophilic design in high-profile projects across multiple spaces and industries, the dearth of answers to such questions in the current research literature is both surprising and troubling.

Figure 1.3

Main Entrance of Khoo Teck Puat Hospital (Khoo Teck Puat Hospital, n. d.)

Figure 1.4

Left: Maggie's Leeds Centre Rooftop; Right: The Kitchen, Center of Maggie's Leeds Centre (Photo by Hufton+Crow; Pintos, 2020)

One way Architectural studies has sought to answer such questions is through Environment-behavior research, which has agonized over the impact of culture and society on individual awareness of and preferences within built environments. One way it has addressed such questions is by situating human behavior within the context of the macro-system, or immediate community.[3] Environment-behavior research approaches to architecture, in other words, seek to situate human behavior in communities by emphasizing structure, social psychology, human ecology, and social systems (Fellin, 1995; Martinez-Brawley, 1995).

However, the rapid growth of the Internet and Social Networking Services (SNS) has reduced the influence of the localized community privileged by some environment-behavior researchers. For example, by watching YouTube channels or searching Google, people are now exposed to cultures and societies from anywhere on Earth (Castells, 2004; Cunningham & Craig, 2016; Kraidy, 2002; Ono & Kwon, 2013; Voiskounsky, 1998). This globalization of information, we argue, has impacted the spaces in which we dwell. The interior settings where urbanites live, work, study, spend time and etc. are very similar in cities all over the world including New York, Toronto, Sydney, Tokyo, Seoul, Shanghai, Berlin, London, and so on. Thus, we need to address the relationship between individual experiences of space and the phenomenon of global

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[3] In environment-behavior research studies, "the community" refers to people living in the same area, especially people with common themes, problems, interests, etc., or ethnic or cultural groups living in a geographically-defined area.

interconnectedness. Incorporating nature within indoor built environment is one way to do this.

The experience of nature in a built environment is complex and multilayered, especially with regard to later cognition. This complexity has led to new approaches to environment-behavior research that seek to firmly establish the role human experiences and judgments play in various aspects of environmental perception, such as spatial navigation, learning, atmospherics, aesthetics, and etc. (Hess, Gryc, & Hareli, 2013; Frenzel, Pekrun, & Goetz, 2007; Jang & Young, 2009; Phelps, 2004; Vartanian et al., 2011). These new approaches to understanding environmental experience are fundamentally interdisciplinary; they draw on wide-ranging fields including environmental, social, and ecological psychology, behavioral economics, and importantly for this dissertation, cognitive neuroscience and cognitive neuropsychology.

Combining traditional environment-behavior research, psychology, and neuroscience, the new field of neuroarchitecture that we draw on here tries to understand how built environments influence our experience and behavior, such that we might design spaces to improve our health and well-being (Goldhagen, 2017). For example, some of the most recent studies in neuroarchitecture examine wayfinding, illumination, thermal comfort, colours, the shape and layout of spaces, perception, and biophilia. Neuroarchitectural research generally focuses on the user experience of built environments and tries to evaluate this experience through various techniques. These techniques include both subjective methods (post-usage questionnaires and surveys) and objective methods (psychophysiological measurement tools) to accurately register a person's experience of built environments.

Electroencephalography (EEG) is one psychophysiological measurement tool that is widely used in clinical science and psychology to empirically measure human experiences. Throughout the past decade, mobile psychophysiological measurement via EEG has restructured the possibilities for environment-behavior research in various fields including environmental psychology, cognitive neuroscience, urban planning, landscape architecture, and architecture. Devices such as Emotiv EPOC (a low-cost consumer grade mobile EEG device used for this dissertation) and several other skin conductance and heart-rate monitoring devices have made measurement via electrophysiology and psychophysiology both mobile and affordable compared to laboratory research-graded equipment. In addition, research in brain-computer interfaces (BCI) has been nurtured by advanced computational tools for the computerized assessment and classification of EEG signals, which help detect the emotional and/or cognitive state of the user. With the aid of such tools, researchers have produced better data on the relationship between contact with nature and good health (Frumkin, 2001; Thompson, 2011) and reached new points of consensus on items like the benefits of natural surroundings for stress reduction (Hartig, Mang, & Evans, 1991; Ulrich et al., 1991) and attention restoration (Berman, Jonides, & Kaplan, 2008; Berto, 2005; Laumann, Gärling, & Stormark, 2003; Staats, Kievet, & Hartig, 2003).

For example, studies have found that nature affects people’s preferences for urbanized environments (Stamps, 1997; Wolf, 2009) and that psychological restoration or expectations of restoration from nature may affect preferences for environmental variations (van den Berg et al., 2003; Staats et al., 2003; Hartig and Staats, 2006). In addition, some attention has been paid to the different settings and degrees of nature’s restorative values of urban green areas, such as the restorative influences of plants on streets in urban environments (Carrus, 2015; Jiang et al., 2014;

Lindal & Hartig, 2015; van Dillen et al., 2012). However, we still need better data on how different natural settings within various environments can have different restorative effects. In particular, the designers and decision-makers of urbanized built environments have inadequately acknowledged the positive benefits of biophilic design. This is unfortunate, because the recent trend of constructing densely developed cities does not entirely occlude the possibility of using natural settings to improve the quality of urban environments and the health and well-being of their dwellers.

This dissertation seeks to identify the influence of vegetation on users in built environments. It explores how people respond to vegetation, built environments, and vegetation within built environments, and in so doing, it applies the biophilic hypothesis to research in environment-behavior and neuroarchitecture paradigms. This dissertation uses surveys and tasks, as well as electroencephalography (EEG), to measure the effects of vegetation on restorative and attentional performance in built environments. For our study, participants experience an indoor space and are the presented with images of vegetation and indoor environments.

1.2. Significance of the Study

Architects, designers, and researchers have long struggled to manipulate the built environment to improve the quality of space and enhance users' health, well-being, and performance. This includes designing spaces to increase restorativeness and cognitive performance. Compared to built environments, though, people tend to prefer natural environments (Herzog, 1989; Kaplan, Kaplan, & Wendt, 1972; Van den Berg, Hartig, & Staats, 2007). Contact with nature

is consistently associated with positive psychological and physiological well-being. Current neuroscience research might help architects design built environments that better achieve these desirable outcomes by harnessing our understanding of human brain functions and neuronal information processing (Kandel et al., 2012).

The aim of this dissertation is to investigate the restorative and attentional cognitive influence of vegetation in indoor environments. As mentioned, nature and built environments produce visual stimuli that differ significantly in their influence on individuals. However, previous studies on restorative and attention enhancing environments only focus on one or the other side of the natural-built dichotomy, and thus do not provide sufficient insight into the grey area of nature within built environments. A well-designed and attractive urban environment may have positive emotional outcomes (for example, reduced stress and enhanced mood), and its restorative effects may be augmented with some natural elements (Berman et al., 2008; Hartig, Mitchell, de Vries, & Frumkin, 2014). However, previous studies on nature in urban environments either mis-select the site (for example, the Eastern Dockland where water is filled; Karmanov & Hamel, 2008) or focus only on urban parks, which are not accessible in most parts of cities (Hartig et al., 2014).

Furthermore, previous studies do not offer guidelines for designing urban built environments that will most effectively provide restoration and increase attention capacity by the type and degree of nature present. In response to these concerns, research has expanded in scope to include diverse environments such as multiple nature settings (Chiang, Li, & Jane, 2017; Gatersleben & Andrews, 2013; Han, 2010; Martens, Gutscher, & Bauer, 2011), streets with nature and other built environments (Antonson, Mårdh, Wiklund, & Blomqvist, 2009; Herzog & Chernick, 2000; Herzog, Maguire, & Nebel, 2003; Jiang, Chang, & Sullivan, 2014; Ng et al., 2015;

Suppakittpaisarn et al., 2019), urban parks (Nordh, Alalouch, & Hartig, 2011; Tyrväinen et al., 2014), built environments with and without green roofs (Lee et al., 2015), urban built environments with water features (Karmanov & Hamel, 2008), and etc. Nevertheless, relatively few studies have focused on nature inside buildings, where urban dwellers spend most of their time, and finally, existing studies on the benefits of indoor plants have mostly focused on the effects of the plants without consider the impact of the amount of the plants (Kiyota, 2009; Raanaas, Patil, & Hartig, 2010; Shibata & Suzuki, 2001, 2002, 2004).

This lack of empirical research on the nuances of biophilic design has led to an over-reliance on the limited extant body of scholarship. For example, earlier studies claimed that users subjectively perceived fully enclosed green spaces as less restorative than open or half-open spaces (Antonson et al., 2009; Han, 2010; Herzog & Chernick, 2000; Herzog et al., 2003). Walking through an enclosed and densely wooded country park, they claim, would increase levels of stress, attentional fatigue, and fear, whereas more open landscapes would promote restoration (Gatersleben & Andrews, 2013). However, most of these findings are based on perceived restorativeness measurement studies, which often leave out differences in quality and volume of restorativeness among various natural settings (Beil & Hanes, 2013; Tsunetsugu et al., 2013; Tyrväinen et al., 2014; Ulrich et al., 1991; Van den Berg, Koole, &Van der Wulp, 2003). Such differences are potentially very significant. For example, what happens when we take bio-diversity and density of vegetation into account? We may assume that people would prefer bio-diverse greenspaces, and it is partially true: high-biodiversity landscapes demonstrate more psychological benefits and improvements to people's subjective health than urban location (Brown & Grant, 2005; Carrus et al., 2015; Fuller, et al., 2007).

However, other studies suggest that a more complex association between biodiversity and preference (Johansson, Gyllin, Witzell, & Kuller, 2014; Qiu, Lindberg, & Nielsen, 2013). A study on forests, for one, revealed that intermediate levels of biodiversity richness reflected positive appraisal, compared to low or high levels of biodiversity (Johansson, Gyllin, Witzell, & Kuller, 2014). Participants showed stress reduction and recovery, and better attentional functioning after encountering medium-high level density of trees and plants, which they also related to positive physiological and psychological well-being (Chiang, Li, & Jane, 2017; Jiang, Chang, & Sullivan, 2014; Jiang, Larsen, Deal, & Sullivan, 2015; Jiang, Li, Larsen, & Sullivan, 2016). While these studies on the forest and streetscape are a good start, they do not account for architectural settings. They also do not fully investigate the density of vegetation - low, medium, and high – and they use only EEG alpha frequency for their analysis (Chiang, Li, & Jane, 2017). There is only one subjective measure in these studies – the Trier Social Stress Test (Jiang, Li, Larsen, & Sullivan, 2016), accompanied by a simple preference rating (Jiang, Larsen, Deal, & Sullivan, 2015) - and their analysis of salivary cortisol and skin conductance levels (Jiang, Chang, & Sullivan, 2014) focuses on stress indicators only, leaving broad areas of human cognition and emotion open to further research.

This dissertation responds to the current state of research on these issues with the following questions: will encountering vegetation in the indoor built environments produce differences in restorative and working memory performance? How does the human brain respond, as measured in brain wave activity, to vegetation in indoor environments? Does exposure to vegetation in indoor built environments work as a calming device? Relatedly, does higher vegetation density promote more restoration and higher working memory capacity? Finally, how

can we measure and quantify the restorativeness and working memory improvements of vegetation settings in indoor spaces?

These questions are important, because while vegetation have been shown to differ in terms of their restorative qualities and effects on cognitive ability, little is known about the amount of exposure to vegetation needed to gain physiological and psychological health benefits. Also, more research is needed to determine the health benefits of vegetation settings in an urbanized built environment context, especially in the interior space of the buildings where people spend most of their time. And finally, further studies are required to identify how people's perceived restoration and working memory when exposed to vegetation differ from their quantitatively measured psychophysiologically restorativeness and performance of working memory.

The results from the two experiments in this dissertation can help us understand architectural biophilic design and apply it to various built environments in the areas of hospitality, home, education, and office. On the first point, hotels and restaurants can relieve the stress of their guests and staff by increasing their restorative potential. For example, guests spend and enjoy 36% more time in hotel lobbies which actively adopt nature (Terrapin Bright Green, n.d.). Second, homes are the major place of restoration for persons and families, and they are also workspaces for in-home workers and students. Technological improvements and other circumstantial factors, such as the current COVID-19 situation in 2020, have increased remote work and study from home. As more people work and study at home, the need for home environments that are designed to aid cognition will grow. Third, access to nature in school settings can help increase concentration and attention in students and teachers, while reducing the impact of cognitive fatigue and stress on academic performance (Wells, 2000; Wells & Evans, 2003). And lastly, by fostering biophilic

design in offices, the productivity, creativity, and well-being of the workers will increase and lead to fewer employee absences (Elzeyadi, 2011; Raanaas et al., 2011) as a partial outcome of improved cognitive performance and restoration. All four sectors demand both restoration and cognition at some level, and this dissertation suggests an optimal volume of vegetation by identifying how varied levels of vegetation positively influence restoration and attention. In other word, it provides a guideline for using adequate amounts of vegetation to promote better attention restoration in resting spaces and better working memory capacity in learning spaces.

2. Literature Review

This section addresses the research questions in the previous section by reviewing the literature on restorative and cognitive mechanisms in our everyday life. Fields including environment and behavior studies, landscape architecture, horticulture, cognitive psychology, behavioral neuroscience, and etc. have examined the positive influence of nature on people via restorativeness and attentional performance. To holistically understand the effects of vegetation in indoor built environments, this section reviews theoretical framework for this dissertation, theories and empirical studies relevant to the study of human-nature interactions in architectural studies, behavioral studies, and cognitive science, the role of nature in built environments, and the methods for measuring such phenomena. Theories in architectural studies explores biophilic design and neuroarchitecutre; theories in behavioral studies describes attention restoration theory, stress recovery theory, and recent trends in restorative theory; theories in cognitive science reviews the attention system and working memory. The role of nature in built environment section discovers the impact of perceived nature in built environments, effects of indoor vegetation, influence of vegetation in built environments on attention restoration, influence of vegetation in built environments on attention capacity, and visual-reward mechanisms for attention restoration and attention capacity. Lastly, methods of measurement reviews self-report versus psychophysiological

experiences, in situ[4] versus substitute image studies, Perceived Restorativeness Scale (PRS), backward digit span task, and Electroencephalography (EEG).

2.1. Theoretical Framework

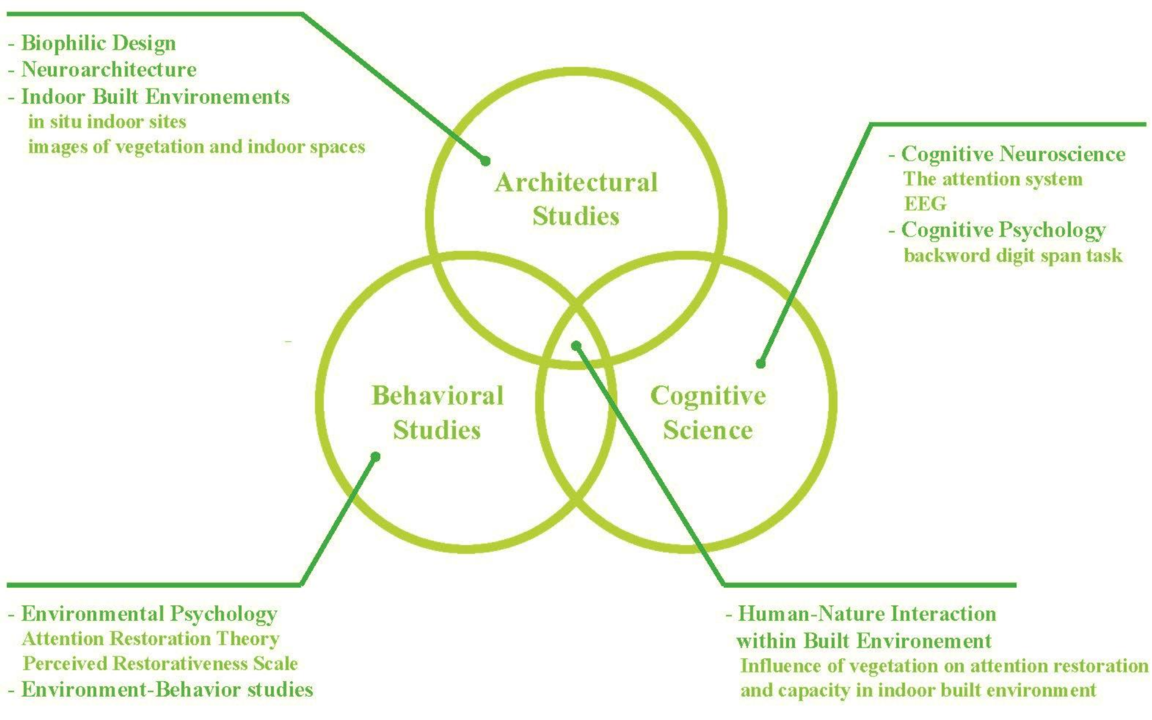
The theoretical framework for this dissertation combines empirical experimental approaches from architectural studies (biophilic design and neuroarchitecture), behavioral studies (environmental psychology and environment-behavior studies), and cognitive science (cognitive neuroscience and cognitive psychology) (Figure 2.1.). Three theories, one from each discipline, are integrated to explain the effects of exposure to vegetation in indoor environment: biophilic design, Attention Restoration Theory, and anatomical approaches to attention. Biophilic design (Kellert, 2008; 2012b) provides a theoretical basis for the benefits of adopting nature, including vegetation, in designing built environments to promote human health and well-being. Attention Restoration Theory (ART, Kaplan, 1995; Kaplan et al., 1998) focuses more on cognitive responses, and provides the foundation for this project's research question on the restoration of attention in mixed vegetation/indoor built environments. ART argues that while experiencing nature, our brain operates on 'soft fascination,' and that this mental rest restores attention capacity from depletion

[4] In situ is a Latin phrase meaning "on site" and defined as "Situated in the original place" (Oxford, 2020a). In this dissertation, in situ describes a built environment without any alternation of original conditions that is used for experimental purposes.

(Kaplan, 1995; Kaplan & Kaplan, 1989). Lastly, another strand of research on the attention system from cognitive neuroscience (Petersen & Posner, 2012; Posner & Petersen, 1990) emphasizes the specific anatomical areas that facilitate attention restoration and capacity. This dissertation argues that bringing these three theories together will help us apprehend nature's ability to restore attention and increase attention capacity in indoor built environments.

Figure 2.1

Venn Diagram Showing the Intersection of Disciplines and Theories Contributing to Theoretical Framework of the Dissertation



2.2. Theories in Architectural Studies

Biophilic Design

The German social psychologist Eric Fromm coined the term "biophilia" to describe our emotional fascination with all living organisms (Fromm, 1964). Later, Wilson (1993) developed the "biophilia hypothesis" to explain this attachment to other existing creatures. The biophilia hypothesis argues that humans are innately interconnected with nature physically, psychologically, and spiritually because human brains evolved in and adapted to nature-oriented (versus technology-oriented) environments. For this reason, exposure to nature increases positive psychological effects like autonomy, competence, and relatedness needs (Kellert, 1997), and furthermore, higher degrees of nature relatedness are positively associated with well-being (Nisbet, Zelenski, & Murphy, 2011) and attentional capacity (Mayer et al., 2009). This hypothesis works from the premise that the techno-centric approach of the past two hundred years of modernity cannot override thousands of years of nature-centered history deeply programmed into the human brain. To Wilson (1993), people's health and well-being rely on connectedness to nature, even in the form of watching nature. Ultimately, then, Wilson (1984) describes biophilia as an "affinity towards nature" that includes associations between living organisms in nature and emotions like pleasure, enchantment, respect, relief, and more (Wilson, 1993). To Wilson, biophilia is a process of human-environment interactions which has developed throughout the evolution of mankind (Beatley, 2011). For Wilson and others, the biophilia hypothesis suggests that modern built environments created by new technologies should recognize and promote this human desire to be connected with nature (Kellert, 2005; Kellert, Heerwagen, & Mador, 2008; Wilson, 1993).

Biophilic design is the practical application of the biophilia hypothesis. Built environments adopting biophilic design encourage links between nature and the individual experience of spaces developed via learning and cultural reinforcement (Kellert et al., 2008; Kellert, 2012b, 2018; Kellert & Finnegan, 2011). Biophilic design is not, therefore, limited to greening buildings; it entails rediscovering the role of humankind (and/or society) in nature and vice versa (Kellert et al., 2008). Applications of biophilic design in built environments include the use of transitional spaces, natural lighting, ventilation, inside-outside spaces, water features, vegetation, and so on (Kellert, 2008; 2012a; Table 2.1). These attributes actively encourage a mutual human-nature relationship, which enriches human well-being by offering a substitute for the experience of nature (Kellert, 2008). For example, converting one-quarter of the community area of a thirty-year old residential neighborhood into open spaces with community farm-gardens and pedestrian paths increased residents' satisfaction and well-being (Kellert, 2012b).

Kellert (2002, 2012b) classified biophilic design into two categories. First, the naturalistic or organic category, which includes direct, indirect, and/or symbolic contact with nature. Direct nature describes active contact and immediate sensory experience in natural settings and habitats, which are seen to maximize biophilic effects: for instance, playing or walking in forests or parks. Indirect nature also includes actual physical contact with nature; however, this contact is limited and occurs via controlled experiences and environments like encountering contained plants or animals. The experience of indoor nature, which this dissertation examines for its first experiment, would fall into this category. Lastly, symbolic or vicarious nature focuses on representations of nature where actual physical contact with nature is absent: for instance, photos, videos, paintings, and even virtual reality (VR) environments. The second experiment in this dissertation examines

symbolic nature as understood in this first naturalistic or organic category of biophilic design.

Table 2.1

Elements and Attributes of Biophilic Design (Adapted from [Kellert, 2012a])

Light and Space	Place Connections	Evolved Relations to Nature
Natural light	Geographical connection to place	Prospect and refuge
Filtered and diffused light	Historical connection to place	Order and complexity
Light and shadow	Cultural connection to place	Change and metamorphosis
Light pools	Indigenous materials	Affection and attachment
Warm light	Landscape orientation	Attraction and beauty
Light as shape and form	Landscape ecology	Exploration and discovery
Spaciousness	Integrating culture and ecology	Fear and awe
Spatial variability	Sense of spirit of place	Information and understanding
Space as shape and form	Avoided placelessness	Mastery and control
Spatial integration of light, mass, and scale	Landscape features that define building form	Security and protection
Inside-outside spaces		Reverence and spirituality

The second category of biophilic design involves a place-based or “vernacular” approach to biophilia that generates place attachment by intertwining culture with the ecology of a specific locale. Vernacular dimensions of biophilia nurture the spirituality and identity of a place by

concentrating on the meaning of the built environment for the people who live in and are attached to it. While the vernacular approach is interesting because of its site-specific and custom-designed nature, it also is not as urgent to study as the first, organic approach since we do not have firmly developed base-line universal guidelines for biophilic design, yet. Therefore, this dissertation does not emphasize the vernacular approach of biophilic design.

Recently, there have been some attempts to apply biophilic design in more practical architectural design fields. For instance, the sustainability consulting firm Terrapin Bright Green adopted Kellert's classification to suggest "14 Patterns of Biophilic Design" that articulate the relationship between nature and the built environments (Browning, Ryan, & Clancy, 2014; Table 2.2). The biophilic design patterns in this document comprise three categories: Nature in the Space, Natural Analogues, and Nature of the Space. Nature in the Space describes everything from direct connections to nature to the ephemeral presence of nature in space and encourages direct and multi-sensory interactions with natural elements. Nature in Space includes visual connections with nature, nonvisual connections with nature, nonrhythmic sensory stimuli, thermal and airflow variability, presence of water, dynamic and diffuse light, and connections with natural systems. Natural Analogues explores an analogical approach to nature that uses shapes, materials, colors, patterns, and etc., to adapt evocations of organic nature to built environments. Natural Analogues consist of biomorphic forms and patterns, material connections with nature, and representations of complexity and order. Finally, Nature of the Space is based on human psychology and embraces the human desire to create safe shelter. Nature of the Space focuses on spatial configurations that incorporate aspects of prospect, refuge, and mystery, and that avoid aspects of risk/peril.

Table 2.2

14 Patterns of Biophilic Design (Browning, Ryan, & Clancy, 2014)

Context	Patterns
Nature in Space	1. Visual Connection with Nature - A view to elements of nature, living systems, and natural processes 2. Nonvisual Connection with Nature - Auditory, haptic, olfactory, or gustatory stimuli that engender a deliberate and positive reference to nature, living systems, or natural processes 3. Nonrhythmic Sensory Stimuli - Stochastic and ephemeral connections with nature that may be analyzed statistically but may not be predicted precisely 4. Thermal & Airflow Variability - Subtle changes in air temperature, relative humidity, airflow across the skin, and surface temperatures that mimic natural environments 5. Presence of Water - A condition that enhances the experience of a place through the seeing, hearing, or touching of water 6. Dynamic and Diffuse Light - Leveraging varying intensities of light and shadow that change over time to create conditions that occur in nature 7. Connection with Natural Systems - Awareness of natural processes, especially seasonal and temporal changes characteristic of a healthy ecosystem
Natural Analoques	8. Biomorphic Forms and Patterns - Symbolic references to contoured, patterned, textured, or numerical arrangements that persist in nature

Context	Patterns
	9. Material Connection with Nature - Material and elements from nature that, through minimal processing, reflect the local ecology or geology to create a distinct sense of place 10. Complexity and Order - Rich sensory information that adheres to a spatial hierarchy similar to those encountered in nature
Nature of The Space	11. Prospect - An unimpeded view over a distance for surveillance and planning 12. Refuge - A place for withdrawal, from environmental conditions or the main flow of activity, in which the individual is protected from behind and overhead 13. Mystery - The promise of more information achieved through partially obscured views or other sensory devices that entice the individual to travel deeper into the environment 14. Risk/Peril - An identifiable threat coupled with a reliable safeguard

In addition, in terms of recent practical applications of the biophilia hypothesis to architecture, the design standard system called WELL Building Standard™ has been implemented to design more positive, human-centered spaces that might increase the health and performance of

its users (International WELL Building Institute, n.d.).[5] To achieve better health and well-being outcomes, the patterns of biophilic design establishes fundamental guidelines for designing the built environment to maximize the positive effects of human experiences with nature.

Beatley (2011) expands these biophilic design principles from individual built environments to entire cities. Most megalopolises are surrounded by concrete and glass with limited or almost no contact with biodiversity (United Nations Environment Programme, 2012). The "biophilic city," by contrast, is a city that has abundant nature to alleviate the health, climate, and economic problems often experienced in urban cities (Newman & Matan, 2013). It is defined as a city in which biodiverse nature exists in proximity to urban dwellers, and in which occupants actively engage, respect, look after and restore biodiversity. Beatley and Newman (2013) summarize some important scopes of biophilic cities (Table 2.3). According to Beatley (2011), biophilic cities can be achieved through combinations of physical conditions and infrastructure, behavior and lifestyle choices of residents, knowledge and awareness of residents, and policies

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[5] WELL Building Standard™ is administered by the International WELL Building Institute™ (IWBI™), and certified by Green Business Certification Inc. There are older and more popular sustainable building rating system, such as LEED (U.S. Green Building Council, 2020) and BREEAM (Building Research Establishment Ltd., 2020). However, LEED and BREEAM tend to focus more on building sustainability performance, while the WELL Building Standard is more focused on the health and well-being of humans in the built environment.

Table 2.3

Important Dimensions of Biophilic Cities (Adapted from [Beatley & Newman, 2013])

Key Qualities	Attributes
Biophilic Conditions and Infrastructure	- Percentage of the Population within a few hundred feet or meters of a park greenspace; - Percentage of city land area covered by trees or other vegetation; - Number of green design features (e.g., green rooftops, green walls, rain gardens); - Extent of natural images, shapes, forms employed in architecture and seen in the city; - Extent of flora and fauna (e.g., species) found within the city;
Biophilic Behaviors, Patterns, Practices, Lifestyles	- Average portion of the day spent outside; - Visitation rates for city parks; - Percent of trips made by walking; - Extent of membership and participation in local nature clubs and organizations;
Biophilic Attitudes and Knowledge	- Percent of residents who express care and concern for nature; - Percent of residents who can identify common species of flora and fauna;
Biophilic Institutions and Governance	- Priority given to nature conservation by local government; percent of municipal budget dedicated to biophilic programs; - Existence of design and planning regulations that promote biophilic condition (e.g., mandatory green rooftop requirement, bird-friendly building design guidelines); - Presence and importance of institutions, from aquaria to natural history museums, that promote education and awareness of nature; - Number/extend of educational programs in local schools aimed at teaching about nature; - Number of nature organizations and clubs of various sorts in the city, from advocacy to social groups.

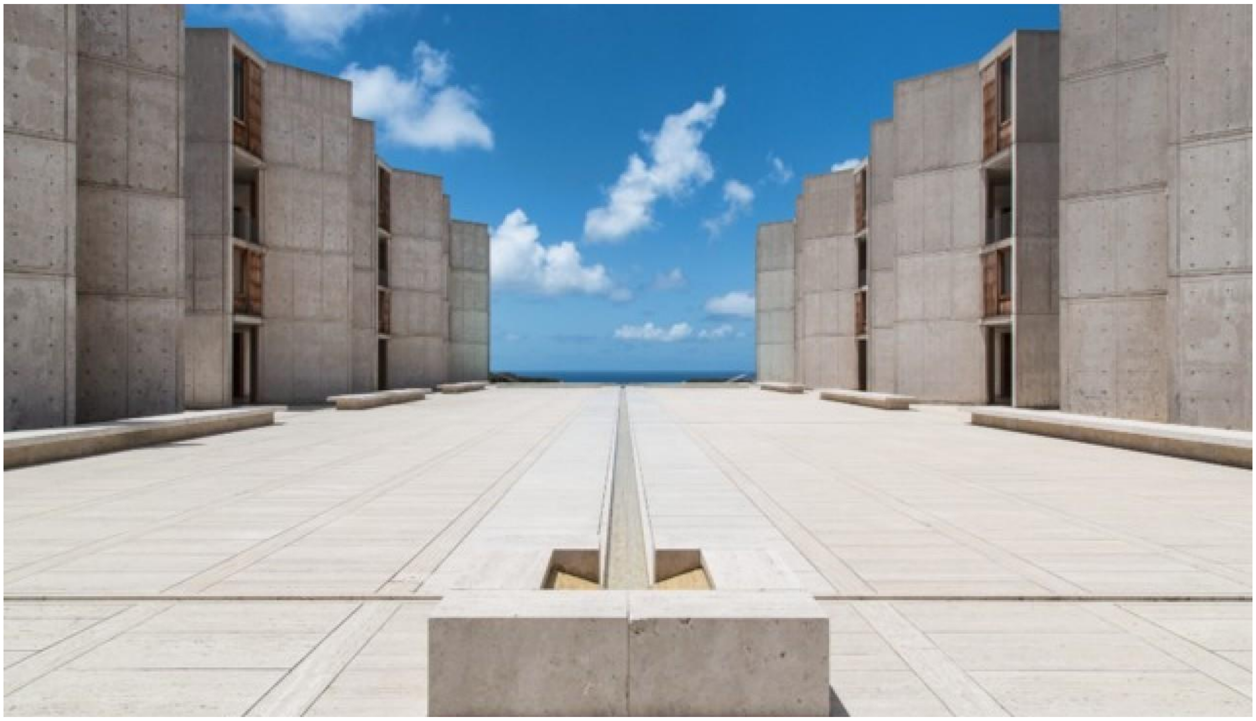
and support from the government and institutions. While biophilic design focuses on the micro scale (a building unit), biophilic cities describe a macro scale including larger geological settings society, and its members. However, regardless of their scale, both biophilic design and biophilic cities are equally important to the well-being of urban dwellers, as they shape and define the places these dwellers live by increasing opportunities to connect with the nature around them.

Neuroarchitecture

Neuroarchitecture bridges the fields of architecture and neuroscience to understand the relationship between human cognition and built environments. One of the early examples of neuroarchitecture describes how Jonas Salk discovered the polio vaccine while on retreat at the Basilica of Assisi in Umbria, Italy. Salk maintained that the architecture and environment of the monastery restored his intellect and led him to create the cure (Eberhard, 2008). As a result, when he built the famous Salk Institute, Salk asked the architect Louis Kahn to create an effective research environment that would enhance creativity (Figure 2.2). Later, Salk's conversations with Norman Koonce (FAIA & CEO of the American Institute of Architects) and others raised the question of why the researchers performed more creatively while working at the Salk Institute. These conversations inspired the creation of the Academy of Neuroscience for Architecture (ANFA) in 2003 by John Eberhard (architect, educator and founding director), and Fred Gage, a neuroscientist from the Salk institute. These researchers started examining how environmental design affect human brain, emotion, and behaviors in order to understand how neuroscience research may help understand human responses to the built environment (ANFA, n.d.).

Figure 2.2

Salk Institute for Biological Studies (Salk, 2020)



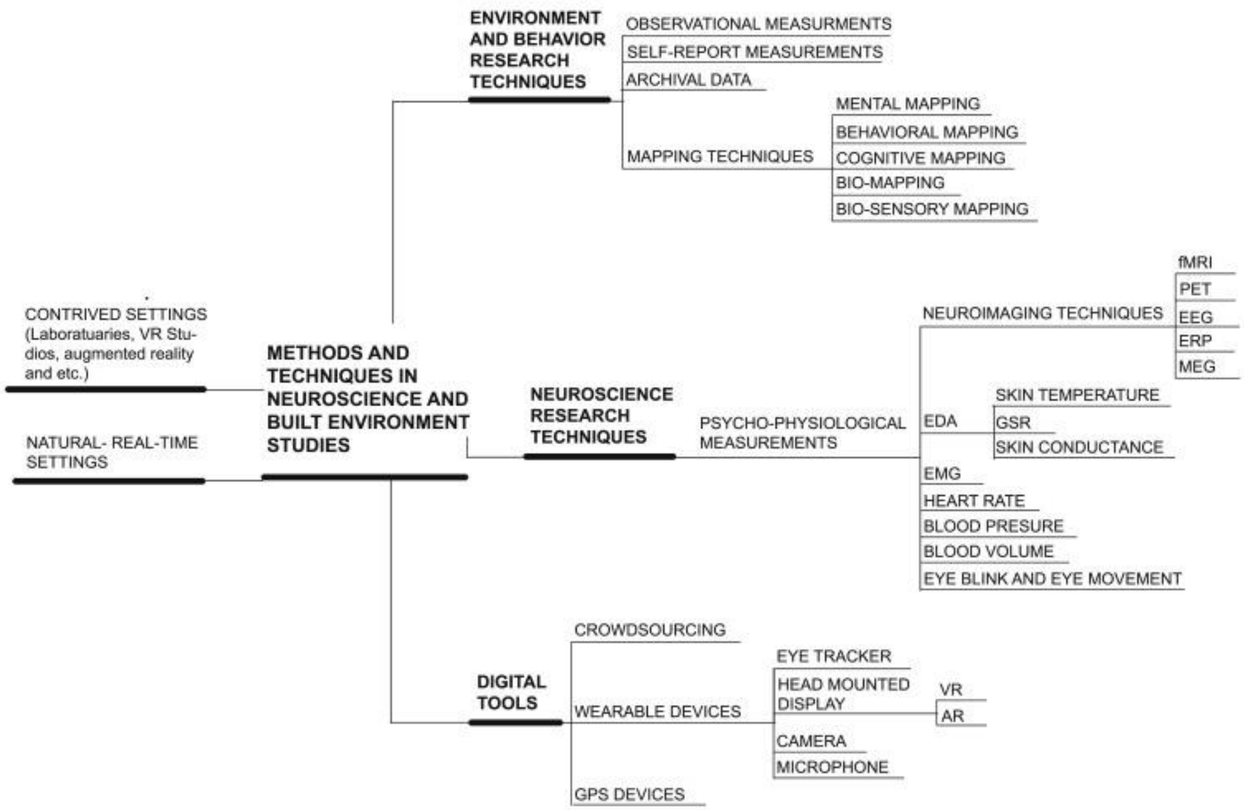
There is an established body of literature in environmental psychology and evidence-based design that shows how built environments influence human responses, feelings, and behaviors (Ulrich, 1991). However, neuroarchitecture tries to understand how the built environment enhances mood states, improves cognitive abilities, alleviates stress, and etc. by observing people's behavior and measuring brain activities (Eberhard, 2008). Mallgrave, for example, claims that understanding the human brain provides architects with fundamental physiological knowledge of people and space that helps with "exploring such issues as memory, consciousness, feelings, thinking, and creativity" (Mallgrave, 2012. p.1). Thus, neuroarchitecture explains how people

perceive and process information as objective attributes which can then be applied to architectural design applications (Eberhard, 2009). In short, neuroarchitecture applies neuroscientific methods to apprehend the influence of architectural environments on users (Banaei et al., 2017). This approach was made possible by technological advancements like the functional magnetic resonance scanning (fMRI) and EEG machines, which allow researchers to empirically understand how specific areas of brain react to particular environmental experiences (Edelstein & Macagno, 2011). Neuroarchitecture uses not only psychophysiological measurements like fMRI, facial electromyography (EMG), electrocardiogram (ECG), electroencephalography (EEG), eye-tracker, and etc., but also traditional environmental and behavior research techniques and relatively new digital tools (Figure 2.3).

In the early days of neuroarchitecture, Eberhard tried to identify the universal foundations of perceived environments in his neuroarchitectural manifesto, *Brain Landscape* (Eberhard, 2008). In the wake of that work, neuroarchitecture researchers gradually focused more on specific place types like schools, hospitals, and offices, and asked more specific questions about how to facilitate students' cognition, how to treat older adults with dementia, and how to improve workers performance and creativity (Karandinou & Turner, 2017). Later, the scope of research expanded to urban spaces and wayfinding issues (Karandinou & Turner, 2017), people's emotions in built environment (Bower et al. 2019), the aesthetics of architectural experiences (Coburn et al., 2017), various architectural styles (Choo et al., 2017), ceiling height and enclosure (Vartanian et al., 2015), contour (Vartanian et al., 2013), and even virtual architectural spaces (Banaei et al., 2017).

Figure 2.3

Research Methods Related to the Neuroarchitecture Studies (Karakas & Yildiz, 2020)



2.3. Theories in Behavioral Studies

Attention Restoration Theory (ART)

Attention Restoration Theory (ART) provides a theoretical background for identifying and restoring a cognitive mechanism (Kaplan, 1995; Kaplan & Kaplan, 1989). ART claims that encounters with nature have restorative effects, while urban built environments impede or even work against recovery (Ulrich et al. 1991).

ART builds on the assumption of limited human cognitive capacity. This limited capacity leads to mental fatigue; Kaplan and Kaplan (1989) describe the excess of directly captured attention taken by urban environments as *hard fascination*. Hard fascination describes how our directed attention capacity is subject to fatigue by encounters with urban environments, leaving individuals less capable of dealing with uncertainty, confusion and demanding tasks. Urban environments, in other words, make extreme demands on attention. In particular, they require directed attention to overcome their excessive stimulation, making urban environments less restorative (Berman, Jonides, & Kaplan, 2008).

ART has also focused on the components of people-environment interactions that promote attentional restoration from "mental fatigue" or the depletion of cognitive resources (Kaplan, Kaplan, & Ryan, 1998). ART posits that environments promoting indirect attention can restore psychological processes and properties in individuals and thus aid in their recovery from mental fatigue (Kaplan, 1995; Hartig et al., 1997). According to ART, features of the environment itself capture attention in a bottom-up fashion. That is, people's attention is involuntarily captured as they live within environments. Kaplan (1995, 2001) refers to this pattern of visual information as *soft fascination*. Studies have provided evidence of improved attention after an interaction with natural environments, such as when people perform better on tasks that depend on directed-attention abilities (Berman, Jonides, & Kaplan, 2008; Bowler, Buyung-Ali, Knight, & Pullin, 2010; Lee, et al., 2015). Natural areas recapture attention involuntarily and gently, thus reducing demands on the limited resources available to voluntarily direct attention from uninteresting environments (Berman et al., 2008; Kaplan, 1995).

ART proposes that when cognitively demanding tasks deplete our attention, four components of environmental experiences can help mitigate attentional fatigue: Being away, Extent or Coherence, Fascination, and Compatibility (Kaplan, 1995; Kaplan et al., 1998). Restoration requires *being away*, meaning psychological and geographical distancing from routines such as daily obligations; it requires a sense of *extent* or connectedness, meaning an active exploration of physical or conceptual environments in order not to be disoriented; it requires *fascination*, meaning effortless attention evoked by aspects of the environment (also referred to as 'soft' fascination); and finally it requires *compatibility*, meaning integration among personal inclinations and purposes, environmental supports for intended activities, and environmental demands for action.

ART suggests that environments with elements of all four components promote involuntary attention, and thus allow individuals restorative opportunities to regain a state of cognitive clarity, enabling a pleasurable and contemplative state of mind (Korpela et al., 2001). Although each of these components can be found in built environments as well as natural settings, ART contends that natural environments tend to offer the four properties of restoration environments and restorative experiences simultaneously, hence the greater restorative potential of natural settings.

Stress Recovery Theory (SRT)

As discussed in the section on the biophilia hypothesis, there is evidence of a positive intrinsic inclination to natural environments owing to the fact that human beings evolved within

natural environments (Wilson, 1984). Ulrich's (1983) Stress Recovery Theory (SRT), a psycho-evolutionary explanation of how nature promotes recovery from stress, is similarly based on the fact that human physiology evolved in natural environments. The theory notes that landscapes containing water, vegetation, complexity, and a degree of curvilinearity have supported human survival throughout its evolution (Ulrich et al. 1991).

Thus, humans have developed the capacity to recover from stress through nature. Foods and resources from nature allowed primitive human beings to survive as a species, and as a result, SRT hypothesizes that such settings should help moderate and reduce the physiological symptoms of stress in contemporary humans as well. It shares with ART the assumption that our brains and sensory systems are tuned to efficiently process natural content and are less efficient at processing urban or built environments, which lead to physiological and cognitive depletion. SRT also proposes that there is an *initial affective response* to environments that drives restoration (Ulrich, 1983; Ulrich et al., 1991). It claims that contact with nature helps recovery from all stress, not just attentional fatigue, and that the response to nature is based on affect, not information processing.

SRT states that a natural environment has a particular aesthetic appeal, and as a result, produces a prompt affective reaction in people at a subconscious level. According to the theory, positive emotions can block negative affects, and hence have a restorative effect in stressful situations (Ulrich, 1983; Ulrich et al., 1991). SRT has focused primarily on contacts with nature that reduce affective and physiological stress and/or replenish emotional resources, and it has detected results not only psychologically but also psycho-physiologically based on heart rate, blood pressure, skin conductance and etc. (Bratman et al., 2012; Ulrich et al., 1991). The affective responses to environments found in participants during SRT studies have led later studies to

explore the impact visual preferences and patterns of nature (Balling & Falk, 1982) have in promoting individual well-being, and the benefit nature settings have in generating restorative aesthetic experiences (Ulrich & Parsons, 1992; Han, 2001).

Both ART and SRT share principal philosophies. Kaplan and Ulrich claim that human beings have developed psychological mechanisms for restoration within nature during a prolonged history of evolution. Even so, there are some fundamental differences between these theories. ART claims that in order to efficiently perform their daily routines, people need to maintain cognitive clarity, which requires the capacity for directed attention. Sadly, the capacity for directed attention is limited and often exhausted by extensive use in modern society, which causes attentional fatigue and consequently obstructs effective functioning (Hartig et al., 1991; Kaplan, Bardwell, & Slakter, 1993). By contrast, SRT emphasizes the emotional and physiological recovery from stress as a cause of fatigue and inefficient behaviors, as opposed to the replenishment of directed attention (Hartig et al., 1991).

As indicated by the literature on both ART and SRT, there is ample empirical weight to the proposition that contact with nature is related to psychological well-being, including recovery of attention and recovery from stress. The importance of overall well-being should be stressed; however, beside well-being, indicators such as restorativeness and cognition are key benefits required from everyday built environments.

Recent Trends in Restorative Theory

In the last several decades, researchers have measured physiological and psychological responses to various nature settings and found that, in urban areas, higher levels of vegetation were tied to higher levels of stress reduction (Alvarsson, Wiens, & Nilsson,2010; Beil & Hanes, 2013; Lee et al., 2009; Roe et al., 2013; Ward Thompson et al., 2012). Moreover, a variety of methods have been used to explore the restorative theory hypothesis, ranging from self-reports to the measurement of psychophysiological indicators including heart-rate, skin conductance, EEG, cortisol levels, and etc. However, until recently, empirical studies on restorative theory were based on laboratory experiments. Ulrich (1981) conducted one pioneering study to measure the EEG of participants watching images of natural environments (with vegetation or/and water aspects) versus urban scenes. The experiment found that natural scenes increased amplitude at the alpha frequency band (4-8 Hz) associated with reduced brain activation or relaxation. Results from more studies using other psychophysiological indicators indicate that people generally recover faster from stressors and/or are able to *immunise* against future stressors with the experience of natural environments (Parsons et al. 1998; Ulrich et al. 1991).

The stimuli used in these studies have been called “environmental surrogates” (Parsons & Tassinary, 2002) and they tend to be less emphasized here than in the field of spatial cognition. The reliance on visual exposure in these studies derives from a belief that vision is by far the most important sense for acquiring stimuli in outdoor environment experience (Ulrich, 1981). Parsons et al. (1998) extended the visual exposure of static images in the laboratory to include an overlay of sound and the use of video walk-throughs. These components add a degree of realism to the visual stimulation provided in the experimental setting, and yet, these efforts still cannot fully

represent real-world settings.

Recent studies discovered the positive psychological effects of short-term visits and/or walk-throughs in natural environments versus built environments. Most of these studies used self-reported measures, and one early study proposed a reliable measurement standard (the Perceived Restorativeness Scale) for assessing the restorative quality of environments (Hartig, Korpela, Evans, & Gärling 1997). Roe and Aspinall (2011) found that thirty-minute walks in green/rural areas had positive effects, especially for people with issues of mental health. Takayama et al. (2014) used several self-reported psychological scales to bolster their claim that walking and viewing forests increased subjective recovery and vitality; such scales included Profile of Mood States (POMS), Positive and Negative Affect Schedule (PANAS), Restorative Outcome Scale (ROS), and Subjective Vitality Scale (SVS). Tyrväinen et al. (2014) used levels of salivary cortisol to measure physiological stress, and found a reduction of salivary cortisol after participants walked in natural environments as opposed to urban settings (Tyrväinen et al., 2014). Aided by technological improvements, Aspinall et al. (2015) adopted mobile EEG to measure the brain activity of people walking in urban areas and natural areas within the city. Their results indicated that getting close to natural areas lowers frustration, engagement and arousal, and increases meditation, while distancing from natural areas promotes higher engagement.[6]

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[6] The indexes stated here such as frustration, engagement, arousal, and meditation are being measured by Emotiv's software. For more information, please refer to chapter 4.5. EEG

2.4. Theories in Cognitive Science

The Attention System

Early attention research provided theoretical background for how visual attention works differently in voluntarily versus involuntarily scenarios (Jonides, 1983; Posner, Cohen, & Rafal, 1982; Warner, Joula & Koshino, 1990). Although various approaches were used to understand the attentional mechanisms of voluntary and involuntary attention, involuntary attention was largely related to peripheral cues, while voluntary attention was related to central cues (Warner, Joula & Koshino, 1990).[7] Kaplan and Kaplan (1989) used attention research to identify "voluntary attention" as a negative mental condition caused by efforts to focus on uninteresting situations, such as urban environmental settings. When such voluntary attention is repeated, "mental fatigue" occurs and debilitates attention function. "Involuntary attention," however, requires no effort (Kaplan, 1993). Involuntary attention caused by natural exposure, therefore, may possibly spur attention restoration.

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recording and data processing.

[7] Later studies argue that peripheral cues are not always associated with involuntary attention, and the dichotomy of voluntary/involuntary attention follows more subtle and complex mechanisms (Kingstone et al., 2003; Prinzmetal et al., 2005). However, this specific discussion is out of the scope of this dissertation.

To further understand processes of attention, "sustained attention" describes the capacity to maintain and control attention over time, which is critical for everyday tasks (Maclean et al., 2010; Sarter, Givens, & Bruno, 2001). It is a fundamental component of general cognitive ability and closely related to learning and memory (Cowan, 1995; Maclean et al., 2010; Sarter et al., 2001). Maintaining attention is essential for focusing on tasks, avoiding distractions, and behaving positively towards others (Lee, Gino, & Staats, 2014; Muraven & Baumeister, 2000; Podsakoff, Whiting, Podsakoff, & Blume, 2009; Schwartz & Kaplan, 2006). Controlling attention, however, requires effort, and the effort to maintain attention may diminish well-being and productivity (Maclean et al., 2010; Sarter et al., 2001; Sonnentag, Binnewies, & Mojza, 2010). According to attention-resource models, sustaining attention control depletes underlying mental resources (Davies & Parasuraman, 1982; Maclean et al., 2010). Neuroimaging studies show that sustaining attention involves two different networks in the brain (Maclean et al., 2009; Sarter et al., 2001). Efforts to maintain attention on work tasks are processed cortically through the dorsal attention network (Paus et al., 1997; Sturm & Willmes, 2001), while external distractions are processed sub-cortically through the ventral attention network (Corbetta & Shulman, 2002; Maclean et al., 2009). These brain areas are less active after performing demanding tasks, emphasizing the effects of exhausted mental resources (Lim et al., 2010).

Posner and Petersen (1990) have established a comprehensive framework to describe the processes of brain areas engaged in attention control, together called the attention system (Petersen & Posner, 2012; Posner & Petersen, 1990). The attention system employs three networks - alerting, orienting, and executive control - which are independent but interconnected. Alerting is responsible for achieving and maintaining alertness; orienting selects information from sensory

input for processing; and executive control monitors and resolves tasks (Petersen & Posner, 2012). Executive control is also related to concentration and control of the orienting network, which requires mental resources and thus voluntary attention (Fuentes, 2004). On the other hand, alerting and orienting networks are both accessible with or without voluntary attention (McCormick, 1997). The orienting network is subdivided into endogenous and exogenous networks. Endogenous networks, or voluntary orienting attention, describe a focus-directed, conscious form of attention controlled by the dorsal attention network. Exogenous networks, or involuntary orienting attention,describe automatic and pre-consciously absorbed attention driven by external stimuli and and controlled by the ventral attention network (Corbetta & Shulman, 2002; Godijn & Theeuwes, 2003).

Posner and Petersen (1990)'s attention system framework may explain Kaplan (1995)'s Attention Restoration Theory (Williams et al., 2018). In this framework, fascinating natural stimuli, which are involuntarily captured, would be processed through exogenous orienting attention by the ventral attention network. This process grants respite and restoration to voluntary and directed attention networks like alerting, endogenous orienting, and executive networks (Berman et al., 2008). The contact with vegetation grant rest to dorsal attention and executive control, while maintaining involuntary attentional and soft-fascination-driven ventral attention and thus enhancing attention restoration and working memory performance.

To measure people's cognitive performances, researchers conducted several experiments. For example, Lan and colleagues (2009) proposed a neurobehavioral approach to evaluate office workers' performance under different thermal environments which measured four cognitive functions: perception, learning, memory, and executive functions. Other studies tested number

calculation, memory, reading, and reaction to evaluate office workers' performance (Hocking, Silberstein, Lau, Stough, & Roberts, 2001; Lan, & Lian, 2009; Lan, Lian, Pan, & Ye, 2009; Toftum, Wyon, Svanekjær, & Lantner; 2005). Finally, text typing speed and accuracy were also considered indicators of cognitive performance by several researchers (Seppanen & Fisk, 2006; Toftum et al., 2005).

Working Memory

Voluntary attention (directed attention) and working memory are closely related (Awh, Vogel, & Oh, 2006; Gazzaley & Nobre, 2012), and since contacts with natural stimuli restore (directed) attention (Kaplan & Kaplan, 1989), exposure to nature may also be expected to enhance performance on memory tasks.

Working memory is associated with controlled attention (the central executive system). It is linked to the prefrontal cortex and the anterior cingulate cortex, and its capacity correlates with the efficiency of controlled attention (Awh et al., 2006; Posner & Peterson, 1990). Baddeley differentiates the central executive system into two slave systems, the phonological loop and a visuospatial sketch pad, which process for verbal information and visuospatial information, respectively (Baddeley, 1992). Studies using EEG, fMRI, and other brain imaging methods confirm the above-mentioned theory that visuospatial working memory is maintained by a prefrontal network and a frontoparietal network of executive functions (Diwadkar et al., 2000, Gazzaley & Nobre, 2012; Sauseng et al., 2004; 2005).

EEG analysis locates working memory in the theta and upper alpha frequency range of the frontoparietal network. Higher memory loads (calculation, working memory task and/or focused attention) increase frontal midline theta EEG (Aftanas and Golocheikine, 2001; Gevins et al., 1997; Onton et al., 2005). In addition, alpha amplitude attenuated with increased task difficulty (Gundel & Wilson, 1992; Sauseng et al., 2005). However, Klimesch et al. (1999) reported the opposite result: an increase of the upper alpha (10-12 Hz) amplitude during a digit-span working memory task.

2.5. Role of Nature in Built Environment

Impact of Perceived Nature in Built Environments

Evidence suggests that, people perceive man-made built environments and natural environment differently (Torralba & Oliva, 2003; Vailaya et al., 1998); thus compared to urban exposure, natural exposure may have a restorative effect on human health and well-being (Bowler et al., 2010; Calogiuri & Chroni, 2014; Velarde, Fry & Tveit, 2007). For example, natural settings, especially urban green spaces, can reduce negative feelings among urban dwellers (Bonnes, Passafaro, & Carrus, 2011; Burgess, Harrison, & Limb, 1988; Henwood & Pidgeon, 2001). Various research shows a number of emotional effects from exposure to the natural environment, including reduced anxiety and stress, improved mood, and etc. (Hartig, Evans, Jamner, Davis, & Gärling, 2003; Nakamura & Fujii, 1992; Pearson & Craig, 2014; Tyrväinen et al., 2014; Ulrich, 1979; Van der Berg et al., 2003). In addition, exposure to nature improves cognition and reduces work stress (Berman, Jonides, & Kaplan, 2008; Bjørnstad, Patil, & Raanaas, 2016; Korpela, De Bloom, &

Kinnunen, 2015; Sianoja, Syrek, de Bloom, Korpela, & Kinnunen, 2018); it also improves working memory and attention (Berman, Jonides & Kaplan, 2008; Lee, Williams, Sargent, Williams, & Johnson, 2015; Taylor & Kuo, 2009). Finally, an epidemiological study claims that the frequency and length of visits to urban parks in neighborhoods promotes better population health indexes and reduces income-related health inequalities (Mitchell & Popham, 2008).

The literature therefore strongly suggests that how we feel and experience the environment affects us physically and psychologically. Several studies trace the relationship between landscape preference and human health (Bixler & Floyd, 1997; Korpela & Hartig, 1996; Van den Berg et al., 2003). For example, Purcell, Peron, and Berto (2001) propose that the restorative quality of landscapes contribute to different preferences for various scene types, with a strong correlation between restoration and preference. Further, streets with trees and plants and savannah-like landscapes are preferred over other types of environments (Jiang et al., 2015; Jorgensen et al., 2002; Williams & Cary, 2002), and these landscapes have also been shown to mediate recovery from stress (Jiang et al., 2016; Li & Sullivan, 2016), provide attention restoration (Kuo, 2001; Li & Sullivan, 2016; Taylor et al., 2001), and decrease criminal behavior while improving pro-social behaviors (Holtan et al., 2015; Kuo & Sullivan, 2001). Similarly, Korpela, Hartig, Kaiser, and Fuhrer (2001) demonstrate that pleasant places elicit significantly higher levels of Kaplan's four restorative qualities (being away, fascination, extent, and compatibility) than unpleasant places. Also, van den Berg and colleagues (2003) conducted an experiment in which subjects viewed a frightening movie followed by a video of either a natural or man-made environment. Their results indicate that a higher beauty rating is associated with greater affective recovery from stress. Furthermore, the researchers found that attentional fatigue resulted in a favorable preference for

natural settings over built environments when simulating a walk-through experience (Staats et al., 2003; Staats & Hartig, 2004).

However, despite the established negative psychological effects of built environments, other research shows that nature can mitigate the negative psychological influences of built environments. Urbanized built environments with more natural elements may, therefore, be more restorative (Hernández & Hidalgo, 2005). Studies demonstrate that the amount of green space in neighborhood environments (defined as a one to three kilometer radius from the home) has a positive association with both perceived general health and physiological health as objectively measured via the salivary cortisol patterns (Maas, Verheij, Groenewegen, Vries, & Spreeuwenberg, 2006; Thompson et al., 2012; Van den Berg, Maas, Verheih, & Groenewegen, 2010).

While some studies argue that nature does not positively influence participants' mood state, according to their subjective self-report (Kuo & Sullivan, 2001; Tennessen & Cimprich, 1995), many show that exposure to natural settings increases the positive mood of participants (Barnicle & Midden, 2003; Hartig et al., 1991; Hartig et al., 2003; Laumann et al., 2003; Ulrich, 1981; Ulrich et al., 1991). For example, research has shown that even mere exposure to photographs of nature, as compared to pictures of urban environments, has positive effects on emotional states and stress reduction (Hartmann & Apaolaza-Ibáñez, 2010; Ulrich et al., 1991), with clear implications for studies of restorativeness. The influence of nature is so powerful that even simple indoor plants, nature seen through the window, or an image/video of nature, can promote human health (Kim, J., Cha, S. H., Koo, C., & Tang, S., 2018; Raanaas, Patil, & Hartig, 2010; Raanaas, Patil, & Alve, 2016; Tzoulas et al., 2007). Such experiments show that nature is a positive resource that can reduce and restore stress from unwanted information. Other experiments reinforce these findings

by suggesting that indoor plants can reduce acute stress (Dijkstra et al., 2008; Lohr, Pearson-Mims, & Goodwin, 1996), and that people evaluate healthcare settings more positively after the introduction of indoor plants (Bringslimark, 2007). Finally, studies comparing photographs and images of urban and natural landscapes with human responses (stress, mental fatigue, recovery from illness, and people's health and well-being) suggest the positive psychological effects of natural environments (Velarde, Fry, & Tveit, 2007).

Some studies have adopted brain functioning mechanisms to analyze the positive effects of natural environments. For example, Kim et al. (2010) use fMRI to examine brain activation in response to images of natural or urban scenery. Their results show that urban scenes enhance activity in the amygdala, which is associated with emotions like impulsivity, anxiety, and stress (Gopal et al., 2013; Kim et al., 2011; Veer et al.,2011). Laumann et al. (2003) have measured heart rate responses before and after viewing a video of either a natural or an urban environment. While viewing the videos, the participants who viewed nature scenes had a lower heart rate (measured as a difference from the baseline) as compared to participants who viewed urban scenes. Other studies reveal the impact of exposure to nature on the brain area associated with tranquility, relaxation, and positive social behavior (Fan, Dunkan, de Greck &, Northoff, 2011; Hunter et al., 2010; Lamm, Decety, & Singer, 2011; Nakamura & Fujii, 1992). Studies that used EEG devices to measure nature's influence discovered an increase in alpha activity in the EEG (Chang, Hammitt, Chen, Machnik, & Su, 2008; Ulrich, 1981) and an enhanced EEG activity related to meditation and arousal (Roe, Aspinall, Mavros, & Coyne, 2013). Recent studies have used affordable and portable EEG equipment to record brain activity outdoors, and have reported results that are consistent with those obtained in laboratory experiments (Aspinall et al., 2015; Chen, He, & Yu, 2016).

Effects of Indoor Vegetation

Studies advocating for the positive influence of outdoor nature have provided the theoretical background for understanding the benefits of indoor vegetation. However, as opposed to outdoor nature experiences, the psychological and physiological benefits of nature experienced via indoor vegetation have not achieved adequate attention, despite the fact that Americans spend approximately 90 percent of their time indoors (Klepeis et al., 2001; U.S. Department of Labor, 2006). The resulting question is whether indoor vegetation offer the same or similar benefits provided by outdoor vegetation in nature. Cognitive psychological research discovered that people visually perceive indoor and outdoor scenes differently (Torralba & Oliva, 2003). If our brains process indoor and outdoor settings distinctively (Henderson et al., 2007), then how might the psychological and physiological benefits of indoor plants differ from their outdoor counterparts?

A number of studies have investigated the effects of indoor plants on the well-being and efficiency of office workers via factors like perceived stress, stress recovery, emotional states, task performance, productivity, sick leaves, and etc. (Adachi et al., 2000; Bringslimark, Hartig, & Patil, 2007; Chang & Chen, 2005; Coleman & Mattson, 1995; Fjeld, Veiersted, Sandvik, Riise, & Levy, 1998; Kaplan, 1993; Khan, Younis, Riaz, & Abbas, 2005; Kim & Mattson, 2002; Larsen, Adams, Deal, Kweon, & Tyler, 1998; Lohr et al., 1996; Raanaas Evensen, Rich, Sjøstrøm, & Patil, 2011; Shibata & Suzuki, 2001, 2002, 2004). Generally, the results support the research questions guiding this dissertation. For example, office workers are more satisfied in work environments with plants and window views (Dravigne, Waliczek, Lineberger, & Zajicek, 2008; Kaplan, 2007; Shoemaker, Randall, Relf, & Geller, 1992). Chang and Chen (2005) also show people are less nervous or anxious when indoor plants are present and/or participants view nature from a window. Larsen and

his colleagues (1998), however, found a somewhat controversial outcome. They argue that while workers' self-reported perceptions of performance, mood, and comfort have a linear association with the number of plants in their office, the actual productivity of these workers decreases with more plants. They also find that indoor plants have greater and more effects on male subjects than on female subjects and suggest leafy plants may increase creativity.

Some studies have looked at the cognitive benefits of indoor plants in office workers and discovered that they do improve cognitive performance (Larsen et.al, 1998; Lohr et al., 1996; Shibata & Suzuki, 2001, 2002, 2004). Shibata and Suzuki (2002) propose that indoor plants enhance performance on creative tasks (association tasks), while they distract a person working on attentionally demanding tasks (but only for male participants). Psychological and physiological benefits and improved student performance have also been reported in classrooms with indoor plants (Doxey, Waliczek, & Zajicek, 2009; Han, 2009). Unfortunately, several studies failed to find that indoor plants have either significant effects (or sometimes any effects) on emotional states (Larsen et al., 1998; Lohr & Pearson-Mims, 2000; Shibata & Suzuki, 2001, 2002, 2004). Yet, in a more recent study, Zhang et al. (2016) claims that wooden indoor environments generate more positive emotions in the Profile of Mood States (POMS) survey and less fatigue compared to non-wooden rooms.

Studies also focused on the therapeutic benefits of contact with nature in healthcare facilities (Park & Mattson, 2008, 2009; Raanaas, Patil, & hartig, 2010; Ulrich, 1984). Ulrich's (1984) initial study discovered the positive effects of a window view of nature including increased positive feelings, reduced anxiety, and greater restoration. Park and Mattson (2008, 2009) proposed the benefits of indoor plants on physiological markers like blood pressure, heart rate, pain, anxiety,

fatigue, positive moods, and satisfaction. Other experiments have shown increased pain tolerance and fast recovery (Diette et al., 2003; Lohr & Pearson-Mims, 2000; Park, Kim, & Mattson, 2004; Raanaas Evensen, Rich, Sjøstrøm, & Patil, 2011), and decreased stress levels (Dijkstra et al., 2008; Kim & Mattson, 2002; Liu et al., 2003) while viewing indoor plants.

Other research in this area has sought to understand the varied effects of different types of foliage. Studies varied the number, size, and distinctions between plants along with the size, location and atmosphere of their experiment environments. Across these variances, a number of studies suggest that flowering plants are more effective compared to foliage plants in reducing stress (Kim & Mattson, 2002), increasing pain tolerance (Park et al., 2004), and boosting the perceived attractiveness of the room (Adachi, Rohde, & Kendle, 2000).

Influence of Vegetation in Built Environments on Attention Restoration

The quality of the built environment clearly influences human health and well-being. Among various urbanized built elements, nature helps people cope with everyday stress and improves the health of residents (Frumkin, 2001; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Maller, Townsend, Pryor, Brown, & St Leger, 2005). Previous research shows that vegetation help reduce stress and enhance restorativeness (Hartig, Evans, Jamner, Davis, & Gärling, 2003; Herzog, Maguire, & Nebel, 2003; Laumann, Gärling, & Stormark, 2003). Van den Berg, Jorgensen, and Wilson (2014) examined the restorative impacts of urban public spaces in different settings. Participants in natural conditions showed stronger recovery from stress compared to urban streets (but did not show significant differences in recovery among the different

natural settings). Proximity to green space has been associated with lower levels of stress (Thompson et al., 2012) and reduced depression and anxiety (Beyer et al., 2014). While it is true that a study conducted in Portland, United States, found no differences in salivary cortisol concentration when exposed to four different urban settings (the setting ranged from very natural to very built) (Beil & Hanes, 2013), the study has significant flaws - in addition to its small sample size (15 people), participants visited each site for only a brief period of time (20 min), and thus may not have stayed long enough to allow for measurable changes in salivary cortisol.

Overwhelmingly, the research shows that natural environments offer a more efficient restorative atmosphere from stress and depleted emotion and attention than built environments (Thompson Coon et al., 2011). Empirical studies generally show the significant restorative potential (improvements in mood) of exposure to natural settings as compared to built environments (Bowler, Buyung-Ali, Knight, & Pullin, 2010; Thompson Coon et al., 2011; Velarde et al., 2007). For example, studies on school children in the Netherlands discovered that greening schoolyards improved attention restoration and social well-being of the students (van Dijk-Wesselius et al., 2018). In addition, studies that compare walking in a park versus walking through an urban street (Hartig et al., 2003), working in a place with a view of trees and parks versus working in a place with a view of buildings, parked cars and paved areas (Shin, 2007), and viewing waterside environments versus urban pedestrian streets on video (Laumann, Garling, & Stormark, 2003) all support the claim of nature's restorative benefits in built settings.

Influence of Vegetation in Built Environments on Attention Capacity

Research indicates that compared to urbanized built environments, natural environments improve attention and task performance along with human mood states (van den Berg, Koole, & van der Wulp, 2003; Hartig et al., 2003; Hartig, Mang, & Evans, 1991; Laumann et al., 2003; Tsunetsugu et al., 2013). For example, one study found that the experience of indoor biophilic environments improved short-term memory by 14%, decreased negative emotion, and increased positive emotion (Yin et al., 2018). Bratman and his colleagues (2015) proposed that 50 minute walks in natural environments enhanced working memory capacity compared to walking in urban environments. Views of nature can improve attention and mood, even with just brief glances (Bratman, Hamilton, & Daily, 2012; Kaplan, 1993, 2001). More specifically, attention can be improved after directly experiencing nature (Hartig, Evans, Jamner, Davis, & Garling, 2003; Lee, Park, Tsunetsugu, Kagawa, & Miyazaki, 2009) or viewing restorative nature scenes (Berman, Jonides, & Kaplan, 2008; Berto, 2005). In high school classroom with green landscape views, too, we can see better attention capacity and stress recovery (Li & Sullivan, 2016).

Literature on plant-human interactions has found that participants perform better on tasks measuring controlled attention if they have a window view of nature (Tennessen & Cimprich, 1995) or green space and trees (Faber-Taylor, Kuo, & Sullivan, 2002, Kuo, 2001; Kuo & Sullivan, 2001; Wells, 2000). Participants also improve their performance on tasks requiring directed attention after they view nature images (Berto, 2005). Moreover, interacting with nature can help children with attention deficits (Taylor & Kuo, 2009) and individuals with depression (Berman et al., 2012). These findings suggest that better performance on controlled and directed attention tasks are due in part to contact with nature, which restores controlled and directed attention. This has potentially

huge implications for architectural studies, as it encourages designs that help users feel comfortable and confident in built spaces through strategic deployments of nature.

Across this body of literature, a wide range of measures have been used to assess cognitive functions when exposed to nature, including the backward digit span task and stroop color tasks (Faber-Taylor & Kuo, 2008; Hartig, Evans, Jamner, Davis & Garling, 2003; Li & Sullivan, 2016), an association task (Shibata & Suzuki, 2002; 2004), an attention network task (Berman et al., 2008), a flanker task (Laumann et al., 2003), a necker cube pattern control task (Hartig et al., 2003), a symbol digit modalities test (Tennessen & Cimprich, 1995), and a vigilance task (Berto, 2005). In terms of specific cognitive performances relating to attention in particular, the backward digit span task is frequently used to measure the working memory's number storage capacity (Ericsson, Delaney, Weaver, & Mahadevan, 2004). The stroop color tasks are also frequently used in restorative research experiments (Gatersleben & Andrews, 2013; Hartig et al., 1991); they require participants to exhibit a high degree of attention and demonstrate suppression and task conversion abilities (Etnier & Chang, 2009).

Visual-reward Mechanisms for Attention Restoration and Attention Capacity

Kaplan's (1995, 2001) Attention Restoration Theory and Ulrich's (1983) Psycho-evolutionary Theory provided a theoretical foundation for understanding the psychological and physiological benefits of nature; however, the actual mechanisms generating these benefits for people were not clear in their work. Thus, research on scene preferences may provide additional insight into how visual reward mechanisms spur restoration and its cognitive benefits in

individuals who make contact with nature.

The way people visually obtain landscape information is critical to their experience of nature; it evokes emotions that influence their landscape preferences (Kaplan & Kaplan, 1989). The resulting preference matrix is based on two binary dimensions: first, whether landscape information is understood or exploratory, and second, whether the scene depends on a two-dimensional or a three-dimensional view (Kaplan et al., 1998; Table 2.4). In this matrix, there are also four cognitive informational variables that work as predictors of environmental preferences: “coherence,” “legibility,” “complexity,” and “mystery.” Coherence (immediate perception) and complexity (immediate cognition) are based on the two-dimensional plane; legibility (exploratory perception) and mystery (exploratory cognition), on the other hand, require three-dimensional insights to comprehend, and demand that people visualize themselves in the scene.

As indicated in table 2.4, coherence and legibility are associated with environments that are well organized and provide direct information that assists people in understanding the environment. Complexity and mystery, however, include the possibility for exploration either through diverse components or the implication of “something more.” Individual preferences for nature and place depend on these four elements, and subtle changes to any one of them can create significant differences in peoples’ perception and cognition (Kaplan et al., 1998).

In research emphasizing biological methods, images preferred by participants were associated with greater blood-oxygen-level-dependent responses in the right parahippocampal cortex (a part of the brain with a high-density of cortical μ-opioid receptors used in scene processing) which resides in the ventral visual pathway (Biederman & Vessel, 2006; Yue, Vessel

& Biederman, 2007). This cortex evokes opioid reward systems which regulate pain, stress, and emotion (Merrer, Becker, Befort, & Kieffer, 2009). When in contact with nature, people reported reductions in pain (Lechtzin et al., 2010) and stress (Valtchanov & Ellard, 2010, and increases in restorativeness (Grinde & Patil, 2009), which is similar to activation of opioid reward systems (Valtchanov & Ellard, 2015).

Table 2.4

The Preference Matrix (Adapted from [Kaplan et al., 1998])

	Understanding	**Exploration**
Two-dimensional	Coherence	Complexity
Three-dimensional	Legibility	Mystery

Neuroscientists explain that visual information from natural scenes is coded and represented through spatial frequencies in the brain (Geisler, 2008; Simoncelli & Olshausen, 2001). Valtchanov and Ellard (2015) suggest an association between visual information processes and restorative responses. They hypothesize that the spatial frequency activated by opioid reward systems stimulates the soft fascination in ART and the initial affective response in SRT. Their results indicate that stress and cognitive load are associated with the low spatial frequencies of the photos, while affective responses are closely related to mid-to-high spatial frequencies (Valtchanov & Ellard, 2015).

2.6. Methods of Measurement

Self-report versus Psychophysiological Experiences

The several ways of measuring how people experience their environments can be sorted into two broad categories: self-reporting and psychophysiological measurement. Self-reporting uses questionnaires, surveys, standardized scales and/or interviews to acquire assessments of subjects' own emotional state and cognitive situation. Mauss and Robinson (2009) reviewed the available means for measuring emotional states, and concluded that self-reports are well adjusted to measure experiences during the moment of the experience in question but are less reliable with regard to past experiences. In addition, participants with high social desirability may not sincerely answer self-reports on negative emotional states.

Psychophysiological measurement techniques, on the other hand, are designed to assess activity in a variety of bodily systems. These techniques may augment self-reports to reach beyond the limitations of subjective evaluations. In other words, psychophysiological measurements complement other research approaches, especially when the other psychological methods, such as conscious recollection and behavioral observation, fail to fully or accurately represent the interests and emotions of subjects (Parsons & Tassinary, 2002). Commonly adopted psychophysiological measurements in precedent studies include fMRI, hormone analysis, the body's electrophysical activity (e.g., EMG, ECG, EEG), and etc. (Gaffey & Wirth, 2014). Research on EEG signals has been associated with the emotional evaluation of stimuli in the brain (Mauss and Robinson, 2009; Davidson, 2004). In particular, relative left frontal activity (rLFA) is seen as a simultaneous and prospective marker of emotional processing; thus 'frontal asymmetry', which refers the relative

activation of the left versus the right hemisphere, works as both a mediator and moderator of emotion (Reznik & Allen, 2018). Furthermore, EEG alpha and theta oscillations are related to attention and memory performance (Klimesch, 1999). In particular, EEG alpha and theta synchronization, oscillation, and coherence reflect working memory and attention capacity (Aftanas & Golocheikine, 2001; Gevins et al., 1997; Sauseng, Klimesch, Doppelmayr et al., 2005; Sauseng, Klimesch, Schabus, et al., 2005). Alpha and theta synchronization are also associated with restorative experience in meditation studies (Cahn & Polich, 2006; Travis & Wallace; 1999), and alpha synchronization is related to cognitive inactivity and the inhibition of sensory information (Knyazev et al., 2006), which describes the conditions for restorative condition.

In Situ versus Substitute Image Studies

The field of environmental psychology conducts three types of studies on the influence of nature: in situ, laboratory setting, and substitute image. In situ studies take place in non-artificial physical environments like the wilderness (Hartig, et al., 1991; Kaplan & Talbot, 1983), forests (Martens, Gutscher, & Bauer, 2011; Takayama et al., 2014; Tsunetsugu et al., 2013), woodlands, urban parks (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007; Grahn & Stigsdotter, 2003; Sianoja et al., 2018), gardens (Dunnett & Qasim, 2000; Ivarsson & Hagerhall, 2008), existing buildings (e.g. care facilities, educational facilities, and offices), and other urban areas (Carrus et al. 2015; Tyrväinen et al., 2014; Qin, Zhou, Sun, Leng, & Lian, 2013). Experiments taking place in in situ settings have limited controls over environmental factors like weather conditions, ambient noise and traffic, and unwanted stimulation from passing persons which may influence

procedures and findings. Until recently, convergence studies like collaborations with neuroscience were not possible with in situ settings because of the size of the measurement devices (e.g. fMRI, PET or MEG scanners) and the need for participants to remain immobile for these devices.

To minimize the undesirable interferences associated with in situ environments, some studies conduct experiments in controlled, semi-artificial physical environments, such as laboratories, offices, and hospitals (Alvarsson, Wiens, & Nilson, 2010; Bringslimark, Hartig, & Patil, 2007; Kim et al., 2018; Larsen et al., 1998; Lohr & Pearson-Mims, 2000; Park & Mattson, 2008, 2009; Raanaas, Patil, & Hartig, 2010; Shibata & Suzuki, 2002; Shibata & Suzuki, 2004).

Also, many studies involve the experience of artificial settings using images, video walk-throughs, or even virtual-reality simulations (Chang et al., 2008; Chiang, Li, & Jane, 2017; Gatersleben & Andrews, 2013; Grassini, et al., 2019; Hartmann & Apaolaza-Ibáñez, 2010; Herzog & Chernick, 2000; Herzog et al., 2003; Jiang, Chang, & Sullivan, 2014; Jiang et al., 2016; Kim et al., 2010; Lee et al., 2015; Lindal & Hartig, 2015; Suppakittpaisarn et al., 2019; Van den Berg, Jorgensen, & Wilson, 2014; Valtchanov & Ellard, 2015; Wilkie & Stavridou, 2013). As mentioned, while some research has been conducted in situ, the majority has been conducted in controlled conditions using photographs as a substitute for the real-world. Stamps (1990) meta-analyzed the validity of the photographic material and concluded that the photographs maintain the representational validity of the in situ setting. In addition, presenting images in the laboratory eliminates many potential inconveniences which researchers may confront during in situ studies and may also increase accessibility for participants, thus reducing bias and increasing the validity of the study by involving more subjects. The proponents of artificial research settings argue that photos and videos replicate the precise visual stimuli of existing experiments and therefore garner

similar results to in situ settings but with the aforementioned advantages.

Using artificial experiences as substitutes for in situ experience, on the other hand, has raised persistent questions of ecological validity. Specifically, it is unclear whether the findings from artificially modified and/or controlled settings' modalities are equivalent, comparable and/or applicable to real-world behavior. In some studies, researchers presented both in situ settings (such as walking in nature) and substitute image setting (such as viewing pictures of nature) and compared the difference (Berman, Jonides, & Kaplan, 2008); however, studies adopting mixed methods of stimuli are relatively rare.

Perceived Restorativeness Scale (PRS)

Various efforts have been made to objectively measure the perceived restorative potential of environments: The Perceived Restorativeness Scale (PRS; Hartig et al., 1997), the Restorative Components Scale (RCS; Laumann et al., 2001), the Restoration Outcome Scale (ROS; Korpela, Ylén, Tyrväinen, & Silvennoinen, 2008), and the Perceived Restorative Characteristics Questionnaire (PRCQ; Pals et al., 2009), to name a few. These scales have been reviewed, validated, and widely adopted in many studies.

The PRS is the most frequently used measure of the restorative components of the environment in a variety of fields, not just environmental psychology (Bodin & Hartig, 2003; Lehto, 2013; Norling, Sibthorp, Ruddell, 2008; Pals, Steg, Siero, & Van der Zee, 2009). It is a 26-item scale that asks participants to rate their opinions regarding questionnaires related to the restorativeness of environments based on their perceived intuition related to surrounding

environmental settings (Hartig, et al., 1997). The scale is designed to measure 5 restorative factors: "being-away" from directed attention; "fascination" as effortless attention; the "coherence" and "scope" perceived in an environment; and lastly, the "compatibility" between an individual and the environment, based on the individual's perception[8] (Berto, 2005; Pasini, Berto, Brondino, Hall, & Ortner, 2014; Purcell, Peron, Berto, 2001).

PRS was originally developed as an instrument to assess the validity of Kaplan's Attention Restoration Theory (ART) (Chang, Hammitt, Chen, Machnik, & Su, 2008), but it has expanded to become an accepted measure of psychophysiological stress responses to nature and built environment settings according to Ulrich's Stress Recovery Theory (SRT) (Berto, 2005).

PRS-11 (Pasini, Berto, Brondino, Hall, & Ortner, 2014) is a shorter version of the PRS scale. It was created to improve the psychometric and factorial properties of the previous PRS scale, and it is considered more suitable for research with significant time constraints. The present study selected the PRS-11, instead of the original PRS, for this reason (see Appendix A). The PRS-11 includes four factors from the PRS (fascination, being-away, coherence, and scope) but eliminates compatibility items since it measures personality instead of subjective environment

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[8] Note that Kaplan (1995) originally categorized restorative factors in 4 components in the ART: being-away, fascination, extent, and compatibility. However, the "extent" was detached as two elements: the "coherence" and the "scope" of an environment described by Hartig and collogues (1997) when developing the PRS measurement.

experience (Pals et al., 2009). Each component of PRS-11 has 3 questions, except scope (2 questions), and coherence and scope components were added. The PRS-11 is as follow:

The PRS-11 (in brackets are the original number and factor in Hartig et al.'s [1997] scale)

Fascination

Places like that are fascinating (FA 12)

In places like this my attention is drawn to many interesting things (FA 7)

In places like this it is hard to be bored (FA 11)

Being Away

Places like that are a refuge from nuisances (BA 1)

To get away from things that usually demand my attention I like to go to places like this (BA 5)

To stop thinking about the things that I must get done I like to go to places like this (BA 4)

Coherence

There is a clear order in the physical arrangement of places like this (COH 15)

In places like this it is easy to see how things are organised (COH 26)

In places like this everything seems to have its proper place (new item)

Scope

That place is large enough to allow exploration in many directions (FA 10)

In places like that there are few boundaries to limit my possibility for moving about (new item)

Backward Digit Span Task

In behavioral neuroscience, primary attention is associated with alerting, orienting, and executive monitoring. Alerting attention, meaning the effortful process of preparedness during task; orienting attention, meaning the response-shifting process from sensory stimulations in the environment; and executive monitoring of performance, meaning the coordination of competing demands, including planning, anticipating, selecting, maintaining, monitoring, modifying, and etc. (Mezzacappa, 2004; Posner & Petersen, 1990). Executive functions are mechanisms that control the cognitive processes that successfully complete tasks (Persson, Welsh, Jonides, & Reuter-Lorenz, 2007). When individuals encounter cognitively challenging tasks, cognitive fatigue or resource depletion takes place (Parasuraman, 1998). As demands overloaded executive control a failure of executive function may occur (Hockey, 2011). When suffering from this failure, the executive function may benefit most from contact with restorative environments, such as nature (Berman, Jonides, & Kaplan, 2008).

The backward digit span task measures essential components of the executive function (Baddeley & Hitch, 1974; Engle, 1996; Lehto, 1996; Lezak, 1995). It is used in numerous experimental studies in both neuroscience (Berka, et al,, 2007; Colom, Jung, & Haier, 2007; Davis & Pratt, 1995; Hadwin, Brogan, & Stevenson, 2010) and nature (Berman et al., 2008; Bodin &

Hartig, 2003; Cimprich & Ronis, 2003; Kuo, 2001; Ottosson & Grahn, 2005; Tennessen & Cimprich, 1995) with reportedly positive effects (Berman et al., 2008; Cimprich & Ronis, 2001; Kuo, 2001; Ottosson & Grahn, 2005). The backward digit span task is highly correlated with working memory capacity (Colom, et al., 2007; Hedden & Gabrieli, 2004; Lefebvre et al., 2005) and short-term memory (Colom, et al., 2005; Richardson, 1977)[9].

During the backward digit span task, the experimenter visually or orally presents digits, beginning with two to three digits and increasing up to a maximum of nine digits. The participants are asked to repeat the strings of digits in the reverse order. There are two examples of each digit combination for a total of fourteen trials, and the task is discontinued when the subject makes two consecutive failures. The total number of correctly recalled digits are reported as a backward digit span (Berman et al., 2008; Hilbert, Nakagawa, Puci, Zech, & Bühner, 2015; Lehto, 1996).

Other cognitive tasks used in earlier studies of the effects of indoor plants' effects include a key response task (Lohr et al., 1996; Shibata & Suzuki, 2001), a letter identification task (Larsen et al., 1998), and a word association test (Shibata & Suzuki, 2002, 2004); however, these tasks do not have a strong association with executive function. Other cognitive tasks that were used in neuropsychology are a Sustained Attention to Response Task (SART; Johnson, Kelly, et al., 2008;

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[9] Some researchers claim that the backward digit span task only taps working memory capacity, while forward digit span task taps short-term memory (Hedden & Gabrieli, 2004). However, specifying the exact use of backward digit span task is out of this study's domain.

Robertson et al., 1997), a Stroop task (Hiatt, Schmitt, William, & Newman, 2004; MacLeod & MacDonald, 2000), an Applied Cognitive Task Analysis (ACTA; Militello & Hutton, 2010), and etc. The present study chose the backward digit span task to assess the executive function of attention.

Electroencephalography (EEG)

Psychophysiology is a branch of psychology that deals with the interaction between the mind (psyche) and body (physiology). It is a multidisciplinary subject that studies the cognitive, emotional, and behavioral phenomena instigated by psychological stimuli (Cacioppo & Tassinary, 2007). There have been several tools and techniques developed to monitor physiological responses to mental processes, such as EEG, fMRI, EMG, electrodermal activity (EDA), and etc. This study focuses on EEG.

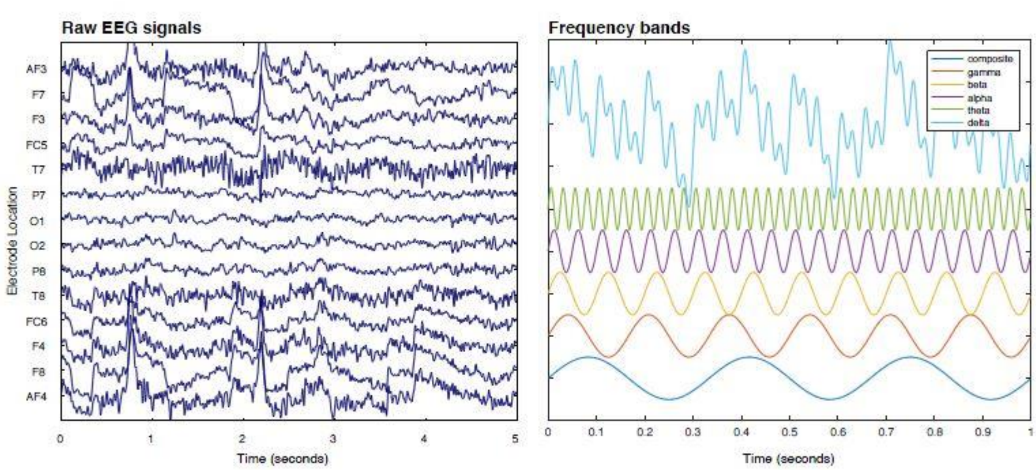
EEG measures brain activity by electrical signals. Human electroencephalogram is a safe and non-invasive neuroimaging method; therefore, it has been used in various fields of research for many years as a way of encoding brain activity related to human behavior, response and emotion. EEG records the electric signals of a human brain produced by the synchronised post-synaptic activity of large neuronal assemblies in the cortex (Buzsáki, 2006; Misulis, 2007; Lopes da Silva, 2009). In other words, the neurons operating with the same frequency and phase oscillation create electrical fields via changes in the electrical capacities between electrodes and reference electrodes (Buzsáki, 2006; Nunez et al., 2001). To detect these changes, electrodes are applied to the scalp. The number of electrodes ranges from 3 up to 256, with two reference

electrodes placed on either the nose, the ear lobe or the mastoid processes. The position of the electrodes on the scalp typically follows the 'International 10-20 system,' a standardized method to place the electrodes consistently regardless of anatomical differences, such as size or shape of head (Jasper, 1958). To acquire close connectivity between the scalp and the electrode, a conductive gel is most often used. However, recent commercially oriented devices use wet (saline solution) or dry electrodes (no medium required) to make devices suitable for everyday use.

EEG signals are only few microvolts (mV) and they are excessively dynamic; as a result, they cannot be analyzed with descriptive statistics (e.g. mean, standard deviation, and etc.) (Figure 2.4). However, one way to analyze raw EEG signals is in the frequency domain, wherein the intensified oscillations are calculated in epoch. More specifically, EEG measures cognitive and mental states or related psychological phenomena using dynamic and non-stationary signals.

Figure 2.4

Left: Example of Raw EEG Signals from Multiple Electrodes. Right: Illustration of the Main EEG Frequency Bands (Delta, Theta, Alpha, Beta, Gamma, and Composite) (Mavros, 2018)



The frequency bands traditionally analyzed in psychophysiological research are Delta (δ; 0.5-4 Hz), Theta (θ; 4-8 Hz), Alpha (α; 8-13 Hz), Beta (β; 13-30 Hz), and Gamma (γ; 30+ Hz) (Sanei & Chambers, 2007; Table 2.5; Figure 2.5). The activities of each band relate to specific brain areas, and specific patterns of frequency bands have therefore been associated with specific cognitive functions (Smelser & Baltes, 2001).

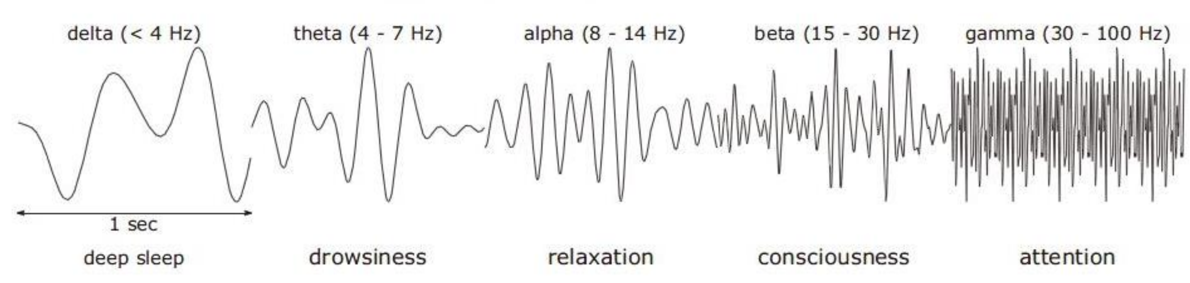
Table 2.5

Major EEG Frequency Bands and Some Associated Brain or Behavioral States (Misulis, 2007)

Name	Frequency band	Associated features
δ (delta)	0.5 - 4 Hz	deep sleep
θ (theta)	4 - 8 Hz	drowsiness, navigation, cognitive load
α (alpha)	8 - 13 Hz	eyes closed, relaxation, deactivation
β (beta)	13 - 30 Hz	alertness or cognitive demands
γ (gamma)	30 > Hz	various cognitive processes

Figure 2.5

Commonly Recorded EEG Frequencies (Roberts, Christopoulos, Car, Soh, & Lu, 2016)



Alpha activity is the most projecting wave among the frequency bands. Increased alpha activity is related to relaxation and restful and meditative states, whereas alpha suppression is related to mental concentration or attention, such as semantic processing demands (Klimesch, 1999; Klimesch, Sauseng, & Hanslmayr, 2007; Pfurtscheller, Stancak, & Neuper, 1996). Increased beta activity is related to wakefulness, active attention, or cognitive demands (McFarland et al., 2000; Pfurtscheller & Neuper, 1997). Delta activity, meanwhile, is associated with deep sleep and restfulness, while delta wave suppression relates to excitement (Knyazev, 2012; Stefanics et al., 2010). Theta bands are associated with drowsiness, REM sleep, and meditative states (Lagopoulos et al., 2009; Misulis 2007; Smelser & Baltes, 2001), while lastly, often-small gamma waves are closely linked with cognitive functions (Engel, Fries, & Singer, 2001; Herrmann & Demiralp, 2005). More specifically, the theta and alpha bands have been used to show the influence of the environment on task performance (Gevins, Smith, & McEvoy, 1997; Klimesch, 1999), and slow EEG waves have a documented relationship with attentional process (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003).

Theta EEG band activity (4-7 Hz) is related to drowsiness, daydreaming, and automatic tasks. When irregular theta activity appears across the entire scalp, it signals drowsiness, which describes the transition between wakefulness and sleep (Lal and Craig, 2001; O'Hanlon and Kelley, 1977). However, when relatively regular theta activity is limited to the frontal cortices, it shows active involvement in cognitive tasks; thus, increasing theta activity in the frontal cortices indicates a surge of cognitive workload (Schacter, 1977). The escalation of theta activity in frontal cortices is due to the activation of executive functions of brain (Asada et al., 1999; Gevins et al., 1997; Pizzagalli et al., 2003; Tsujimoto et al., 2006).

Alpha EEG band activity (8-13 Hz), traditionally known as ‘‘cortical idling,’’ in other words cognitive inactivity, is recorded from the parietal cortex (Pfurtscheller, Stancák, & Neuper, 1996). When alpha activity increases, the number of neurons engaging in task performance decreases (Gevins & Schaffer, 1980; Pfurtscheller & Klimesch, 1992). Increased alpha activity is therefore considered an indicator of low alertness, relaxation, and restful states (Pfurtscheller et al., 1996), while decreased alpha activity is associated with increased task difficulty (Gevins et al., 1979) and mental workload (Scerbo et al., 2001). Moreover, Cooper and colleagues (2003) claim that increased internally directed attention loads - that is, increased alpha activity – indicates an active inhibition of sensory information and non-task relevant cortical areas. There were strong associations between alpha amplitude and both attention and increased task, suggesting the importance of active inhibition on internally driven mental processes.

Theta and alpha EEG activity illustrate a frontal-parietal network controlled by executive functions (Sauseng et al., 2006). Measurements of theta and alpha activity have consequently been widely used in research to discover the adaptive response of task takers (Gevins & Smith, 2000; Gevins et al., 1996; McEvoy et al., 2000). However, increases in theta and/or decreases in alpha activity are not always consistent. One study, for instance, found that individuals with high cognitive ability showed parietal alpha responses, while those with low cognitive ability revealed changes in frontal theta (Gevins & Smith, 2000).

Along with frequency bands, the origin (location) of EEG signals is also important. For example, frontal asymmetrical brain activities have been researched using EEG and fMRI. The results indicate that the left-hemisphere of the brain is more associated with approach emotion, such as happiness or anger, and the right-hemisphere of the brain is more correlated with

withdrawal emotion, such as fear or sadness (Harmon-Jones, 2003; 2004). Recently, researchers have employed the frontal asymmetry model to assess how participants feel (subjectively experience) when exposed to stimuli. Schmidt and Trainor (2001), for instance, applied the frontal EEG asymmetry (alpha) to identify the influence of music on emotions.

Measuring Relaxation (Restoration) with EEG

Attention and relaxation states of mind have been widely studied using EEG (Aftanas & Golocheikine, 2001; Jacobs & Friedman, 2004; Kaur & Singh, 2015; Liu, Chiang & Chu, 2013; Vyšata et al., 2014). Attention and relaxation are significant in various fields, including clinical studies (stress reduction, sleep deprivation, and fatigue), educational studies, and etc.

Relaxation is a state of voluntary resting in both the body and the mind (Teplan, Krakovská & Špajdel, 2014). Though it is difficult to define with exact physiological variables, relaxation has been measured via breath, heart rates, skin conductance, and EEG (Travis, 2001). There are no consistent findings regarding EEG patterns and relaxation. However, increases and severe changes of the alpha and theta activity (Jacobs & Friedman, 2004) and frontal alpha coherence (Travis, 2001) are mostly accepted as neurophysiological indicators of relaxation. As previously mentioned, alpha band activity is associated with relaxed states, while theta band activity is related to drowsiness. Therefore, the ratio of signal power in alpha and theta bands can potentially assess relaxation (Lagopoulos et al., 2009; Mason, Alexander, & Travis, 1997; Travis, 2001). Moreover, Lin and John (2006) suggest that the sum of alpha and theta, and the sum of alpha, beta and theta,

may act as an indicator of neurological relaxation.[10]

Use of Mobile EEG

Until recently, EEG systems were very expensive, bulky, and difficult to operate. Using EEG as a research methodology therefore required firmly controlled experimental settings due to the large equipment and cables, and complicated analytical tools (Gilliam et al., 1999). Thus, the tool was traditionally restricted to medical uses in laboratories aiming to diagnose and manage various brain abnormalities. However, the first mobile EEG device was developed in the 1980s to monitor epileptic seizure patients in hospitals using magnetic tape-recorders (Askamp & van Putten, 2014). Technological advances, such as smaller signal amplifiers and the use of wireless protocols for data-transfer, increased the number of portable low-cost EEG systems available to researchers, and the capabilities and handiness of EEG systems continues to improve.

Today, there are both high-end mobile EEG devices with a large number of electrodes and high sampling rates and consumer-grade mobile EEG with reasonable specification and price, are existing. For example, Emotiv Epoc and Muse are affordable and portable EEG devices. The

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[10] The external validity of this study is not entirely certain as it used computer games as a stimulus and included only ten participants. However, the ratio they discovered may be potentially effective.

technology has even improved enough to enable mobile brain imaging, which scans brain activities while individuals are in active conditions (Makeig et al., 2009; Gramann et al., 2014). EEG devices have unique advantages compared to other brain imaging devices such as fMRI, MEG (Magneto-encephalography) or PET (Positron Emission Tomography) scanner. Lastly, there have been significant developments in EEG recording systems, which have shifted from magnetic tape-recorders, to computers, and now to tablets and smartphones. Software tools for recording EEG run a variety of operating systems, and the 'Smartphone Brain Scanner' project, one of the first to use Android smartphone to acquire and analyze EEG signals, has made mobile EEG more accessible to ambulatory research (Stopczynski et al., 2014).

Recent studies have used portable EEGs to monitor brain function, information processing, and cognition in the real-world, outside the laboratory and to monitor affective states initiated by the surrounding environment (Mavros, Austwick, & Smith, 2016; Potter & Bolls, 2012). The validity of low-cost EEG systems in research has been proven in various studies (Krigolson, et al., 2017) and as a result its use has expanded to disciplines such as architecture, spatial cognition, urban design and planning, landscape architecture, and others (Marvros, Austwick, & Smith, 2016). EEG has been adopted in plant-human research as well; Ulrich's (1981) pioneering study used EEG alpha values as an indicator of physiological stress and claimed dense vegetation stimulates alpha waves. Chang et al. (2008) used EEG as an indicator of attention, and Aspinall and colleagues (2008) used it as a sign of restorative experience. However, EEG is not limited to monitoring the brain. Brain Computer Interfaces (BCI), for example, work as a communication system through which an individual's will and/or commands are sent out to the external world without passing along the brain's nerves and muscles (Wolpaw et al., 2002).

Analyzing EEG

EEG analysis involves signal processing techniques intended to identify and remove noise (irrelevant signals) from the oscillations (raw EEG) reflecting the environmental stimulus. Electrical noise (meaning an alteration in the EEG recording which is not from the human brain electrical potential) is called an artifact (Fisch & Spehlmann, 1999). The sources of artifacts can be either biological or technological. For example, eye artifacts (blinks) are the most common biological cause of noise. Other biological causes of noise include the pulse, ECG, face and neck muscle movement, body or head movements, and skin and sweat (Fisch & Spehlmann, 1999; Lutzenberger et al., 1985). Non-biological artifacts are often caused by the unwanted movement of electrodes on the scalp, interference from external electromagnetic activity or static electric fields, or the cables of electrodes to the EEG recording device (Fisch & Spehlmann, 1999; Lutzenberger et al., 1985). When recording EEG, recognizing the source of artifacts and minimizing their influence is crucial. Artifacts must be suppressed when analyzing EEG data; however, sometimes they are hard to distinguish from real EEG activity. There are many ways to reject unwanted artifacts. The most common approach is to take the visual analysis conducted by EEG experts and eliminate the artifacts manually. After this manual process, researchers run computer-based artifact recognition and removal tools like Independent Component Analysis (ICA), Automated Subspace Removal (ASR), Automatic Artifact Removal (AAR) toolbox, and so on. Once unwanted artifacts are rejected through both manual and automatic processes, the EEG signal is divided into epochs, or segments of equal duration, which are then compared as a form of frequency and/or power over time.

There are numerous EEG signal processing techniques to deploy at this stage; however, the most used are Event-Related Potential (ERP), Event-Related Desynchronization (ERD), and/or Event-Related Synchronization (ERS). ERP analyzes the time- and phase- locked experimental event of the EEG and compares the changes in signal with different conditions (Coles & Rugg, 1995; Jung et al., 2001). ERD/ERS are not phase-locked to the event, and are therefore extremely specific to the frequency band: the signals across the scalp can display ERD and ERS simultaneously (Pfurtscheller & de Silva, 1999). The aim of these analyses is to identify conspicuous signals associated with a targeted stimulus or behavior. These signals can be computed by imaging spectral analysis tools like fast Fourier transforms (FFT; Cooley, Lewis, & Welch, 1969; Welch, 1967), or wavelet transforms (WT; Akin, 2002; Daubechies, 1990). The computation of EEG signals using the above-mentioned tools can also be done with open-source software like EEGLab, a peer-reviewed plug-in for Matlab (Dolorme & Makeig, 2004).

3. Methodology

3.1. Research Questions

The main questions posed by this dissertation relate to research in the fields of human-nature interaction, environmental psychology, cognitive psychology, cognitive neuroscience, neuroarchitecture, and architectural studies. Broadly, this dissertation asks whether exposure to visual stimuli of vegetation influences people's restorative potential and working memory capacity. More specifically, it addresses the following series of questions:

1. **Do indirect and symbolic visual contacts with vegetation in indoor built environment restore people's attention?** [11] Although many studies already demonstrate the relationship between visual contacts and attention restoration (Ulrich, 1981; Hartig, Korpela, Evans, & Gärling 1997), the role of visual contacts with vegetation on attention restoration in Aspinall built environment is still unclear. Among the three methods of contact with nature (direct, indirect, and symbolic), this dissertation

[11] The terms "indirect" and "symbolic" come from Kellert (2002, 2012b)'s classification of contact with nature in biophilic design described in the sub-section *Biophilc Design*, in page 21-22.

focuses on attention restoration from involuntary attention and increased attention capacity due to the restored attention fatigue; thus, it omits direct contact as this would involve voluntary attention by participating in activities in nature. The dissertation looks at both indirect and symbolic visual contact for two reasons: first, the selected sites can partially represent the varying degrees of vegetation, but cannot represent the full spectrum of 0% to 100% vegetation. Second, we cannot argue that one specific site represents an entire single category of vegetation level, since there is always the possibility that other factors in that space may unknowingly influence participants. In real-world experiments, there are numerous factors that may affect the result, beside the level of vegetation. Therefore, symbolic visual contact was also used to address the limitations of indirect in situ experiments, as a supporting representation of real-world vegetation. To answer the initial research question, the first experiment used in situ environments to identify the impact of indirect visual stimulations of vegetation by exposing participants to different amounts of vegetation at each indoor site. The second experiment showed images of nature in indoor built environments to identify the effects of symbolic visual contact with vegetation, as participants viewed images of vegetation within built environments.

2. **Does indirect and symbolic visual contact with vegetation improve people's attention capacity, especially with working memory tasks?** Soft fascination during contact with vegetation may increase attention capacity by restoring controlled attention. As working memory encompasses controlled attention and executive processing, we can assume that restored attention, which exerts attention capacity, will also have an effect

on working memory tasks.

3. **Do different amounts of exposure to vegetation have different influences on attention restoration and working memory capacity?** Unlike natural settings, vegetation within built environments varies in density. Although higher vegetation density has a greater affect on restorativeness and cognitive performance (Chiang, Li, & Jane, 2017), increasing the density of vegetation in indoor built environments may not always be feasible or advised. Also, there is a U-shape curvilinear relationship between exposure to nature and stress reduction (Jiang, Chang, & Sullivan, 2014). This begs the question: what is the most appropriate or efficient level of vegetation in indoor built environments?

4. **Lastly, do varied types of exposure to vegetation (for example, indirect and symbolic) influence attention restoration and working memory capacity differently?** Comparisons of different types of exposure, especially within the in situ environment, have not been fully treated in the literature. While symbolic visual stimuli are thought to represent their indirect visual counterparts, the in situ environment involves other senses as well, which influence the overall experience of people.

3.2. Research Design Overview

Individual emotional responses result from a complex, temporal chain of physiological and psychophysiological responses. As a result, this study uses both physiological and psychological indices/measures. Moreover, although visual signals are probably among the most

important stimuli in experiencing the environments, researchers believe that visual stimuli only partially reflect the differences between the environments. Multi-sensory experiments are necessary to cover the holistic experience of an environment. However, outside field research confronts many obstacles that make it difficult to tell whether the results stem directly from differences in the amount of nature absorbed by each participant.

As a result, the research design employed in the experimental part of this dissertation consists of several elements. Two behavioral experiments were conducted, one concerning the participant's in situ experience of being in indoor vegetated environment, and another concerning the participant's viewing of images of natural settings in an isolated room. An electroencephalographic (EEG) spectral analysis was used to quantify the general effects on brain activity during exposure to the in situ built environment in nature and in images. In addition, a perceived restorative survey was used to measure self-reports of restorativeness and cognitive tasks were conducted to identify attention capacity, especially, working memory modification.

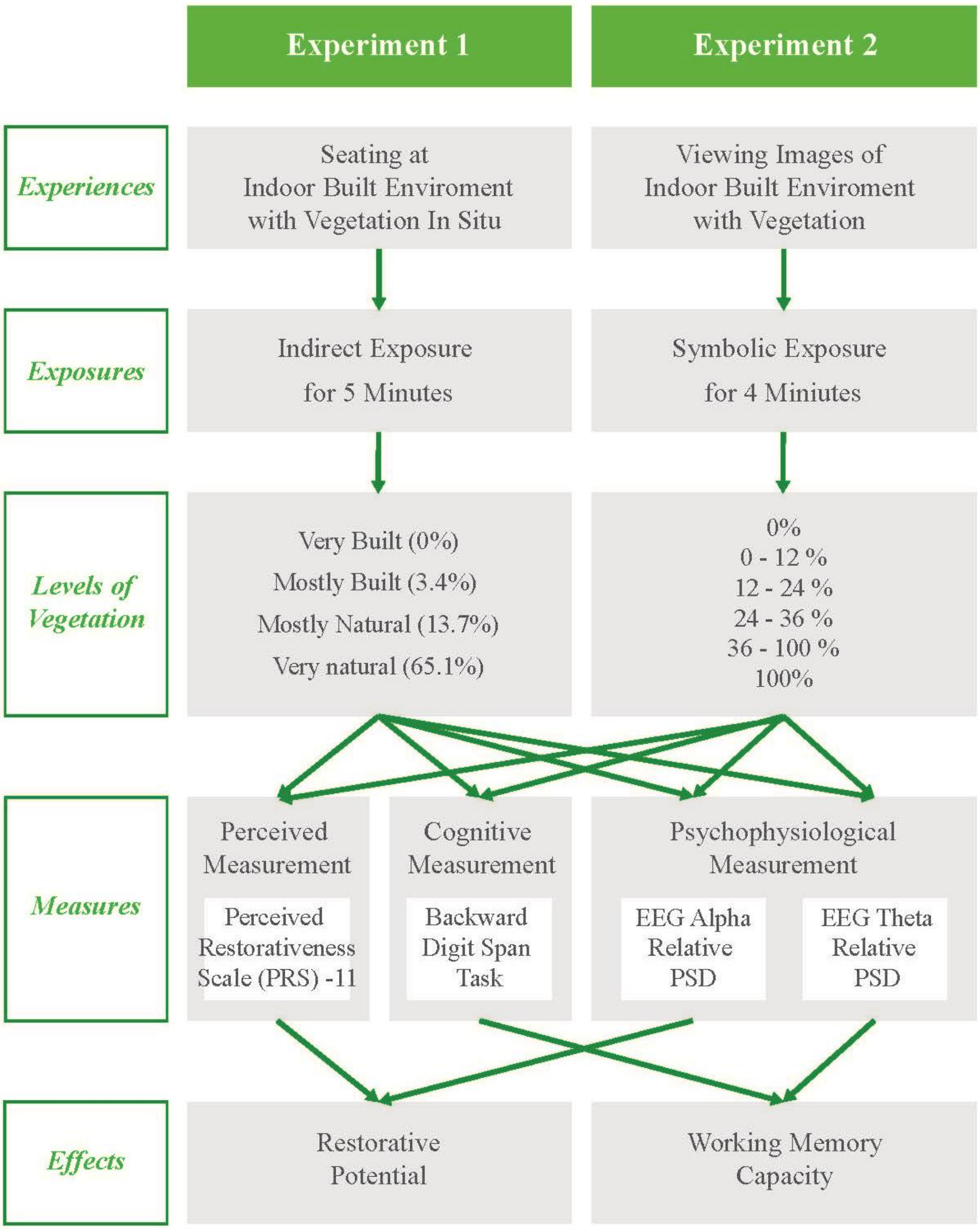
More specifically, the research for this dissertation has two phases outlined in a detailed research design process (Figure 3.1). The first phase asks how the level of vegetation within the indoor built environment influences people's restoration and working memory. To acquire controlled results on the influence of different levels of vegetation, the first experiment selected four in situ spaces with different levels of vegetation and the second experiment presented six sets of pictorial representations of nature in indoor built environments. The second phase examines how different types exposures – for example, the indirect exposure (in situ settings) of indoor vegetated environments and the symbolic exposures (images of nature in indoor built environment) of viewing pictures - impact people's restoration and working memory. To assess the differences,

this dissertation studies the effects of both the in-person experience and viewing of nature on self-reported restoration (PRS-11), psychophysiological restoration (EEG), working memory capacity (backward digit span task), and psychophysiological measure of working memory (EEG).

Further, it examines how neurophysiological data, recorded with the use of portable EEG devices, can help us understand how the brain responds to physical environments. The research looks at how participants subjectively experience nature in urban environments with a PRS-11 survey, and compares the responses with psychophysiological data from the EEG device. Moreover, it assesses how the working memory capacity identified with the backward digit span task differs from the psychophysiological working memory activity identified with EEG device. Finally, the study explores the application of mobile EEG device to in situ environments and, by extension, to the experiences of nature by different users within indoor built environment. Overall, it hypothesizes that indoor built environments with more vegetation will be more restorative and working memory-enhancing.

Figure 3.1

Diagram of Research Design Overview of the Dissertation



3.3. Participants

Thirty people (8 males and 22 females, average age 30.1±7.8 years [mean±standard deviation] ranging from 21 to 48 years) participated in the first experiment, and forty-one people (15 males and 26 females, average age 30.9±7.2 years [mean±standard deviation] ranging from 21 to 48 years) participated in the second experiment. All of the participants were psychologically healthy, with no history of neurological illness, and with normal or corrected-to-normal vision. Participants were recruited at the Seoul Botanic Park and through the Seoul National University of Science and Technology architecture department's group chat room for hiring and volunteering (see Appendix D). To be eligible for enrollment, interested participants also agreed to do the following prior to each study visit: refrain from using alcohol and recreational drugs for at least 24 hours; get a good night's sleep; avoid strenuous activity or caffeine for 12 hours; and not consume any food or liquid (except water) for one hour. The restrictions were set because some studies claim that caffeine and glucose (blood sugar level) influence electroencephalography (Banoczi, 2015; Gilbert, Dibb, Plath, & Hiyane, 2000; Lorist & Tops, 2003). Alcohol, drugs, and drowsiness from not enough sleep are prohibited to acquire untainted EEG signals.

In addition, inclusion criteria included both men and women in their 20s to 40s (20 - 49 years old). These criteria were set because neurological diseases are frequent in adults aged 55 and older (Callixte et al., 2015; Hofman et al., 2014; Murray et al., 2010) and it is therefore possible that participants over 50 may have a minor or early stage of neurological illness that they are not aware of. Thus, the age limits were set to people who are 49 years or younger to have a buffer zone. Also, the patterns of child and young adult's electroencephalography are different from those of adult's; thus, they were omitted from participation as well.

The experiment was conducted with the understanding and written consent of each participant (see Appendix E), and accepted by the institutional review board of the University of Wisconsin-Milwaukee (see Appendix B). Each participant was paid 30,000 won (approximately $25) as a value gift certificate for attending both experiments, and 10,000 won (approximately $8.5) as a value gift certificate for attending only the second experiment.

3.4. Procedures

Participants were exposed on separate days to the selected study site of Seoul botanic park. The experiments were performed from February to March, 2020. The entire study was conducted during weekdays from Tuesday through Friday. Weekends were exempted due to a large number of visitors, which may have unduly influenced participants. Also, the experiment site closed on Mondays. The first experiment (the in situ environment study) began at 9:00 am finished around 11:00 am. The second experiment began after 20 minutes break and preparation time. The complete study finished before 1:00 pm. Participants who only assisted with the second experiments came to the meeting room from 3:00 pm to 5:00 pm, according to their pre-scheduled time.

When participants arrived at the Seoul botanic park, the researcher informed them of the study procedures and provided a consent form. After obtaining their consent signature, the researcher explained the backward digit span task, and the task was performed twice before the beginning of the experiment to familiarize participants with the task. Participants heard digit sequences and were required to repeat them in backwards order. Sequences were four to ten digits in length and were presented at increasing lengths if participants successfully completed the task

two times in a row.[12] The length of the list increased until the participant failed to accurately inversely recall a list of that length on two succeeding trials. The backward digit span task score was calculated based on the length of the longest list the subject was able to recall. This task tested directed-attention abilities because participants needed to move items in and out of their attentional focus, which is a major component of working memory (Cowan, 2001; Jonides et al., 2008). Thus, the test measures possible cognitive effects including attentional processes when participants are presented with given sceneries. The backward digit span has been successfully used in previous studies to assess the restorative effects of natural settings (Bermann, Jonides, & Kaplan, 2008; Ohly et al., 2016). During the experiments, researchers used an internet-based backward digit span task. It is available at https://www.memorylosstest.com/digit-span/ (Memory Health Check, 2020) (Figure 3.2).

After the introduction, participants wore the EEG device (Emotive Epoc) and the researcher adjusted the electrode connectivity with a synchronized laptop (Samsung NT900X5N).

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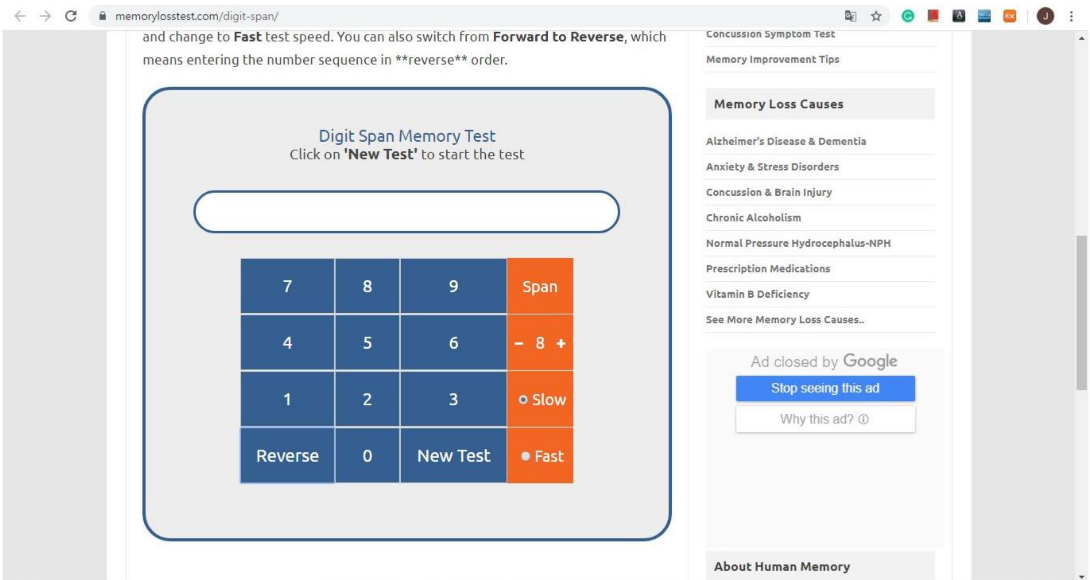
[12] Typically the digit-span tasks starts from two to three digits; however, all of the five participants from pilot study correctly answered three digits. Thus, to reduce the time of the experiment, this study started from four digits.

Figure 3.2

Internet-based Backward Digit Span Task (https://www.memorylosstest.com/digit-span/, MyBrainTest.org, 2019)



Experiment 1

The first part of study placed participants in vegetated indoor built environments in situ. Participants came to the Seoul botanic park and performed the first experiment early in the morning to minimize wandering people and noise. During the first experiment, participants sat at selected spaces and saw designated views for five minutes (Figure 3.3). These views included four spaces inside the Seoul botanic park, with each space holding different vegetation settings. The visiting order of selected spaces was random to eliminate order bias and the influence of participant fatigue.

Figure 3.3

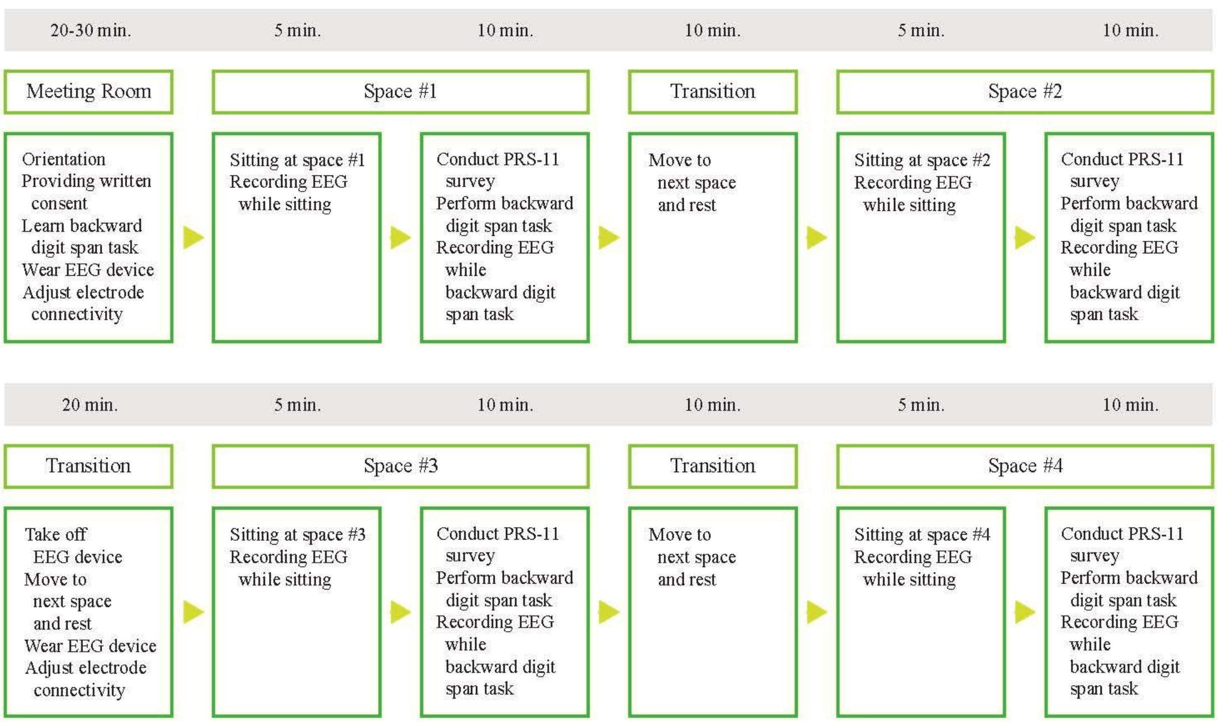
A Participant Wearing EEG Device, Sat at Greenhouse (Very Built Sites), and Saw Designated Views in Vegetated Indoor Built Environments In Situ (Experiment 1)

While the participants performed the experiment, their EEG was recorded. After five minutes, they were asked to perform the backward digit span task and answer their subjective restorativeness with the PRS (Perceived Restorativeness Scale)-11 survey. The Perceived Restorativeness Scale (PRS)-11 is an eleven-item, 0-10 rating scale used to collect participants' perceived levels of restorativeness. This survey was given ten times during the entire study: four times during the first experiment after five minutes of exposure to each environmental setting, and six times during the second experiment after viewing four minutes of image slideshows. The time

between each environmental setting was three to ten minutes; however, between each experiment participants took ten to fifteen minutes to rest, move, and prepare. EEG was also recorded during the backward digit span tasks. The total duration of the first experiment was about 120 minutes, including preparation, break time, task and survey between each space (Figure 3.4).

Figure 3.4

Sequence of the First Experiment



Experiment 2

The second part of study involved viewing images of various environmental settings. After the first experiment, participants moved to a meeting room on the administrator office floor of the Seoul botanic park, which functioned as a designated experimental space for the second experiment. Those who only participated in the second experiment met directly in the meeting room to perform the study.

Figure 3.5

A Participant Wearing EEG Device, Sat at Isolated Meeting Room, and Watch Images of Vegetated Indoor Built Environments (Experiment 2)

After a 20 minute break, the second experiment began. Participants wore earplugs and watched images of nature, built environments, and nature-built environments while seated approximately 70cm from 13.3 inch LCD laptop monitor (Sony pcg-51111p) showing pictures sized 29.5 cm by 16.5 cm (Figure 3.5). The monitor resolution was set to 1280 pixels x 720 pixels. The participants observed the stimuli without any other task requirements. The stimulation consisted of a serial presentation of 240 images that pictured nature, built environments, or nature-built environments. Each image showed for 6 seconds. There were 6 sets of images ranging from 0 percent nature to 100 percent nature, and each image set has 40 images. The six image sets were photos of 0%, 0 to 12%, 12 to 24%, 24 to 36%, more than 36%, and 100% nature aspects. The duration of a set of images was 4 minutes (240 seconds), and the sets of images were randomly provided to minimize order bias and the influence of participant fatigue. After viewing a set of images, participants were asked to perform the backward digit span task while viewing the repeated image set. The same images were continuously shown and the participants were asked to answer the PRS -11 survey to gain a subjective measure of restorativeness. EEG was recorded while participants watched images and took backward digit span tasks. After 3 sets of images, there was a 10 minutes break without the EEG device, as it was re-adjusted and synchronized before the remaining 3 sets. The duration of the second study was about 120 minutes, including 20 minutes for a preliminary phase of the experimental session and EEG preparation, 10 minutes of break time, and finally, time for the backward digit span task and the PRS-11 survey between each image set (Figure 3.6).

Figure 3.6

Sequence of the Second Experiment

3.5. Study Sites

The study was conducted at Seoul Botanic Park with permission and full cooperation (see Appendix C). The site is situated in Seoul, the capital of Republic of Korea, home to approximately 10 million people. Seoul Botanic Park is located in western part of Seoul, directly south of the Han River, and adjacent to the Kimpo international airport. It is 50.4 ha (approximately 124.5 acre) and opened in May 2019. The Seoul Botanic Park has a well-designed green area with large grass lawns, a small lake, wetlands, a greenhouse, performing art center, gardening school for children,

local cultural museum, and a support facility with administration office.

Selected spaces included four different vegetation settings in the greenhouse and support facility, including the meeting room, cafeteria, café, and greenhouse. All settings were located within a 10 minute walk, and selected on the basis of: (1) appropriate amount of vegetation, (2) availability during the dates of the study visits, (3) minimum control of people and noise, and (4) sufficient level of safety, as perceived by the researcher.

Four types of green settings were used for the first study, varying by level of vegetation richness (None to Very High). The settings were categorized on an ordinal scale from "Very Natural" to "Very Built" (Figure 3.7 [a - d] & Figure 3.8 [a - d]), adopting and modifying the method used by Matsuoka (2010) and Beil & Hanes (2013) as follows:

Very Natural: Trees, shrubs, and other natural elements with minimal evidence of human influence. Study setting was inside the greenhouse with trees and plants.

Mostly Natural: Presence of significant amounts of vegetation and some human influence such as walkways, buildings and furniture. Study setting was a coffee shop with small island garden with plants and vegetation.

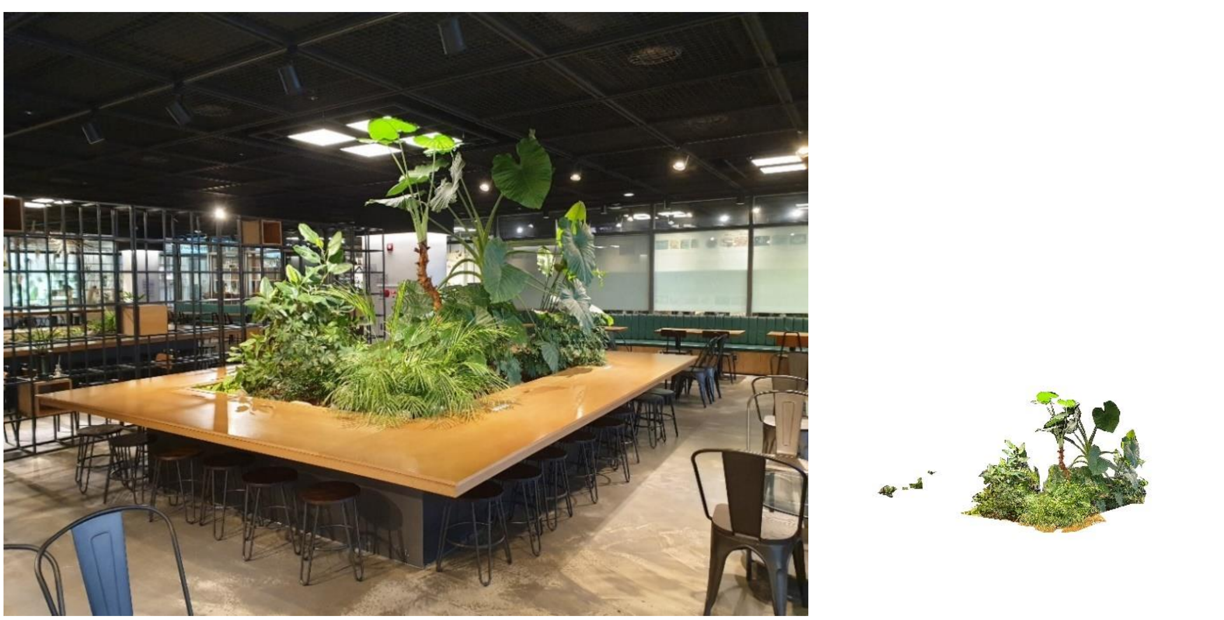
Mostly Built: Majority of viewable landscape is due to human influence, with some natural elements such as trees and plants. Study setting was a cafeteria with some indoor plants.

Very Built: Entirety of viewable landscape is due to human influence, with minimal presence of natural elements. Study settings was a meeting room without vegetation.

Figure 3.7

Photos of Four Vegetation Settings in Indoor Built Environment. (a) Greenhouse with Trees and Plants (Very Natural / 65.1%); (b) Coffee Shop with Small Island Garden with Plants and Vegetation (Mostly Natural / 13.7%); (c) Cafeteria with Some Indoor Plants (Mostly Built / 3.4%); and (d) Meeting Room without Vegetation (Very Built / 0.0%)

(a) Greenhouse with Trees and Plants (Very Natural / 65.1%)

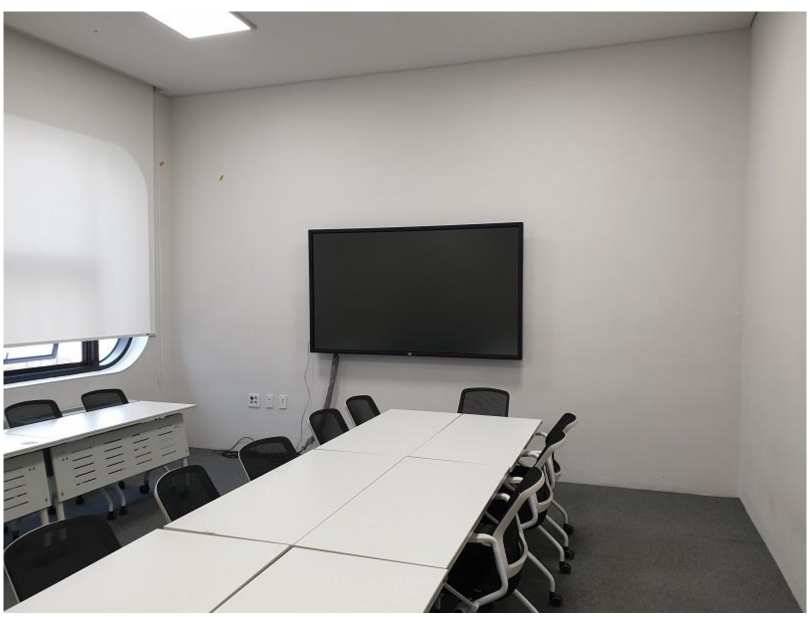


(b) Coffee Shop with Small Island Garden with Plants and Vegetation (Mostly Natural / 13.7%)

Figure 3.8

Photos of Four Vegetation Settings in Indoor Built Environment. (a) Greenhouse with Trees and Plants (Very Natural / 65.1%); (b) Coffee Shop with Small Island Garden with Plants and Vegetation (Mostly Natural / 13.7%); (c) Cafeteria with Some Indoor Plants (Mostly Built / 3.4%); and (d) Meeting Room without Vegetation (Very Built / 0.0%)

(c) Cafeteria with Some Indoor Plants (Mostly Built / 3.4%)



(d) Meeting Room without Vegetation (Very Built / 0.0%)

However, besides the level of vegetation in each selected site, there are other differing environmental stimuli from site to site that may have affected the outcome. Unlike pictorial representations of spaces, people are influenced by multisensory experiences in in situ environments. As a result, during the experiment, some possible attributes that may have influenced participants' in situ viewing experience are only quasi-controlled. The uncontrolled or differentiated circumstances of each site are in part a limitation of this dissertation, and yet, they also represent the natural conditions of in situ experiences.

First, visual stimuli were controlled in two ways: number of people and amount of light. To control exposure to people, the experiment took place in the early morning when there are fewer visitors at the Seoul Botanic Park. However, during the EEG recording, people appeared in some attempts, mostly at the greenhouse (very natural site), and rarely at the coffee shop (mostly natural site) and the cafeteria (mostly built site). The meeting room (very built site) was an enclosed space with no people trespassing. To make the experiment more valid and to limit potential influences from people's presence, the researchers checked the time of people's appearance during the experiment and deleted that section from the EEG recordings.

The amount of light was also semi-controlled. The researcher could not fully control the amount of light in each space because the spaces have different lighting fixtures and conditions. However, all of the windows in the meeting room (very built site), the cafeteria (mostly built site), and the coffee shop (mostly natural site) were shaded with blinds during the experiment to eliminate influence of daylight as well as other outside visual stimuli. However, the greenhouse (very natural site) is made of a glass façade and ETFE (Ethylene tetrafluoroethylene) film ceiling; thus, it was impossible to cover. Nevertheless, the experiments were conducted in the morning

during the winter season, meaning there was no direct sunlight. The luminance was measured at table level (0.75m) with the Light Meter app by My Mobile Tools Dev and the Lux Light Meter Free app by Doggo Apps on the Samsung Galaxy Note 9 Android phone. Illumination was measured by both apps for better accuracy, but the illuminance level were not kept and were only used as a guideline. The illuminance level for all four sites was between 500 lux and 900 lux.

Acoustic stimuli were also controlled. Undesirable noises such as music in the cafeteria (mostly built site) and coffee shop (mostly natural site) were turned off, and people's conversations were excluded when the researcher deleted the sections in the EEG recordings containing the presence of other people. The acoustic intensity of each site was as follows: the meeting room (very built site) 34.92 ± 0.74 db, the cafeteria (mostly built site) 49.67 ± 2.90 db, the coffee shop (mostly natural site) 53.46 ± 1.66 db, and the greenhouse (very natural site) 65.86 ± 0.55 db. The meeting room (very built site) was enclosed and thus quieter than other sites, and the greenhouse (very natural site) was noisier due to ventilating fans. To minimize the effects of different noise levels, participants wore 3M earplugs while sitting and viewing; however, they took off the earplugs during the backward digit span task to hear the researcher's voice. The acoustic level was measured with both the Sound Meter app by melon soft and the Sound Meter app by Smart Tools co. for the Samsung Galaxy Note 9 android phone. The researcher averaged the results from the two apps.

Finally, haptic, olfactory, and body movement stimuli were considered. The haptic conditions of the four sites were relatively similar, the overall temperature of the sites were around 18°C (64.4°F), with the humidity at 40-50% including in the greenhouse (very natural site). Olfactory conditions were also controlled; there were no strong smells, no food preparation or

eating at the cafeteria (mostly built site), and no coffee preparing or drinking at the coffee shop (mostly natural site) during the experiment. Body movements were controlled as well. Participants were asked to relax and sit still during the EEG recordings. However, eye movements were not controlled and the participants spoke and responded to the researcher during the backward digit span task.

3.6. Stimuli

The visual stimuli for the second study were 240 images showing natural environments, indoor built environments, and vegetation in indoor built environments (40 images of natural scenery, 40 images of indoor built environments, and 160 images of vegetation in indoor built environment; see Appendix F). As previously mentioned, visual representations of attractive nature evoke positive emotional preferences (Colarelli & Dettmann, 2003). Several studies support the notion that the photographic pictures may emulate a similar effect to the real natural exposure (Coeterier, 1983; Hull & Stewart, 1992; Penning-Rowsell, 1981).

Images of vegetation in indoor built environments were further divided into sub-groups according to the amount of vegetation in the photos. The images were grouped based on whether the amount was less than 12 percent, 12-24 percent, 24-36 percent, or more than 36 percent. This sub-grouping was adapted from study results by Jiang, Chang, and Sullivan (2014). They claim that the dose-response curve was an inverted-U shape for men and that stress recovery improved with increased tree cover density in the streets from 1.7% to 24%. In their study, there were no changes in stress recovery in the range of 24% to 34% tree density. Tree densities above 34%,

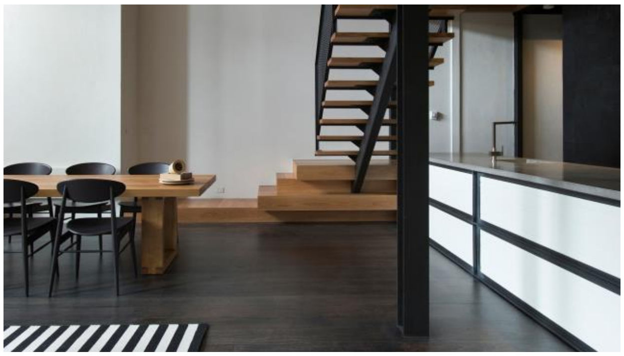
however, were associated with slower recovery times. To assess the density of vegetation in the indoor built environment in each photo, the researcher used Adobe Photoshop CS5 to identify and measure the number of pixels associated with plants and other natural vegetation in each of photos (Figure 3.9 [a - f]). Then, the researcher divided the number of pixels associated with plants and vegetation by the number of pixels in the entire photograph (921,600 pixels) and multiplied this number by 100 to obtain the measure of nature density in each photo of indoor built environment. To mitigate bias, 1.5 percent margins were applied at each end; thus, the photos comprised 0%, 1.5 to 10.5%, 13.5 to 22.5%, 25.5 to 34.5%, more than 37.5%, and 100% nature aspects in respective sets.

The images of vegetation in indoor built environment were carefully selected. The images were subdivided to explore the impact of the level and quantity of vegetation in indoor built environment settings. A large sample of images was chosen to avoid selection biases. A diversity of environmental settings as well as natural vegetation settings were considered to alleviate preferences and emotional prejudices towards different kind of nature settings in indoor built environments. However, due to a low number of trials and limited time for each subcategory, comparisons between the subcategories may not demonstrate strong, reliable results.

The images for this dissertation had the size of 1280 pixels x 720 pixels (presented full screen) and were selected from a larger sample of more than 1000 images retrieved from the internet. All images portrayed environments from the realistic point of view of a human observer. For the images of urban scenery, elements that may cause strong attention and/or receive special processing in the visual cortex (e.g., faces, numbers, letters, etc.) were excluded. Also, to avoid the effects of outside vegetation, photos containing window views of trees and plants were excluded.

Figure 3.9

The Example Images of Vegetation in Indoor Built Environment. (a) 0%; (b) 0% - 12% (7.5%); (c) 12% - 24% (19.3%); (d) 24% - 36% (29.0%); (e) 36% and more (65.5%); and (f) 100%



(a) 0%

(b) 0% - 12% (7.5%)

(c) 12& - 24% (19.3%)

Figure 3.9

The Example Images of Vegetation in Indoor Built Environment. (a) 0%; (b) 0% - 12% (7.5%); (c) 12% - 24% (19.3%); (d) 24% - 36% (29.0%); (e) 36% and more (65.5%); and (f) 100%

(f) 24% - 36% (29.0%)

(e) 36% and more (65.5%)

(f) 100%

All images avoided recognizable or familiar scenes (to avoid familiarity bias) and resisted directly suggesting positive or negative emotions. No special treatment was done to control color, since previous research demonstrates that color information is not critical for processing natural scenes (Codispoti, De Cesarei, & Ferrari, (2012). Lastly, photos with obvious photographic modifications including contrast, hue/saturation, exposure, color-balance, and etc. were omitted.

In this experiment, the researcher acquires validity in three ways. First, real-world environments are perceived differently from semantic visual stimuli such as objects, faces, and text (Henderson, 2005), photos with faces, letters, numbers and strong colors were excluded. Second, each category of built environment includes at least forty different photos of diverse examples. The median data from these photos minimizes peripheral influences and represents the impact of each attribute. Lastly, photos were carefully reviewed by three different field experts holding masters degrees or higher and/or some experience in fields including architecture, interior design, or psychology. The final forty images were chosen by the expert reviewers from among the sixty images in the final pool.

However, different types of spaces and their corresponding images may influence participant restorativeness and/or working memory. Hidalgo et al. (2006) found that people feel more restoration in pleasant built environments like historic, cultural, and recreational spaces. Abdulkarim and Nasar (2014) argued that elements such as seats, foods, and sculptures influence a plaza's restorative potential. Therefore, in our study, it is possible that the specific characteristics of each place and image, such as room types and furniture, may cause potential bias and influence participants' perceived restorativeness. To mitigate this bias, we evenly selected the photos from four categories: Bedroom & Restroom, Livingroom & Lobby Area, Kitchen & Dining, and Shop

& Office for the built environment settings (0% vegetation to less than 100% vegetation) (Table 3.1), and Forest & Jungle, Mountain & Trail, Garden & Meadow, and Lake & Water for the natural environment setting (100% vegetation) (Table 3.2). However, photos of bedrooms and restrooms with vegetation were rare, for two expected reasons: first, people do not often grow vegetation in private spaces, such as bedrooms and restrooms, compared to other room types. Second, bedrooms and restrooms are relatively small in size compared to other room types; thus it is harder to find good quality photos with enough wide angles. Therefore, the Livingroom and Lobby Area category has more images (38.5%) and the Bedroom and Restroom category has fewer (Table 3.1). Also, in natural environments, Lake and Water images are more difficult to find, because vegetation is the focus of this study, and the selected photos of lakes and water must therefore include vegetation (i.e. the water elements cannot be the main theme of the image). Thus, more Forest and Jungle photos were selected (35.0%) over Lake and Water photos (17.5%) to fully represent the vegetation among the natural environments (Table 3.2).

Table 3.1

Types of Indoor Built Environments in Selected Image Sets

		Types of Indoor Built Environments				
		Bedroom & Restroom (%)	**Livingroom & Lobby (%)**	**Kitchen & Dining (%)**	**Shop & Office (%)**	**Total (%)**
Image Sets	0%	10 (25.0)	14 (35.0)	8 (20.0)	8 (20.0)	40 (100)
	0-12%	4 (10.0)	17 (42.5)	12 (30.0)	7 (17.5)	40 (100)
	12-24%	3 (7.5)	17 (42.5)	11 (27.5)	8 (20.0)	40 (100)
	24-36%	1 (2.5)	16 (40.0)	9 (22.5)	14 (35.0)	40 (100)
	36-100%	2 (5.0)	13 (32.5)	10 (25.0)	16 (40.0)	40 (100)
Total		20 (10.0)	77 (38.5)	50 (25.0)	53 (26.5)	200 (100)

Table 3.2

Types of Natural Environments in Selected Image Sets

		Types of Natural Environments				
		Forest & Jungle (%)	**Mountain & Trail (%)**	**Garden & Meadow (%)**	**Lake & Water (%)**	**Total (%)**
Image Sets	100%	14 (35.0)	10 (25.0)	9 (22.5)	7 (17.5)	40 (100)

3.7. EEG Recording and Data Processing

EEG was continuously monitored and recorded with an Emotiv EPOC during the viewing and while conducting the backward digit span task. The Emotiv EPOC is a low-cost consumer oriented EEG device. It uses a wireless headset with fourteen-channel, saline-base electrode sensors (Figure 3.10). There are fourteen EEG sensors for sense brain activity and two for CMS/DRL references.[13] The fourteen sensors were positioned on the scalp of the subject according to the international 10–20 system: antero-frontal (AF3, AF4, F3, F4, F7, F8), frontocentral (FC5, FC6), occipital (O1, O2), parietal (P7, P8) and temporal sites (T7, T8). The two reference sensors were placed on the ears to acquire basic input data (Figure 3.11). The Emotiv EPOC also includes a two-axis gyroscope to detect head movement of the wearer.

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[13] The Driven Right Leg (DRL) and the Common Mode Sense (CMS) connections correspond to the electrical reference, or “ground”, of the system. The CMS is the reference channel, compared to which all the EEG signals are measured. The DRL is responsible for bringing the potential of the subject as close as possible to the “zero” of the electrical system (Neuroelectrics’ Wiki, 2019).

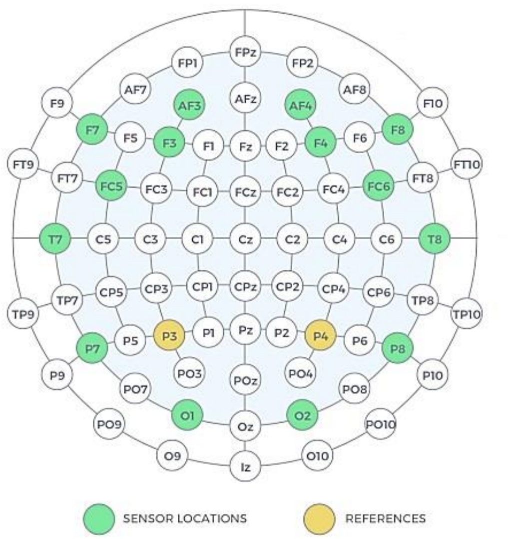
Figure 3.10

Emotiv Epoc Headset (Emotiv, 2019)

Brain waves were measured in terms of amplitude (10-100 microvolts) and frequency (1-70 Hz). Recorded raw EEG signals were classified into mental and emotional states by Emotiv Pro, a neurofeedback application, to control some feedback from the user. Emotiv Pro indicates ‘excitement,’ ‘long term excitement,’ ‘meditation,’ and ‘engagement’. Although the exact EEG classification algorithms are often not disclosed or peer-reviewed, these metrics offer an accessible basic analysis for users and researchers without a neuroscience background. Furthermore, some precedent studies have used Emotiv PRO’s affectiv metrics to record complex cognitive processes such as insight (Cernea et al. 2011), and other studies found it useful for psychological assessment of environmental experiences (Aspinall et al. 2015), discrimination of environmental images (Roe et al. 2013).

Figure 3.11

Location of Sixteen EEG Sensors (Fourteen Channel) (Emotiv, 2019)



The researcher chose the Emotiv EPOC EEG device because it was one of the first low-cost, wireless and multi-electrode EEG devices on the market and was validated by various independent studies. Also, it has more electrodes compared to other low-cost EEG devices (e.g. MUSE, NeuroSky Mindwave, B-Alert X10 EEG Headset), and is considered more reliable (Maskeliunas, Damasevicius, Martisius, & Vasiljevas, 2016). Thus, it is a low-cost alternative to high-end EEG equipment. Several studies have compared the consumer-grade Emotiv EPOC with higher-grade EEG recording devices, in terms of signal quality and application for standard EEG tests like detecting auditory event-related potentials (Debener, Minow, Emkes, Gandras, & de Vos, 2012; Duvinage et al., 2013; De Vos and Debener, 2014). Noise was higher and voltage and time resolution were lower compared to medical grade device, but in general, the signals and waves were well reflected (Debener et al. 2012). The research suggests that Emotiv EPOC's accuracy is

sufficient for experiments aiming for frequency-domain analyses (Allen et al., 2004; Cohen, 2014), including analyzing the power of select EEG frequency bands such as alpha (8-13 Hz), and recognition accuracy measurement (Maskeliunas, et al., 2016).

Emotiv EPOC has been validated for both laboratory and outdoor settings (Badcock et al., 2013; Debener et al., 2012; Hairston et al., 2014; Masood & Farooq, 2017). Badcock et al. (2013) compared auditory Event Related Potentials (ERPs) using Emotiv and Neuroscan (a medical grade, widely-used EEG system) and found that Emotiv EPOC, the consumer grade EEG system, is a valid alternative for Neuroscan, the medical grade system, for recording late auditory ERPs over the frontal cortices. Hairston et al. (2014) assessed the usability of commercially-oriented wireless EEG systems, and claimed the Emotiv EPOC's signal connectivity was sufficiently stable over the time period of recording to use it outside of laboratory settings. Masood and Farooq (2017) concluded that Emotiv EPOC has 82.99% accuracy with visual stimulators, making it a reliable choice for consumer or research grade uses considering the medical grade device has 94.79% accuracy.

To process the acquired EEG data, Emotiv Pro software was used to allow real-time data acquisition, filtering and visualisation of brain activity on a laptop (Samsung NT900X5N). The Emotiv Pro software recoded raw EEG data and exported it as "edf" file; the exported .edf file was then imported by EEGLAB (v2019.0), the widely used EEG analyze software running under the Metlab environment (Delorme & Makeig, 2004). The resulting EEG data were pre-processed with various plug-ins using the EEGLAB toolbox. The pre-processing steps included filtering, using 2-Hz high-pass finite impulse response (FIR) filters, artifact rejection using Clean Rawdata (Version

2.1)[14], the Automated Subspace Removal (ASR)[15], and the Automatic Artifact Removal (AAR)[16] toolbox plug-ins for EEGLAB and IC Artifact Classification (MARA; Winkler et al., 2014)[17]

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[14] Clean Rawdata plug-in is the default EEGLAB tool for rejecting EEG data artifacts. The plug-in detects and removes low-frequency drifts, flatlines and noisy channels and also applies ASR to detect and reject high-amplitude artifacts produced by eye blinks, muscle activity, sensor motion, etc. by comparing its structure to that of known artifact-free reference data (SCCN, 2020).

[15] ASR was originally designed as a real-time, online data cleaning algorithm for high-density, wearable, and dry EEG (Mullen et al., 2015). However, it has an option to detect bad portions of data before correcting them, and can thus be used in offline data processing as well (SCCN, 2020).

[16] AAR was implemented to remove ocular (EOG) and muscular (EMG) artifacts using regression techniques based on Least Mean Squares (LMS), Recursive Least Squares (RLS), and other adaptive algorithms (Gomez-Herrero, 2007). Among many options, this dissertation chose an improved Weight-Adjusted Second-Order Blind Identification (iWASOBI) method for detecting artifactual components.

[17] Multiple Artifact Rejection Algorithm (MARA) is a machine-learning based algorithm that evaluates the ICA-derived components of EEG data (Winkler et al., 2014). It is regarded particularly efficient at detecting and removing muscle artifacts (Gabard-Durnam et al., 2018). Since the experiments in this dissertation contain relatively high head movements, the MARA has

which removes ocular and muscular artifacts in the EEG signals. For artifact removal, Clean Rawdata, ASR, and AAR were executed first; the researcher then re-referenced the data to reset across the channels, and ran the MARA for final artifact removal.

Oscillatory activity from each site location and each presentation of vegetation and built environment images were compared for every participant (41) and frequency band (from 2 to 51 Hz). Then, the mean values of Power Spectral Density (PSD) for the five frequencies were calculated for every subject with Matlab. The EEG power was grouped into the following frequency bands: delta (2-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-51 Hz). Statistics were computed using IBM SPSS v. 24. The data were then treated by parametric analysis with an ANOVA with repeated measures.

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been selected for use. The efficiency of MARA is well-proven and it has been chosen in many pre-processing pipelines for EEG data, including the Harvard Automated Processing Pipeline for Electroencephalography (HAPPE; Gabard-Durnam et al., 2018), and Automagic (Pedroni, Bahreini, & Langer, 2019).

4. Results

4.1. Level of Vegetation's Effects on PRS-11 Score

PRS-11 Score of In Situ Environments (Experiment 1)

The first question was whether indirect and symbolic visual contacts with vegetation in indoor built environment restore people's attention. The main assumption was that the PRS-11 score would be positively affected by the level of vegetation in the indoor built environment. The study thus constructed an ANOVA with repeated measures and examined the effects of the level of vegetation in the indoor built environment based on participants' perceived restorative scale. Among PRS-11 scores, questions were divided into four categories and analyzed in accordance with Kaplan's ART: fascination (question numbers 1, 2, and 3), being away (question numbers 4, 5, and 6), coherence (question numbers 7, 8, and 9), and scope (question numbers 10 and 11). Among PRS-11 scores, questions under the coherence category (question numbers 7, 8, and 9) were seen as reverse coded questions and equivalent to the initial PRS study (Hartig et al., 1997). Therefore, in the results, the mean of the total PRS-11 scores with reversal of the item codes of coherence category were analyzed separately from and the mean of the fascination, being away, and scope categories (Table 4.1 & Figure 4.1 [a - f]). The first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in the Seoul Botanic Park, and found that a trend emerged in relation to the level of vegetation.

Table 4.1

Level of Vegetation by Mean Number of PRS-11 Scores (Experiment 1)

	Level of Vegetation (N = 30)					
	Very Built (A)	**Mostly Built (B)**	**Mostly Natural (C)**	**Very Natural (D)**	**F**	***p***
Fascination (SD)	3.07 (1.929) B, C, D	4.71 (1.443) A, C, D	7.03 (1.334) A, B, D	7.98 (1.117) A, B, C	60.167	0.000***
Being Away (SD)	3.64 (2.535) C, D	4.64 (2.009) C, D	6.97 (1.613) A, B	7.56 (1.385) A, B	24.411	0.000***
Coherence (SD)	2.97 (2.251)	3.36 (1.602) D	4.48 (1.448)	5.03 (1.572) B	6.440	0.004**
Scope (SD)	4.00 (1.829) C, D	4.62 (1.760) C, D	6.37 (1.756) A, B	6.93 (1.425) A, B	22.216	0.000***
Total (F+B+C+S) (SD)	3.37 (1.446) B, C, D	4.31 (1.154) A, C, D	6.20 (0.994) A, B, D	6.87 (0.867) A, B, C	48.524	0.000***
Total (F+B+S) (SD)	3.52 (1.798) C, D	4.66 (1.473) C, D	6.84 (1.247) A, B, D	7.56 (0.938) A, B, C	48.789	0.000***

*** $p < .005$, ** $p < .01$

Significance level for upper case letters (A, B, C, D): .05[1]

1. Tests are adjusted for all pairwise comparisons within a row of each innermost sub-table using the Bonferroni correction.

2. The coherence (question numbers 7, 8, and 9) scores were reversely coded.

For fascination, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(5) = 12.324$, $p = 0.031$; therefore, degrees of freedom were corrected using Huynh-Feldt estimates of Sphericity ($\varepsilon = 0.863$). Table 4.1 shows that participants felt significantly more restoration by fascination attributes in spaces filled with more vegetation, $F(2.589, 72.485) = 60.167$, $p = 0.000$, $\eta_p^2 = 0.68$ (Figure 4.1a). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the fascination score of self-report tests in Very Natural sites ($M = 7.98$, $SD = 1.117$) was significantly higher than in Mostly Natural sites ($M = 7.03$, $SD = 1.334$), $t(26) = 0.975$, $SEM = 0.281$, $p = 0.010$, Mostly Built sites ($M = 4.71$, $SD = 1.443$), $t(26) = 3.341$, $SEM = 0.379$, $p = 0.000$, and Very Built sites ($M = 3.07$, $SD = 1.929$), $t(26) = 4.953$, $SEM = 0.488$, $p = 0.000$. The fascination score of self-report tests in Mostly Natural sites ($M = 7.03$, $SD = 1.334$) was significantly lower than in Very Natural sites ($M = 7.98$, $SD = 1.117$), $t(26) = -0.975$, $SEM = 0.281$, $p = 0.010$, and significantly higher than in Mostly Built sites ($M = 4.71$, $SD = 1.443$), $t(26) = 2.366$, $SEM = 0.377$, $p = 0.000$, and Very Built sites ($M = 3.07$, $SD = 1.929$), $t(26) = 3.977$, $SEM = 0.493$, $p = 0.000$. The fascination score of self-report tests in Mostly Built sites ($M = 4.71$, $SD = 1.443$) was significantly lower than in Very Natural sites ($M = 7.98$, $SD = 1.117$), $t(26) = -3.341$, $SEM = 0.379$, $p = 0.000$, and Mostly Natural sites ($M = 7.03$, $SD = 1.334$), $t(26) = -2.366$, $SEM = 0.377$, $p = 0.000$, but significantly higher than in Very Built sites ($M = 3.07$, $SD = 1.929$), $t(26) = 1.612$, $SEM = 0.403$, $p = 0.003$. Lastly, the fascination score of self-report tests in Very Built sites ($M = 3.07$, $SD = 1.929$) was significantly lower than in Very Natural sites ($M = 7.98$, $SD = 1.117$), $t(26) = -4.953$, $SEM = 0.488$, $p = 0.000$, Mostly Natural sites ($M = 7.03$, $SD = 1.334$), $t(26) = -3.977$, $SEM = 0.493$, $p = 0.000$, and Mostly Built sites ($M = 4.71$, *SD*

= 1.443), *t*(26) = -1.612, *SEM* = 0.403, *p* = 0.003 (Table 4.1).

For being away, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(5) = 16.677$, *p* = 0.005; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (ε = 0.740). Table 4.1 shows that participants felt significantly more restoration by being away attributes in spaces filled with more vegetation, *F*(2.219, 62.145) = 24.411, *p* = 0.000, $\eta_p^2 = 0.47$ (Figure 4.1b). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the being away score of self-report tests in Very Natural sites (*M* = 7.56, *SD* = 1.385) was significantly higher than in Mostly Built sites (*M* = 4.64, *SD* = 2.009), *t*(26) = 3.098, *SEM* = 0.508, *p* = 0.000, and Very Built sites (*M* = 3.64, *SD* = 2.535), *t*(26) = 4.152, *SEM* = 0.597, *p* = 0.000. The being away score of self-report tests in Mostly Natural sites (*M* = 6.97, *SD* = 1.613) was significantly higher than in Mostly Built sites (*M* = 4.64, *SD* = 2.009), *t*(26) = 2.564, *SEM* = 0.487, *p* = 0.000, and Very Built sites (*M* = 3.64, *SD* = 2.535), *t*(26) = 3.617, *SEM* = 0.710, *p* = 0.000. The being away score of self-report tests in Mostly Built sites (*M* = 4.64, *SD* = 2.009) was significantly lower than in Very Natural sites (*M* = 7.56, *SD* = 1.385), *t*(26) = -3.098, *SEM* = 0.508, *p* = 0.000, and Mostly Natural sites (*M* = 6.97, *SD* = 1.613), *t*(26) = -2.564, *SEM* = 0.487, *p* = 0.000. Lastly, the being away score of self-report tests in Very Built sites (*M* = 3.07, *SD* = 1.929) was significantly lower than in Very Natural sites (*M* = 7.56, *SD* = 1.385), *t*(26) = -4.152, *SEM* = 0.597, *p* = 0.000, and Mostly Natural sites (*M* = 6.97, *SD* = 1.613), *t*(26) = -3.617, *SEM* = 0.710, *p* = 0.000 (Table 4.1).

For coherence, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(5) = 22.368$, *p* = 0.000; therefore, degrees of freedom were corrected using Greenhouse-Geisser

estimates of Sphericity (ε = 0.633). Table 4.1 shows that participants felt significantly more restoration by coherence attributes in spaces filled with more vegetation, $F(1.899, 53.176) = 6.440$, $p = 0.004$, $\eta_p^2 = 0.19$ (Figure 4.1c). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the coherence score of self-report tests in Very Natural sites ($M = 5.03$, $SD = 1.572$) was significantly higher than in Mostly Built sites ($M = 3.36$, $SD = 1.602$), $t(26) = 1.409$, $SEM = 0.481$, $p = 0.040$ (Table 4.1). The coherence (question numbers 7, 8, and 9) scores were reversely coded.

For scope, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(5) = 16.461$, $p = 0.006$; therefore, degrees of freedom were corrected using Huynh-Feldt estimates of Sphericity (ε = 0.866). Table 4.1 shows that participants felt significantly more restoration by scope attributes in spaces filled with more vegetation, $F(2.597, 72.728) = 22.216$, $p = 0.000$, $\eta_p^2 = 0.44$ (Figure 4.1d). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the scope score of self-report tests in Very Natural sites ($M = 6.93$, $SD = 1.425$) was significantly higher than in Mostly Built sites ($M = 4.62$, $SD = 1.760$), $t(26) = 2.474$, $SEM = 0.431$, $p = 0.000$, and Very Built sites ($M = 4.00$, $SD = 1.829$), $t(26) = 2.875$, $SEM = 0.476$, $p = 0.000$. The scope score of self-report tests in Mostly Natural sites ($M = 6.37$, $SD = 1.756$) was significantly higher than in Mostly Built sites ($M = 4.71$, $SD = 1.443$), $t(26) = 1.969$, $SEM = 0.376$, $p = 0.000$, and Very Built sites ($M = 3.07$, $SD = 1.929$), $t(26) = 2.369$, $SEM = 0.515$, $p = 0.000$. The scope score of self-report tests in Mostly Built sites ($M = 4.71$, $SD = 1.443$) was significantly lower than in Very Natural sites ($M = 7.98$, $SD = 1.117$), $t(26) = -2.474$, $SEM = 0.431$, $p = 0.000$, and

Mostly Natural sites (*M* = 7.03, *SD* = 1.334), *t*(26) = -1.969, *SEM* = 0.376, *p* = 0.000. Lastly, the scope score of self-report tests in Very Built sites (*M* = 3.07, *SD* = 1.929) was significantly lower than in Very Natural sites (*M* = 7.98, *SD* = 1.117), *t*(26) = -2.875, *SEM* = 0.476, *p* = 0.000, Mostly Natural sites (*M* = 7.03, *SD* = 1.334), *t*(26) = -2.369, *SEM* = 0.515, *p* = 0.000 (Table 4.1).

For the mean total PRS-11 score, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(5) = 22.393$, *p* = 0.000; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (ε = 0.673). Table 4.1 shows that participants felt significantly more restoration by all of PRS-11 attributes in spaces filled with more vegetation, *F*(2.020, 56.561) = 48.524, *p* = 0.000, $\eta_p^2 = 0.63$ (Figure 4.1e). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the mean total PRS-11 score of self-report tests in Very Natural sites (*M* = 6.87, *SD* = 0.867) was significantly higher than in Mostly Natural sites (*M* = 6.20, *SD* = 0.994), *t*(26) = 0.600, *SEM* = 0.184, *p* = 0.018, Mostly Built sites (*M* = 4.31, *SD* = 1.154), *t*(26) = 2.590, *SEM* = 0.331, *p* = 0.000, and Very Built sites (*M* = 3.37, *SD* = 1.446), *t*(26) = 3.484, *SEM* = 0.393, *p* = 0.000. The mean total PRS-11 score of self-report tests in Mostly Natural sites (*M* = 6.20, *SD* = 0.994) was significantly lower than in Very Natural sites (*M* = 6.87, *SD* = 0.867), *t*(26) = -0.600, *SEM* = 0.184, *p* = 0.018, but significantly higher than in Mostly Built sites (*M* = 4.31, *SD* = 1.154), *t*(26) = 1.991, *SEM* = 0.323, *p* = 0.000, and Very Built sites (*M* = 3.37, *SD* = 1.446), *t*(26) = 2.884, *SEM* = 0.410, *p* = 0.000. The mean total PRS-11 score of self-report tests in Mostly Built sites (*M* = 4.31, *SD* = 1.154) was significantly lower than in Very Natural sites (*M* = 6.87, *SD* = 0.867), *t*(26) = -2.590, *SEM* = 0.331, *p* = 0.000, and Mostly Natural sites (*M* = 6.20, *SD* = 0.994), *t*(26) = -1.991, *SEM* = 0.323, *p* = 0.000, but

significantly higher than in Very Built sites (*M* = 3.37, *SD* = 1.446), *t*(26) = 0.894, *SEM* = 0.308, *p* = 0.043. Lastly, the mean total PRS-11 score of self-report tests in Very Built sites (*M* = 3.37, *SD* = 1.446) was significantly lower than in Very Natural sites (*M* = 6.87, *SD* = 0.867), *t*(26) = -3.484, *SEM* = 0.393, *p* = 0.000, Mostly Natural sites (*M* = 6.20, *SD* = 0.994), *t*(26) = -2.884, *SEM* = 0.410, *p* = 0.000, and Mostly Built sites (*M* = 4.31, *SD* = 1.154), *t*(26) = -0.894, *SEM* = 0.308, *p* = 0.043 (Table 4.1).

For mean of fascination, being away, and scope scores, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(5) = 19.954$, $p = 0.001$; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (ε = 0.734). Table 4.1 shows that participants felt significantly more restoration by fascination, being away, and scope attributes in spaces filled with more vegetation, $F(2.201, 61.616) = 48.789$, $p = 0.000$, $\eta_p^2 = 0.64$ (Figure 4.1f). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the mean of fascination, being away, and scope scores of self-report tests in Very Natural sites (*M* = 7.56, *SD* = 0.938) was significantly higher than in Mostly Natural sites (*M* = 6.84, *SD* = 1.247), *t*(26) = 0.692, *SEM* = 0.220, *p* = 0.023, Mostly Built sites (*M* = 4.66, *SD* = 1.473), *t*(26) = 3.033, *SEM* = 0.359, *p* = 0.000, and Very Built sites (*M* = 3.52, *SD* = 1.798), *t*(26) = 4.133, *SEM* = 0.430, *p* = 0.000. The mean of fascination, being away, and scope scores of self-report tests in Mostly Natural sites (*M* = 6.84, *SD* = 1.247) was significantly lower than in Very Natural sites (*M* = 7.56, *SD* = 0.938), *t*(26) = -0.692, *SEM* = 0.220, *p* = 0.023, and significantly higher than in Mostly Built sites (*M* = 4.66, *SD* = 1.473), *t*(26) = 2.341, *SEM* = 0.357, *p* = 0.000, and Very Built sites (*M* = 3.52, *SD* = 1.798), *t*(26) = 3.440, *SEM* = 0.487, *p* = 0.000. The mean of

fascination, being away, and scope scores of self-report tests in Mostly Built sites (M = 4.66, SD = 1.473) was significantly lower than in Very Natural sites (M = 7.56, SD = 0.938), $t(26) = -3.033$, SEM = 0.359, p = 0.000, and Mostly Natural sites (M = 6.84, SD = 1.247), $t(26) = -2.341$, SEM = 0.357, p = 0.000. Lastly, the mean of fascination, being away, and scope scores of self-report tests in Very Built sites (M = 3.52, SD = 1.798) was significantly lower than in Very Natural sites (M = 7.56, SD = 0.938), $t(26) = -4.133$, SEM = 0.430, p = 0.000, and Mostly Natural sites (M = 6.84, SD = 1.247), $t(26) = -3.440$, SEM = 0.487, p = 0.000 (Table 4.1).

Figure 4.1

Graph of Level of Vegetation by Mean Number of PRS-11 Scores (Experiment 1): (a) Fascination; (b) Being Away; (c) Coherence; (d) Scope; (e) Mean Total PRS-11 Score / Total (F+B+C+S); and (f) Mean of Fascination, Being Away, and Scope Scores / Total (F+B+S)

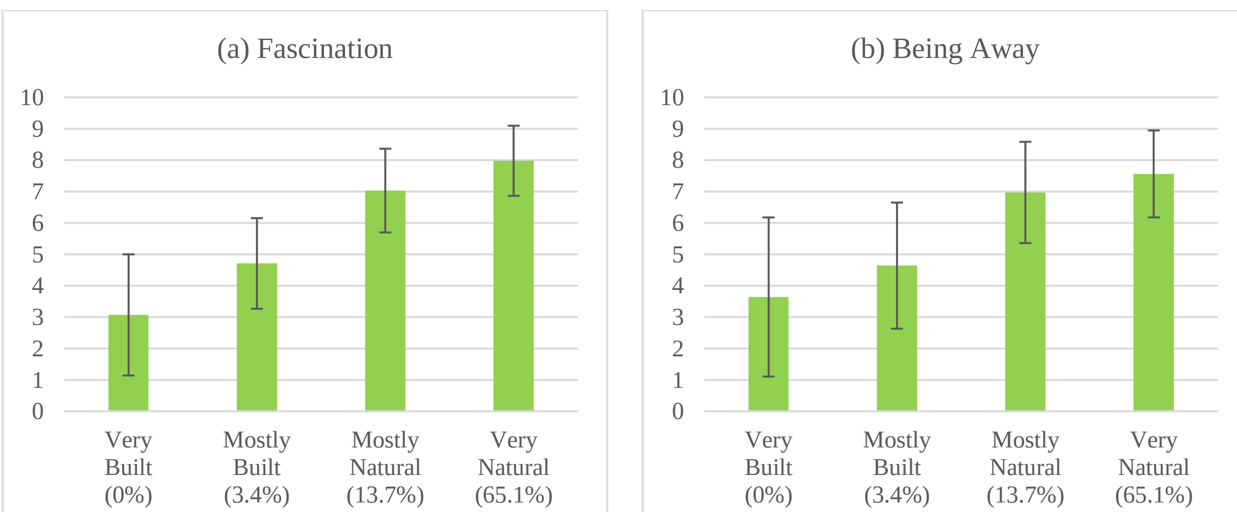
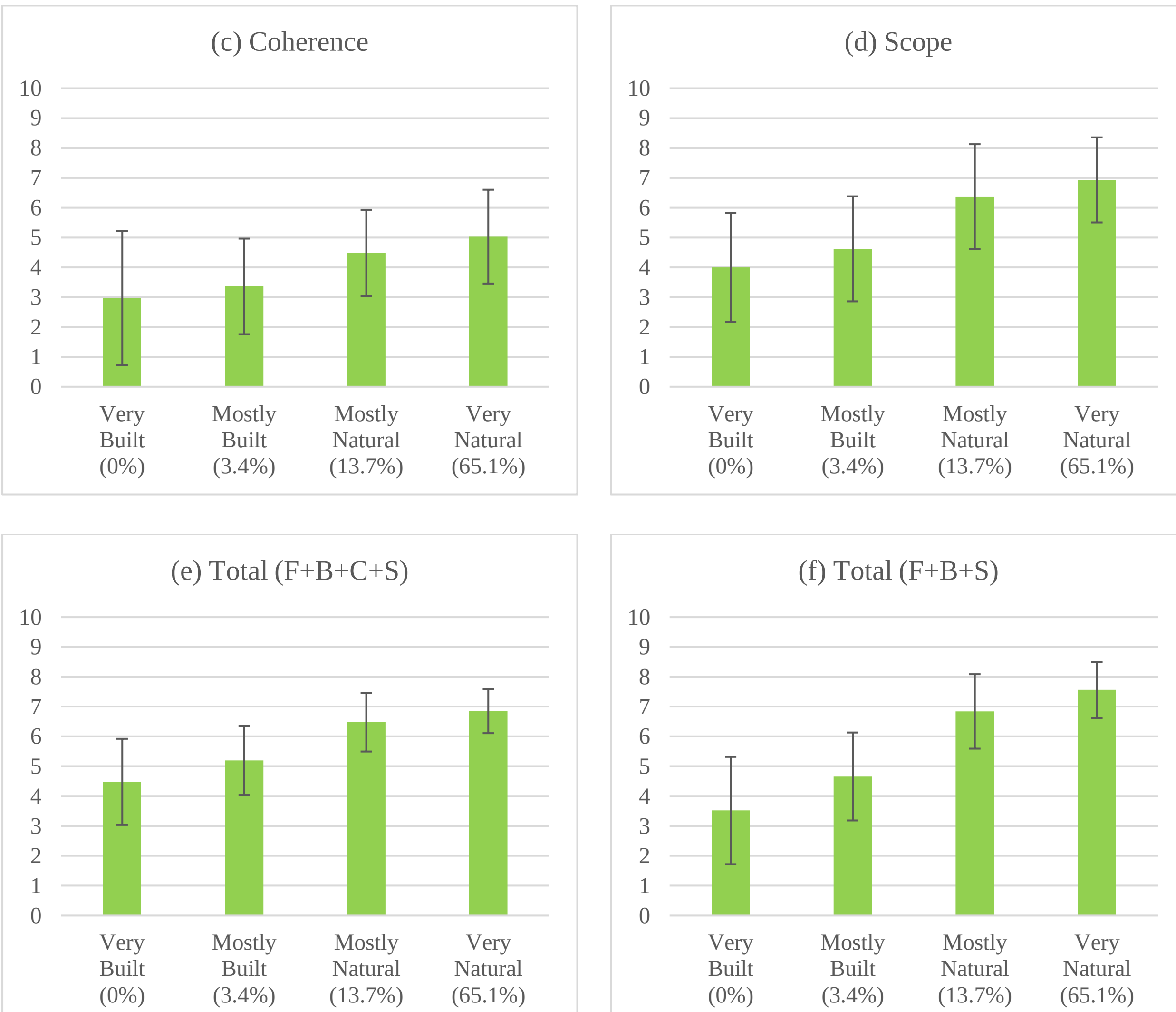


Figure 4.1

Graph of Level of Vegetation by Mean Number of PRS-11 Scores (Experiment 1): (a) Fascination; (b) Being Away; (c) Coherence; (d) Scope; (e) Mean Total PRS-11 Score / Total (F+B+C+S); and (f) Mean of Fascination, Being Away, and Scope Scores / Total (F+B+S)



1. The coherence (question numbers 7, 8, and 9) scores were reversely coded.

PRS-11 Score of Image Sets (Experiment 2)

A second experiment also employed an ANOVA with repeated measures to examine PRS-11 scores by the level of vegetation in the images using six items representing the following vegetation levels: 0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%. For in-depth analysis, PRS-11 scores were also sub-divided into fascination, being away, coherence, scope, the mean of total PRS-11 scores, and the mean of fascination, being away, and scope.

For fascination, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(14) = 35.574$, $p = 0.001$; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity ($\varepsilon = 0.733$). Table 4.2 shows that there was a significant increase in restoration according to the level of vegetation from 0% to 24% vegetation, $F(3.663, 142.865) = 7.887$, $p = 0.000$, $\eta_p^2 = 0.17$; however, the increase stabilized in 24% to less than 100% levels, and went up in 100% vegetation (Figure 4.2a). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .008 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the fascination score of self-report tests in the 100% vegetation image sets ($M = 7.67$, $SD = 1.433$), was significantly higher than in the 0 to 12 % vegetation image sets ($M = 6.54$, $SD = 1.579$), $t(36) = 1.034$, $SEM = 0.237$, $p = .001$, and 0% vegetation image sets ($M = 6.02$, $SD = 1.715$), $t(36) = 1.503$, $SEM = 0.325$, $p = 0.001$. The fascination score of self-report tests in the 12 to 24 % vegetation image sets ($M = 7.05$, $SD = 1.421$) was significantly higher than in the 0% vegetation image sets ($M = 6.02$, $SD = 1.715$), $t(36) = 0.911$, $SEM = 0.253$, $p = 0.013$. The fascination score of self-report tests in the 0 to 12 % vegetation image sets ($M = 6.54$, $SD = 1.579$) was significantly lower than in the 100% vegetation image sets ($M = 7.67$, $SD = 1.433$), $t(36) = -1.034$, $SEM = 0.237$, $p = 0.001$. Lastly, the fascination score of

self-report tests in the 0 % vegetation image sets (*M* = 6.02, *SD* = 1.715) was significantly lower than in the 100% vegetation image sets (*M* = 7.67, *SD* = 1.433), *t*(36) = -1.503, *SEM* = 0.325, *p* = 0.001, and 12 to 24 % vegetation image sets (*M* = 7.05, *SD* = 1.421), *t*(36) = -0.911, *SEM* = 0.253, *p* = 0.013 (Table 4.2).

For being away, Mauchly's test indicated that the assumption of Sphericity has been met, $x^2(14) = 16.301$, *p* = 0.296. Table 4.2 shows that there was a significant increase in restoration in 0% vegetation to 24% vegetation, *F*(5, 195) = 7.632, *p* = 0.000, $\eta_p{}^2 = 0.16$; however, the increase stabilized in 24% to 100% vegetation, and went up in 100% vegetation as similar to fascination (Figure 4.2b). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .008 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the being away score of self-report tests in the 100 % vegetation image sets (*M* = 7.67, *SD* = 1.69), was significantly higher than in the 36 to 100 % vegetation image sets (*M* = 6.47, *SD* = 1.742), *t*(35) = 1.170, *SEM* = 0.275, *p* = 0.002, 24 to 36 % vegetation image sets (*M* = 6.62, *SD* = 1.804), *t*(35) = 1.059, *SEM* = 0.307, *p* = 0.021, 0 to 12 % vegetation image sets (*M* = 6.31, *SD* = 1.669), *t*(35) = 1.364, *SEM* = 0.290, *p* = 0.000, and 0% vegetation image sets (*M* = 5.63, *SD* = 2.003), *t*(35) = 1.902, *SEM* = 0.379, *p* = 0.000. The being away score of self-report tests in the 36 to 100 % vegetation image sets (*M* = 6.47, *SD* = 1.742) was significantly lower than in the 100% vegetation image sets (*M* = 7.67, *SD* = 1.69), *t*(35) = -1.170, *SEM* = 0.275, *p* = 0.002. The being away score of self-report tests in the 24 to 36 % vegetation image sets (*M* = 6.62, *SD* = 1.804) was significantly lower than in the 100% vegetation image sets (*M* = 7.67, *SD* = 1.69), *t*(35) = -1.059, *SEM* = 0.307, *p* = 0.021. The being away score of self-report tests in the 0 to 12 % vegetation image sets (*M* = 6.31, *SD* = 1.669) was significantly lower than in the 100% vegetation image sets

(*M* = 7.67, *SD* = 1.69), *t*(35) = -1.364, *SEM* = 0.290, *p* = 0.000. Lastly, the being away score of self-report tests in the 0% vegetation image sets (*M* = 5.63, *SD* = 2.003) was significantly lower than in the 100% vegetation image sets (*M* = 7.67, *SD* = 1.69), *t*(35) = -1.902, *SEM* = 0.379, *p* = 0.000 (Table 4.2).

For coherence, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(14) = 39.162$, *p* = 0.000; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (ε = 0.670). Table 4.2 shows that there was a significant increase in restoration according to the level of vegetation, *F*(3.352, 130.713) = 20.734, *p* = 0.000, η_p^2 = 0.35 (Figure 4.2c). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .008 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the coherence score of self-report tests in the 100% vegetation image sets (*M* = 5.75, *SD* = 2.383), was significantly higher than in the 12 to 24 % vegetation image sets (*M* = 3.99, *SD* = 1.677), *t*(35) = 1.911, *SEM* = 0.400, *p* = 0.000, 0 to 12 % vegetation image sets (*M* = 3.78, *SD* = 1.704), *t*(35) = 2.035, *SEM* = 0.444, *p* = 0.001, and 0% vegetation image sets (*M* = 2.97, *SD* = 1.529), *t*(35) = 2.874, *SEM* = 0.477, *p* = 0.000. The coherence score of self-report tests in the 36 to 100 % vegetation image sets (*M* = 5.32, *SD* = 1.734) was significantly higher than in the 12 to 24 % vegetation image sets (*M* = 3.99, *SD* = 1.677), *t*(35) = 1.365, *SEM* = 0.305, *p* = 0.001, 0 to 12 % vegetation image sets (*M* = 3.78, *SD* = 1.704), *t*(35) = 1.489, *SEM* = 0.328, *p* = 0.001, and 0% vegetation image sets (*M* = 2.97, *SD* = 1.529), *t*(35) = 2.327, *SEM* = 0.345, *p* = 0.000. The coherence score of self-report tests in the 24 to 36% vegetation image sets (*M* = 5.03, *SD* = 1.673) was significantly higher than in the 12 to 24 % vegetation image sets (*M* = 3.99, *SD* = 1.677), *t*(35) = 1.168, *SEM* = 0.266, *p* = 0.001, 0 to 12 % vegetation image sets (*M* = 3.78, *SD* = 1.704), *t*(35) =

1.293, *SEM* = 0.265, *p* = 0.000, and 0% vegetation image sets (*M* = 2.97, *SD* = 1.529), *t*(35) = 2.131, *SEM* = 0.320, *p* = 0.000. The coherence score of self-report tests in the 12 to 24 % vegetation image sets (*M* = 3.99, *SD* = 1.677) was significantly lower than in the 100% vegetation image sets (*M* = 5.75, *SD* = 2.383), *t*(35) = -1.911, *SEM* = 0.400, *p* = 0.000, 36 to 100 % vegetation image sets (*M* = 5.32, *SD* = 1.734), *t*(35) = -1.365, *SEM* = 0.305, *p* = 0.001, 24 to 36 % vegetation image sets (*M* = 5.03, *SD* = 1.673), *t*(35) = -1.168, *SEM* = 0.266, *p* = 0.001, but was significantly higher than in the 0% vegetation image sets (*M* = 2.97, *SD* = 1.529), *t*(35) = 0.963, *SEM* = 0.279, *p* = 0.020. The coherence score of self-report tests in the 0 to 12 % vegetation image sets (*M* = 3.78, *SD* = 1.704) was significantly lower than in the 100% vegetation image sets (*M* = 5.75, *SD* = 2.383), *t*(35) = -2.035, *SEM* = 0.444, *p* = 0.001, 36 to 100 % vegetation image sets (*M* = 5.32, *SD* = 1.734), *t*(35) = -1.489, *SEM* = 0.328, *p* = 0.001, 24 to 36 % vegetation image sets (*M* = 5.03, *SD* = 1.673), *t*(35) = -1.293, *SEM* = 0.265, *p* = 0.000. Lastly, the coherence score of self-report tests in the 0 % vegetation image sets (*M* = 7.03, *SD* = 1.529) was significantly lower than in the 100% vegetation image sets (*M* = 2.97, *SD* = 2.383), *t*(35) = -2.874, *SEM* = 0.477, *p* = 0.000, 36 to 100 % vegetation image sets (*M* = 5.32, *SD* = 1.734), *t*(35) = -2.327, *SEM* = 0.345, *p* = 0.000, 24 to 36 % vegetation image sets (*M* = 5.03, *SD* = 1.673), *t*(35) = -2.131, *SEM* = 0.320, *p* = 0.000, and 12 to 24 % vegetation image sets (*M* = 3.99, *SD* = 1.677), *t*(35) = -0.963, *SEM* = 0.279, *p* = 0.020 (Table 4.2). The coherence (question numbers 7, 8, and 9) scores were reversely coded.

Table 4.2

Level of Vegetation by Mean Number of PRS-11 Scores (Experiment 2).

	Level of Vegetation (N = 41)							
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**	**F**	***p***
	(A)	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**		
Fascination (SD)	6.02 (1.715) C, F	6.54 (1.579) F	7.05 (1.421) A	7.01 (1.557)	6.98 (1.439)	7.67 (1.433) A, B	7.887	0.000 ***
Being Away (SD)	5.63 (2.003) F	6.31 (1.669) F	6.69 (1.664)	6.62 (1.804) F	6.47 (1.742) F	7.67 (1.686) A, B, C, D	7.632	0.000 ***
Coherence (SD)	2.97 (1.529) C, D, E, F	3.78 (1.704) D, E, F	3.99 (1.677) A, D, E, F	5.03 (1.673) A, B, C	5.32 (1.734) A, B, C	5.75 (2.383) A, B, C	20.734	0.000 ***
Scope (SD)	5.54 (1.797) C, F	6.32 (1.580)	6.46 (1.671) A	6.26 (1.496)	6.49 (1.712)	6.96 (1.715) A	4.184	0.002 **
Total (F+B+C+S) (SD)	4.99 (1.111) B, C, D, E, F	5.68 (0.965) A, D, E, F	6.01 (0.989) A, F	6.23 (1.052) A, B, F	6.30 (0.942) A, B, F	7.02 (1.021) A, B, C, D, E	23.099	0.000 ***
Total (F+B+S) (SD)	5.75 (1.536) C, F	6.40 (1.333) F	6.77 (1.357) A	6.67 (1.463) F	6.67 (1.402) F	7.50 (1.358) A, B, D, E	9.881	0.000 ***

*** $p < .005$, ** $p < .01$

Significance level for upper case letters (A, B, C, D, E, F): .05[1]

1. Tests are adjusted for all pairwise comparisons within a row of each innermost sub-table using the Bonferroni correction.

2. The coherence (question numbers 7, 8, and 9) scores were reversely coded.

For scope, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(14) = 27.536$, $p = 0.017$; therefore, degrees of freedom were corrected using Huynh-Feldt estimates of Sphericity ($\varepsilon = 0.909$). Table 4.2 shows that there was a significant increase in restoration according to the level of vegetation from 0% to 24% vegetation, $F(4.545, 177.238) = 4.184$, $p = 0.002$, $\eta_p^2 = 0.10$; however, the increase stabilized in 24% to less than 100% levels, and went up in 100% vegetation (Figure 4.2d). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .008 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the scope score of self-report tests in the 100% vegetation image sets ($M = 6.96$, $SD = 1.715$), was significantly higher than in the 0% vegetation image sets ($M = 5.54$, $SD = 1.797$), $t(35) = 1.344$, $SEM = 0.372$, $p = 0.013$. The scope score of self-report tests in the 12 to 24 % vegetation image sets ($M = 6.46$, $SD = 1.671$) was significantly higher than in the 0% vegetation image sets ($M = 5.54$, $SD = 1.797$), $t(35) = 0.886$, $SEM = 0.281$, $p = 0.046$. Lastly, the scope score of self-report tests in the 0 % vegetation image sets ($M = 5.54$, $SD = 1.797$) was significantly lower than in the 100% vegetation image sets ($M = 6.96$, $SD = 1.715$), $t(35) = -1.344$, $SEM = 0.372$, $p = 0.013$, and 12 to 24 % vegetation image sets ($M = 6.46$, $SD = 1.671$), $t(35) = -0.886$, $SEM = 0.281$, $p = 0.046$ (Table 4.2).

For the mean total PRS-11 score, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(14) = 37.290$, $p = 0.001$; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity ($\varepsilon = 0.707$). Table 4.2 shows that there was a significant increase in restoration scores in accordance with levels of vegetation, $F(3.537, 137.954) = 23.099$, $p = 0.000$, $\eta_p^2 = 0.37$ (Figure 4.2e). Bonferroni post hoc tests indicated that the coherence score of self-report tests in the 100% vegetation image sets ($M = 7.02$, $SD = 1.021$), was

significantly higher than in the 36 to 100 % vegetation image sets (*M* = 6.30, *SD* = 0.942), *t*(35) = 0.745, *SEM* = 0.157, *p* = 0.000, 24 to 36 % vegetation image sets (*M* = 6.23, *SD* = 1.052), *t*(35) = 0.810, *SEM* = 0.170, *p* = 0.000, 12 to 24 % vegetation image sets (*M* = 6.01, *SD* = 0.989), *t*(35) = 1.031, *SEM* = 0.222, *p* = 0.001, 0 to 12 % vegetation image sets (*M* = 5.68, *SD* = 0.965), *t*(35) = 1.327, *SEM* = 0.185, *p* = 0.000, and 0% vegetation image sets (*M* = 4.99, *SD* = 1.111), *t*(35) = 1.957, *SEM* = 0.265, *p* = 0.000. The mean total PRS-11 score of self-report tests in the 36 to 100 % vegetation image sets (*M* = 6.30, *SD* = 0.942) was significantly lower than in the 100% vegetation image sets (*M* = 7.02, *SD* = 1.021), *t*(35) = -0.745, *SEM* = 0.157, *p* = 0.000, but was significantly higher than in the 0 - 12 % vegetation image sets (*M* = 5.68, *SD* = 0.965), *t*(35) = 0.582, *SEM* = 0.177, *p* = 0.032, and 0% vegetation image sets (*M* = 4.99, *SD* = 1.111), *t*(35) = 1.212, *SEM* = 0.212, *p* = 0.000. The mean total PRS-11 score of self-report tests in the 24 to 36 % vegetation image sets (*M* = 6.23, *SD* = 1.052) was significantly lower than in the 100% vegetation image sets (*M* = 7.02, *SD* = 1.021), *t*(35) = -0.810, *SEM* = 0.170, *p* = 0.000, but was significantly higher than in the 0 - 12 % vegetation image sets (*M* = 5.68, *SD* = 0.965), *t*(35) = 0.517, *SEM* = 0.164, *p* = 0.047, and 0% vegetation image sets (*M* = 4.99, *SD* = 1.111), *t*(35) = 1.146, *SEM* = 0.239, *p* = 0.000. The mean total PRS-11 score of self-report tests in the 12 to 24 % vegetation image sets (*M* = 6.01, *SD* = 0.989) was significantly lower than in the 100% vegetation image sets (*M* = 7.02, *SD* = 1.021), *t*(35) = -1.031, *SEM* = 0.222, *p* = 0.001, but was significantly higher than in the 0% vegetation image sets (*M* = 4.99, *SD* = 1.111), *t*(35) = 0.926, *SEM* = 0.214, *p* = 0.002. The mean total PRS-11 score of self-report tests in the 0 to 12 % vegetation image sets (*M* = 5.68, *SD* = 0.965) was significantly lower than in the 100% vegetation image sets (*M* = 7.02, *SD* = 1.021), *t*(35) = -1.327, *SEM* = 0.185, *p* = 0.000, 36 - 100 % vegetation image sets (*M* = 6.30, *SD* = 0.942), *t*(35) =

-0.582, *SEM* = 0.177, *p* = 0.032, and 24 - 36 % vegetation image sets (*M* = 6.23, *SD* = 1.052), *t*(35) = -0.517, *SEM* = 0.164, *p* = 0.047, but was significantly higher than in the 0% vegetation image sets (*M* = 4.99, *SD* = 1.111), *t*(35) = 0.630, *SEM* = 0.194, *p* = 0.036. The mean total PRS-11 score of self-report tests in the 0% vegetation image sets (*M* = 4.99, *SD* = 1.111) was significantly lower than in the 100% vegetation image sets (*M* = 7.02, *SD* = 1.021), *t*(35) = -1.957, *SEM* = 0.265, *p* = 0.000, 36 - 100 % vegetation image sets (*M* = 6.30, *SD* = 0.942), *t*(35) = -1.212, *SEM* = 0.212, *p* = 0.000, 24 - 36 % vegetation image sets (*M* = 6.23, *SD* = 1.052), *t*(35) = -1.146, *SEM* = 0.239, *p* = 0.000, 12 - 24 % vegetation image sets (*M* = 6.01, *SD* = 0.989), *t*(35) = -0.926, *SEM* = 0.214, *p* = 0.002, and 0 - 12 % vegetation image sets (*M* = 5.68, *SD* = 0.965), *t*(35) = -0.630, *SEM* = 0.194, *p* = 0.036 (Table 4.2).

For mean of fascination, being away, and scope scores, Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(14) = 29.613$, *p* = 0.009; therefore, degrees of freedom were corrected using Huynh-Feldt estimates of Sphericity (ε = 0.883). Table 4.2 shows that there was a significant increase in restoration in 0% vegetation to 24% vegetation, *F*(4.414, 172.160) = 9.881, *p* = 0.000, $\eta_p^2 = 0.20$; however, the increase stabilized in 24% to 100% vegetation, and went up in 100% vegetation (Figure 4.2f). Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .008 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the mean of fascination, being away, and scope scores of self-report tests in the 100 % vegetation image sets (*M* = 7.50, *SD* = 1.358), was significantly higher than in the 36 to 100 % vegetation image sets (*M* = 6.67, *SD* = 1.402), *t*(35) = 0.820, *SEM* = 0.212, *p* = 0.006, 24 to 36 % vegetation image sets (*M* = 6.67, *SD* = 1.463), *t*(35) = 0.836, *SEM* = 0.254, *p* = 0.032, 0 to 12 % vegetation image sets (*M* = 6.40, *SD* = 1.333), *t*(35) =

1.062, *SEM* = 0.230, *p* = 0.001, and 0% vegetation image sets (*M* = 5.75, *SD* = 1.536), *t*(35) = 1.613, *SEM* = 0.292, *p* = 0.000. The mean of fascination, being away, and scope scores of self-report tests in the 36 to 100 % vegetation image sets (*M* = 6.67, *SD* = 1.402) was significantly lower than in the 100% vegetation image sets (*M* = 7.50, *SD* = 1.358), *t*(35) = -0.820, *SEM* = 0.212, *p* = 0.006. The mean of fascination, being away, and scope scores of self-report tests in the 24 to 36 % vegetation image sets (*M* = 6.67, *SD* = 1.463) was significantly lower than in the 100% vegetation image sets (*M* = 7.50, *SD* = 1.358), *t*(35) = -0.836, *SEM* = 0.254, *p* = 0.032. The mean of fascination, being away, and scope scores of self-report tests in the 12 to 24 % vegetation image sets (*M* = 6.62, *SD* = 1.804) was significantly higher than in the 0% vegetation image sets (*M* = 6.77, *SD* = 1.357), *t*(35) = 0.912, *SEM* = 0.234, *p* = 0.006. The mean of fascination, being away, and scope scores of self-report tests in the 0 to 12 % vegetation image sets (*M* = 6.40, *SD* = 1.333) was significantly lower than in the 100% vegetation image sets (*M* = 7.50, *SD* = 1.358), *t*(35) = -1.062, *SEM* = 0.230, *p* = 0.001. Lastly, the mean of fascination, being away, and scope scores of self-report tests in the 0% vegetation image sets (*M* = 5.75, *SD* = 1.536) was significantly lower than in the 100% vegetation image sets (*M* = 7.50, *SD* = 1.358), *t*(35) = -1.613, *SEM* = 0.292, *p* = 0.000, and 12 to 24 % vegetation image sets (*M* = 6.62, *SD* = 1.804), *t*(36) = -0.912, *SEM* = 0.234, *p* = 0.006 (Table 4.2).

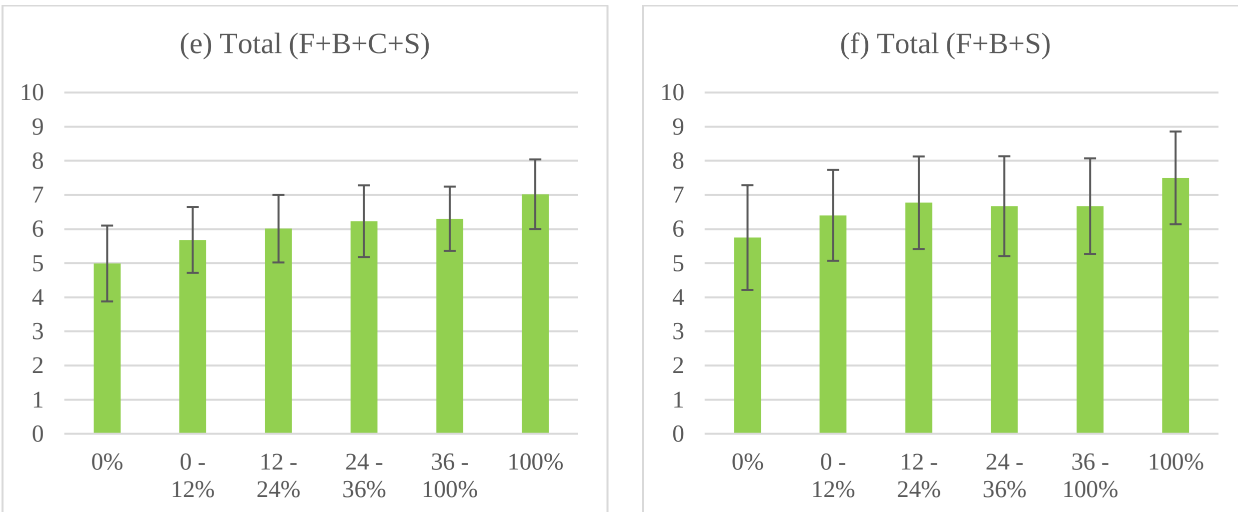
Figure 4.2

Graph of Level of Vegetation by Mean Number of PRS-11 Scores (Experiment 2): (a) Fascination; (b) Being Away; (c) Coherence; (d) Scope; (e) Mean Total PRS-11 Score / Total (F+B+C+S); and (f) Mean of Fascination, Being Away, and Scope Scores / Total (F+B+S)

1. The coherence (question numbers 7, 8, and 9) scores were reversely coded.

Figure 4.2

Graph of Level of Vegetation by Mean Number of PRS-11 Scores (Experiment 2): (a) Fascination; (b) Being Away; (c) Coherence; (d) Scope; (e) Mean Total PRS-11 Score / Total (F+B+C+S); and (f) Mean of Fascination, Being Away, and Scope Scores / Total (F+B+S)



1. The coherence (question numbers 7, 8, and 9) scores were reversely coded.

4.2. Level of Vegetation's Effects on Backward Digit Span Score

Backward Digit Span Score of In Situ Environments (Experiment 1)

The second question was whether indirect and symbolic visual contacts with vegetation in indoor built environments improve people's attention capacity, especially with memory tasks. Our expectation was that the backward digit span score would be positively related to the level of vegetation within the indoor built environment. An ANOVA with repeated measures was conducted between the backward digit span score and the four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in the Seoul Botanic Park. The results of an ANOVA with repeated measures indicated no significant differences among the level of plants in four locations (Table 4.3) emerged in the backward digit span scores. However, there were a small increase of the task scores with higher levels of vegetation (figure 4.3).

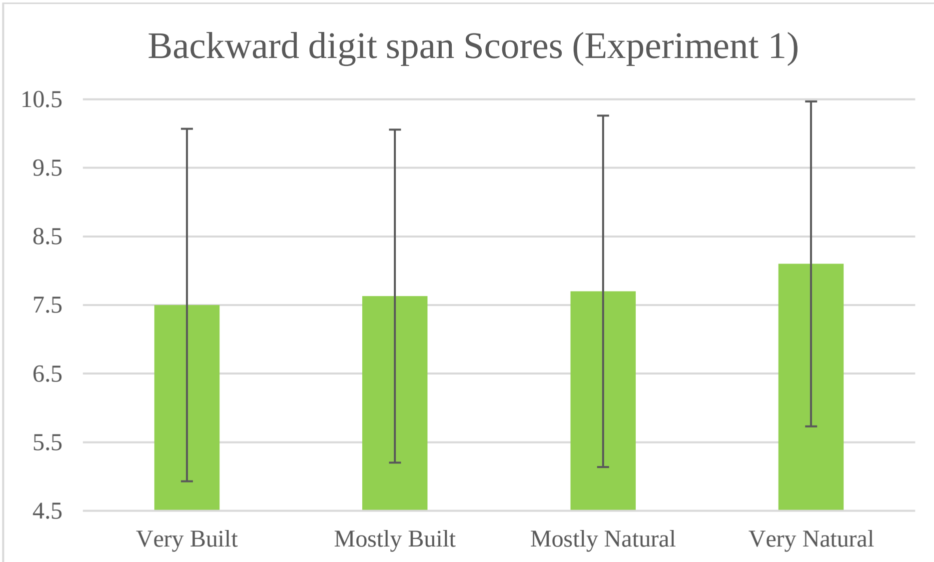
Table 4.3

Level of Vegetation by Mean Number of Backward Digit Span Score (Experiment 1)

	Level of Vegetation (N = 30)					
	Very Built (A)	**Mostly Built (B)**	**Mostly Natural (C)**	**Very Natural (D)**	**F**	***p***
Mean backward digit span score (SD)	7.50 (2.570)	7.63 (2.428)	7.70 (2.562)	8.10 (2.369)	.730	.524

Figure 4.3

Graph of Level of Vegetation by Mean Number of Backward Digit Span Score (Experiment 1)



Backward Digit Span Score of Image Sets (Experiment 2)

The experiment with images shows more interesting results. An ANOVA with repeated measures was conducted between the backward digit span score and the level of vegetation in the six sets of images (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%). Mauchly's test indicated that the assumption of Sphericity had been met, $x^2(14) = 18.624$, $p = 0.181$. The results show that the level of vegetation had a significant effect on the backward digit span task scores, $F(5, 200) = 2.489$, $p = .033$, $\eta_p^2 = 0.06$ (Table 4.4). The backward digit span task scores show an inverted-U shape (Figure 4.4).

Bonferroni's post-hoc tests using a Bonferroni adjusted alpha level of .008 per test (.05/6), did not show significant differences in the backward digit span task scores among the six sets of images. However, Fisher's Least Significant Difference (LSD) test showed that the backward digit span task scores for the 0% vegetation image sets (M = 7.49, SD = 2.368) were significantly lower than the 0 to 12% vegetation image sets (M = 8.20, SD = 2.411), 12 to 24 % vegetation image sets (M = 8.44, SD = 2.419), 24 to 36 % vegetation image sets (M = 8.51, SD = 2.491), and 36 to 100 % vegetation image sets (M = 8.44, SD = 2.460) (Table 4.4).

Table 4.4

Level of Vegetation by Mean Number of Backward Digit Span Score (Experiment 2)

	Level of Vegetation (N = 41)							
	0 (A)	**0-12 (B)**	**12-24 (C)**	**24-36 (D)**	**36-100 (E)**	**100 (F)**	**F**	***p***
Mean backward digit span score (SD)	7.49 (2.368) B, C, D, E	8.20 (2.411) A	8.44 (2.419) A	8.51 (2.491) A	8.44 (2.460) A	8.29 (2.305)	2.489	.033*

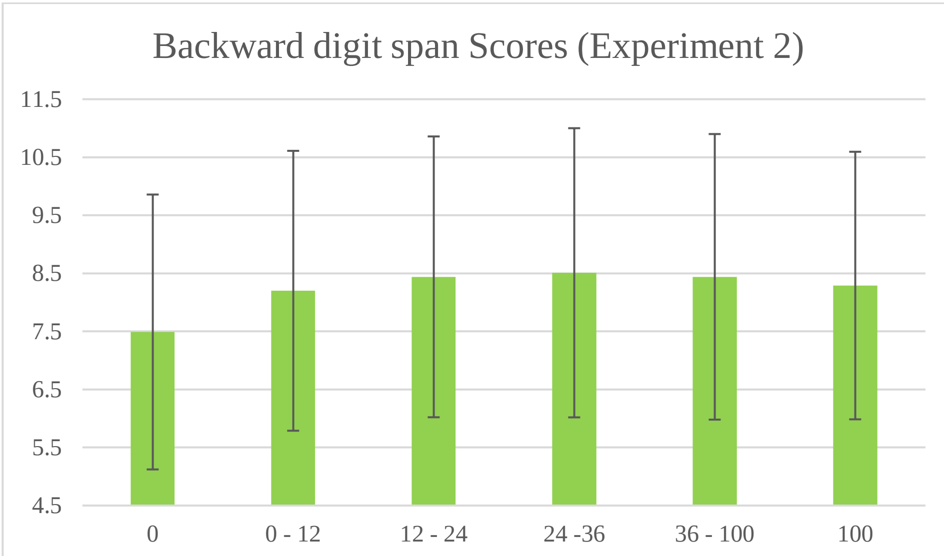
* $p < .05$

Significance level for upper case letters (A, B, C, D, E, F): .05[1]

1. Fisher's LSD test

Figure 4.4

Graph of Level of Vegetation by Mean Number of Backward Digit Span Score (Experiment 2)



Although Fisher's LSD test found significant differences, the LSD test was not designed for multiple comparisons above 3 groups, and cannot keep the familywise Type I error below 0.05 (Hayter, 2012; Williams & Abdi, 2010). Thus, an ANOVA with repeated measures was conducted again, among three groups: 0% image set, 0 - 100% image set (mean backward digit span task score of four image sets, excluding 0% and 100%), 100% image set. Mauchly's test indicated that the assumption of Sphericity was violated, $x^2(2) = 16.255$, $p = 0.000$; thus degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity ($\varepsilon = 0.746$). The results indicate significant differences in the backward digit span task scores among 0% vegetation (no vegetation), 0% to 100% vegetation (any level of vegetation within indoor environment) and 100% vegetation (no indoor built environment), $F(1.492, 59.664) = 4.805$, $p = .019$, $\eta_p^2 = 0.11$. Bonferroni's post-

hoc tests using a Bonferroni adjusted alpha level of .016 per test (.05/3) were conducted. The backward digit span task scores for the 0% to 100% vegetation image sets (any level of vegetation within indoor environment) (*M* = 8.40, *SD* = 2.074) were significantly higher than the 0% vegetation (no vegetation) image sets (*M* = 7.49, *SD* = 2.368), *t*(39) = -.909, *SEM* = .307, *p* = .015. There was no significant difference between 0% vegetation (no vegetation) image sets (*M* = 7.49, *SD* = 2.368) and 100% vegetation (no indoor built environment) (*M* = 8.29, *SD* = 2.305), 0% to 100% vegetation (any level of vegetation within indoor environment) (*M* = 8.40, *SD* = 2.074), and 100% vegetation (no indoor built environment) (*M* = 8.29, *SD* = 2.305) image sets.

4.3. Level of Vegetation's Effects on EEG

Mean Relative PSD in All Channels

Mean Relative PSD of In Situ Environments in All Channels during Neutral Setting (Experiment 1). Returning to the first question, the study asked whether indirect and symbolic visual contacts with vegetation in indoor built environment restores people's attention. To verify the influence of indirect contact with vegetation, we assumed that the EEG alpha oscillation would be positively affected by the level of vegetation in indoor built environments. Therefore, this study constructed an ANOVA with repeated measures to examine the effects the level of vegetation in indoor built environments have on the mean relative PSD of participants' EEG bandpowers in all

fourteen channels as assessed during neutral setting.[18] The first experiment analyzed the four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in the Seoul Botanic Park, and found that there were significant differences in delta, beta, and gamma waves in relation to the level of vegetation (Table 4.5).

Mauchly's test in delta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 6.254$, $p = 0.283$. Table 4.5 shows that there was a significant difference between level of plants and delta relative PSD, $F(3, 84) = 3.128$, $p = 0.030$, $\eta_p^2 = 0.10$. Three paired samples t-tests were conducted to make post hoc comparisons between conditions. A first paired samples t-tests indicated that there was not a significant difference in delta relative PSD for Very Built sites ($M = 0.543$, $SD = 0.0960$) and Mostly Built sites ($M = 0.504$, $SD = 0.107$), $t(29) = 1.928$, $p = 0.064$. A second paired samples t-tests indicated that there was a significant difference in delta relative PSD for Very Built sites ($M = 0.543$, $SD = 0.0960$) and Mostly Natural sites ($M = 0.487$, $SD = 0.0716$), $t(29) = 2.711$, $p = 0.011$. A third paired sample t-tests indicated that there was not a significant difference in delta relative PSD for Very Built sites ($M = 0.543$, $SD = 0.0960$) and Very Natural sites ($M = 0.503$, $SD = 0.0500$), $t(29) = 2.046$, $p = 0.050$ (Figure 4.5a).

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[18] To differentiate between the two phases of EEG recordings (one seating in situ and viewing images during eye-open resting state, and the other seating in situ and viewing images during backward digit span task performing state) we called the prior resting state "neutral setting (NS)" and the latter task performing state "cognitive task (CT)."

Table 4.5

Level of Vegetation by Mean Relative PSD in All Channels during Neutral Setting (Experiments 1)

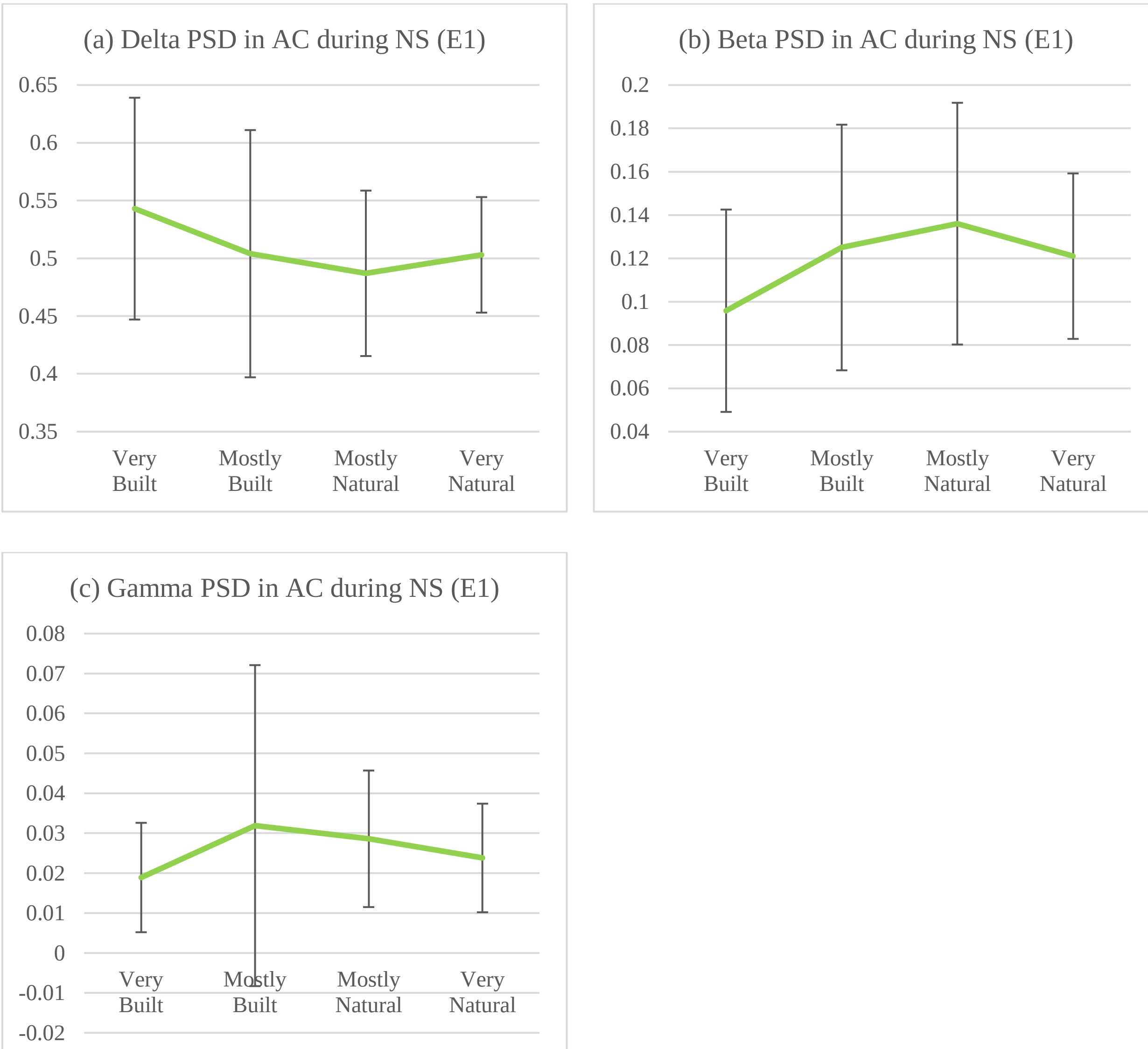
	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta	0.543	0.504	0.487	0.503	3.128	0.030*
(sd)	(0.0960)	(0.107)	(0.0716)	(0.0500)		
PSD_theta	0.208	0.205	0.215	0.213	1.174	0.324
(sd)	(0.0271)	(0.0292)	(0.0278)	(0.0259)		
PSD_alpha	0.128	0.134	0.138	0.136	0.751	0.525
(sd)	(0.0620)	(0.0580)	(0.0400)	(0.0384)		
PSD_beta	0.0958	0.125	0.136	0.121	5.865	0.001**
(sd)	(0.0467)	(0.0567)	(0.0558)	(0.0382)		
PSD_gamma	0.0189	0.0319	0.0286	0.0238	3.497	0.048*
(sd)	(0.0137)	(0.0402)	(0.0171)	(0.0136)		

* $p < .05$, ** $p < .01$

Mauchly's test in beta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 6.371$, $p = 0.272$. Table 4.5 and Figure 4.5b shows that there was an inverted U-shape relationship between level of plants and beta relative PSD, $F(3, 84) = 5.865$, $p = 0.001$, $\eta_p^2 = 0.17$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for Very Built sites (*M* = 0.0958, *SD* = 0.0467) was significantly lower than Mostly Built sites (*M* = 0.125, *SD* = 0.0567), $t(26) = -0.032$, *SEM* = 0.010, $p = 0.019$ and Mostly Natural sites (*M* = 0.136, *SD* = 0.0558), $t(26) = -0.043$, *SEM* = 0.011, $p = 0.003$ (Figure 4.5b).

Figure 4.5

Mean Relative PSD in All Channels during Neutral Setting (Experiment 1). (a) Delta; (b) Beta; and (c) Gamma



Mauchly's test in gamma waves indicated that the assumption of Sphericity was violated, $x^2(5) = 34.955$, $p = 0.000$; therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity ($\varepsilon = 0.537$). Table 4.5 shows a significant difference between level of plants

and gamma relative PSD, $F(1.611, 45.119) = 3.497$, $p = 0.048$, $\eta_p^2 = 0.11$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the gamma relative PSD for Mostly Natural sites ($M = 0.0286$, $SD = 0.0171$) was significantly higher than Very Built sites ($M = 0.0189$, $SD = 0.0137$), $t(26) = 0.011$, $SEM = 0.004$, $p = 0.028$ (Figure 4.5c).

Mean Relative PSD of In Situ Environments in All Channels during Cognitive Task (Experiment 1). The second question of whether indirect and symbolic visual contacts with vegetation in indoor built environment improve people's attention capacity, especially with memory tasks. To verify the influence of indirect contact with vegetation, we assumed that the EEG theta oscillation would be positively affected by the level of vegetation in the indoor built environment. Therefore, this study constructed an ANOVA with repeated measures to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in all fourteen channels during the backward digit span task. The second phase of the first experiment analyzed the four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) in four designated spaces in Seoul Botanic Park, and found that there was no significant difference in brain waves relating to the level of vegetation (Table 4.6).

Table 4.6

Level of Vegetation by Mean Relative PSD in All Channels during Cognitive Task (Experiment 1)

	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta	0.565	0.558	0.559	0.566	0.268	0.848
(sd)	(0.118)	(0.0931)	(0.109)	(0.0806)		
PSD_theta	0.204	0.208	0.207	0.217	0.904	0.443
(sd)	(0.0294)	(0.0317)	(0.0400)	(0.0233)		
PSD_alpha	0.116	0.105	0.106	0.104	0.395	0.704
(sd)	(0.0676)	(0.0458)	(0.0494)	(0.0426)		
PSD_beta	0.0962	0.104	0.104	0.0948	0.919	0.436
(sd)	(0.0573)	(0.0504)	(0.0556)	(0.0471)		
PSD_gamma	0.0184	0.0246	0.0236	0.0187	0.772	0.471
(sd)	(0.0155)	(0.0247)	(0.0217)	(0.00851)		

Mean Relative PSD of Image Sets in All Channels during Neutral Setting (Experiment 2). To assess the influence of symbolic visual contacts with vegetation in indoor built environments on attention restoration, we assumed that the EEG alpha oscillation would be positively affected by the level of vegetation in the indoor built environment. Therefore, this study constructed an ANOVA with repeated measures to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in all fourteen channels in neutral setting. The second experiment analyzed the six sets of images according to the level of vegetation in the images (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found that there was a significant differences in alpha waves in relation to the level of vegetation (Table 4.7).

Mauchly's test in alpha waves indicated that the assumption of Sphericity had been violated, $x^2(14) = 30.938$, $p = 0.006$; therefore, degrees of freedom were corrected using Huynh-Feldt estimates of Sphericity (ε = 0.914). Table 4.7 shows that the relative alpha PSD increased during the 0% to 12 - 24% sets and that this increase remained through the 100% set, $F(4.569, 178.186) = 4.204$, $p = 0.002$, $\eta_p^2 = 0.10$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0083 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the alpha relative PSD for the 0% vegetation set (M = 0.110, SD = 0.0408) was significantly lower than the 36 - 100% vegetation set (M = 0.132, SD = 0.0425), $t(35) = -0.021$, $SEM = 0.006$, $p = 0.014$ and 100% vegetation set (M = 0.130, SD = 0.0420), $t(35) = -0.020$, $SEM = 0.005$, $p = 0.002$ (Figure 4.6).

To further identify differences, nine paired samples t-tests were conducted to make post hoc comparisons between conditions. A first paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation set (M = 0.110, SD = 0.0408) and 0 - 12% vegetation set (M = 0.120, SD = 0.0363), $t(40) = -2.115$, $p = 0.041$. A second paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation set (M = 0.110, SD = 0.0408) and 12 - 24% vegetation set (M = 0.129, SD = 0.0422), $t(40) = -2.808$, $p = 0.008$. A third paired samples t-tests indicated a significant difference in alpha relative PSD for the 0% vegetation set (M = 0.110, SD = 0.0408) and 24 - 36% vegetation set (M = 0.129, SD = 0.0510), $t(40) = -3.299$, $p = 0.002$. A fourth paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation set (M = 0.110, SD = 0.0408) and 36 - 100% vegetation set (M = 0.132, SD = 0.0425), $t(40) = -4.003$, $p = 0.000$. A fifth paired samples t-test showed a significant difference in alpha relative PSD for the 0% vegetation set (M = 0.110, SD = 0.0408) and 100% vegetation set

(*M* = 0.130, *SD* = 0.0420), *t*(40) = -4.630, *p* = 0.000. A sixth paired samples t-test did not show a significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.120, *SD* = 0.0363) and 12 - 24% vegetation set (*M* = 0.129, *SD* = 0.0422), *t*(40) = -1.671, *p* = 0.103. A seventh paired samples t-test showed a significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.120, *SD* = 0.0363) and 24 - 36% vegetation set (*M* = 0.129, *SD* = 0.0510), *t*(40) = -1.544, *p* = 0.130. A eighth paired samples t-test showed a significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.120, *SD* = 0.0363) and 36 - 100% vegetation set (*M* = 0.132, *SD* = 0.0425), *t*(40) = -2.209, *p* = 0.033. A ninth paired samples t-test showed a significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.120, *SD* = 0.0363) and 100% vegetation set (*M* = 0.130, *SD* = 0.0420), *t*(40) = -2.022, *p* = 0.050.

Table 4.7

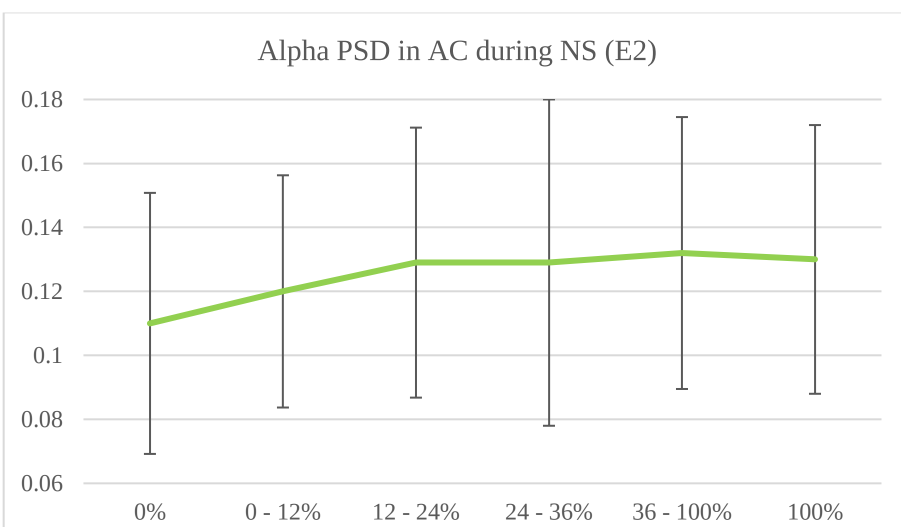
Level of Vegetation by Mean Relative PSD in All Channels during Neutral Setting (Experiment 2)

	Level of Plants						F	p
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.481 (0.167)	0.439 (0.153)	0.454 (0.146)	0.436 (0.148)	0.414 (0.146)	0.413 (0.160)	1.935	0.114
PSD_ theta (sd)	0.215 (0.0277)	0.218 (0.0316)	0.213 (0.0202)	0.219 (0.0230)	0.216 (0.0252)	0.210 (0.0358)	1.218	0.303
PSD_ alpha (sd)	0.110 (0.0408)	0.120 (0.0363)	0.129 (0.0422)	0.129 (0.0510)	0.132 (0.0425)	0.130 (0.0420)	4.204	0.002 **
PSD_ beta (sd)	0.102 (0.0503)	0.114 (0.0536)	0.113 (0.0476)	0.118 (0.0543)	0.123 (0.0498)	0.120 (0.0477)	2.182	0.062
PSD_ gamma (sd)	0.0207 (0.0159)	0.0232 (0.0160)	0.0218 (0.0124)	0.0241 (0.0162)	0.0261 (0.0167)	0.0257 (0.0203)	1.235	0.300

** $p < .01$

Figure 4.6

Alpha Mean Relative PSD in All Channels during Neutral Setting (Experiment 2)



Mean Relative PSD of Image Sets in All Channels during Cognitive Task (Experiment 2). The dissertation assessed the influence of symbolic visual contacts with vegetation on people's attention capacity, especially with working memory tasks, in indoor built environments. We assumed that the EEG theta oscillation would be positively affected by the level of vegetation in indoor built environments. Therefore, this study constructed an ANOVA with repeated measures to examine the effects of the level of vegetation on the mean relative PSD of participants' EEG bandpowers in all fourteen channels during the backward digit span task. The second phase of second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found significant differences in theta waves in relation to the level of vegetation (Table 4.8).

Mauchly's test in theta waves indicated that the assumption of Sphericity had been met, $x^2(14) = 20.576$, $p = 0.114$. Table 4.8 shows the relative theta PSD increases along with the level of vegetation in the image sets, $F(5, 195) = 2.986$, $p = 0.013$, $\eta_p^2 = 0.07$. Bonferroni's post-hoc test were used with a Bonferroni adjusted alpha level of .0083 per test (.05/6) to make post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the theta relative PSD for 0% vegetation set ($M = 0.201$, $SD = 0.0188$) was significantly lower than 24 - 36% vegetation set ($M = 0.218$, $SD = 0.0260$), $t(35) = -0.018$, $SEM = 0.006$, $p = 0.035$ (Figure 4.7).

To further identify differences, five paired samples t-tests were conducted to make post hoc comparisons between different levels of vegetation. A first paired samples t-test indicated that there was not a significant difference in theta relative PSD for 0% vegetation set ($M = 0.201$, $SD = 0.0188$) and 0 - 12% vegetation set ($M = 0.209$, $SD = 0.0268$), $t(40) = -1.221$, $p = 0.229$. A second paired samples t-test indicated no significant difference in the theta relative PSD for 0% vegetation

set (M = 0.201, SD = 0.0188) and the 12 - 24% vegetation set (M = 0.210, SD = 0.0287), $t(40)$ = -1.367, p = 0.179. A third paired samples t-test indicated a significant difference in theta relative PSD for the 0% vegetation set (M = 0.201, SD = 0.0188) and the 24 - 36% vegetation set (M = 0.218, SD = 0.0260), $t(40)$ = -3.106, p = 0.003. A fourth paired samples t-test showed a significant difference in theta relative PSD for the 0% vegetation set (M = 0.201, SD = 0.0188) and the 36 - 100% vegetation set (M = 0.215, SD = 0.0241), $t(40)$ = -2.776, p = 0.008. A fifth paired samples t-test showed a significant difference in theta relative PSD for the 0% vegetation set (M = 0.201, SD = 0.0188) and the 100% vegetation set (M = 0.216, SD = 0.0242), $t(40)$ = -2.647, p = 0.012.

Table 4.8

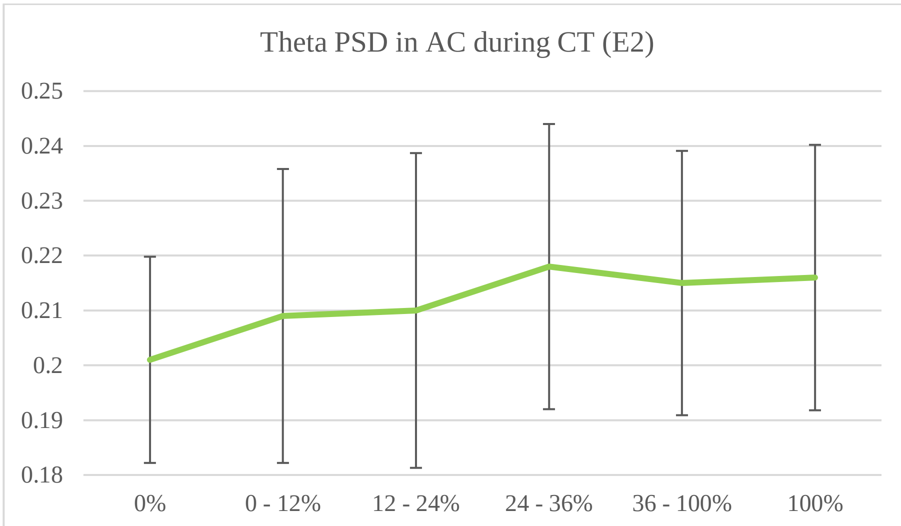
Level of Vegetation by Mean Relative PSD in All Channels during Cognitive Task (Experiment 2)

	Level of Plants						F	p
	0	0-12	12-24	24-36	36-100	100		
PSD_ delta (sd)	0.546 (0.0947)	0.570 (0.0873)	0.561 (0.0985)	0.553 (0.0974)	0.553 (0.102)	0.558 (0.0867)	0.799	0.545
PSD_ theta (sd)	0.201 (0.0188)	0.209 (0.0268)	0.210 (0.0287)	0.218 (0.0260)	0.215 (0.0241)	0.216 (0.0242)	2.986	0.013 *
PSD_ alpha (sd)	0.108 (0.0575)	0.105 (0.0469)	0.111 (0.0625)	0.108 (0.0496)	0.110 (0.0533)	0.107 (0.0495)	0.365	0.740
PSD_ beta (sd)	0.106 (0.0514)	0.0976 (0.0458)	0.0987 (0.0463)	0.101 (0.0501)	0.101 (0.0552)	0.0992 (0.0472)	0.595	0.692
PSD_ gamma (sd)	0.0226 (0.0164)	0.0193 (0.0123)	0.0193 (0.0109)	0.0195 (0.0131)	0.0206 (0.0166)	0.0196 (0.0137)	1.499	0.219

* $p < .05$

Figure 4.7

Theta Mean Relative PSD in All Channels during Cognitive Task (Experiment 2)



Mean relative PSD of different brain areas

Since the power of frequency bands varies in different regions of the brain, regional analyses of EEG data varied significantly from the results of the mean bandpower from all channels. Within-group analysis (among different spaces and different images) was undertaken using multivariate regional analyses wherein the 14 electrode sites are broken down into antero-frontal (AF3, AF4, F3, F4, F7, and F8), frontocentral (FC5 and FC6), temporal (T7 and T8), parietal (P7 and P8), and occipital (O1 and O2) regions.

Mean Relative PSD in Antero-Frontal Region.

Mean Relative PSD of In Situ Environments in Antero-Frontal Region during Neutral Setting (Experiment 1). An ANOVA with repeated measures was used to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in six channels in the antrero-frontal region (AF3, AF4, F3, F4, F7, and F8) during neutral setting. The first experiment analyzed the four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found that there was a significant differences in beta waves in relation to the level of vegetation (Table 4.9).

Mauchly's test in beta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 7.543$, $p = 0.184$. Table 4.9 and Figure 4.8 shows an inverted U-shape relationship between level of plants and beta relative PSD, $F(3, 84) = 4.383$, $p = 0.006$, $\eta_p{}^2 = 0.14$. Bonferroni's post-hoc test were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for the Very Built site ($M = 0.0960$, $SD = 0.0580$) was significantly lower than for the Mostly Built site ($M = 0.124$, $SD = 0.0645$), $t(26) = -0.031$, $SEM = 0.010$, $p = 0.032$ and the Mostly Natural site ($M = 0.133$, $SD = 0.0650$), $t(26) = -0.041$, $SEM = 0.013$, $p = 0.032$ (Figure 4.8).

Table 4.9

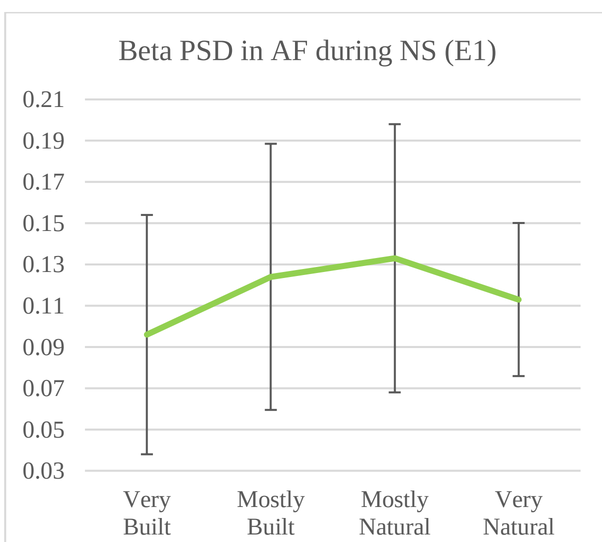
Level of Vegetation by Mean Relative PSD in Antero-Frontal Region during Neutral Setting (Experiment 1)

	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta	0.554	0.519	0.504	0.524	2.270	0.088
(sd)	(0.102)	(0.112)	(0.0825)	(0.0518)		
PSD_theta	0.208	0.203	0.217	0.216	2.217	0.092
(sd)	(0.0320)	(0.0323)	(0.0305)	(0.0301)		
PSD_alpha	0.119	0.121	0.123	0.120	0.305	0.806
(sd)	(0.0589)	(0.0534)	(0.0414)	(0.0330)		
PSD_beta	0.0960	0.124	0.133	0.113	4.383	0.006**
(sd)	(0.0580)	(0.0645)	(0.0650)	(0.0371)		
PSD_gamma	0.0202	0.0336	0.0288	0.0235	3.368	0.055
(sd)	(0.0174)	(0.0427)	(0.0181)	(0.0108)		

** $p < .01$

Figure 4.8

Beta Mean Relative PSD in Antero-Frontal Region during Neutral Setting (Experiment 1)



Mean Relative PSD of In Situ Environments in Antero-Frontal Region during Cognitive Task (Experiment 1). An ANOVA with repeated measures was used to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in six channels in the antrero-frontal region (AF3, AF4, F3, F4, F7, and F8) during the backward digit span task. The second phase of the first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in the Seoul Botanic Park, and found no significant differences in any brain waves in relation to the level of vegetation (Table 4.10).

Table 4.10

Level of Vegetation by Mean Relative PSD in Antero-Frontal Region during Cognitive Task (Experiment 1)

	Level of Plants					
	Very Built	Mostly Built	Mostly Natural	Very Natural	F	p
PSD_delta (sd)	0.586 (0.116)	0.580 (0.0917)	0.588 (0.102)	0.597 (0.0707)	0.285	0.836
PSD_theta (sd)	0.207 (0.0318)	0.209 (0.0353)	0.212 (0.0414)	0.221 (0.0247)	1.006	0.394
PSD_alpha (sd)	0.103 (0.0606)	0.0961 (0.0406)	0.0922 (0.0398)	0.0896 (0.0353)	0.453	0.656
PSD_beta (sd)	0.0852 (0.0537)	0.0920 (0.0527)	0.0877 (0.0510)	0.0760 (0.0354)	1.068	0.366
PSD_gamma (sd)	0.0176 (0.0174)	0.0226 (0.0265)	0.0203 (0.0181)	0.0166 (0.00805)	0.547	0.566

Mean Relative PSD of Image Sets in Antero-Frontal Region during Neutral Setting (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative Power Spectrum Density (PSD) of participants' EEG bandpowers in six channels in the antrero-frontal region (AF3, AF4, F3, F4, F7, and F8) during neutral setting. The second experiment analyzed the six sets of images with differing levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found a significant differences in alpha waves in relation to the level of vegetation (Table 4.11).

Mauchly's test in alpha waves indicated that the assumption of Sphericity had been violated, $x^2(14) = 27.490$, $p = 0.017$; therefore, degrees of freedom were corrected using Huynh-Feldt estimates of Sphericity (ε = 0.946). Table 4.11 shows an increase in the relative alpha PSD during the 0% to 12 - 24% sets which remained through the 100% set, $F(4.731, 184.528) = 3.169$, $p = 0.010$, $\eta_p^2 = 0.08$. Bonferroni's post-hoc test were used with a Bonferroni adjusted alpha level of .0083 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the alpha relative PSD for the 0% vegetation set (*M* = 0.100, *SD* = 0.0365) was significantly lower than the 36 - 100% vegetation set (*M* = 0.121, *SD* = 0.0362), *t*(35) = -0.019, *SEM* = 0.005, *p* = 0.008 and the 100% vegetation set (*M* = 0.116, *SD* = 0.039), *t*(35) = -0.016, *SEM* = 0.005, *p* = 0.024 (Figure 4.9).

To further review the differences, nine paired samples t-tests were conducted to make post hoc comparisons between levels of vegetaion. A first paired samples t-test indicated no significant differences in alpha relative PSD for the 0% vegetation set (*M* = 0.100, *SD* = 0.0365) and the 0 - 12% vegetation set (*M* = 0.107, *SD* = 0.0332), *t*(40) = -1.359, *p* = 0.182. A second paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation set (*M* = 0.100,

SD = 0.0365) and the 12 - 24% vegetation set (*M* = 0.116, *SD* = 0.0354), *t*(40) = -2.366, *p* = 0.023. A third paired sample t-tests indicated a significant difference in alpha relative PSD for the 0% vegetation set (*M* = 0.100, *SD* = 0.0365) and the 24 - 36% vegetation set (*M* = 0.118, *SD* = 0.0481), *t*(40) = -2.665, *p* = 0.011. A fourth paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation set (*M* = 0.100, *SD* = 0.0365) and the 36 - 100% vegetation set (*M* = 0.121, *SD* = 0.0362), *t*(40) = -4.268, *p* = 0.000. A fifth paired samples t-test showed a significant difference in alpha relative PSD for the 0% vegetation set (*M* = 0.100, *SD* = 0.0365) and the 100% vegetation set (*M* = 0.116, *SD* = 0.039), *t*(40) = -3.587, *p* = 0.001. A sixth paired samples t-test indicated no significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.107, *SD* = 0.0332) and the 12 - 24% vegetation set (*M* = 0.116, *SD* = 0.0354), *t*(40) = -1.703, *p* = 0.096. A seventh paired samples t-test indicated no significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.107, *SD* = 0.0332) and the 24 - 36% vegetation set (*M* = 0.118, *SD* = 0.0481), *t*(40) = -1.756, *p* = 0.087. A eighth paired samples t-test indicated a significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.107, *SD* = 0.0332) and the 36 - 100% vegetation set (*M* = 0.121, *SD* = 0.0362), *t*(40) = -2.738, *p* = 0.009. A ninth paired samples t-test indicated no significant difference in alpha relative PSD for the 0 - 12% vegetation set (*M* = 0.107, *SD* = 0.0332) and the 100% vegetation set (*M* = 0.116, *SD* = 0.039), *t*(40) = -1.701, *p* = 0.097.

Table 4.11

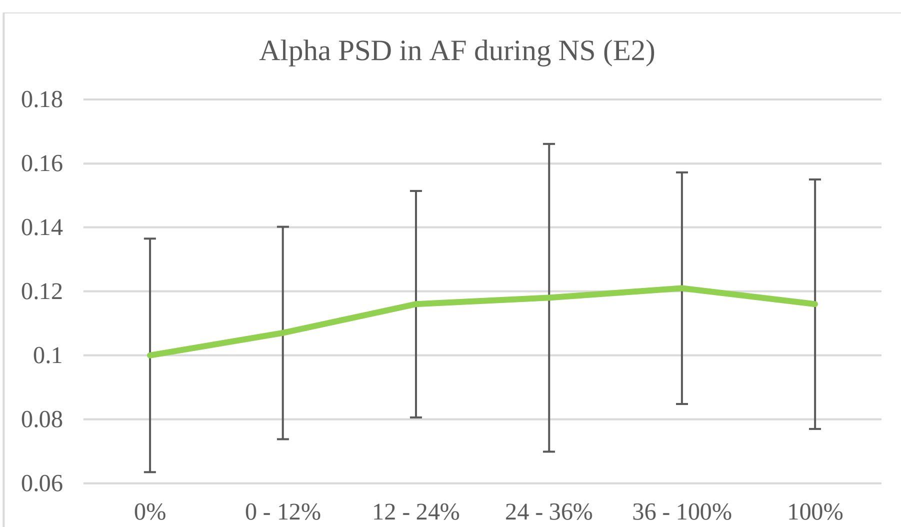
Level of Vegetation by Mean Relative PSD in Antero-Frontal Region during Neutral Setting (Experiment 2)

	Level of Plants						F	p
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.498 (0.170)	0.452 (0.158)	0.469 (0.146)	0.449 (0.151)	0.426 (0.152)	0.424 (0.170)	2.103	0.090
PSD_ theta (sd)	0.219 (0.0338)	0.224 (0.0342)	0.219 (0.0256)	0.223 (0.0278)	0.220 (0.0299)	0.216 (0.0375)	0.646	0.665
PSD_ alpha (sd)	0.100 (0.0365)	0.107 (0.0332)	0.116 (0.0354)	0.118 (0.0481)	0.121 (0.0362)	0.116 (0.039)	3.169	0.010 **
PSD_ beta (sd)	0.0919 (0.0505)	0.101 (0.0497)	0.103 (0.0475)	0.111 (0.0531)	0.113 (0.0446)	0.106 (0.0475)	1.909	0.097
PSD_ gamma (sd)	0.0191 (0.0148)	0.0221 (0.0159)	0.0219 (0.0147)	0.0238 (0.0154)	0.0247 (0.0147)	0.0249 (0.0238)	0.929	0.430

** $p < .01$

Figure 4.9

Alpha Mean Relative PSD in Antero-Frontal Region during Neutral Setting (Experiment 2)



Mean Relative PSD of Image Sets in Antero-Frontal Region during Cognitive Task (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in six channels in the antrero-frontal region (AF3, AF4, F3, F4, F7, and F8) during the backward digit span task. The second phase of second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found a significant difference in theta waves in relation to the level of vegetation (Table 4.12).

Table 4.12

Level of Vegetation by Mean Relative PSD in Antero-Frontal Region during Cognitive Task (Experiment 2)

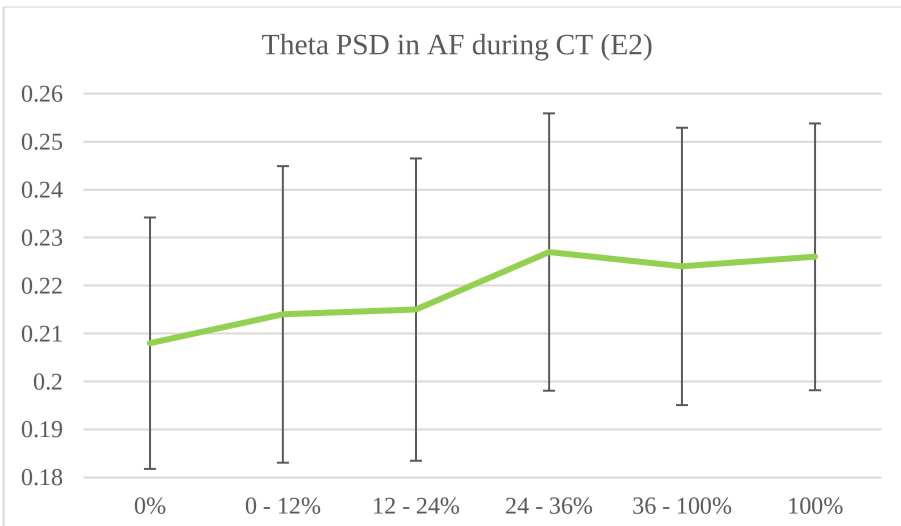
	Level of Plants						F	p
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.569 (0.0902)	0.600 (0.0826)	0.588 (0.0952)	0.576 (0.0904)	0.579 (0.0932)	0.579 (0.0837)	1.154	0.333
PSD_ theta (sd)	0.208 (0.0262)	0.214 (0.0309)	0.215 (0.0315)	0.227 (0.0289)	0.224 (0.0289)	0.226 (0.0278)	3.137	0.010 *
PSD_ alpha (sd)	0.0967 (0.0475)	0.0905 (0.0345)	0.0985 (0.0478)	0.0986 (0.0433)	0.0969 (0.0423)	0.0963 (0.0403)	0.527	0.677
PSD_ beta (sd)	0.0883 (0.0476)	0.0791 (0.0418)	0.0814 (0.0428)	0.0820 (0.0419)	0.0820 (0.0447)	0.0819 (0.0412)	0.552	0.737
PSD_ gamma (sd)	0.0203 (0.0166)	0.0162 (0.0092)	0.0166 (0.0097)	0.0163 (0.0110)	0.0173 (0.0130)	0.0168 (0.0111)	1.976	0.113

* $p < .05$

Mauchly's test in theta waves indicated that the assumption of Sphericity had been met, $x^2(14) = 13.536$, $p = 0.486$. Table 4.12 shows that the relative theta PSD increase as the level of vegetation in the image sets enlarged, $F(5, 195) = 3.137$, $p = 0.010$, $\eta_p^2 = 0.07$ (Figure 4.10).

Figure 4.10

Theta Mean Relative PSD in Antero-Frontal Region during Cognitive Task (Experiment 2)



To further review the differences, nine paired samples t-tests were conducted to make post hoc comparisons between conditions. A first paired samples t-test indicated no significant difference in theta relative PSD for the 0% vegetation set ($M = 0.208$, $SD = 0.0262$) and the 0 - 12% vegetation set ($M = 0.214$, $SD = 0.0309$), $t(40) = -0.972$, $p = 0.337$. A second paired samples t-test indicated no significant difference in theta relative PSD for the 0% vegetation set ($M = 0.208$, $SD = 0.0262$) and the 12 - 24% vegetation set ($M = 0.215$, $SD = 0.0315$), $t(40) = -1.103$, $p = 0.277$.

A third paired samples t-test indicated a significant difference in theta relative PSD for the 0% vegetation set (*M* = 0.208, *SD* = 0.0262) and the 24 - 36% vegetation set (*M* = 0.227, *SD* = 0.0289), *t*(40) = -3.011, *p* = 0.004. A fourth paired samples t-test showed a significant difference in theta relative PSD for the 0% vegetation set (*M* = 0.208, *SD* = 0.0262) and the 36 - 100% vegetation set (*M* = 0.224, *SD* = 0.0289), *t*(40) = -2.779, *p* = 0.008. A fifth paired samples t-test showed a significant difference in theta relative PSD for the 0% vegetation set (*M* = 0.208, *SD* = 0.0262) and the 100% vegetation set (*M* = 0.226, *SD* = 0.0278), *t*(40) = -2.811, *p* = 0.008. A sixth paired samples t-test indicated no significant difference in theta relative PSD for the 0 - 12% vegetation set (*M* = 0.214, *SD* = 0.0309) and the 12 - 24% vegetation set (*M* = 0.215, *SD* = 0.0315), *t*(40) = -0.217, *p* = 0.830. A seventh paired samples t-test indicated no significant difference in theta relative PSD for the 0 - 12% vegetation set (*M* = 0.214, *SD* = 0.0309) and the 24 - 36% vegetation set (*M* = 0.227, *SD* = 0.0289), *t*(40) = -2.014, *p* = 0.051. A eighth paired samples t-test indicated no significant difference in theta relative PSD for the 0 - 12% vegetation set (*M* = 0.214, *SD* = 0.0309) and the 36 - 100% vegetation set (*M* = 0.224, *SD* = 0.0289), *t*(40) = -1.986, *p* = 0.054. A ninth paired samples t-test indicated a significant difference in theta relative PSD for the 0 - 12% vegetation set (*M* = 0.214, *SD* = 0.0309) and the 100% vegetation set (*M* = 0.226, *SD* = 0.0278), *t*(40) = -2.195, *p* = 0.034.

Mean Relative PSD in Frontocentral Region.

Mean Relative PSD of In Situ Environments in Frontocentral Region during Neutral Setting (Experiment 1). An ANOVA with repeated measures was used to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the frontocentral region (FC5 and FC6) during neutral setting. The first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found a significant differences in delta, beta, and gamma waves in relation to the level of vegetation (Table 4.13).

Table 4.13

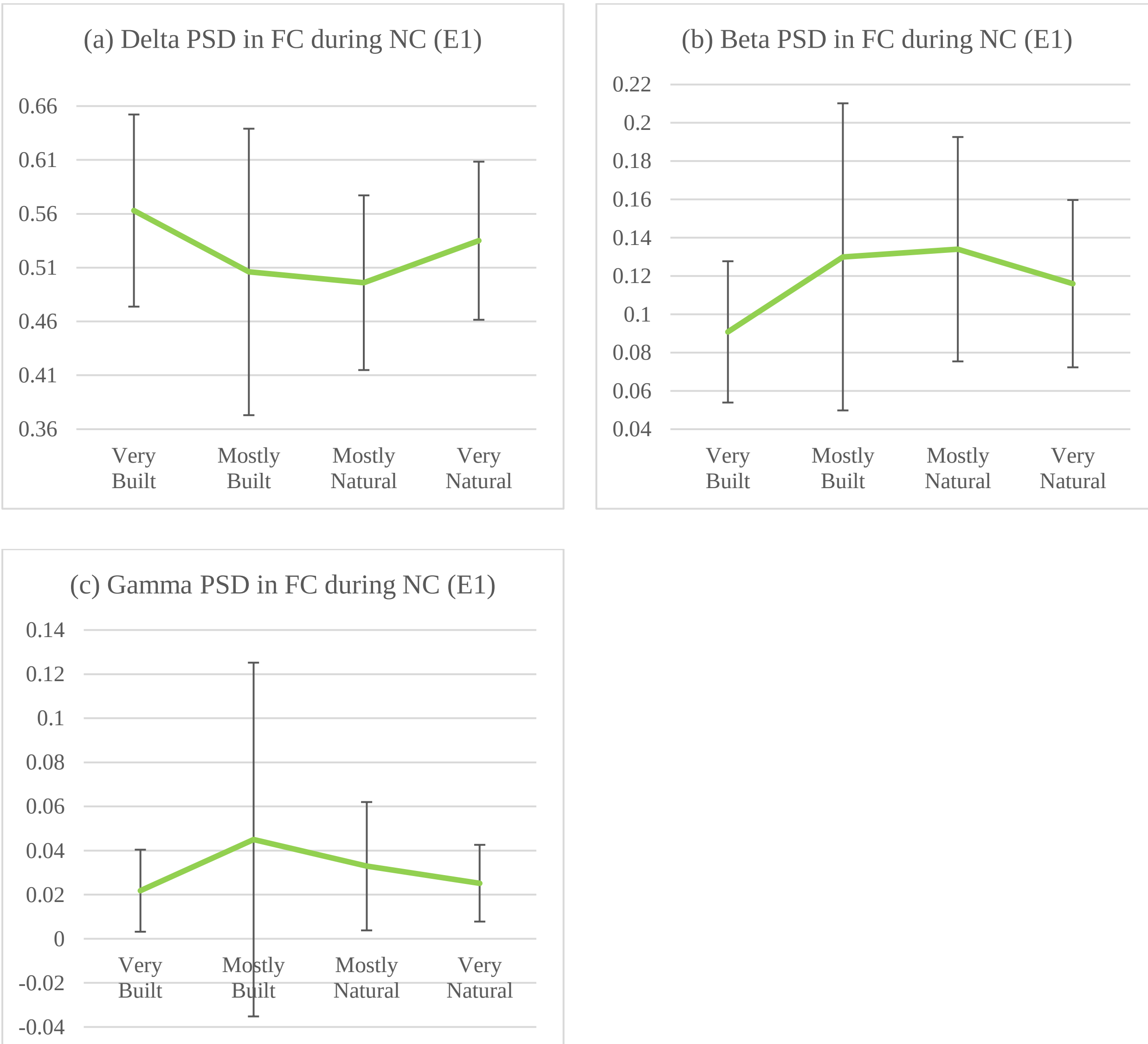
Level of Vegetation by Mean Relative PSD at Frontocentral Region in Neutral Setting (Experiment 1)

	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta (sd)	0.563 (0.0892)	0.506 (0.133)	0.496 (0.0811)	0.535 (0.0734)	3.673	0.015*
PSD_theta (sd)	0.212 (0.0385)	0.205 (0.0483)	0.217 (0.0428)	0.209 (0.0318)	1.080	0.362
PSD_alpha (sd)	0.106 (0.0470)	0.114 (0.0456)	0.122 (0.0342)	0.118 (0.0334)	0.985	0.404
PSD_beta (sd)	0.0908 (0.0369)	0.130 (0.0802)	0.134 (0.0586)	0.116 (0.0437)	4.403	0.014**
PSD_gamma (sd)	0.0218 (0.0186)	0.0450 (0.0802)	0.0329 (0.0291)	0.0252 (0.0174)	4.466	0.034*

* $p < .05$, ** $p < .01$

Figure 4.11

Mean Relative PSD at Frontocentral Region in Neutral Setting (Experiment 1). (a) Delta; (b) Beta; and (c) Gamma



Mauchly's test in delta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 3.540$, $p = 0.618$. Table 4.13 shows a significant difference between level of plants and delta relative PSD, $F(3, 84) = 3.673$, $p = 0.015$, $\eta_p^2 = 0.12$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to make post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the delta relative PSD for Very Built site ($M = 0.563$, $SD = 0.0892$) was significantly higher than Mostly Natural site ($M = 0.496$, $SD = 0.0811$), $t(26) = 0.071$, $SEM = 0.024$, $p = 0.039$ (Figure 4.11a).

Mauchly's test in beta waves indicated that the assumption of Sphericity had been violated, $x^2(5) = 14.237$, $p = 0.014$; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity ($\varepsilon = 0.726$). Table 4.13 and Figure 4.11b shows that there was an inverted U-shape relationship between level of plants and beta relative PSD, $F(2.179, 61.016) = 4.403$, $p = 0.014$, $\eta_p^2 = 0.14$. Bonferroni's post-hoc test were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to make post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for the Very Built site ($M = 0.0908$, $SD = 0.0369$) was significantly lower than the Mostly Built ($M = 0.130$, $SD = 0.0802$), $t(26) = -0.042$, $SEM = 0.014$, $p = 0.033$ and Mostly Natural sites ($M = 0.134$, $SD = 0.0586$), $t(26) = -0.040$, $SEM = 0.011$, $p = 0.005$ (Figure 4.11b).

Mauchly's test in gamma waves indicated that the assumption of Sphericity had been violated, $x^2(5) = 73.659$, $p = 0.000$; therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity ($\varepsilon = 0.412$). Table 4.13 shows that there was a significant difference between level of plants and gamma relative PSD, $F(1.235, 34.579) = 4.466$, $p = 0.034$, $\eta_p^2 = 0.14$. Three paired samples t-tests were conducted to make post hoc comparisons

between conditions. A first paired samples t-test indicated a significant difference in gamma relative PSD for the Very Built (*M* = 0.0218, *SD* = 0.0186) and Mostly Built sites (*M* = 0.0450, *SD* = 0.0802), $t(29) = -1.811$, $p = 0.080$. A second paired samples t-test indicated a significant difference in gamma relative PSD for the Very Built (*M* = 0.0218, *SD* = 0.0186) and Mostly Natural sites (*M* = 0.0329, *SD* = 0.0291), $t(29) = -2.508$, $p = 0.018$. A third paired samples t-test indicated no significant difference in gamma relative PSD for the Very Built (*M* = 0.0218, *SD* = 0.0186) and Very Natural sites (*M* = 0.0252, *SD* = 0.0174), $t(29) = -0.817$, $p = 0.421$ (Figure 4.11c).

Mean Relative PSD of In Situ Environments in Frontocentral Region during Cognitive Task (Experiment 1). An ANOVA with repeated measures was used to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the frontocentral region (FC5 and FC6) during the backward digit span task. The second phase of the first experiment analyzed the four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found no significant differences in brain waves in relation to the level of vegetation (Table 4.14).

Table 4.14

Level of Vegetation by Mean Relative PSD in Frontocentral Region during Cognitive Task (Experiment 1)

	Level of Plants					
	Very Built	Mostly Built	Mostly Natural	Very Natural	F	p
PSD_delta (sd)	0.588 (0.121)	0.561 (0.105)	0.590 (0.101)	0.589 (0.0715)	0.767	0.516
PSD_theta (sd)	0.201 (0.0344)	0.204 (0.0301)	0.206 (0.0381)	0.215 (0.0294)	0.520	0.659
PSD_alpha (sd)	0.100 (0.0539)	0.0976 (0.0370)	0.0876 (0.0292)	0.0937 (0.0287)	0.633	0.588
PSD_beta (sd)	0.0923 (0.0593)	0.107 (0.0653)	0.0931 (0.0611)	0.0845 (0.0407)	1.413	0.252
PSD_gamma (sd)	0.0176 (0.0174)	0.0226 (0.0265)	0.0203 (0.0181)	0.0166 (0.00805)	0.547	0.566

Mean Relative PSD of Image Sets in Frontocentral Region during Neutral Setting (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the frontocentral region (FC5 and FC6) during neutral setting. The second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found no significant differences in brain waves in relation to the level of vegetation (Table 4.15).

Table 4.15

Level of Vegetation by Mean Relative PSD in Frontocentral Region during Neutral Setting (Experiment 2)

	Level of Plants						F	p
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.487 (0.177)	0.442 (0.158)	0.460 (0.170)	0.453 (0.165)	0.419 (0.171)	0.434 (0.176)	1.453	0.210
PSD_ theta (sd)	0.214 (0.0318)	0.220 (0.0417)	0.212 (0.0279)	0.215 (0.0403)	0.209 (0.0362)	0.199 (0.0408)	2.134	0.064
PSD_ alpha (sd)	0.100 (0.0411)	0.113 (0.0406)	0.116 (0.0510)	0.114 (0.0455)	0.115 (0.0479)	0.117 (0.0399)	1.550	0.182
PSD_ beta (sd)	0.0947 (0.0533)	0.117 (0.0708)	0.109 (0.0664)	0.118 (0.0648)	0.120 (0.0621)	0.119 (0.0541)	1.893	0.125
PSD_ gamma (sd)	0.0211 (0.0207)	0.0236 (0.0181)	0.0232 (0.0235)	0.0274 (0.0255)	0.0293 (0.0311)	0.0274 (0.0222)	2.316	0.054

Mean Relative PSD of Image Sets in Frontocentral Region during Cognitive Task (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the frontocentral region (FC5 and FC6) during backward digit span task. The second phase of the second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found no significant differences in brain waves in relation to the level of vegetation (Table 4.16).

Table 4.16

Level of Vegetation by Mean Relative PSD in Frontocentral Region during Cognitive Task (Experiment 2)

	Level of Plants						F	p
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.557 (0.0989)	0.567 (0.0950)	0.572 (0.110)	0.559 (0.101)	0.560 (0.104)	0.575 (0.0930)	0.705	0.611
PSD_ theta (sd)	0.207 (0.0257)	0.217 (0.0402)	0.211 (0.0389)	0.217 (0.0336)	0.211 (0.0301)	0.212 (0.0313)	0.728	0.600
PSD_ alpha (sd)	0.105 (0.0477)	0.102 (0.0407)	0.106 (0.0553)	0.104 (0.0378)	0.105 (0.0462)	0.100 (0.0462)	0.371	0.786
PSD_ beta (sd)	0.0947 (0.0533)	0.117 (0.0708)	0.109 (0.0664)	0.118 (0.0648)	0.120 (0.0621)	0.119 (0.0541)	1.893	0.125
PSD_ gamma (sd)	0.0221 (0.0123)	0.0197 (0.0143)	0.0186 (0.0107)	0.0201 (0.0121)	0.0215 (0.0144)	0.0189 (0.0098)	1.393	0.235

Mean Relative PSD in Temporal Region.

Mean Relative PSD of In Situ Environments in Temporal Region during Neutral Setting (Experiment 1). An ANOVA with repeated measures was used to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the temporal region (T7 and T8) during neutral setting. The first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found a significant differences in beta waves in relation to the level of vegetation (Table 4.17).

Table 4.17

Level of Vegetation by Mean Relative PSD in Temporal Region during Neutral Setting (Experiment 1)

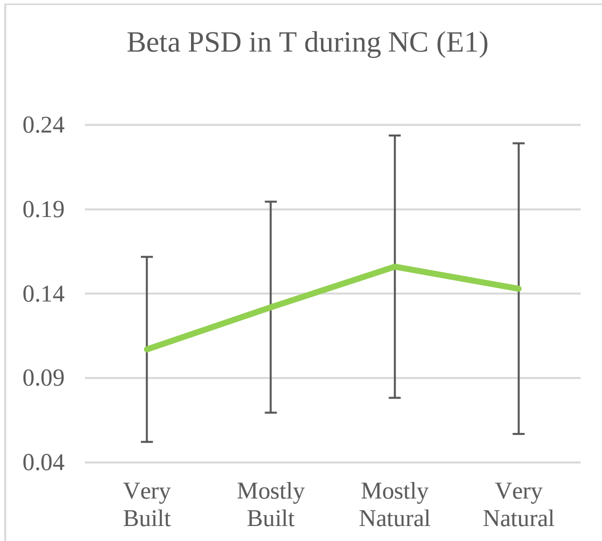
	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta	0.527	0.492	0.471	0.480	1.395	0.250
(sd)	(0.115)	(0.120)	(0.0983)	(0.110)		
PSD_theta	0.210	0.210	0.209	0.208	0.184	0.903
(sd)	(0.0305)	(0.0412)	(0.0422)	(0.0491)		
PSD_alpha	0.125	0.134	0.137	0.137	0.834	0.479
(sd)	(0.0597)	(0.0666)	(0.0449)	(0.0575)		
PSD_beta	0.107	0.132	0.156	0.143	3.349	0.023*
(sd)	(0.0548)	(0.0625)	(0.0777)	(0.0861)		
PSD_gamma	0.0214	0.0310	0.0313	0.0287	1.782	0.159
(sd)	(0.0199)	(0.0317)	(0.0191)	(0.0239)		

* $p < .05$

Mauchly's test in beta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 3.989$, $p = 0.551$. Table 4.17 shows a difference between level of plants and beta relative PSD, $F(3, 84) = 3.349$, $p = 0.023$, $\eta_p^2 = 0.11$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for the Very Built site ($M = 0.107$, $SD = 0.0548$) was significantly lower than the Mostly Natural site ($M = 0.156$, $SD = 0.0777$), $t(26) = -0.052$, $SEM = 0.016$, $p = 0.017$ (Figure 4.12).

Figure 4.12

Beta Mean Relative PSD in Temporal Region during Neutral Setting (Experiment 1)



Mean Relative PSD of In Situ Environments in Temporal Region during Cognitive Task (Experiment 1). An ANOVA with repeated measures was used to examine the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the temporal region (T7 and T8) during the backward digit span task. The second phase of the first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found significant differences in beta waves in relation to the level of vegetation (Table 4.18).

Table 4.18

Level of Vegetation by Mean Relative PSD in Temporal Region during Cognitive Task (Experiment 1)

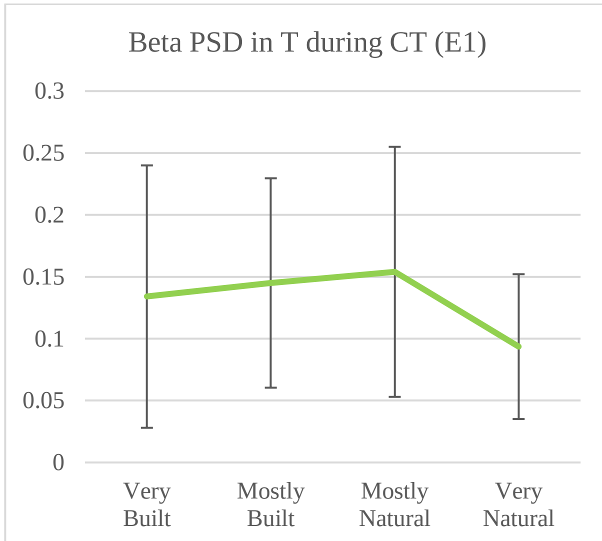
	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta (sd)	0.541 (0.145)	0.528 (0.111)	0.518 (0.141)	0.502 (0.126)	0.400	0.746
PSD_theta (sd)	0.200 (0.0468)	0.194 (0.0464)	0.195 (0.0527)	0.208 (0.0470)	0.489	0.691
PSD_alpha (sd)	0.0977 (0.0494)	0.0974 (0.0407)	0.0965 (0.0374)	0.107 (0.0454)	0.283	0.818
PSD_beta (sd)	0.134 (0.106)	0.145 (0.0846)	0.154 (0.101)	0.0936 (0.0585)	4.261	0.007**
PSD_gamma (sd)	0.0272 (0.0267)	0.0355 (0.0311)	0.0373 (0.0438)	0.0297 (0.0178)	0.557	0.592

** $p < .01$

Mauchly's test in beta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 4.420$, $p = 0.491$. Table 4.18 shows a difference between level of plants and beta relative PSD, $F(3, 84) = 4.261$, $p = 0.007$, $\eta_p^2 = 0.13$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for the Mostly Built site ($M = 0.145$, $SD = 0.0846$) was significantly higher than the Very Natural site ($M = 0.0936$, $SD = 0.0585$), $t(26) = 0.067$, $SEM = 0.018$, $p = 0.005$ (Figure 4.13).

Figure 4.13

Beta Mean Relative PSD in Temporal Region during Cognitive Task (Experiment 1)



Mean Relative PSD of Image Sets in Temporal Region during Neutral Setting (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the temporal region (T7 and T8) during neutral setting. The second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found no significant differences in brain waves in relation to the level of vegetation (Table 4.19).

Table 4.19

Level of Vegetation by Mean Relative PSD in Temporal Region during Neutral Setting (Experiment 2)

	Level of Plants						**F**	**p**
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.450 (0.170)	0.423 (0.171)	0.430 (0.171)	0.424 (0.158)	0.396 (0.156)	0.404 (0.164)	1.047	0.388
PSD_ theta (sd)	0.207 (0.0407)	0.201 (0.0425)	0.198 (0.0320)	0.205 (0.0337)	0.203 (0.0494)	0.207 (0.0578)	0.309	0.898
PSD_ alpha (sd)	0.112 (0.0486)	0.126 (0.0431)	0.133 (0.0552)	0.130 (0.0549)	0.127 (0.0519)	0.126 (0.0482)	1.914	0.099
PSD_ beta (sd)	0.128 (0.0894)	0.143 (0.0937)	0.141 (0.0902)	0.129 (0.0737)	0.146 (0.0960)	0.143 (0.0842)	0.780	0.564
PSD_ gamma (sd)	0.0264 (0.0288)	0.0274 (0.0202)	0.0259 (0.0176)	0.0239 (0.0159)	0.0303 (0.0269)	0.0287 (0.0229)	0.637	0.612

Mean Relative PSD of Image Sets in Temporal Region during Cognitive Task (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the temporal region (T7 and T8) during the backward digit span task. The second phase of the second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found no significant differences in brain waves in relation to the level of vegetation (Table 4.20).

Table 4.20

Level of Vegetation by Mean Relative PSD in Temporal Region during Cognitive Task (Experiment 2)

	Level of Plants						F	p
	0	0-12	12-24	24-36	36-100	100		
PSD_ delta (sd)	0.524 (0.122)	0.528 (0.121)	0.528 (0.128)	0.523 (0.129)	0.526 (0.140)	0.531 (0.120)	0.233	0.941
PSD_ theta (sd)	0.188 (0.0385)	0.191 (0.0420)	0.191 (0.0464)	0.204 (0.0372)	0.198 (0.0385)	0.206 (0.0433)	2.135	0.066
PSD_ alpha (sd)	0.0973 (0.0594)	0.104 (0.0505)	0.100 (0.0463)	0.102 (0.0471)	0.105 (0.0503)	0.100 (0.0472)	0.468	0.793
PSD_ beta (sd)	0.145 (0.104)	0.147 (0.0976)	0.149 (0.106)	0.144 (0.0922)	0.141 (0.107)	0.135 (0.0908)	0.455	0.767
PSD_ gamma (sd)	0.0308 (0.0275)	0.0301 (0.0224)	0.0320 (0.0298)	0.0275 (0.0188)	0.0298 (0.0273)	0.0274 (0.0209)	0.411	0.774

Mean Relative PSD in Parietal Region.

Mean Relative PSD of In Situ Environments in Parietal Region during Neutral Setting (Experiment 1). An ANOVA with repeated measures examines the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the parietal region (P7 and P8) during neutral setting. The first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found a significant difference in beta waves in relation to the level of vegetation (Table 4.21).

Table 4.21

Level of Vegetation by Mean Relative PSD in Parietal Region during Neutral Setting (Experiment 1)

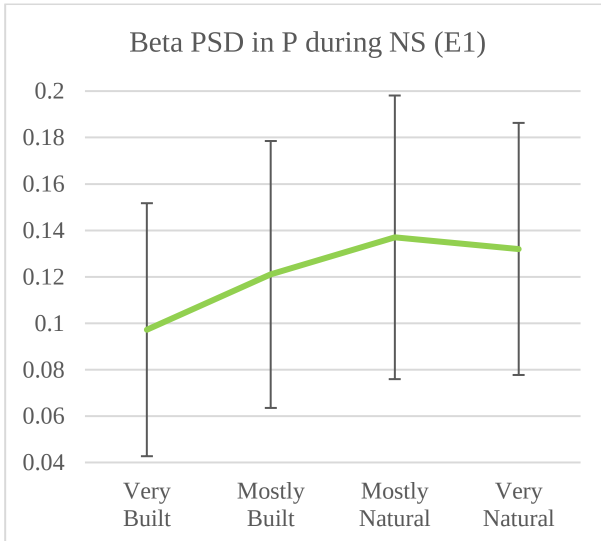
	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta	0.520	0.486	0.454	0.462	2.306	0.083
(sd)	(0.121)	(0.126)	(0.0931)	(0.0882)		
PSD_theta	0.210	0.210	0.218	0.214	0.266	0.850
(sd)	(0.0412)	(0.0375)	(0.0391)	(0.0316)		
PSD_alpha	0.146	0.159	0.169	0.164	0.870	0.460
(sd)	(0.0836)	(0.0849)	(0.0575)	(0.0561)		
PSD_beta	0.0972	0.121	0.137	0.132	4.067	0.009^{**}
(sd)	(0.0545)	(0.0575)	(0.0611)	(0.0543)		
PSD_gamma	0.0157	0.0250	0.0261	0.0236	2.702	0.069
(sd)	(0.00797)	(0.0264)	(0.0172)	(.0194)		

** $p < .01$

Mauchly's test in beta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 5.167$, $p = 0.396$. Table 4.21 shows a difference between level of plants and beta relative PSD, $F(3, 84) = 4.067$, $p = 0.009$, $\eta_p^2 = 0.13$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for the Very Built site (M = 0.0972, SD = 0.0545) was significantly lower than the Mostly Natural site (M = 0.137, SD = 0.0611), $t(26) = -0.041$, SEM = 0.012, p = 0.009 (Figure 4.14).

Figure 4.14

Beta Mean Relative PSD in Parietal Region during Neutral Setting (Experiment 1)



Mean Relative PSD of In Situ Environments in Parietal Region during Cognitive Task (Experiment 1). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the parietal region (P7 and P8) during the backward digit span task. The second phase of the first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found no significant differences in brain waves in relation to the level of vegetation (Table 4.22).

Table 4.22

Level of Vegetation by Mean Relative PSD in Parietal Region during Cognitive Task (Experiment 1)

	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta (sd)	0.523 (0.144)	0.531 (0.133)	0.516 (0.146)	0.544 (0.109)	0.470	0.700
PSD_theta (sd)	0.201 (0.0456)	0.212 (0.0397)	0.205 (0.0536)	0.214 (0.0413)	0.601	0.616
PSD_alpha (sd)	0.149 (0.102)	0.126 (0.0711)	0.131 (0.0789)	0.118 (0.0670)	0.834	0.439
PSD_beta (sd)	0.109 (0.0729)	0.109 (0.0694)	0.122 (0.0770)	0.104 (0.0674)	0.713	0.547
PSD_gamma (sd)	0.0183 (0.0175)	0.0231 (0.0231)	0.0264 (0.0226)	0.0201 (0.0120)	1.224	0.306

Mean Relative PSD of Image Sets in Parietal Region during Neutral Setting (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the parietal region (P7 and P8) during neutral setting. The second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found significant differences in alpha waves in relation to the level of vegetation (Table 4.23).

Table 4.23

Level of Vegetation by Mean Relative PSD in Parietal Region during Neutral Setting (Experiment 2)

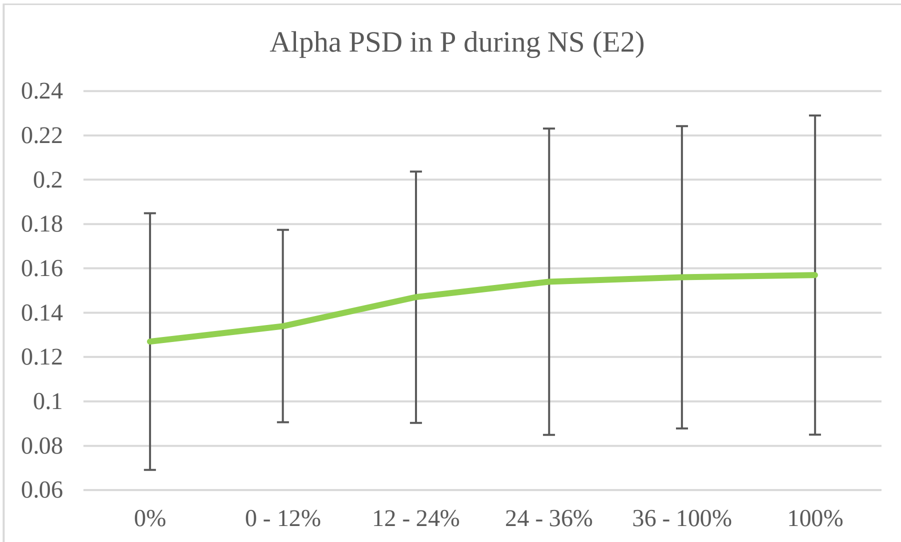
	Level of Plants						F	p
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.461 (0.179)	0.438 (0.157)	0.448 (0.157)	0.409 (0.148)	0.391 (0.158)	0.391 (0.160)	1.848	0.112
PSD_ theta (sd)	0.211 (0.0414)	0.222 (0.0518)	0.207 (0.0287)	0.225 (0.0441)	0.216 (0.0482)	0.208 (0.0490)	1.811	0.112
PSD_ alpha (sd)	0.127 (0.0579)	0.134 (0.0434)	0.147 (0.0567)	0.154 (0.0691)	0.156 (0.0682)	0.157 (0.0720)	3.141	0.009 **
PSD_ beta (sd)	0.114 (0.0641)	0.121 (0.0686)	0.115 (0.0550)	0.130 (0.0811)	0.136 (0.0730)	0.137 (0.0754)	2.462	0.056
PSD_ gamma (sd)	0.0225 (0.0205)	0.0245 (0.0231)	0.0197 (0.0097)	0.0260 (0.0322)	0.0279 (0.0228)	0.0270 (0.0249)	2.139	0.106

** $p < .01$

Mauchly's test in alpha waves indicated that the assumption of Sphericity had been met, $x^2(14) = 17.981$, $p = 0.209$. Table 4.23 shows an increase in the relative alpha PSD during the 0% to 24 - 36% sets that remained through the 100% set, $F(5, 195) = 3.141$, $p = 0.009$, $\eta_p^2 = 0.08$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0083 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the alpha relative PSD for the 0% vegetation set ($M = 0.127$, $SD = 0.0579$) was significantly lower than the 100% vegetation set ($M = 0.157$, $SD = 0.0720$), $t(35) = -0.029$, $SEM = 0.009$, $p = 0.026$ (Figure 4.15).

Figure 4.15

Alpha Mean Relative PSD in Parietal Region during Neutral Setting (Experiment 2)



To further identify the differences, nine paired samples t-tests were conducted to complete post hoc comparisons between conditions. A first paired samples t-test indicated no significant difference in alpha relative PSD for the 0% vegetation (M = 0.127, SD = 0.0579) and 0 - 12% vegetation sets (M = 0.134, SD = 0.0434), t(40) = -0.877, p = 0.386. A second paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation (M = 0.127, SD = 0.0579) and 12 - 24% vegetation sets (M = 0.147, SD = 0.0567), t(40) = -2.176, p = 0.035. A third paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation (M = 0.127, SD = 0.0579) and 24 - 36% vegetation sets (M = 0.154, SD = 0.0691), t(40) = -3.155, p = 0.003. A fourth paired samples t-test indicated a significant difference in alpha relative PSD for the 0% vegetation (M = 0.127, SD = 0.0579) and 36 - 100% vegetation sets (M = 0.156, SD = 0.0682), t(40) = -2.848, p = 0.007. A fifth paired samples t-test showed a significant

difference in alpha relative PSD for the 0% vegetation (*M* = 0.127, *SD* = 0.0579) and 100% vegetation sets (*M* = 0.157, *SD* = 0.0720), *t*(40) = -3.648, *p* = 0.001. A sixth paired samples t-test indicated no significant difference in alpha relative PSD for and the 0 - 12% vegetation (*M* = 0.134, *SD* = 0.0434) and 12 - 24% vegetation sets (*M* = 0.147, *SD* = 0.0567), *t*(40) = -1.769, *p* = 0.084. A seventh paired samples t-test indicated a significant difference in alpha relative PSD for the 0 - 12% vegetation (*M* = 0.134, *SD* = 0.0434) and 24 - 36% vegetation sets (*M* = 0.154, *SD* = 0.0691), *t*(40) = -2.218, *p* = 0.032. A eighth paired samples t-test indicated a significant difference in alpha relative PSD for the 0 - 12% vegetation (*M* = 0.134, *SD* = 0.0434) and 36 - 100% vegetation sets (*M* = 0.156, *SD* = 0.0682), *t*(40) = -2.449, *p* = 0.019. A ninth paired samples t-test indicated a significant difference in alpha relative PSD for the 0 - 12% vegetation (*M* = 0.134, *SD* = 0.0434) and 100% vegetation sets (*M* = 0.157, *SD* = 0.0720), *t*(40) = -2.284, *p* = 0.028.

Mean Relative PSD of Image Sets in Parietal Region during Cognitive Task (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participant's EEG bandpowers in two channels in the parietal region (P7 and P8) during the backward digit span task. The second phase of the second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found no significant differences in brain waves in relation to the level of vegetation (Table 4.24).

Table 4.24

Level of Vegetation by Mean Relative PSD in Parietal Region during Cognitive Task (Experiment 2)

	Level of Plants						F	p
	0	0-12	12-24	24-36	36-100	100		
PSD_delta (sd)	0.502 (0.130)	0.538 (0.123)	0.525 (0.135)	0.519 (0.139)	0.504 (0.147)	0.519 (0.125)	0.661	0.636
PSD_theta (sd)	0.195 (0.0335)	0.204 (0.0393)	0.211 (0.0509)	0.208 (0.0433)	0.212 (0.0456)	0.215 (0.0418)	1.266	0.283
PSD_alpha (sd)	0.128 (0.0842)	0.124 (0.0790)	0.133 (0.0984)	0.129 (0.0822)	0.132 (0.0808)	0.125 (0.0702)	0.302	0.804
PSD_beta (sd)	0.128 (0.0798)	0.112 (0.0635)	0.110 (0.0687)	0.120 (0.0803)	0.125 (0.0922)	0.117 (0.0846)	1.071	0.369
PSD_gamma (sd)	0.0272 (0.0358)	0.0220 (0.0249)	0.0201 (0.0164)	0.0241 (0.0290)	0.0256 (0.0359)	0.0242 (0.0325)	2.128	0.129

Mean Relative PSD in Occipital Region.

Mean Relative PSD of In Situ Environments in Occipital Region during Neutral Setting (Experiment 1). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participant's EEG bandpowers in two channels in the occipital region (O1 and O2) during neutral setting. The first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found significant differences in delta, beta, and gamma waves in relation to the level of vegetation (Table 4.25).

Table 4.25

Level of Vegetation by Mean Relative PSD in Occipital Region during Neutral Setting (Experiment 1)

	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta (sd)	0.529 (0.120)	0.490 (0.105)	0.472 (0.0886)	0.473 (0.0733)	3.462	0.020*
PSD_theta (sd)	0.201 (0.0462)	0.199 (0.0394)	0.211 (0.0362)	0.215 (0.0458)	1.532	0.212
PSD_alpha (sd)	0.161 (0.0912)	0.167 (0.0824)	0.172 (0.0685)	0.174 (0.0629)	0.370	0.775
PSD_beta (sd)	0.0882 (0.0431)	0.124 (0.0560)	0.129 (0.0577)	0.118 (0.0432)	4.851	0.004**
PSD_gamma (sd)	0.0127 (0.00619)	0.0217 (0.0184)	0.0232 (0.0174)	0.0185 (0.00995)	4.155	0.010**

* $p < .05$, ** $p < .01$

Mauchly's test in delta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 3.734$, $p = 0.589$. Table 4.25 shows a significant difference between level of plants and delta relative PSD, $F(3, 84) = 3.462$, $p = 0.020$, $\eta_p^2 = 0.11$. Three paired samples t-tests were conducted to make post hoc comparisons between conditions. A first paired samples t-test indicated no significant difference in gamma relative PSD for the Very Built ($M = 0.529$, $SD = 0.120$) and Mostly Built sites ($M = 0.490$, $SD = 0.105$), $t(29) = 1.775$, $p = 0.086$. A second paired samples t-test indicated a significant difference in gamma relative PSD for the Very Built ($M = 0.529$, $SD = 0.120$) and Mostly Natural sites ($M = 0.472$, $SD = 0.0886$), $t(29) = 2.376$, $p = 0.024$. A third paired samples t-test indicated a significant difference in gamma relative PSD for the Very

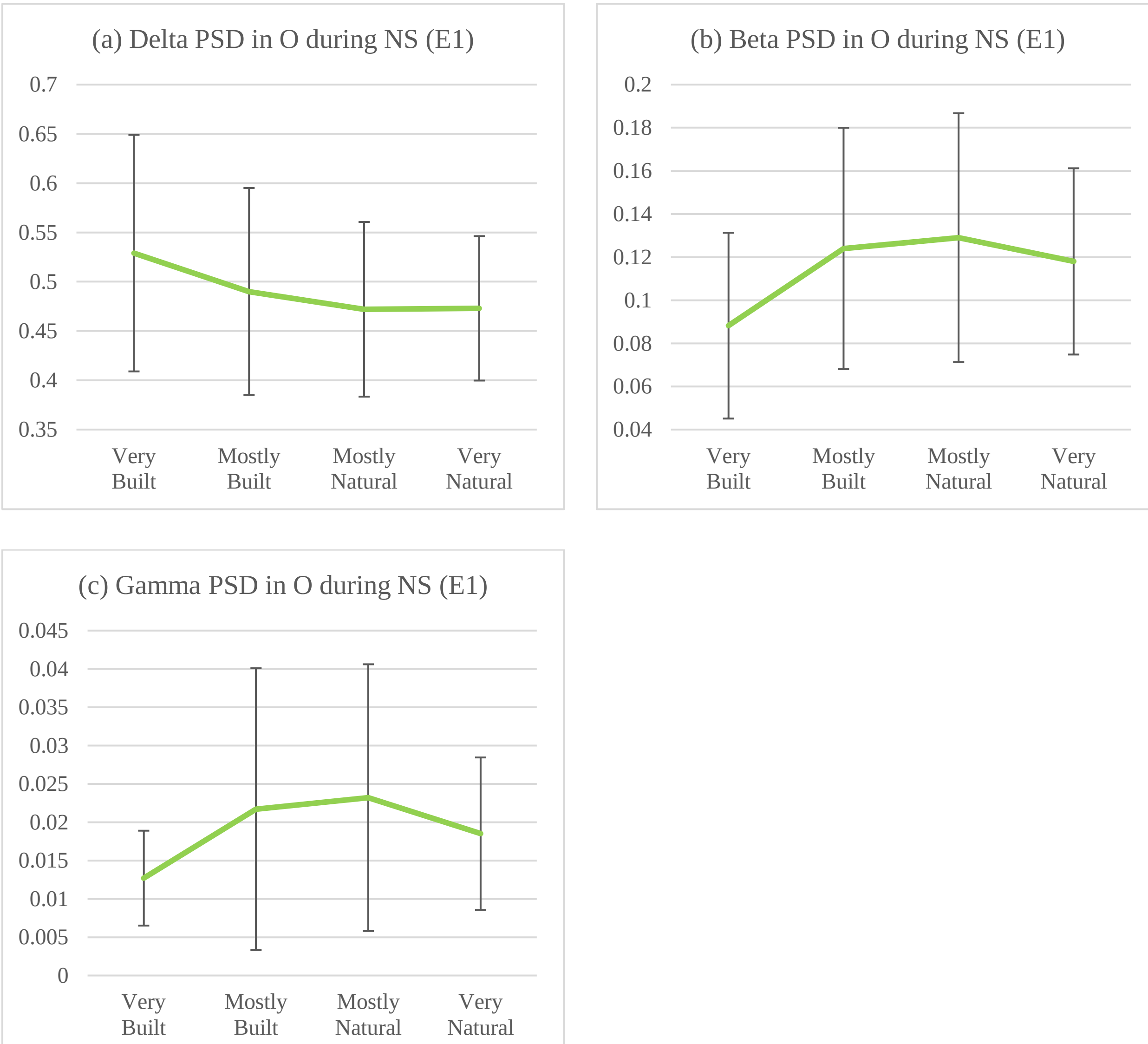
Built (*M* = 0.529, *SD* = 0.120) and Very Natural sites (*M* = 0.473, *SD* = 0.0733), *t*(29) = 2.605, *p* = 0.014 (Figure 4.16a).

Mauchly's test in beta waves indicated that the assumption of Sphericity had been met, $x^2(5) = 7.211$, $p = 0.206$. Table 4.25 and Figure 4.16b shows an inverted U-shape relationship between the level of plants and beta relative PSD, $F(3, 84) = 4.851$, $p = 0.004$, $\eta_p^2 = 0.15$. Bonferroni's post-hoc tests were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for the Very Built site (*M* = 0.0882, *SD* = 0.0431) was significantly lower than the Mostly Built (*M* = 0.124, *SD* = 0.0560), *t*(26) = -0.035, *SEM* = 0.010, *p* = 0.016 and Mostly Natural sites (*M* = 0.129, *SD* = 0.0577), *t*(26) = -0.043, *SEM* = 0.012, *p* = 0.008 (Figure 4.16b).

Mauchly's test in gamma waves indicated that the assumption of Sphericity had been violated, $x^2(5) = 11.807$, $p = 0.038$; therefore, degrees of freedom were corrected using Huynh-Feldt estimates of Sphericity (ε = 0.948). Table 4.25 and Figure 4.16c shows an inverted U-shape relationship between the level of plants and gamma relative PSD, $F(2.845, 79.670) = 4.155$ $p = 0.010$, $\eta_p^2 = 0.13$. Bonferroni's post-hoc test were used with a Bonferroni adjusted alpha level of .0125 per test (.05/4) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the beta relative PSD for the Very Built site (*M* = 0.0127, *SD* = 0.00619) was significantly lower than Mostly Built (*M* = 0.0217, *SD* = 0.0184), *t*(26) = -0.011, *SEM* = 0.004, *p* = 0.027 and Mostly Natural sites (*M* = 0.0232, *SD* = 0.0174), *t*(26) = -0.011, *SEM* = 0.004, *p* = 0.033 (Figure 4.16c).

Figure 4.16

Mean Relative PSD in Occipital Region during Neutral Setting (Experiment 1). (a) Delta; (b) Beta; and (c) Gamma



Mean Relative PSD of In Situ Environments in Occipital Region during Cognitive Task (Experiment 1). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the occipital region (O1 and O2) during the backward digit span task. The second phase of the first experiment analyzed four levels of vegetation (Very Built, Mostly Built, Mostly Natural, and Very Natural) among four designated spaces in Seoul Botanic Park, and found no significant differences in brain waves in relation to the level of vegetation (Table 4.26).

Table 4.26

Level of Vegetation by Mean Relative PSD in Occipital Region during Cognitive Task (Experiment 1)

	Level of Plants					
	Very Built	**Mostly Built**	**Mostly Natural**	**Very Natural**	**F**	**p**
PSD_delta (sd)	0.546 (0.144)	0.549 (0.135)	0.530 (0.156)	0.536 (0.128)	0.320	0.811
PSD_theta (sd)	0.203 (0.0443)	0.218 (0.0480)	0.208 (0.0556)	0.219 (0.0448)	0.559	0.643
PSD_alpha (sd)	0.155 (0.112)	0.127 (0.0749)	0.149 (0.108)	0.138 (0.0881)	0.837	0.449
PSD_beta (sd)	0.0830 (0.0520)	0.0900 (0.0538)	0.0957 (0.0630)	0.0936 (0.0585)	0.397	0.755
PSD_gamma (sd)	0.0120 (0.00989)	0.0160 (0.0136)	0.0172 (0.0132)	0.0136 (0.00817)	1.188	0.315

Mean Relative PSD of Image Sets in Occipital Region during Neutral Setting (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation in the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the occipital region (O1 and O2) during neutral setting. The second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found significant differences in alpha waves in relation to the level of vegetation (Table 4.27).

Table 4.27

Level of Vegetation by Mean Relative PSD in Occipital Region during Neutral Setting (Experiment 2)

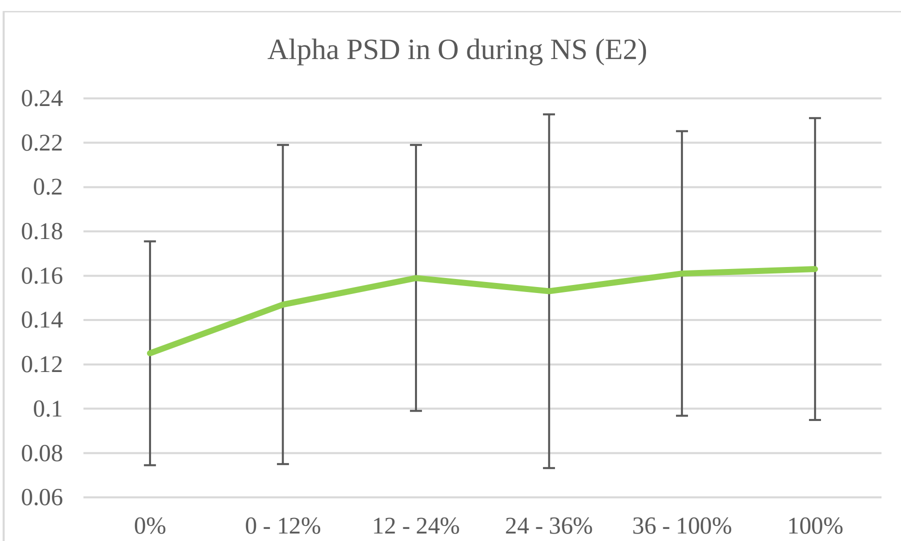
	Level of Plants						F	p
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.477 (0.180)	0.416 (0.155)	0.433 (0.140)	0.424 (0.158)	0.412 (0.152)	0.388 (0.162)	2.518	0.051
PSD_ theta (sd)	0.217 (0.0408)	0.214 (0.0307)	0.217 (0.0364)	0.220 (0.0385)	0.219 (0.0510)	0.209 (0.0425)	0.781	0.553
PSD_ alpha (sd)	0.125 (0.0505)	0.147 (0.0720)	0.159 (0.0600)	0.153 (0.0798)	0.161 (0.0642)	0.163 (0.0681)	3.794	0.003 **
PSD_ beta (sd)	0.101 (0.0532)	0.113 (0.0484)	0.116 (0.0514)	0.113 (0.0532)	0.118 (0.0497)	0.120 (0.0619)	1.525	0.205
PSD_ gamma (sd)	0.0177 (0.0130)	0.0206 (0.0130)	0.0184 (0.0108)	0.0203 (0.0134)	0.0211 (0.0136)	0.0220 (0.0211)	0.695	0.575

** $p < .01$

Mauchly's test in alpha waves indicated that the assumption of Sphericity had been met, $x^2(14) = 17.958$, $p = 0.210$. Table 4.27 shows an increase in the relative alpha PSD during 0% to 12 - 24% sets that remained through the 100% set, $F(5, 195) = 3.794$, $p = 0.003$, $\eta_p^2 = 0.09$. Bonferroni's post-hoc test were used with a Bonferroni adjusted alpha level of .0083 per test (.05/6) to complete post hoc analyses between levels of vegetation. Bonferroni post hoc tests indicated that the alpha relative PSD for the 0% vegetation set ($M = 0.127$, $SD = 0.0579$) was significantly lower than the 12 - 24% vegetation ($M = 0.159$, $SD = 0.0600$), $t(35) = -0.032$, $SEM = 0.010$, $p = 0.037$, 36 - 100% vegetation ($M = 0.161$, $SD = 0.0642$), $t(35) = -0.035$, $SEM = 0.009$, $p = 0.005$, and 100% vegetation sets ($M = 0.163$, $SD = 0.0681$), $t(35) = -0.034$, $SEM = 0.009$, $p = 0.010$ (Figure 4.17).

Figure 4.17

Alpha Mean Relative PSD in Occipital Region during Neutral Setting (Experiment 2)



Mean Relative PSD of Image Sets in Occipital Region during Cognitive Task (Experiment 2). An ANOVA with repeated measures examined the effects of the level of vegetation within the indoor built environment on the mean relative PSD of participants' EEG bandpowers in two channels in the occipital region (O1 and O2) during the backward digit span task. The second phase of the second experiment analyzed six sets of images with varying levels of vegetation (0%, 0 - 12%, 12 - 24%, 24 - 36%, 36% and more, and 100%), and found significant differences in theta waves in relation to the level of vegetation (Table 4. 28).

Table 4.28

Level of Vegetation by Mean Relative PSD in Occipital Region during Cognitive Task (Experiment 2)

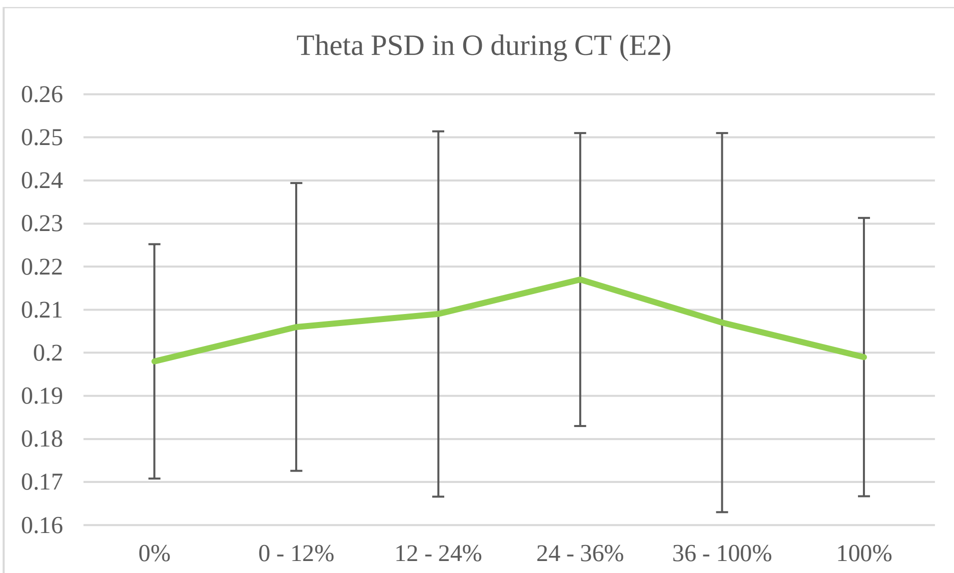
	Level of Plants						**F**	**p**
	0	**0-12**	**12-24**	**24-36**	**36-100**	**100**		
PSD_ delta (sd)	0.534 (0.128)	0.557 (0.110)	0.535 (0.153)	0.544 (0.130)	0.545 (0.135)	0.544 (0.134)	0.318	0.899
PSD_ theta (sd)	0.198 (0.0272)	0.206 (0.0334)	0.209 (0.0424)	0.217 (0.0340)	0.207 (0.0440)	0.199 (0.0323)	2.297	0.047 *
PSD_ alpha (sd)	0.133 (0.0943)	0.131 (0.0796)	0.146 (0.124)	0.127 (0.0860)	0.138 (0.0950)	0.138 (0.0952)	0.404	0.716
PSD_ beta (sd)	0.0995 (0.0513)	0.0911 (0.0443)	0.0947 (0.0511)	0.0957 (0.0567)	0.0946 (0.0593)	0.103 (0.0691)	0.397	0.840
PSD_ gamma (sd)	0.0169 (0.0105)	0.0150 (0.0089)	0.0148 (0.0088)	0.0160 (0.0115)	0.0155 (0.0103)	0.0161 (0.0139)	0.902	0.455

* $p < .05$

Mauchly's test in theta waves indicated that the assumption of Sphericity had been met, $x^2(14) = 12.554$, $p = 0.563$. Table 4.28 shows an inverted V-shape relationship between the relative theta PSD and the level of vegetation in the image sets; the relative theta PSD was highest during 24 - 36% image set, $F(5, 195) = 2.297$, $p = 0.047$, $\eta_p^2 = 0.06$ (Figure 4.18).

Figure 4.18

Theta Mean Relative PSD in Occipital Region during Cognitive Task (Experiment 2)



To further assess the differences, five paired samples t-tests were conducted to make post hoc comparisons between conditions. A first paired samples t-test indicated a significant difference in theta relative PSD for the 24 - 36% vegetation ($M = 0.217$, $SD = 0.0340$) and 0% vegetation sets ($M = 0.198$, $SD = 0.0272$), $t(40) = 2.500$, $p = 0.017$. A second paired samples t-test indicated a significant difference in theta relative PSD for the 24 - 36% vegetation ($M = 0.217$, $SD = 0.0340$)

and 0 - 12% vegetation sets (*M* = 0.206, *SD* = 0.0334), *t*(40) = 1.563, *p* = 0.126. A third paired samples t-test indicated no significant difference in theta relative PSD for the 24 - 36% vegetation (*M* = 0.217, *SD* = 0.0340) and 12 - 24% vegetation sets (*M* = 0.209, *SD* = 0.0424), *t*(40) = 0.851, *p* = 0.400. A fourth paired samples t-test showed no significant difference in theta relative PSD for the 24 - 36% vegetation (*M* = 0.217, *SD* = 0.0340) and 36 - 100% vegetation sets (*M* = 0.207, *SD* = 0.0440), *t*(40) = 1.238, *p* = 0.233. A fifth paired samples t-test showed a significant difference in theta relative PSD for the 24 - 36% vegetation (*M* = 0.217, *SD* = 0.0340) and 100% vegetation sets (*M* = 0.199, *SD* = 0.0323), *t*(40) = 2.783, *p* = 0.008.

5. Conclusion

This dissertation used a biophilic design and attention restoration framework to examine whether vegetation within indoor built environment offers users restorative potential and better working memory. It was designed to investigate whether (1) indirect and symbolic visual contacts with vegetation in indoor built environment improve people's restorative potential, (2) indirect and symbolic visual contact with vegetation improve people's attention capacity, especially with regard to working memory tasks, (3) exposure to different amounts of vegetation influence attention restoration and working memory capacity differently, and lastly (4) varied types of exposure to indirect and symbolic vegetation influence attention restoration and working memory capacity differently. In short, this dissertation explored how visual stimuli that combine vegetation and built environments influence the people who occupy built environments.

An experimental study with 30 healthy adults sitting in situ with different levels of vegetation in an indoor built environment (indirect contact with nature), and 41 healthy adults viewing images of various built environments with vegetation through laptop screen in an isolated room (symbolic contact with nature) was conducted.[19] This study employed the Perceived

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[19] The terms "indirect" and "symbolic" come from Kellert (2002, 2012b)'s classification of contact with nature in biophilic design, which are further described in this project's sub-chapter *Biophilc Design* on in page 21-22.

Restorativeness Scale (PRS) -11 survey, the backward digit span task, and electroencephalography (EEG) recording. Results from each methodological were presented in the previous chapter.

This study delve into two questions on the impact of visual contact with vegetation on restoration and working memory. First, we assumed that indirect and symbolic visual contacts with vegetation in indoor built environments would restore people's attention, demonstrating a general positive relationship between levels of vegetation and attention restoration. Second, we assumed that indirect and symbolic visual contacts with vegetation in indoor built environments would improve people's attention capacity and performance on a working memory task, demonstrating a general positive relationship between levels of vegetation and working memory capacity. Our results strongly support both assumptions. Considering the positive effects on restoration potential and working memory capacity demonstrated by our study, we believe there is clear evidence for the environmental benefits of incorporating vegetation into the indoor built environments of our everyday living spaces.

This concluding chapter revisits the research questions mentioned with the findings from our study. It consists of four sections: Section 1 discusses the effects of vegetation in indoor built environments and the impact vegetation levels have on restoration. Section 2 discusses the effects of vegetation in indoor built environments and the impact vegetation levels have on working memory capacity. Section 3 discusses different EEG activities among brain regions and the different influence on EEG oscillations of varied types of exposure to vegetation. Section 4 discusses the implications and limitations of the study.

5.1. The Effects of Vegetation in Indoor Built Environment on Restoration

Our first assumption was that sitting in indoor environments with vegetation would help rest voluntary attention and thus increase restorativeness. Further, we believed that more vegetation in the indoor built environment would lead to better attention restoration. The ideas drew from previous research validating the restoration of attention through the experience of nature, including Attention Restoration Theory and the biophilic hypothesis. Our findings expand on previous studies by clarifying the grey areas between strict nature/urban dichotomies, and by explaining how different levels of vegetation in indoor built environments may influence peoples' restoration. The findings from the PRS-11 survey results and EEG oscillation support the claim that natural exposure may provide a restorative environment by demonstrating significantly positive associations between levels of vegetation, improvements in perceived restorativeness, and EEG alpha relative PSD.

PRS-11 mean scores increased with greater levels of vegetation as participants sat for 5 minutes among four sites going from Very Built to Very Natural (Experiment 1). More specifically, fascination (question numbers 1, 2, and 3), being away (question numbers 4, 5, and 6), reversal of the item codes of coherence (question numbers 7, 8, and 9), scope (question numbers 10 and 11), the mean of total PRS-11 scores, and the mean of fascination, being away, and scope categories showed positive association between levels of vegetation and perceived restoration scores (Figure 5.1a). Mean scores also increased with greater levels of vegetation in the image sets. The results were confirmed by Experiment 2, wherein the PRS-11 results also showed something interesting: the mean PRS-11 scores in fascination, being away, reversal of the item codes of coherence, scope, the mean of total PRS-11 scores, and the mean of fascination, being away, and scope categories,

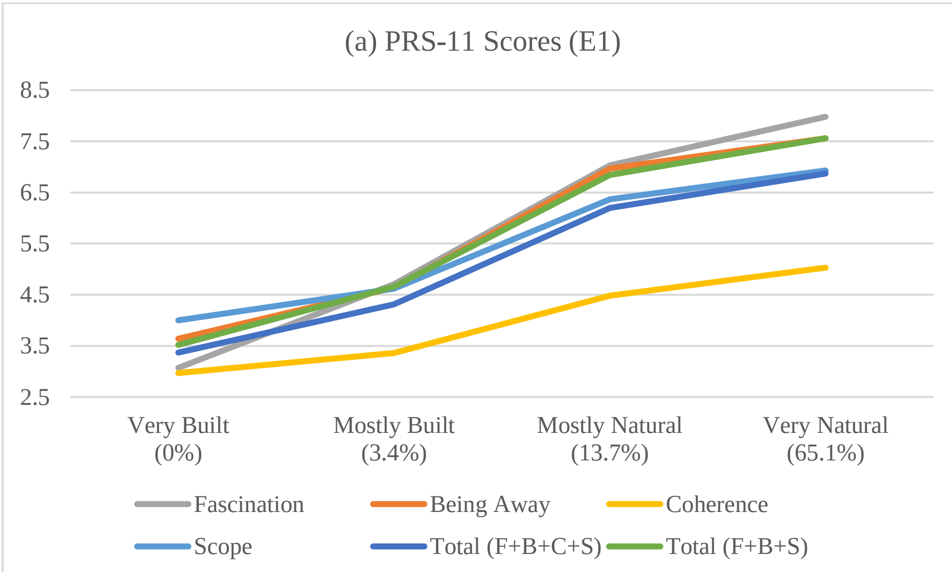
increased with the level of plants until reaching 24%. The mean scores then stabilized from 24% to less than 100% (even slightly lower in some cases) but became highest in 100% vegetation (Figure 5.1b). The coherence (question numbers 7, 8, and 9) scores were reversely coded.

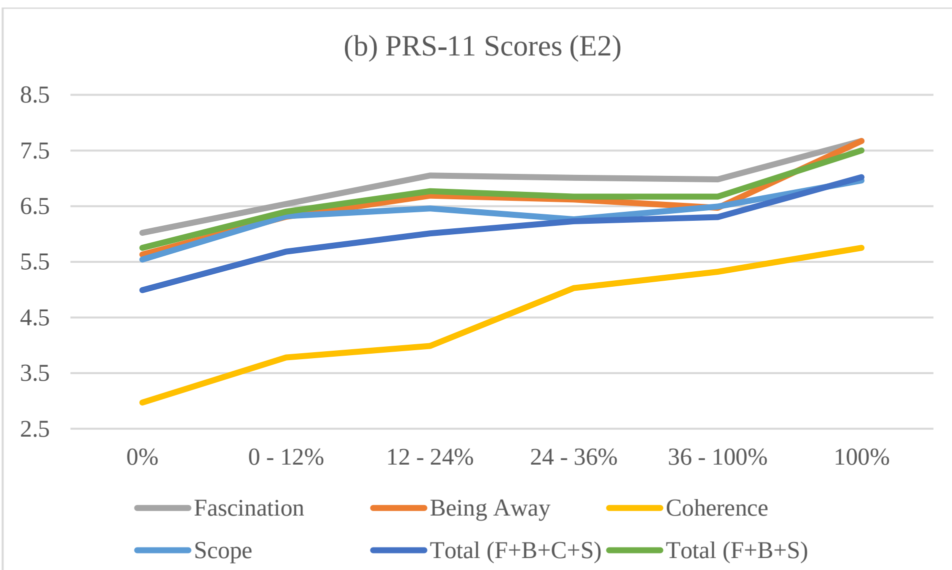
Previous studies claimed that high complexity may lower coherence (Hidalgo et al., 2006; Scopelliti & Giuliani, 2004). The mean coherence scores were noticeably lower compared to other restorative scores in both experiments (Figure 5.1), and this result may be related to the previous research, since most of the sites and the images were attractive as well as complex environments full of furniture, artifacts, vegetation, and etc. In addition, participants' perceived restoration scores were much higher in second experiment at 0% vegetation and 0 - 12 % vegetation as compared to first experiment. These results may indicate that well-designed and attractive built environments increase restoration as related to previous research (Abdulkarim & Nasar, 2014; Karmanov & Hamel, 2008).

The results of post-hoc analysis indicate that people's perceived restoration score is positively related to levels of vegetation. However, the second experiment of images with different vegetation levels found that restorative potential is significantly higher when there is 12% or more vegetation within the space compared to no vegetation. Furthermore, in spaces with more than 12% vegetation, the restoration score was slightly higher, but there were no significant differences in perceived restoration scores compared to 100% vegetation (full nature) in fascination, being away, scope, and the total of the three categories excepting coherence.

Figure 5.1

Graphs of PRS-11 Scores. (a) Experiment 1; (b) Experiment 2





1. The coherence (question numbers 7, 8, and 9) scores were reversely coded.

These results were also confirmed by participant EEG alpha oscillations. EEG alpha oscillation for the in situ sitting experiment (experiment 1) had a positive but not significant relationship with levels of vegetation in indoor built environments. The relative alpha PSD increased from Very Built (0%) to Mostly Built (13.7%), following the trend of the PRS-11 scores (Figure 5.2a). In the image viewing experiment (experiment 2), similar increases were observed in the mean relative PSD alpha for all channels during neutral setting; the mean relative PSD alpha increased until 12% and stabilized from 24% to 100%. However, unlike the PRS-11 scores, the EEG alpha oscillation for 100% vegetation was similar to other vegetation levels presenting more than 12 vegetation (Figure 5.2b).

Figure 5.2

Graph of Alpha Mean Relative PSD in All Channels during Neutral Setting. (a) Experiment 1; (b) Experiment 2

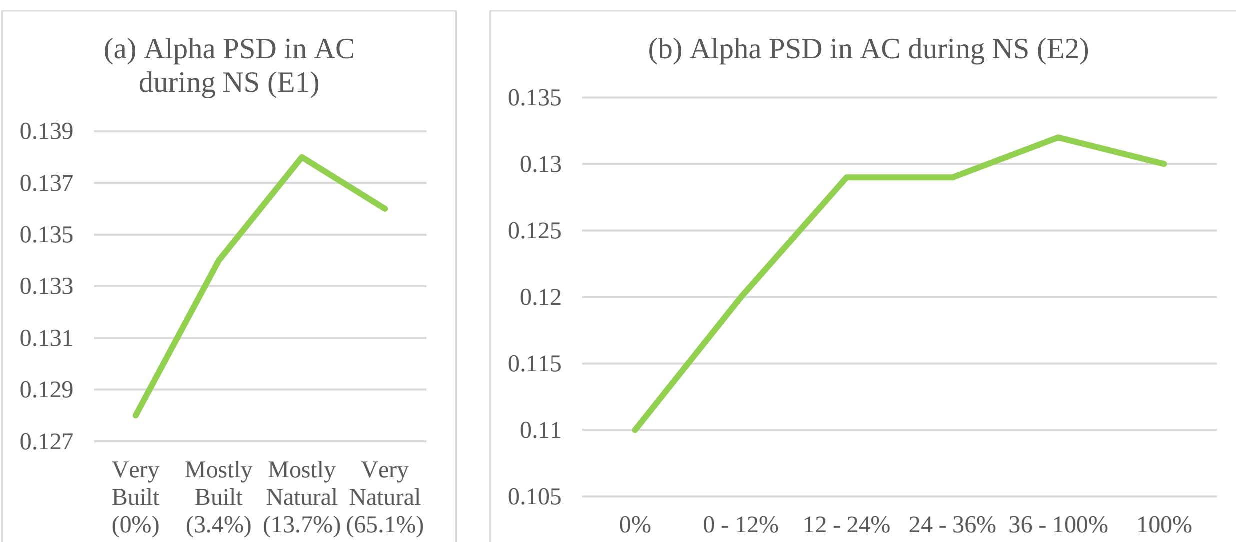
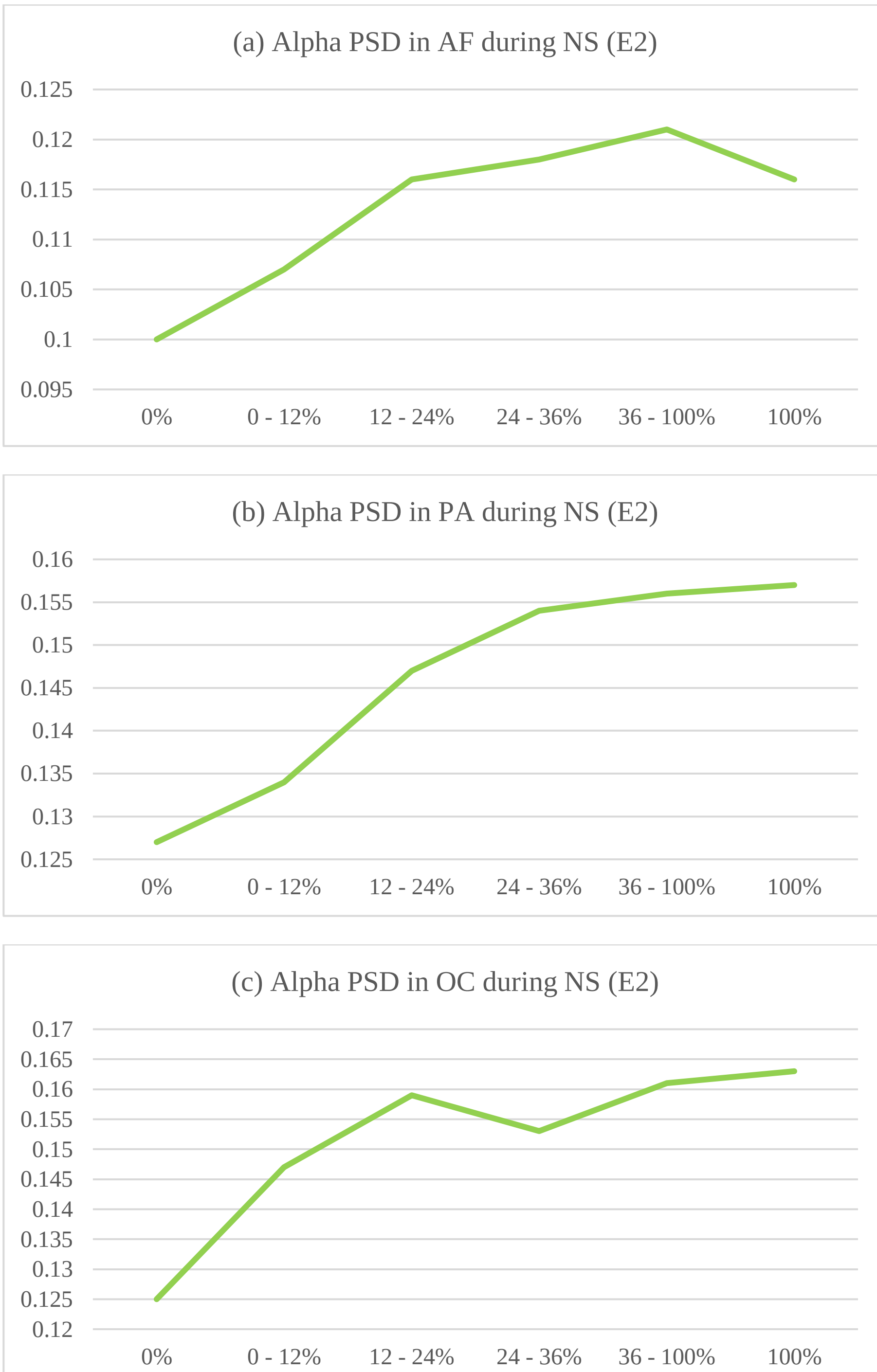


Figure 5.3

Graph of Alpha Mean Relative PSD during Neutral Setting (Experiment 2). (a) Antero-Frontal; (b) Parietal; and (c) Occipital Region



Increases in the mean related PSD alpha were also observed in the antero-frontal, parietal, and occipital regions during the image viewing experiment (experiment 2). There were slight differences between the mean related PSD alpha of the antero-frontal, parietal, and occipital regions after 12 - 24% vegetation; however, all three results showed the mean related PSD alpha increased from 0% vegetation to 12 - 24% vegetation. Although there was also some increase in vegetation denser than 24%, the increment was relatively small compared to the 0% to 24% vegetation settings (Figure 5.3).

The findings from this study suggest that vegetation in indoor built environment is beneficial for both perceived restoration and psychophysiological restoration. Moreover, when there was more than 12% vegetation in an indoor space, the restorative potential was closely equivalent to a 100% vegetation setting approximating outdoor, full nature.

Ratios of the PRS-11 scores for Mostly Natural sites (13.7% vegetation) versus Very Built (0% vegetation) sites (experiment 1) indicate that people perceived around 100 - 200 % more restoration in the Mostly Natural site compare to Very Built site. Ratios of the PRS-11 scores for 12 - 24 % vegetation image set versus 0% vegetation image set (experiment 2) indicate that people perceived about 16 - 34 % more restoration in the 12 - 24 % vegetation setting compare to 0% vegetation setting (Table 5.1). Ratios of the mean EEG alpha relative PSD in Mostly Natural (13.7% vegetation) sites mean versus Very Built (0% vegetation) sites (experiment 1) indicate that people perceived around 3 - 16 % more restoration in the Mostly Natural site compared to Very Built sites. Ratios of the mean EEG alpha relative PSD for 12 - 24 % vegetation image sets versus 0% vegetation image sets (experiment 2) indicate that people perceived about 16 - 27 % more restoration in the 12 - 24 % vegetation setting compare to 0% vegetation setting (Table 5.2).

Table 5.1

Ratios of PRS-11 Scores for Mostly Natural (13.7% Vegetation) to Very Built (0% Vegetation) (Experiment 1) and 12 - 24 % Vegetation to 0% Vegetation (Experiment 2)

PRS-11 Scores	MN to VB Ratio	12 - 24% to 0% Ratio
Fascination	**2.290**	**1.171**
Being Away	**2.915**	**1.188**
Coherence	**2.508**	**1.343**
Scope	**2.593**	**1.166**
Total (F+B+C+S)	**2.840**	**1.204**
Total (F+B+S)	**2.943**	**1.177**

1. Statistically significant cases in RM-ANOVA results in bold characters.

Table 5.2

Ratios of Mean EEG Alpha Relative PSD to Mostly Natural (13.7% Vegetation) to Very Built (0% Vegetation) (Experiment 1) and 12 - 24 % Vegetation to 0% Vegetation (Experiment 2)

EEG Alpha PSD	MN to VB Ratio	12 - 24% to 0% Ratio
All Channels	1.078	**1.173**
Antero-Frontal	1.034	**1.160**
Frontocentral	1.151	1.160
Temporal	1.096	1.188
Parietal	1.158	**1.157**
Occipital	1.068	**1.272**

1. Statistically significant cases in RM-ANOVA results in bold characters.

The findings corroborate previous studies that suggest the presence of nature like vegetation promotes restoration in built environments (e.g., Felsten, 2009; Hernández & Hidalgo, 2005; Lindal & Hartig, 2015; Takayama, et al., 2014). Chen et al. (2020) found higher PRS survey scores and alpha and theta oscillations in the occipital lobes when participants sat in natural environment compared to urban built environment. This dissertation confirms the findings of Chen et al.'s study.

On the other hand, it partially contradicts Kaplan's restoration theory (Kaplan, 1995; Kaplan et al., 1998) and other comparative studies on restoration in natural and urban environments (e.g, Berto, 2005; Hartig & Staats, 2006; Ulrich, 1981; Van den Berg et al., 2014; Velarde, et al., 2007). For instance, Hauru et al. (2012) argue that urban attributes in urban forests in Helsinki decreased people's perceived restorativeness. This dissertation shares the claim that encounters with nature have restorative effects. However, it also notes that built environments do not always work against recovery; people can restore in built environment as long as there is enough nature (12% or more vegetation according to the findings). This result agrees with Tyrväinen et al. (2014), who observed no notable differences in peoples' perceived restorativeness if adequate amounts of vegetation were present in urban parks and urban woodlands.

Traditionally, urban built environments are considered less restorative as they are full of attention-requiring attributes that demanded directed attention (Berman et al., 2008; Kaplan, 1995; Kaplan et al., 1998). However, we argue that urban built environments are complex systems which cannot be understood as a single setting. Although they may be somewhat less restorative compared to natural environment, well-designed urban built environments with some vegetation have the potential to act as restorative environments. Previous research comparing natural and

urban environments mostly chose undesirable urban environmental settings to emphasize the differences in restorativeness between the two settings. Thus, they found that urban built environments mostly lacked restorative potential. However, this dissertation concords with Karmanov and Hamel (2008) to argue that well designed built environment might enhance moods, reduce stress, and in general hold similar benefits for affective restoration as nature. More research is required to fully understand the restorative potential of urban built environments.

5.2. The Effects of Vegetation in Indoor Built Environment on Working Memory Capacity

In this study, vegetation in indoor built environments had a significant association with attention capacity, especially working memory. This dissertation confirms its second assumption regarding attention capacity: indirect and symbolic visual contacts with vegetation in indoor built environments improved the working memory performance of participants. Backward digit span task scores suggest a positive association based on the level of vegetation in indoor built environments. Mean backward digit span scores of the in situ seating experiment (experiment 1) had positive (but not significant) interactions with the level of vegetation in indoor built environments. In general, as the volume of vegetation increased, participants recalled backward digits more correctly (Figure 5.4a).

The image viewing experiment (experiment 2) also produced interesting results. There was a significant relationship between mean backward digit span scores and levels of vegetation in indoor built environment. However, although there were a positive association until reaching 24 - 36% vegetation, the mean backward digit span scores decreased slightly as the level of vegetation

increased to 100%, creating an inverted U-shape graphs (Figure 5.4b).

And while descriptive statistics revealed that participants' mean backward digit span scores for the second experiment were slightly higher when they had only participated in the second experiment (groups of people who had less backward digit span task experiences, $M = 8.53$) compared to both the first and second experiments (groups of people who had previous backward digit span task experiences from first experiment, $M = 8.12$), the repeated measures ANOVA revealed that this difference (levels of vegetation x previous backward digit span task experience from first experiment) was not significant $F(5, 195) = 0.890$, $p = 0.489$, $\eta_p^2 = 0.02$. This result indicates that there is no practice and/or fatigue effects on backward digit span tasks within both experiments.[20] The differences in mean backward digit span scores for the second experiment could possibly be explained by gender difference. However, the results of the repeated measures ANOVA also revealed that participants' gender produced no significant differences of mean backward digit span scores for the second experiment on $F(5, 195) = 0.725$, $p = 0.606$, $\eta_p^2 = 0.02$, although male participants' mean backward digit span scores for the second experiment ($M = 8.41$) were slightly higher than female participants' ($M = 8.12$).

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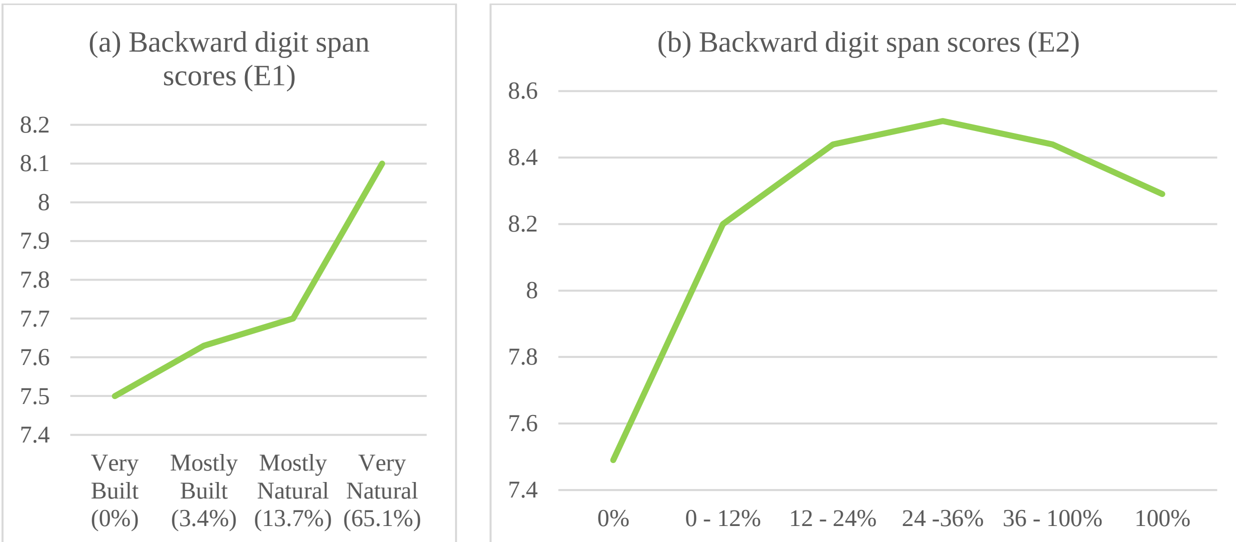
[20] Research shows that practice effects are occasionally found when participants do cognitive task repetitively (Hausknecht et al., 2006). However, practice effects for verbal memory tasks (Benedict & Zgaljardic, 2010) and digit span tasks (Bartels et al., 2010) were considered less influential.

Figure 5.4

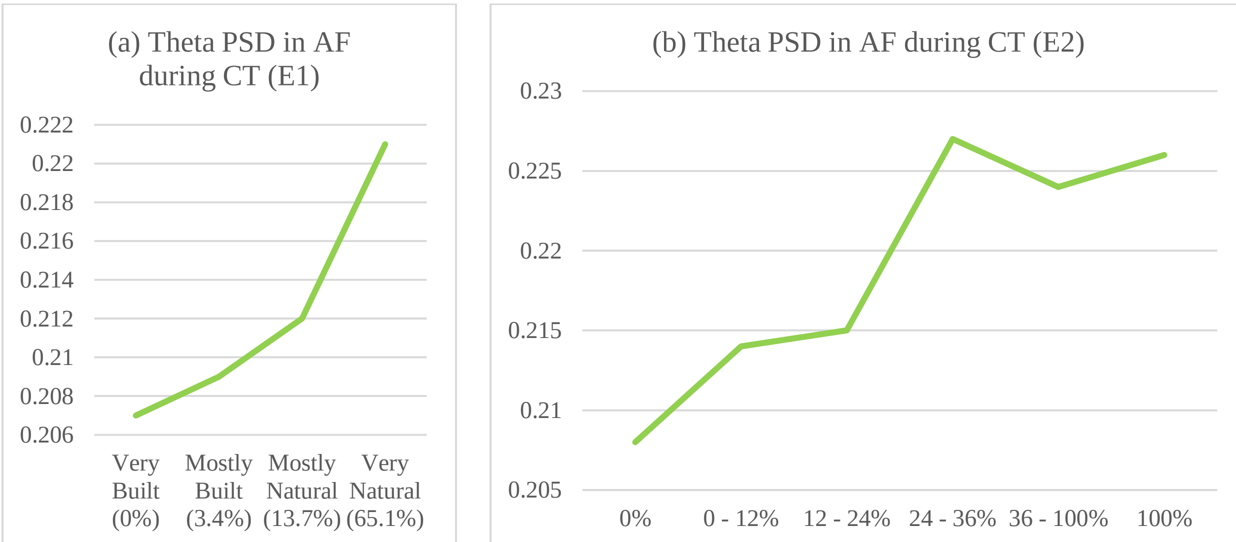
Graphs of Mean Backward Digit Span Scores. (a) Experiment 1; (b) Experiment 2



The theta relative PSD in antero-frontal region during the in situ seating experiment (experiment 1) showed no significant result; however, positive interactions with the levels of vegetation in indoor built environments were visually identified (Figure 5.5a). The second experiment (the image viewing experiment) found significant results: during the cognitive task, the mean relative PSD theta oscillation in antero-frontal region increased along with the level of vegetation in the built environment. Although the results of the theta oscillation did not show an inverted U-shape as with the pervious backward digit span task scores, we found that the theta relative PSD were highest in the 24 - 36% vegetation in indoor built environment setting (Figure 5.5b).

Figure 5.5

Graphs of Theta Relative PSD in Antero-Frontal Region during Cognitive Task. (a) Experiment 1; (b) Experiment 2



The ratios of backward digit span task scores for Mostly Natural (13.7% vegetation) sites to Very Built (0% vegetation) sites (experiment 1) indicate that people performed around 2.7% better in working memory in the Mostly Natural site compared to the Very Built site. The ratios of backward digit span task scores for 24 - 36 % vegetation image sets to 0% vegetation image sets (experiment 2) indicate that people performed about 12.7% better in working memory in the 24 - 36 % vegetation setting compared to 0% vegetation setting (Table 5.3). The ratios of the mean EEG theta relative PSD for Mostly Natural (13.7% vegetation) sites to Very Built (0% vegetation) sites (experiment 1) indicate that people performed around 2.5% better in working memory in the Mostly Natural site compared to Very Built site. The ratios of the mean EEG theta relative PSD for 24 - 36 % vegetation image sets to 0% vegetation image sets (experiment 2) indicates that people performed about 5 - 10 % better in working memory in the 24 - 36 % vegetation setting

compared to 0% vegetation setting (Table 5.4).

Table 5.3

Ratios of Cognitive Task (Backward Digit Span) Scores for Mostly Natural (13.7% Vegetation) to Very Built (0% Vegetation) (Experiment 1) and 12 - 24 % Vegetation to 0% Vegetation (Experiment 2)

Cognitive Task Scores	MN to VB Ratio	12 - 24% to 0% Ratio
Backward Digit Span	1.027	**1.127**

1. Statistically significant cases in RM-ANOVA results in bold characters.

Table 5.4

Ratios of Mean EEG Theta Relative PSD for Mostly Natural (13.7% Vegetation) to Very Built (0% Vegetation) (Experiment 1) and 24 - 36 % Vegetation to 0% Vegetation (Experiment 2)

EEG Theta PSD	MN to VB Ratio	24 - 36% to 0% Ratio
All Channels	1.015	**1.085**
Antero-Frontal	1.024	**1.091**
Frontocentral	1.025	1.048
Temporal	0.975	1.085
Parietal	1.020	1.067
Occipital	1.025	**1.096**

1. Statistically significant cases in RM-ANOVA results in bold characters.

The results resonated with previous research comparing cognitive task performances in urbanized built environments and natural environments and motivated by ART and the biophilia hypothesis (e.g., Berman et al., 2008; Bratman et al, 2015; Li & Sullivan, 2018; van den Berg et al., 2003; Yin et al., 2018). Shibata and Suzuki (2002) for example reported improvements in task performance when leafy plants were visually present. Lee et al. (2015) found that brief glimpses of green roofs, compared to concrete roofs, increased sustained attention performance. Natural environments promote better attention capacity than urbanized built environments; in particular, they enhance working memory task performance.

The findings were somewhat different than Hartig and his colleagues' study (2003). They found that walking in nature improved performance on the Necker Cube Pattern Control task, while walking in urban environments with trees strained performance on the same task. Also, they claimed that the environment does not significantly affect memory tasks (SMT; Search and Memory task). Bratman et al. (2015) found that after walking in nature participants only performed better on the operation span task (other cognitive tasks including the backward digit span did not show significant effects). Larsen et al. (1998) claimed that as the number of plants increased, letter identification productivity task scores decreased. Raanaas et al. (2011)'s study of the effects of indoor plants on attention capacity failed to show improved Reading Span Task scores after 5 minutes of sitting in an isolated office with and without plants. Other research shows that indoor vegetation may improve creative task abilities, but decrease continuous attention to simple tasks in office settings (Shibata & Suzuki, 2002; 2004; Chang & Chen, 2005).

This dissertation found that even a small amount of vegetation in indoor built environments improves working memory performance. It also shows that the quality of the

environment, as determined by factors like the amount of vegetation, affects people's working memory performance. These findings are important because they indicate that working memory performs efficiently in mixed nature/built environments, and that working memory is most effective in the range of 24 - 36% vegetation in indoor environment settings. This result is comparable to Jiang et al. (2014)'s study which identified a maximum stress reduction effect in the range of 24% and 34 % tree cover along single-family residential streets for male participants. When vegetation is too dense it may become visually distracting (Isen, 1993; Larsen et al., 1998). These tendencies are also somewhat related to previous studies which claim people had only slight arousal (only borderline statistically significant results) in denser vegetated environment (Staats et al., 1997), and that people both prefer and show higher emotional responses to intermediate biodiversity than low and high biodiversity in nature (Edwards et al., 2012; Johansson, 2014).

As mentioned above, previous studies show mixed results on the effect of vegetation on cognitive tasks. Our findings on the backward digit span task and EEG theta oscillation provide the first evidence of the influence of vegetation with various densities on attention capacity, focusing working memory, and EEG theta.

5.3. Different EEG Activities among Brain Regions and Different Influence of Varied Types of Exposure to Vegetation on EEG Oscillations

EEG records altered frequency bands that illustrate different brain states. The sub-frequency bands we covered are: delta (2–4 Hz), theta (4–8 Hz), alpha1 (8–13 Hz), beta (13–30 Hz) and gamma (30–50 Hz). The relative PSD was obtained by dividing the PSD of each frequency

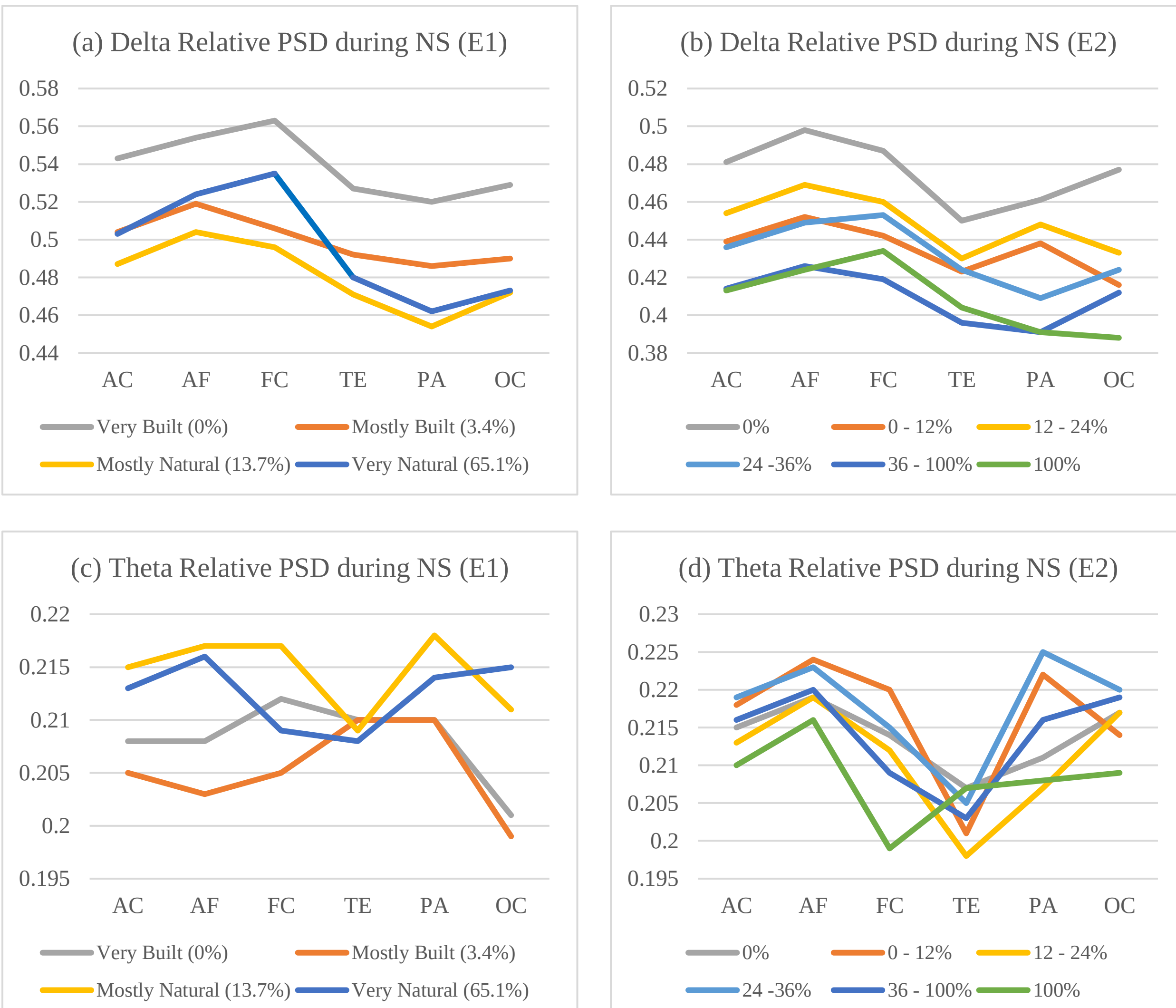
band by the total PSD of all the bands as estimated by a fast Fourier transform (FFT) algorism using Metlab.

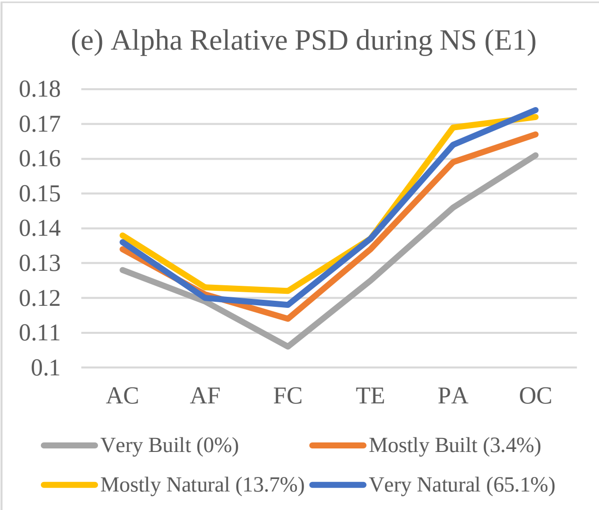
Figure 5.6 shows the relative PSD of EEG oscillation in different regions of the brain in five frequency bands for exposure to different levels of vegetation during neutral setting in the in situ experiment (experiment 1) and image viewing experiment (experiment 2). For both experiments it was shown that the relative PSD decreased when the frequency increased. The mean relative PSD values of the delta frequency band in all brain regions during neutral setting ranged from [0.454, 0.563] (experiment 1) to [0.388, 0.498] (experiment 2), while the mean relative PSD of the gamma frequency band in all brain regions during neutral setting oscillated between [0.0127, 0.0450] (experiment 1) and [0.0177, 0.0303] (experiment 2). The majority ratio of lower frequencies indicates that participants were in a calm, resting state.

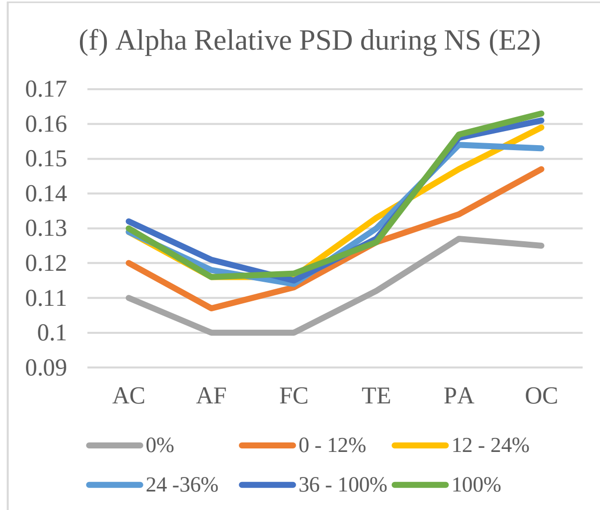
Figure 5.7 shows the relative PSD of EEG oscillation in different regions of the brain in five frequency bands from exposure to different levels of vegetation during the cognitive task in the in situ experiment (experiment 1) and image viewing experiment (experiment 2). The results are similar to the neutral setting in that the relative PSD decreased as the frequency increased; however, during the cognitive task, delta relative PSD increased as the alpha PSD decreased. The mean relative PSD values of the delta frequency band in all brain regions during cognitive task ranged from [0.502, 0.597] (experiment 1) to [0.502, 0.600] (experiment 2) while the mean relative PSD of the gamma frequency band in all brain regions during the cognitive task oscillated between [0.0120, 0.0373] (experiment 1) and [0.0148, 0.0308] (experiment 2). Decreased alpha relative PSD during the cognitive task [0.0876, 0.155] versus the neutral setting [0.1, 0.174] indicates that participants were in a more focused state.

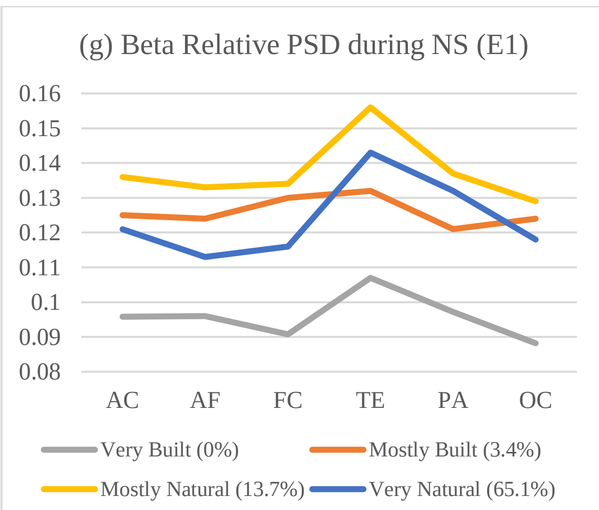
Figure 5.6

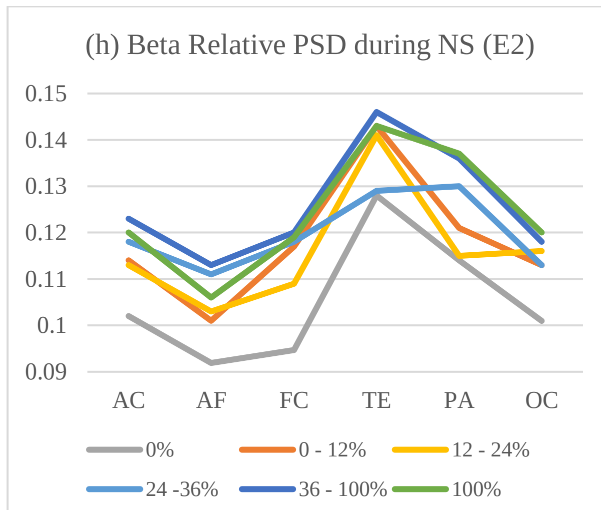
Graphs of Mean Relative PSD by Different Regions of Brain during Neutral Setting. (a) Delta (Experiment 1); (b) Delta (Experiment 2); (c) Theta (Experiment 1); (d) Theta (Experiment 2); (e) Alpha (Experiment 1); (f) Alpha (Experiment 2); (g) Beta (Experiment 1); (h) Beta (Experiment 2); (i) Gamma (Experiment 1); and (j) Gamma (Experiment 2)

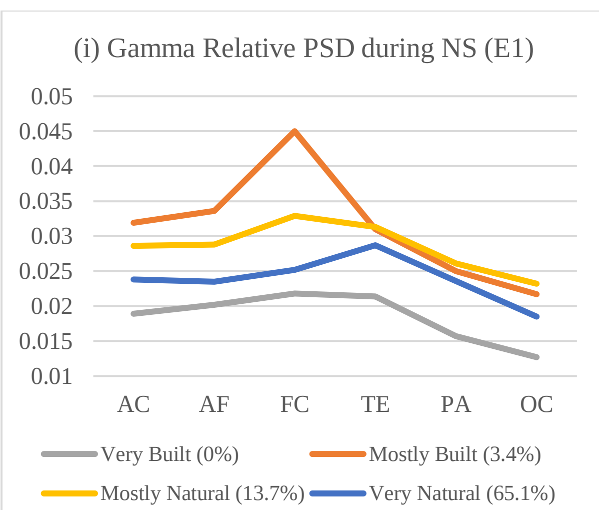



(e) Alpha Relative PSD during NS (E1)
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
AC AF FC TE PA OC
Very Built (0%)
Mostly Built (3.4%)
Mostly Natural (13.7%)
Very Natural (65.1%)


(f) Alpha Relative PSD during NS (E2)
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
AC AF FC TE PA OC
0%
0 - 12%
12 - 24%
24 -36%
36 - 100%
100%


(g) Beta Relative PSD during NS (E1)
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
AC AF FC TE PA OC
Very Built (0%)
Mostly Built (3.4%)
Mostly Natural (13.7%)
Very Natural (65.1%)


(h) Beta Relative PSD during NS (E2)
0.15
0.14
0.13
0.12
0.11
0.1
0.09
AC AF FC TE PA OC
0%
0 - 12%
12 - 24%
24 -36%
36 - 100%
100%


(i) Gamma Relative PSD during NS (E1)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
AC AF FC TE PA OC
Very Built (0%)
Mostly Built (3.4%)
Mostly Natural (13.7%)
Very Natural (65.1%)

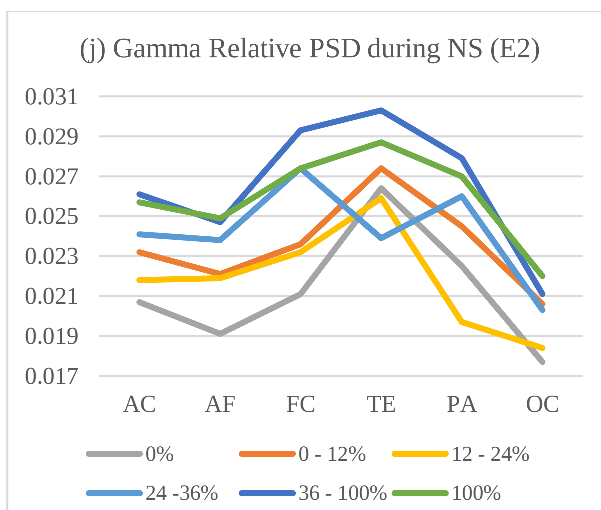
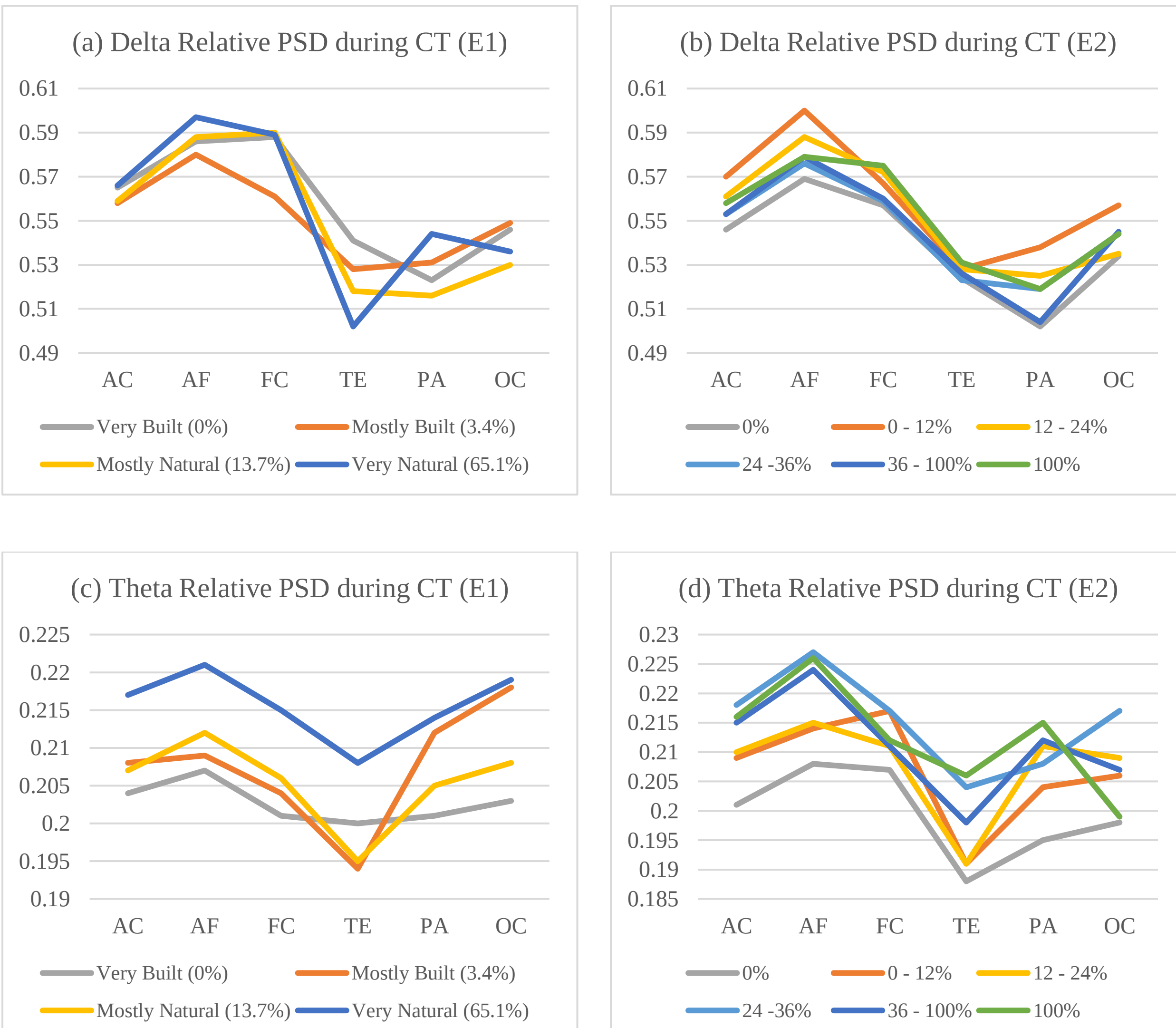
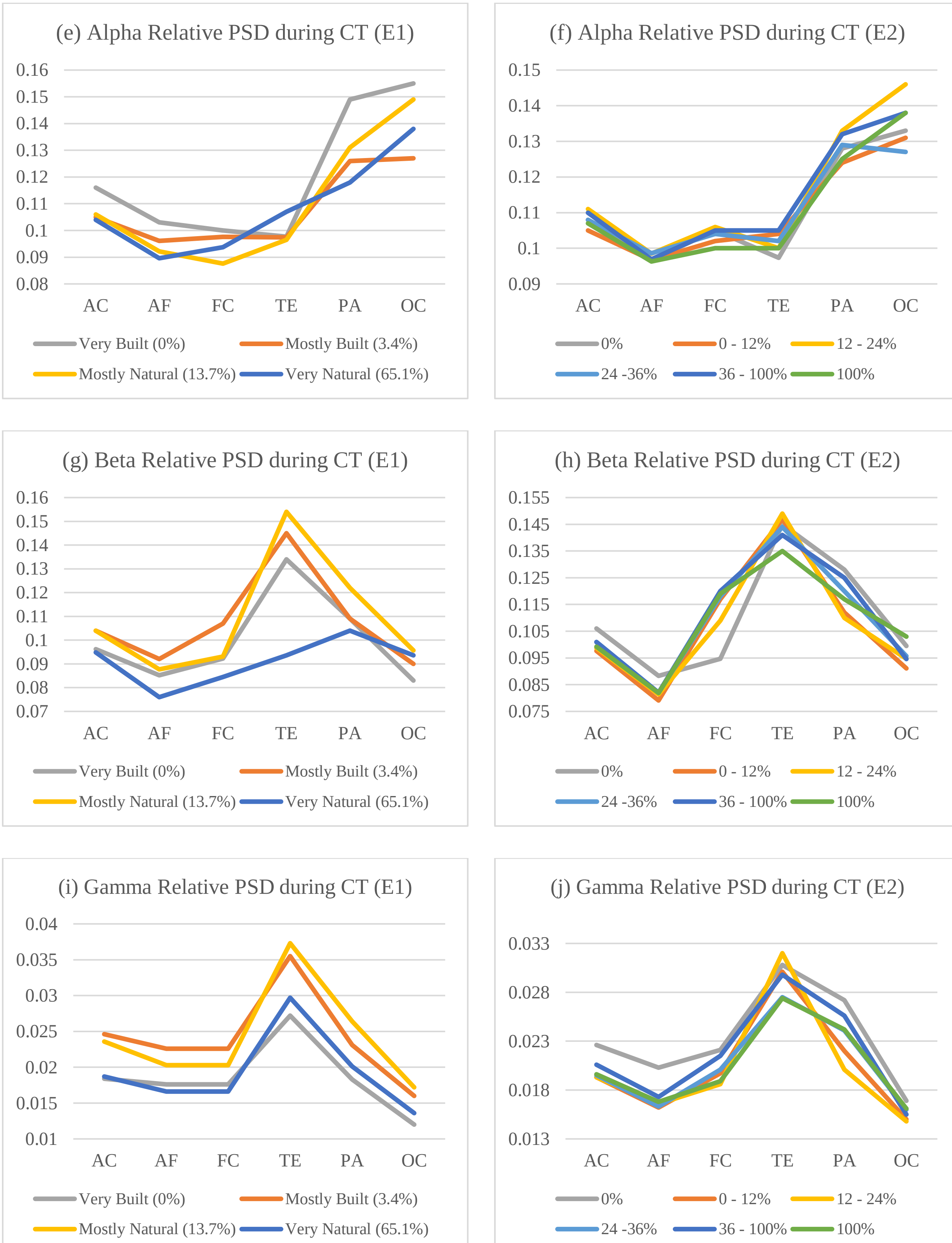

(j) Gamma Relative PSD during NS (E2)
0.031
0.029
0.027
0.025
0.023
0.021
0.019
0.017
AC AF FC TE PA OC
0%
0 - 12%
12 - 24%
24 -36%
36 - 100%
100%

Figure 5.7

Graphs of Mean Relative PSD by Different Regions of Brain during Cognitive Task. (a) Delta (Experiment 1); (b) Delta (Experiment 2); (c) Theta (Experiment 1); (d) Theta (Experiment 2); (e) Alpha (Experiment 1); (f) Alpha (Experiment 2); (g) Beta (Experiment 1); (h) Beta (Experiment 2); (i) Gamma (Experiment 1); and (j) Gamma (Experiment 2)




(e) Alpha Relative PSD during CT (E1)
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
AC AF FC TE PA OC
Very Built (0%)
Mostly Built (3.4%)
Mostly Natural (13.7%)
Very Natural (65.1%)
(f) Alpha Relative PSD during CT (E2)
0.15
0.14
0.13
0.12
0.11
0.1
0.09
AC AF FC TE PA OC
0%
0 - 12%
12 - 24%
24 -36%
36 - 100%
100%
(g) Beta Relative PSD during CT (E1)
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
AC AF FC TE PA OC
Very Built (0%)
Mostly Built (3.4%)
Mostly Natural (13.7%)
Very Natural (65.1%)
(h) Beta Relative PSD during CT (E2)
0.155
0.145
0.135
0.125
0.115
0.105
0.095
0.085
0.075
AC AF FC TE PA OC
0%
0 - 12%
12 - 24%
24 -36%
36 - 100%
100%
(i) Gamma Relative PSD during CT (E1)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
AC AF FC TE PA OC
Very Built (0%)
Mostly Built (3.4%)
Mostly Natural (13.7%)
Very Natural (65.1%)
(j) Gamma Relative PSD during CT (E2)
0.033
0.028
0.023
0.018
0.013
AC AF FC TE PA OC
0%
0 - 12%
12 - 24%
24 -36%
36 - 100%
100%

The relative PSD values for different level of vegetation indicate the following additional results: (1) during both the in situ and image viewing experiments, the delta and theta frequency bands become more active in the antero-frontal (AF3, AF4, F3, F4, F7, and F8) region; when cognitive task were given (Figure 5.6 [a – d] & Figure 5.7 [a - d]); (2) in the alpha frequency band, the relative PSD values in the parietal (P7, P8) and occipital (O1, O2) regions were particularly large in both first and second experiments, and both neutral and cognitive task settings (Figure 5.6e, f; Figure 5.7e, f). The relative alpha PSD values of Very Built (0%) sites and 0% Vegetation image setting were smaller than the other sites and images with vegetation during neutral settings (Figure 5.6e, f). However, when cognitive tasks were given, the gap became smaller, and even reversed during in situ experiment (Figure 5.7e, f); (3) in the beta and gamma frequency bands in the in situ (Experiment 1; Figure 5.6g, h, i, j) and image viewing experiment (Experiment 2; Figure 5. 7g, h, i, j), the mean relative PSD value was high in the temporal (T7 and T8) region except for gamma PSD during the in situ experience in the neutral setting (Figure 5.6i). Also, beta and gamma relative PSD values for Mostly Built and Mostly Natural sites in the neutral setting were larger than those for the Very Built and Very Natural sites during the in situ experiment (Experiment 1; Figure 5.6g, i), while beta and gamma relative PSD increased along with the levels of vegetation in the images (Experiment 2; Figure 5. 6h, j). The differences in beta and gamma value diminish participants were given cognitive tasks (Experiment 1; Figure 5.7g, i), and even lost the positive correlation in image viewing (Experiment 2; Figure 5. 7h, j). Though we could identify some visual trends in relative PSD graphs in various areas of brain, we could not explain the reasons for these results, and ultimately they fell beyond the scope of this study.

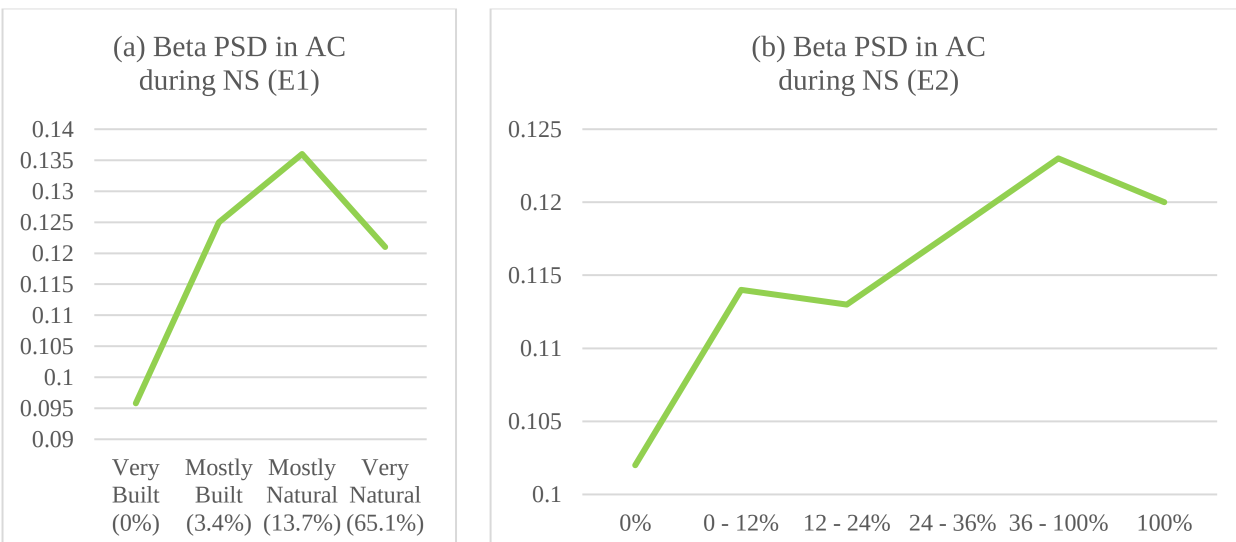
By comparing matching band frequencies between the first and second experiments, we can understand how indirect (in situ, experiment 1) and symbolic (viewing image, experiment 2) exposure to vegetation affects people differently. Backing up previous research that conducted both in situ and image viewing experiments (e.g. Berman et al., 2008) and used environment surrogate such as images (e.g. Chang et al., 2008; Herzog et al., 2003; Jiang et al., 2016; Kim et al., 2010; Lindal & Hartig, 2015; Van den Berg et al., 2014, Wilkie & Stavridou, 2013), this study establishes that symbolic vegetation exposure works just as much as indirect vegetation exposure in promoting restoration and working memory capacity. Figure 5.6 and Figure 5.7 show that the graphs that tell us how band frequencies activate throughout different regions of brain are mostly visually similar in most of cases in both neutral settings and during the cognitive task. However, further study is required to understand the effect of direct contact with vegetation (e.g. taking care of plants, doing activities in nature, etc.), on attention restoration and working memory capacity to fully understand the benefits of vegetation for people.

Beside the alpha and theta band mean relative PSD that we discussed in prior chapters, beta oscillation was conspicuous. During eye-open resting states in the neutral setting of both the 5-minute seated experiment (experiment 1) and the image viewing experiment (experiment 2), beta mean relative PSD was lower with no vegetation (Figure 5.6 & Figure 5.7). Furthermore, there were significant differences between levels of vegetation and beta mean relative PSD in all channels and all regions of brain (including antero-frontal, frontocentral, temporal, parietal, and occipital regions) during the neutral settings of the in situ experiment (Experiment 1; Figure 5.8a). No significant statistical results were found during the image viewing experiment despite a visual association between levels of vegetation and beta mean relative PSD (Figure 5.8b). Gola et al.

(2013) claim that EEG beta activity in occipital regions is associated with visual attention. And empirical evidence identifies nature as a more preferable environment compared to built environments (Han, 2011; Hartig & Staats, 2006). Thus, we may assume that vegetation can visually attract peoples' attention in indoor built environments. Decreased beta relative PSD values in Very Natural sites can be seen as a limitation of the in situ experience, wherein other environmental conditions, which we cannot specify or fully control, may influence the results.

Figure 5.8

Graphs of Beta Relative PSD in All Channels during Neutral Setting. (a) Experiment 1; (b) Experiment 2



5.4. Implication and Limitations

Implications

This research contributes further insights on human-nature interaction, and more specifically, on how varying degrees of visual contact with vegetation within indoor built environments influence restorative potential and working memory performance. Previous studies have mostly concentrated on comparisons between natural and urban settings, or between vegetation and no vegetation. In this experimental study we demonstrated a positive association between levels of vegetation, people's restorative potential, and their cognitive capacity. Further, we found that implementing at least 12% vegetation in indoor built environment provides a similar restoration effect as being in a nature. We also found that working memory capacity maxes out in spaces where 24 - 36 % of the indoor built environment is filled with vegetation. These findings can help design spaces for rest and work. Architects and interior designers previously knew that vegetation is not only aesthetically pleasing, but also beneficial to its users. However, they were unaware of precisely how much vegetation is required to fully receive its benefits. Thus, the results of this study can work as guidelines for the practical fields of architectural design to provide better space and environmental quality for users. On the basis of our results, we suggest that researchers and designers actively adopt vegetation in the built environment, and encourage designing indoor spaces like schools, hospitals, offices, etc. with proper levels of vegetation to better promote the aesthetics, performance, and well-being of users.

The study design of this dissertation is a second major contribution, as it incorporates various fields of study and assessment methods. There will be more demand to know the effects

of different natural settings as we further explore more evidence of nature's positive effects on psychological and physical health and wellbeing. The use of advanced technologies in various fields like environmental psychology, cognitive psychology, and neuroscience can actively fulfil such demand. To our knowledge, this is the first study on the impact of different levels of indoor vegetation that employed a multi assessment model using perceived measures (PRS-11 survey), behavioral scientific methods (backward digit span task) and psychophysiological measures (EEG PSD oscillations). In future research, our study design can be replicated and expanded to assess other biophilic design attributes in the field of architecture, such as materials, natural light, water features, biomorphic shapes, and etc. Furthermore, the study design can be replicated and expanded beyond biophilic design in architecture. It can be adapted to assess the influence of surrounding environments on people in various scales including single product size, furniture size, room-scale, building scale, and neighborhood scale. We can also modify the measures to identify the different influences of materials, colors, space types, space size, space layouts, building styles, building dimensions, neighborhood characteristics and so much more.

From a theoretical perspective, this study expands our understanding of Attention Restoration Theory. When conducting the experiment, we did not mentally deplete the participants prior to the backward digit span task and EEG recording. However, seeing indoor vegetation in situ and/or in images increased participants' backward digit span task scores and EEG theta PSD. Thus, the results of this dissertation imply that existing mental fatigue is not necessary for vegetation to enhance working memory performances in indoor built environments. This means that there is more potential for vegetation to influence people above and beyond the framework of ART, which hypothesizes that contact with nature restores directed attentional fatigue, and that

attention capacity improves with the restoration of directed attention. Although ART is well developed and adopted in academia, the underlying mechanism of restoration and attention system is still unclear. The findings from this dissertation may help extend ART to support exposure to nature as an active booster of restorativeness and attentional capacity beyond restorative supplements. Perhaps more empirical studies can expand the scope of the ART by solidifying the relationship between restorative potential (in this case, "not yet restored" or "no restoration required" conditions) and attention capacity.

Finally, this dissertation expands on the potential use of environmental surrogates, such as photos of vegetation, in real-world settings. When we first designed the experiment, we were concerned that olfactory senses beside vision, such as smells of fresh plants and soil, higher oxygen levels due to the vegetation, distance and spatial depth to vegetation, and etc., may affect participants' restoration and attention. In fact, studies found that scents are related to human cognition and behaviors (Holland et al., 2005). By comparing the first and second experiments, we found that being in situ and viewing images of vegetation within indoor built environment showed similar results. Thus, we can assume that the level of visual exposure is the key factor with the greatest influence on peoples' restorative potential and working memory capacity. However, we must further study the effects of various sensory stimuli to confirm the previous claim. In most indoor built environment settings, it is not feasible to fill one-quarter to one-third of the space with real plants and/or vegetation. Thus, this study offers an alternative solution: good quality photos and/or digital images of vegetation also help improve restorative quality and cognitive capacity. However, additional research is needed to fully understand the mechanism of vegetation's influences on humans, whether artificial or digital vegetation have similar effects on living

vegetation, and whether such effects differ according to peoples' perception of artificial vegetation.

Limitations

This study addressed many of the shortcomings of previous research on indoor vegetation by employing a design with various levels of vegetation in built environments. The intent was to overcome the natural/built environment dichotomy and thus to better represent real-world settings, where we have different levels of indoor vegetation. We also combined self-report measurement, cognitive task, and psychophysiological measurement.

However, this research has some limitations. First, as a quasi-experimental design study (experiment 1), it does not randomly assign the site and/or space to experiment. Empirical studies found that strong contextual objects (such as stoves, beds, and couches in indoor spaces) produced significant differences in the posterior region of the parahippocampal cortex (pPHC) in the medial temporal lobe fMRI signals, compared to the weak association objects (Bar & Amioff, 2003). They found similar results in the parahippocampal place area (PPA) fMRI signals (Henderson et al., 2008). These results suggest that the unequal environmental conditions of the selected sites may have led to a selection bias as spaces do not have the same environmental qualities such as height, volume, design layouts, furniture, quality of vegetation and etc. Also, each space has different programs, meeting rooms, cafeterias, cafés, and greenhouses; thus, participant may have had a pre-inclination to some spaces. The site selection was mainly based on diverse levels of vegetation within indoor spaces; thus, we had to compromise on some of the differences in environmental settings. However, we carefully matched other controllable environmental qualities to reduce the

bias.[21] In addition, we created the second experiment in which participants viewed images of vegetation in built environments. The image sets were carefully subcategorized and contained 40 images of different environments comprising different programs and vegetation qualities, thus alleviating the potential selection bias of the in situ experiment. In addition, we categorized the built environment into four space types: Bedroom & Restroom, Livingroom & Lobby Area, Kitchen & Dining, and Shop & Office; we also categorized the natural environment into four types: Forest & Jungle, Mountain & Trail, Garden & Meadow, and Lake & Water. Although we tried to select the images as evenly possible - as described in subchapter 3.6 Stimuli (page 95 - 96) - we cannot claim with complete certainty to have neutralized the effects of room type and furniture. Nevertheless, Bar and Aminoff (2013)'s experiment found that objects with strong contextual association did not show significant differences in the posterior region of the parahippocampal cortex (pPHC) in the medial temporal lobe fMRI signal change regardless of their background, whether it was a close-up or full scene view. Which means that if people perceive the vegetation as a major contextual object, the influence of the vegetation may have similar effects on people and therefore minimize the effects from the differences of background.

Second, the study sites and selected images are from well-conditioned spaces, with good air quality and thermal comfort for the in situ experiment, and good aesthetic quality for both the

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[21] Please refer to sub-chapter 3.5 Study Sites, pages 88-90, for more detailed environmental control efforts.

in situ and image viewing experiments. There are some studies on the relationship between environmental preferences and restoration (Han, 2007, 2010; Staats et al., 203; Van den Berg et al., 2003). Also, Abdulkarim and Nasar (2014) report that different settings in urban plazas have varied effects on peoples' restorativeness. The previous studies indicate that the quality of built environments itself matters to people's restorative and attentional abilities. There are many factors that differentiate the user experience of indoor built environments. Even excluding olfactory senses such as noise, odors, and etc., unpleasant visual information (for instance, uncleaned spaces, densely furnished and/or packed rooms, aesthetically unappealing environments, and so on) may act as mediating attributes and influence the results. Thus, altered results are possible if the study settings include potential distractions. However, this dissertation only focused on above-average condition indoor environment to eliminate unwanted and unspecified components of the indoor built environment.

Third, there is also a possibility that the quality of vegetation may produce different effects. We did not make distinctions as to the quality of vegetation in both selected sites and photos; therefore, it is difficult to ascertain whether the results are due to the vegetation density or quality. Because quality is a very subjective measure, there are no readily available methods or assessments to evaluate the quality of vegetation in small scale contexts such as indoor vegetation settings. Pre-exiting assessments, such as Floristic Quality Assessment (FQA), target larger areas (Taft et al., 1997). Instead, previous studies often focused on people's vegetation preferences, and explored the relationship between vegetation density and bio-diversity (Bjerke et al, 2006; Harris, et al, 2017; Johansson et al., 2014; Kurz & Baudains, 2012; Williams & Cary, 2002; Qiu, 2013). However, those studies used only vegetation density or bio-diversity as a variable, and did not

compare nor identify the interconnectedness between the two variables. This study instead took a quantitative approach to people' restorative potential and working memory capacity when exposed to varying levels of vegetation. For this, it used survey, task, and psychophysiological measures. Participants' own individual qualitative interpretations of the indoor built environment and vegetation were not included. Thus, this dissertation has a limited capacity to explain the influence of the quality of vegetation, and reveals the need for further studies of vegetation quality.

Fourth, this study focused on the influence of vegetation on visual stimuli: in other words, indirect contact with vegetation. Direct and active involvement, such as caring for vegetation, is shown to provide more meaningful impact on health and wellbeing, especially in older adults, than visual contact alone (Robson, Jr. & Troutman-Jordan; 2015; Wang & MacMillan, 2013). Caring for vegetation promotes more physical exercise and social interaction, and thus increases physical, psychological, and cognitive health (Brown et al., 2004; Gigliotti & Jarrott, 2005; Simons et al., 2006). In addition, this study omitted the vernacular approach to biophilic design. Place attachment and place identity are critical to understanding the built environment. Place attachment works as a motivational factor in promoting visits to natural environments like urban parks (Kyle et al., 2004) and increases the pro-environmental behaviors of park visitors (Halpenny, 2010). Therefore, in later studies both physical (levels of people's activity) and psychological (place attachment and cultural background) involvement could be intertwined in a multilayered analysis to produce a more thorough understanding of the effects of vegetation.

Fifth, this study recruited about half of its participants from the Seoul Botanic Park and this group may have stronger preferences for plants and vegetation; it is therefore worth asking whether the study can be generalized to people who do not have any preferences for plants and

vegetation. Also, Wilkie and Stavridou (2013) claim that people with higher urban preferences showed more restoration potential in urban environments; thus restoration is potentially possible in both natural and urban environments. All of the participants currently live in the Seoul metropolitan vicinity, meaning that people living in more rural, closer-to-nature areas may show different results. To alleviate the influence of vegetation preferences, we recruited the other half of the participants from architecture students from Seoul National University of Science and Technology.

Sixth, this study evaluated a brief (four to five minutes) exposure to vegetation. Different results may arise when people are exposed long-term or repeatedly. However, due to the difficulty of experimental design, most previous research on the effects of vegetation and nature uses a short-term study design. Thus, for future understandings of human-nature interaction in built environments, it is important to study the longitudinal effects of vegetation on peoples' health, wellbeing, and performance. Moreover, the experiments of this dissertation were conducted in the winter season. During the winter season people's cognitive performance and mood states decrease (Keller et al., 2005; Rohan & Sigmon, 2000; Spinks & Dalgleish, 2001). Furthermore, human brain responses differ according to seasonal changes; sustained attention task results are lower in the winter season, and working memory task results are lower in spring equinoxes (Meyer et al., 2016). While this study was conducted indoors with carefully maintained temperatures, long-term seasonal effects may already have affected participants as their bodies adjusted to the winter season. Thus, conducting the experiments in other seasons besides winter may produce different outcomes, and studies of the seasonal influence of vegetation remain to be done.

Seventh, we did not measure the baseline value of the PRS-11 scores, the backward digit span task scores, and the EEG relative PSD. The duration of entire experiment (both first and second experiments) was four hours and finishing the whole experiment within the four hours was a very tight time frame. During the four-hour experiment time, participants were asked to perform the PRS-11 survey and the backward digit span task ten times each (four times during the first experiment and six times during the second experiment), and asked to record EEG twenty times (eight times during the first experiment and twelve times during the second experiment). The participants and the researcher were exhausted after the experiment. Thus, we had to minimize the number and duration of the experiments, and could not ask the participants to conduct two more PRS-11 surveys and backward digit span tasks, and four more EEG recordings, for extra baseline measures. We decided to use the results of the Very Built site (0% vegetation) for the first experiment, and the 0% vegetation image set for the second experiment, as the baseline scores. The two backward digit span tasks from the introduction were done solely as a preparatory exercise, and their scores were very low, because the participants were new to the task; as a result, results from this preparatory exercise cannot work as the baseline measure.

Lastly, previous studies reported gender differences in the influence of vegetation (Jiang, Chang, & Sullivan, 2014; Shibata & Suzuki, 2002). However, when recruiting participants, we found many more female participants than male participants (8 males [26.7%] and 22 females [73.3%]) for the first experiment. To reduce this large male to female ratio, we recruited 11 more participants for the second experiment (15 males [36.6%] and 26 females [63.4%]), and moderated the gender gap.

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APPENDICES

APPENDIX A:

The PRS (Perceived Restorativeness Scale)-11

The PRS(Perceived Restorativeness Scale)-11	Study ID :	
	Study # :	Survey # :

Questions	not at all										completely
	0	1	2	3	4	5	6	7	8	9	10
1. Places like those/this are fascinating											
2. In places like those/this my attention is drawn to many interesting things											
3. In places like those/this it is hard to be bored											
4. Places like those/this are a refuge from nuisances											
5. To get away from things that usually demand my attention I like to go to places like those/this											
6. To stop thinking about the things that I must get done I like to go to places like those/this											
7. There is a clear order in the physical arrangement of places like those/this											
8. In places like those/this it is easy to see how things are organized											
9. In places like those/this everything seems to have its proper place											
10. Those/This place is large enough to allow exploration in many directions											
11. In places like those/this there are few boundaries to limit my possibility for moving about											

The PRS(Perceived Restorativeness Scale)-11 **인지 회복환경지각 척도**	**Study ID :** **Study # :** **Survey # :**

질문	전혀 그렇지 않다										매우 그렇다
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. 이런 곳(들)은 매력적이다.											
2. 이런 곳(들)에서 나는 많은 흥미로운 것들에 끌린다.											
3. 이런 곳(들)에서는 지루하지 않다.											
4. 이런 곳(들)은 성가신 일에서의 피난처로 알맞다.											
5. 신경 써야 하는 일들로부터 벗어나기 위해, 나는 이런 곳(들)에 가는 것을 좋아한다.											
6. 내가 처리해야 할 일들에 대해 생각하는 것을 멈추기 위해, 나는 이런 곳(들)에 가는 것을 좋아한다.											
7. 이런 곳(들)과 같은 장소의 물리적인 배치에는 명확한 순서가 있다.											
8. 이런 곳(들)에서는 모든 것들이 어떻게 구성되어 있는지 쉽게 알 수 있다.											
9. 이런 곳(들)에서는 모든 것들이 제자리가 있는 것처럼 보인다.											
10. 이런 곳(들)은 다양한 방면으로 관심을 가지기에 충분하다.											
11. 이런 곳(들)에서는 나의 이동 가능성은 제한되지 않는다.											

APPENDIX B:

Institutional Review Board Approval Letter

UNIVERSITY of WISCONSIN
UWMILWAUKEE
Department of University Safety & Assurances

Leah Stoiber
IRB Administrator
Institutional Review Board
Engelmann 270
P. O. Box 413
Milwaukee, WI 53201-0413
(414) 229-7455 *phone*
(414) 229-6729 *fax*

http://www.irb.uwm.edu
lstoiber@uwm.edu

New Study - Notice of IRB Expedited Approval

Date: February 17, 2020

To: Brian Schermer, PhD
Dept: School of Architecture and Urban Planning

CC: Jee Heon Rhee

IRB#: 20.152
Title: Bring Nature to the Built Environment: Measuring the Impact of Nature within Built Environment on Restorativeness and Cognition

After review of your research protocol by the University of Wisconsin – Milwaukee Institutional Review Board, your protocol has been approved as minimal risk Expedited under Category 4 and 7 as governed by 45 CFR 46.110.

This protocol has been approved on **February 17, 2020** for one year. IRB approval will expire on **February 16, 2021**. Before the expiration date, you will receive an email notifying you how to keep the study open or close it.

This study may be selected for a post approval review by the IRB. The review will include an in person meeting with members of the IRB to verify that study activities are consistent with the approved protocol and to review signed consent forms and other study related records.

Any proposed changes to the protocol must be reviewed by the IRB before implementation, unless the change is specifically necessary to eliminate apparent immediate hazards to the subjects. It is the principal investigator's responsibility to adhere to the policies and guidelines set forth by the UWM IRB, maintain proper documentation of study records and promptly report to the IRB any adverse events which require reporting. The principal investigator is also responsible for ensuring that all study staff receive appropriate training in the ethical guidelines of conducting human subjects research.

As Principal Investigator, it is also your responsibility to adhere to UWM and UW System Policies, and any applicable state and federal laws governing activities which are independent of IRB review/approval (e.g., FERPA, Radiation Safety, UWM Data Security, UW System policy on Prizes, Awards and Gifts, state gambling laws, etc.). When conducting research at institutions outside of UWM, be sure to obtain permission and/or approval as required by their policies.

Contact the IRB office if you have any further questions. Thank you for your cooperation and best wishes for a successful project.

Respectfully,

Leah Stoiber

Leah Stoiber
IRB Administrator

APPENDIX C:

Seoul Botanic Park Experiment Permission

I·SEOUL·U
너와 나의 서울

서울식물원

서울시 홈페이지
seoul.go.kr

수신 이지헌님 귀하(University of Wisconsin-Milwaukee, School of Architecture and Urban Planning)

(경유)

제목 **연구 협조 요청사항에 대한 회신**

1. 서울식물원 내에서 계획 및 추진 중인 연구와 관련하여 아래와 같이 회신드립니다.
2. 서울식물원 식물문화센터는 건물내부의 다양한 식물재료(벽면녹화 등)가 적용된 상태로 한국환경산업기술원으로부터 "녹색건축인증"을 받았으며, 도심형 식물원으로 식물문화 확산의 중심적 역할이 설립목적이므로 귀하께서 서울식물원 내에서 추진 중인 아래의 연구와 관련한 장소사용에 적극 협조코자 하며 장소사용 및 조건을 다음과 같이 알려드립니다.

□ 장소별 연구(실험)내용 및 조건

구분	실험1	실험2	비고
장소	도서관	카페, 온실 등 6개소	
기간	1월 중 ~ 3월 31일(화), 주말 제외 및 장소별 사용시간 협의 후 사용		
소요시간	2시간 이내	장소별 5분 (총 2시간 이내)	장소별 시간은 변동가능
인원	2인(실험자 1명 및 대상자 1명)	2인(실험자 1명 및 대상자 1명)	
실험내용	노트북을 통한 이미지 제시에 대한 대상자의 뇌파반응 측정	장소별 식물요소가 상이하며, 이에 대응하는 대상자의 뇌파반응 측정	

3. 또한 귀하께서 수행하시는 연구결과(논문)를 추후 회신하여 주시면 서울식물원 식물전문도서관에 비치 후 소중히 이용토록하겠습니다. 끝.

서울식물원장

★주무관	이건영	기획행정과장	01/10 문선엽			
협조자	주무관	강희연	주무관	김은수	주무관	최우경

시행 기획행정과-301 (2020.1.10.) 접수 ( )

우 07789 서울특별시 강서구 마곡동로 161 식물문화센터 3층 기획운영과 /

전화 2104-9725 /전송 / / 부분공개(6)

Seoul Botanic Park

Correspondence: Jee Heon Rhee (University of Wisconsin-Milwaukee, School of Architecture and Urban Planning)

Title: Reply to the Request for Research Cooperation

1. We are responding to the request for research permission in Seoul Botanic Park.

2. Seoul Botanic Park has various plants within the buildings and awarded "Green Building Certification" from Korea Environmental Industry and Technology Institute (KEITI). It is an inner-city botanic garden and its purpose of establishment is to extend plant-culture within the society; thus we will actively support your research and give permission to conduct research within the Seoul Botanic Park Complex. The use and conditions of the Seoul Botanic Park are as follows:

<table>
<tr><th></th><th>Experiment 1</th><th>Experiment 2</th><th>Note</th></tr>
<tr><td>Location</td><td>Meeting Room</td><td>6 spaces
(e.g. Café, Greenroom)</td><td rowspan="3">Locations and durations can be changed</td></tr>
<tr><td>Date</td><td colspan="2">January, 2020 – March, 31, 2020 / Weekdays only /
Prior notice required before use</td></tr>
<tr><td>Duration</td><td>Within 2 hours</td><td>About 5 minutes at each space (within 2 hours total)</td></tr>
<tr><td>Number of People</td><td>2 People (1 Researcher & 1 Participant)</td><td>2 People (1 Researcher & 1 Participant)</td><td></td></tr>
<tr><td>Experiment Contents</td><td>Showing images through laptop and measuring brain waves</td><td>Measuring brain waves at different spaces in Seoul Botanic Park</td><td></td></tr>
</table>

3. Also, please give us copy of your research work (dissertation). We will add it to the Plants Library's collection. End of document.

APPENDIX D:

Recruitment Materials

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Experiment Participants Wanted (Recruiting from SNS Group Chat Room of Architecture Students at Seoul National University of Science and Technology)

Hello,

My name is Jee Heon Rhee. I was former lecturer, from 2017 to 2019, in Architecture program at SNUST.

Some of you might have taken classes from me in the past, and some of you may never heard of me before. I'm here to recruiting participants for the experiments that I am prepare for my dissertation in School of Architecture and Urban Planning at University of Wisconsin-Milwaukee. .

The purpose of experiment is to understand how indoor greeneries help people relax and support the brain work better.

1. Experiment participants requirements
   1) Both men and women in their 20s to 40s
   2) Psychologically healthy
   3) No history of neurological illness
   4) With normal or corrected-to-normal vision (above 1.0)

2. Experiment date and Place
   1) Date : February 18, 2020 (Tue) ~ March, 20, 2020 (Fri) (Schedules subject to change)

      Every Tuesday through Friday from 09:00 am – 12:30 pm (3 and a half hours)

      / The date of participation is reservation based
   2) Place : Seoul Botanic Park (Kangseo-gu Magukdong-ro 161, Seoul)

      Subway Line 9 Yangchunhanggyo Station or Line 9/Airport Express Line Maguknaru Station

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3. Experiment procedures

There are two experiments. Participating both experiments are encouraged, but you can only participate the second experiments, if you want. The participation is 100% voluntary, and there are no negative consequences of not/partially participating.

1) 1st experiment: Recording brain wave, complete survey, and conduct simple tasks at designated places in Seoul botanic park (09:00 am – 10:30 am / 90 minutes)

2) 2nd experiment: Recording brain wave, complete survey, and conduct simple tasks at conference room in Seoul botanic park (11:00 am – 12:30 pm / when participating only 2nd experiment: 2:30 pm – 4:00 pm / 90 minutes)

Please Attention: Before coming, please do not drink and/or take recreational drugs for 24 hours. Also, please avoid strenuous activity or caffeine for 12 hours and have a good night's sleep (at least 7 hours). Finally, please do not consume any food or liquid (except water) for one hour before the experiment.

4. Benefit of participation

1) Free entrance of Seoul botanic park (Entrance fee: ₩ 5,000 (approximately $4.25))

2) ₩ 30,000 (approximately $25) gift card when participating both experiments
₩ 10,000 (approximately $8.50) gift card when participating only second experiment

5. Contact information

- Researcher : Jee Heon Rhee 010-9053-6400 / hellojeeheon@daum.net

This experiment is not only for students in architecture department at SNUST. Feel free to spread information to anyone (who met the participant requirements) interested.

Thank you very much!

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실험 참여자 모집 (서울과학기술대학교 건축과 학생 단체톡을 통한 모집)

안녕하세요.

저는 2017년부터 2019년까지 서울과학기술대학교 건축과 강사였던 이지헌 입니다.

예전에 제게 수업을 들으신 분들도 있고, 저를 처음 들으신 분도 있으실 것이라 생각됩니다.

이렇게 단체 톡을 통해 연락을 드리는 이유는,

제가 현재 진행하고 있는, 미국 위스콘신대학교 밀워키캠퍼스 건축도시대학원에서의 박사논문을 위한 실험 참여자를 모집을 위함입니다.

연구는 **건축물 내부의 식물이 사람들의 긴장 해소와 인지 능력 향상에 도움이 되는지**를 알아보고자 합니다.

1. 연구 참여 요건

   1) 20대 ~ 40대 남녀

   2) 정신질환 병력이 없는 분

   3) 과거 뇌 관련 질환 병력이 없는 분

   4) 정상 시력 (교정시력 포함 1.0 이상)

2. 연구 일시 및 장소

   1) 일시 : 2020년 2월 18일(화) ~ 2020년 3월 20일(금) (일정 조정 가능)

      매주 화~금 오전 09:00~12:30 (약 3시간 반) / 사전 예약을 통해 참여 날짜 결정

   2) 장소 : 서울식물원 (서울특별시 강서구 마곡동로 161)

      지하철 9호선 양천향교역 혹은 9호선/공항철도 마곡나루역

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3. 연구절차

실험은 총 2가지로 진행되며, 2가지 모두 참여가 권장되나 희망에 따라 2번째 실험만 참여하실 수 있습니다. 실험의 참여는 100% 자발적이며, 불참 혹은 일부 참여에 대한 불이익은 없습니다.

1) 1번째 실험: 서울식물원 내의 지정된 장소에서 뇌파 측정 및 설문, 간단한 과업 수행 (09:00~10:30 / 90분)

2) 2번째 실험: 서울식물원의 회의실에서 뇌파 측정 및 설문, 간단한 과업 수행 (11:00~12:30 / 두 번째 실험만 참여시 14:30~16:00 / 90분)

주의사항 : 오시기 전에는 24시간 동안 음주 및 약물의 복용 (건강상 필수 약물 제외)을 금해주시고, 12시간 동안 (전날 저녁 9시 이후) 카페인 섭취와 격렬한 활동은 삼가 주십시오. 가능하면 충분한 (최소 7시간 이상) 수면을 취해 주십시오. 실험 시작 전 1시간 동안은 식사 및 음료 (물 제외) 섭취는 금해 주십시오.

4. 연구 참여시 혜택

1) 참여시 서울식물원 온실 무료관람 가능 (입장료 5천원)

2) 소정의 상품권 (2가지 실험 모두 참여시 3만원 상당 / 2번째 실험만 참여시 1만원 상당)

5. 문의 사항

- 연구자 : 이지헌 010-9053-6400 / hellojeeheon@daum.net

본 실험은 서울과학기술대학교 건축학과 학생만을 대상으로 하는 것이 아닙니다. 주변의 관심 있는 지인들에게 전달해 주셔도 좋습니다.

감사합니다.

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Recruitment of Experiment Participants (Scripts for in-person recruiting for volunteers at Seoul botanic park)

Approach the volunteers at Seoul botanic park. Introduce researcher and ask if it is okay to explain about the experiment recruitment.

Hello, my name is Jee Heon Rhee. I'm a doctoral student in School of Architecture and Urban Planning at University of Wisconsin-Milwaukee. I'm here to recruiting participants for the experiments that I am preparing for my dissertation. If you are interested in participating, would you spare me five minutes for explanation?

Once the volunteer agrees to hear more about the experiment, explain the purpose of experiment and ask if the participant meets the requirements.

The purpose of experiment is to understand how indoor greeneries help people relax and support the brain work better. If you want to participate, you must be in your 20s to 40s, psychologically healthy, have no history of neurological illness, and have normal or corrected-to-normal vision (above 1.0). Do you qualify for the four requirements?

If the participant meets the requirements, explain date, place, and procedures of experiment.

The experiments will take place in this Seoul botanic park, between February 18, 2020 and March 20, 2020, every Tuesday through Friday from 09:00 am to 12:30 pm. The total duration of experiment is approximately 3 and a half hours. You can reserve the exact date, according to your preference.

There are two experiments. Participating both experiments are encouraged, but you can only participate the second experiments, if you want. The participation is 100% voluntary, and there are no negative consequences of not/partially participating.

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During the first experiment I will record your brain wave, give you a survey, and conduct simple tasks at designated places in Seoul botanic park. It will starts at 09:00 am and ends at 10:30 am, total duration will be about 90 minutes. In second experiment, you will do the same, record brain wave, complete survey, and conduct simple tasks at conference room in Seoul botanic park. It will starts at 11:00 am and ends at 12:30 pm. If you decided to participate only second experiment, you may come at 2:30 pm and the experiment will end at 4:00 pm. The total duration is also about 90 minutes

Before coming, please do not drink and/or take recreational drugs for 24 hours. Also, please avoid strenuous activity or caffeine for 12 hours and have a good night's sleep (at least 7 hours). Finally, please do not consume any food or liquid (except water) for one hour before the experiment.

Lastly, explain the benefit of participation, give a contact information, questions and answers.

If you participate both experiments, you will get ₩ 30,000 (approximately $25) gift card. If you only participate second experiment, you will get ₩ 10,000 (approximately $8.50) gift card.

Do you have any questions regarding the experiment and participation?

If you have any questions later, please contact me, Jee Heon Rhee 010-9053-6400 / hellojeeheon@daum.net at any time.

Ask the willingness to participate the experiment and make reservation for experiment date.

Thank you so much for your time. Would you like to participate the experiment?

When would be the most convenient date for you?

Conclusion and express gratitude. Handout participant information brochure.

This experiment is not only for the volunteers at Seoul botanic park. Feel free to give information to anyone who is interested and meet the participant requirements. Thank you very much and have a great day!

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Experiment Participant Information Brochure (for Seoul Botanic Park Volunteers)

The purpose of experiment is to **understand how indoor greeneries help people relax and support the brain work better.**

1. Experiment date and Place

1) Date : , , 2020 ( )
from 09:00 am – 12:30 pm (3.5 hours) or 2:30 pm – 4:00 pm (1.5 hour)

2) Place : Seoul Botanic Park

2. Experiment procedures

There are two experiments. Participating both experiments are encouraged, but you can only participate the second experiments, if you want. The participation is 100% voluntary, and there are no negative consequences of not/partially participating.

1) 1st experiment: Recording brain wave, complete survey, and conduct simple tasks at designated places in Seoul botanic park (09:00 am – 10:30 am / 90 minutes)

2) 2nd experiment: Recording brain wave, complete survey, and conduct simple tasks at conference room in Seoul botanic park (11:00 am – 12:30 am / when participating only 2nd experiment: 14:30 am – 16:00 am / 90 minutes)

Please Attention: Before coming, please do not drink and/or take recreational drugs for 24 hours. Also, please avoid strenuous activity or caffeine for 12 hours and have a good night's sleep (at least 7 hours). Finally, please do not consume any food or liquid (except water) for one hour before the experiment.

4. Benefit of participation

- ₩ 30,000 (approximately $25) gift card when participating both experiments
  ₩ 10,000 (approximately $8.50) gift card when participating only second experiment

5. Contact information

- Researcher : Jee Heon Rhee 010-9053-6400 / hellojeeheon@daum.net

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실험 참여자 모집 (서울식물원 자원봉사자들 개별 접촉)

서울식물원 내 자원봉사 활동을 하고 있는 자원봉사자들에게 접근. 연구자 소개 및 잠시 실험 참여자 모집에 대해 여쭤봐도 좋은지 확인.

안녕하세요. 저는 이지헌 이라고 합니다. 현재 미국 위스콘신대학교 밀워키캠퍼스 건축도시대학원에서 박사과정 중에 있으며, 박사논문을 위한 실험 참여자를 모집하고 있습니다. 실험 참여에 관심이 있으시다면, 설명을 위해 잠시 5분 정도만 시간을 내어 주실 수 있으신가요?

자원봉사자가 연구 참여의사를 보인다면, 연구의 목적을 설명하고 연구 참여 조건 충족여부를 질문.

연구는 건축물 내부의 식물이 사람들의 긴장 해소와 인지 능력 향상에 도움이 되는지를 알아보고자 합니다. 먼저 연구에 참여가 가능 하시려면, 1) 20대 ~ 40대 남녀 / 2) 정신질환 병력이 없는 분 / 3) 과거 뇌 관련 질환 병력이 없는 분 / 4) 정상 시력 (교정시력 포함 1.0 이상)을 만족하셔야 합니다. 혹시 네 가지 조건을 만족하시는지요?

연구 참여자가 참여 조건을 만족한다면, 연구 일시, 장소 및 연구절차 설명

연구는 2020년 2월 18일 화요일에서 2020년 3월 20일 금요일까지 진행될 예정이며, 매주 화~금 오전 09:00에서 12:30까지 약 3시간 반 가량 진행 됩니다. 정확한 날짜는 편하신 날짜를 사전 예약을 통해 정하실 수 있습니다. 장소는 봉사활동을 하고 계시는 서울식물원에서 진행됩니다.

실험은 총 2가지로 진행되며, 2가지 모두 참여가 권장되나 희망에 따라 2번째 실험만 참여하실 수 있습니다. 실험의 참여는 100% 자발적이며, 불참 혹은 일부 참여에 대한 불이익은 없습니다.

첫 번째 실험은 서울식물원 내의 지정된 장소에서 뇌파 측정 및 설문, 간단한 과업 수행을 진행하며, 09:00에서 10:30까지 약 90분 정도 소요됩니다. 두 번째 실험은 서울식물원의 회의실에서 동일하게 뇌파 측정 및 설문, 간단한 과업 수행을 진행하며, 11:00에서 12:30까지 약 90분 간 진행됩니다. 두

번째 실험만 참여시 14:30에서 16:00까지 90분간 진행됩니다.

주의사항으로는 약속하신 전날 24시간 동안 음주 및 약물의 복용 (건강상 필수 약물 제외)을 금해주시고, 12시간 동안 (전날 저녁 9시 이후) 카페인 섭취와 격렬한 활동은 삼가 주십시오. 가능하면 충분한 (최소 7시간 이상) 수면을 취해 주십시오. 실험 시작 전 1시간 동안은 식사 및 음료 (물 제외) 섭취는 금해 주십시오.

마지막으로 연구 참여시 혜택 및 연락처 전달, 질의 응답.

연구 참여시에는 소정의 상품권을 지급해 드립니다. 두 가지 실험 모두 참여시 3만원 상당의 상품권을 드리며, 두 번째 실험만 참여시 1만원 상당의 상품권을 드립니다.

실험과 관련하여 문의 사항은 연구자 이지헌 010-9053-6400 / hellojeeheon@daum.net 으로 연락해주시면 됩니다.

혹시 실험과 관련하여 궁금하신 점이 있으신가요?

실험 참가 의사 질문 및 날짜 예약.

시간을 내어 설명을 들어 주셔서 감사합니다. 실험에 참가하실 의향이 있으신지요?

날짜는 언제가 편하신가요?

마무리 및 감사인사. 참여자 안내문 지급.

본 실험은 서울식물원 자원봉사자 분들만을 대상으로 하는 것이 아닙니다. 주변의 관심 있는 지인들이 있으시다면 말씀 드린 연락처로 연락을 부탁 드리겠습니다. 좋은 하루 되세요! 감사합니다.

UNIVERSITY of WISCONSIN
UWMILWAUKEE

실험 참여자 안내문 (서울식물원 자원봉사자용)

연구는 **건축물 내부의 식물이 사람들의 긴장 해소와 인지 능력 향상에 도움이 되는지**를 알아보고자 합니다.

1. **연구 일시 및 장소**

   1) 일시 : 2020년 월 일 ( ) 오전 09:00~12:30 (약 3시간 반) 혹은 14:30~16:00 (90분)

   2) 장소 : 서울식물원

2. **연구절차**

실험은 총 2가지로 진행되며, 2가지 모두 참여가 권장되나 희망에 따라 2번째 실험만 참여하실 수 있습니다. 실험의 참여는 100% 자발적이며, 불참 혹은 일부 참여에 대한 불이익은 없습니다.

1) 1번째 실험: 서울식물원 내의 지정된 장소에서 뇌파 측정 및 설문, 간단한 과업 수행 (09:00~10:30 / 90분)

2) 2번째 실험: 서울식물원의 회의실에서 뇌파 측정 및 설문, 간단한 과업 수행 (11:00~12:30 / 두 번째 실험만 참여시 14:30~16:00 / 90분)

주의사항 : 오시기 전에는 24시간 동안 음주 및 약물의 복용 (건강상 필수 약물 제외)을 금해주시고, 12시간 동안 (전날 저녁 9시 이후) 카페인 섭취와 격렬한 활동은 삼가 주십시오. 가능하면 충분한 (최소 7시간 이상) 수면을 취해 주십시오. 실험 시작 전 1시간 동안은 식사 및 음료 (물 제외) 섭취는 금해 주십시오.

4. **연구 참여시 혜택**

- 소정의 상품권 (2가지 실험 모두 참여시 3만원 상당 / 2번째 실험만 참여시 1만원 상당)

5. **연락처**

- 연구자 : 이지헌 010-9053-6400 / hellojeeheon@daum.net

APPENDIX E:

Informed Consent Form

UNIVERSITY of WISCONSIN
UWMILWAUKEE

Informed Consent for Research Participation
IRB #: 20.152
IRB Approval Date: February 17, 2020

Study title	Bring Nature to the Built Environment: Measuring the Impact of Nature within Built Environment on Restorativeness and Cognition
Researchers	**Brian Schermer**, PhD, RA, Associate Professor, the School of Architecture and Urban Planning at UW-Milwaukee **Jee Heon Rhee**, PhD candidate, the School of Architecture and Urban Planning at UW-Milwaukee

We're inviting you to participate in a research study. Participation is completely voluntary. If you agree to participate now, you can always change your mind later. There are no negative consequences, whatever you decide. Especially for the park volunteers, your decision to participate or not has no impact on your relationship with Seoul Botanic Park.

What is the purpose of this study?

We want to understand how indoor greeneries help people relax and support the brain work better.

What will I do?

- There are two experiments. You may have come to participate the both experiment or may have come to participate the second experiments. During the first experiment you will be sitting at selected spaces in Seoul Botanic Park, and during the second experiment you will be sitting and watch images in the meeting room of Seoul Botanic Park.
- At Seoul Botanic Park:
    - You'll be instructed the study procedures, learn a simple short-term memory test, and wear EEG device, which will record your brain wave, and test if it is working properly. The EEG device is a commercially oriented and on the market since 2009. There is no complication in setting up, all you need is put the device on your head like a headphone. I will adjust the location of electrode after you put on the device. The device use wet electrode using saline solution, thus you may have disheveled hair after the experiment, but it works as a sanitary purpose as well. (30 minutes)
    - You'll sit and stay in four different spaces (e.g. office room, café, restaurant, and greenhouse) for five minutes each. After five minutes, you'll complete a survey regarding your moods (4 times), and perform a backward digit-span task (4 times). There will be five minute break and moving time between each space. (80 minutes)
- At Meeting Room in Seoul Botanic Park:
    - You'll be instructed the study procedures, complete surveys about your thoughts to nature and your moods, learn a backward digit-span task, and wear the same EEG device, which will record your brain wave, and test if it is working properly. (20 minutes)
    - You'll watch an image for 6 seconds. There are 6 sets of image, and each image set has 40 images (240 images total). The images are photos of indoor built environment, mix of nature and indoor built environment, and nature. (30 minutes)
    - You'll be complete the same mood survey (6 times) and perform a backward digit-span task (6 times) after each set of photos. There will be 10 minutes break after 3 sets. (40 minutes)

Risks

Possible risks	**How we're minimizing these risks**
Breach of confidentiality (your data being seen by someone who shouldn't have access to it)	• All identifying information is removed and replaced with a study ID. • We'll store all electronic data on a password-protected, encrypted computer that only the researchers has access to. • There is no paper data at all.
Discomforts for wearing the EEG device	• We will check if you feel uncomfortable at any time of the study. • There will be a break if you wear it for more than 30 minutes.
Minor embarrassment	• Since the first experiment is done in public, there is a risk that other people may know you are participating in a research study. • To reduce this embarrassment, the experiment will take place before and right after the botanic park open, and there will be not many people around.
Minor frustration	• The task is not a competition with other participants. • Good score is not required in this experiment. The task results are only important among the differences that you made at each environment and/or image settings. • You can always take a rest or stop the task if you feel uncomfortable.

There may be risks we don't know about yet. Throughout the study, we'll tell you if we learn anything that might affect your decision to participate.

Other Study Information

Possible benefits	• You may help understand more about the effectiveness of nature to your everyday space.
Estimated number of participants	40 healthy adults (psychologically healthy, no history of neurological illness, with normal or corrected-to-normal vision)
How long will it take?	• If you participate both first and second part of study, it will take about 210 minutes including preparation and rest. • If you are only participating the second part of study, it will take about 90 minutes including preparation and rest.
Costs	None
Compensation	• ₩ 30,000 (approximately $25) gift card when participating entire study. • ₩ 10,000 (approximately $8.50) gift card when participating only second part of study. • If you participate the entire study, you can visit the greenhouse for free (entrance fee ₩ 5,000 / $4.25).
Future research	De-identified (all identifying information removed) data may be shared with other researchers. You won't be told specific details about these future research studies.

Confidentiality and Data Security

We'll collect the following identifying information for the research: your electroencephalography and brief survey results. This information is necessary and will used for analyzing the goals of study.

Where will data be stored?	The electroencephalography and survey results will be saved on a password protected computer that only the researchers listed above has access to.
How long will it be kept?	All of the data collected for this study will be destroyed after five years of the study completion.

Who can see my data?	**Why?**	**Type of data**
The researchers	To conduct the study and analyze the data	De-identified (no names, birthdate, address, etc. attached to the data) electroencephalography and brief survey results
The IRB (Institutional Review Board) at UWM The Office for Human Research Protections (OHRP) or other federal agencies	To ensure we're following laws and ethical guidelines	De-identified (no names, birthdate, address, etc. attached to the data) electroencephalography and brief survey results
Anyone (public)	If we share our findings in publications or presentations	• Aggregate (grouped) data • De-identified (no names, birthdate, address, etc.) data

Contact information:

For questions about the research	Brian Schermer * Jee Heon Rhee	1-414-813-0328 / bscherm@uwm.edu 010-9053-6400 / jrhee@uwm.edu
For questions about your rights as a research participant	IRB (Institutional Review Board; provides ethics oversight) *	1-414-229-3173 / irbinfo@uwm.edu
For complaints or problems	Jee Heon Rhee	010-9053-6400 / jrhee@uwm.edu
	IRB *	414-229-3173 / irbinfo@uwm.edu

* Please note that Brian Schermer and the IRB staffs are English speaking personal.

Signatures

If you have had all your questions answered and would like to participate in this study, sign on the lines below. Remember, your participation is completely voluntary, and you're free to withdraw from the study at any time.

____

Name of Participant (print)

____ ______________

Signature of Participant Date

____

Name of Researcher obtaining consent (print)

____ ______________

Signature of Researcher obtaining consent Date

UNIVERSITY of WISCONSIN
UWMILWAUKEE

연구 참여 동의서
IRB #: 20.152
IRB Approval Date: 2020. 2. 17.

연구 제목	자연을 건축환경으로 끌어들이기: 건축환경 내의 자연이 회복환경지각과 인지능력에 미치는 영향 측정
연구자	**브라이언 셔머**, 박사, 미국 건축사, 부교수, 건축 및 도시계획학부, 위스콘신-밀워키 주립대 **이지헌**, 박사수료, 건축 및 도시계획학부, 위스콘신-밀워키 주립대

본 연구에 귀하의 참여를 부탁 드립니다. 참여는 전적으로 자발적이고, 지금 참가하시기로 동의하시더라도 나중에 언제든지 마음을 바꾸실 수 있습니다. 어떤 결정을 내리셔도 불이익은 없습니다. 특히, 서울식물원 자원봉사자 분들의 참여 혹은 불참 결정은 서울식물원과 당신의 관계에 어떠한 영향도 없음을 알려드립니다.

본 연구의 목적은?

본 연구는 실내의 자연물이 어떻게 사람들의 긴장 해소와 인지 능력 향상에 도움이 되는지 알아보고자 합니다.

연구참여자는 무엇을 할까요?

- 실험은 총 2 가지로 진행됩니다. 당신은 두 실험 모두 참가하기 위해 오셨거나, 두 번째 실험에만 참가하기 위해 오셨습니다. 첫 번째 실험에서는 당신은 서울식물원의 지정된 곳에서 앉아계실 것입니다. 두 번째 실험에서는 서울식물원 미팅룸에서 앉아 사진들을 보실 것입니다.
- 서울식물원에서:
  - 당신은 실험 절차 설명을 듣고, 간단한 단기기억 과제를 배웁니다. 뇌파를 측정할 EEG 장비를 착용하고, 각 전극이 활성화 되었는지 확인합니다. 뇌파측정 장비는 의학용이 아닌 소비자 판매용으로 2009 년부터 시판된 모델입니다. 장비 착용은 매우 쉬우며, 헤드폰을 착용하시는 것과 같습니다. 착용이 끝나시면, 연구자가 전극을 조정합니다. 장비는 전극에 렌즈세척액을 사용하며, 실험이 끝난 후 머리가 부스스해질 수 있습니다. 하지만, 이 렌즈세척액은 소독 및 세척의 역할도 합니다. (30 분)
  - 당신은 4 개의 공간 (사무실, 카페, 레스토랑, 온실)에서 5 분씩 앉아있습니다. 5 분이 지난 후, 당신은 당신의 기분에 관한 설문을 작성하고 (4 회), 역방향 숫자 기억처리 과제 (a backward digit-span task)를 수행합니다 (4 회). 실험 종료 후 5 분의 이동 및 휴식이 주어집니다. (80 분)
- 서울식물원의 미팅룸에서:
  - 당신은 실험 절차 설명을 듣고, 자연친화도 설문과 당신의 기분에 대한 설문을 작성하고, 역방향 숫자 기억처리 과제 (a backward digit-span task)를 배웁니다. 뇌파를 측정할 첫 번째 실험과 동일한 EEG 장비를 착용하고, 각 전극이 활성화 되었는지 확인합니다. (20 분)
  - 당신은 6 초간 사진들을 보게 됩니다. 사진들은 40 개의 이미지가 한 세트로 총 6 개 세트, 240 개의 이미지가 있습니다. 사진들은 실내 건축공간, 실내 건축공간과 자연, 그리고 자연으로 구성되어 있습니다. (30 분)
  - 각 세트가 끝난 후, 당신은 사진들을 본 뒤 당신의 기분에 대한 동일한 설문을 작성하고 (6 회), 역방향 숫자 기억처리 과제 (a backward digit-span task)를 수행합니다 (6 회). 3 회의 실험이 끝난 후 10 분의 휴식이 주어집니다. (40 분)

위험

가능한 위험	위험을 최소화 하기 위한 우리의 노력
개인정보 유출(데이터에 액세스해서는 안 되는 사람이 데이터를 확인함)	• 모든 식별 정보를 제거하고 연구대상 ID 로 대체. • 모든 전자 데이터를 암호화된 문서로 암호화된 컴퓨터에 저장. • 모든 데이터는 컴퓨터 파일로만 존재.
EEG 장비 착용시 불편함	• 우리는 당신이 불편한지 지속적으로 확인할 것입니다. • 30 분 이상 EEG 장비 착용 시에는 휴식이 주어집니다.
심하지 않은 곤란한 상황	• 첫 번째 실험은 공공장소에서 이루어지므로, 다른 사람들이 당신이 실험에 참여하는 것을 볼 수 있습니다. • 부외자들에 대한 노출을 최소화하기 위해, 실험은 서울식물원 개장 전 및 직후에 이루어지며, 외부인들이 많이 않을 것입니다.
심하지 않은 좌절 상황	• 역방향 숫자 기억처리 과제는 다른 참가자들과의 경쟁이 아닙니다. • 본 실험에서 과제에 대한 좋은 점수는 요구되지 않습니다. 과제 점수는 당신이 각 공간 혹은 이미지들에서 얼마나 차이가 있는지 만이 의미를 갖습니다. • 당신이 좌절 혹은 불편을 느낀다면, 과제 도중 언제라도 쉬거나 과제 중단을 요청할 수 있습니다.

연구를 진행하면서, 우리가 파악하지 못한 추가적인 위험이 도출될 수 있습니다. 당신의 참여 결정에 영향을 미칠 수 있을 내용이 확인된다면, 알려드리겠습니다.

추가 연구 관련 정보

가능한 혜택	• 일상 공간에 미치는 자연의 효과에 대해 더 잘 이해하는 데 도움이 될 수 있습니다.
예상 참가자 수	건강한 (심리적으로 건강하고, 과거 뇌 관련 질환 병력이 없으며, 교정시력을 포함하여 정상시력인) 40 명의 성인
얼마나 걸리는지?	• 만약 당신이 두 실험에 모두 참가한다면, 이동시간과 준비시간, 쉬는 시간을 모두 포함하여 210 분 정도 걸립니다. • 만약 당신이 두 번째 실험만 참가한다면, 준비시간을 포함하여 90 분 정도 걸립니다.
비용	없음
보상	• 두 실험에 모두 참가한다면: 30,000 원 상당의 상품권 (대략 $25) • 두 번째 실험에만 참가한다면: 10,000 원 상당의 상품권 (대략 $8.50) • 전체 연구에 참여하시면, 온실에 무료로 입장하실 수 있습니다 (입장료 5,000 원).
추가적인 연구	당신에 대한 모든 식별 정보가 제거된 데이터는 다른 연구자들과 공유될 수 있습니다. 차후 당신의 데이터를 이용하여 추가적인 연구가 진행되더라도 추가연구에 대한 정보를 공유 받지 못할 것입니다.

개인정보 보호 및 데이터 보안

우리는 연구를 위해 당신의 뇌파 및 설문결과 등의 정보를 수집할 것입니다. 이 정보들은 연구의 결과를 도출하는 데 사용될 것이며, 꼭 필요합니다.

데이터는 어디에 저장되나요?	뇌파 및 설문결과 등은 위에서 언급한 연구자들만이 접근할 수 있는 암호로 보호되는 컴퓨터에 저장됩니다.
얼마나 오래 보관되나요?	이 연구를 위해 수집된 모든 데이터는 연구 완료 후 5 년 후에 삭제될 것입니다.

당신의 데이터는 누가 볼 수 있나요?	**그 이유는?**	**접근 가능 데이터**
연구진	연구 수행 및 데이터 분석	개인 식별이 되지 않는(이름, 생년월일, 주소 등이 제외된) 뇌파 및 설문 결과
위스콘신-밀워키 대학 IRB (연구 윤리 위원회) 미국 인간연구보호국(OHRP) 혹은 기타 연방 기관	연구진들이 법률 및 윤리 지침을 준수하는지 관리 감독	개인 식별이 되지 않는(이름, 생년월일, 주소 등이 제외된) 뇌파 및 설문 결과
모든 사람들(공공 공개)	논문 출판 혹은 발표를 통해 연구 결과를 공유할 시	• 그룹화 된 데이터 • 개인 식별이 되지 않는(이름, 생년월일, 주소 등이 제외된) 데이터

연락처:

연구에 관련된 질문	브라이언 셔머 * 이지헌	1-414-813-0328 (미국) / bscherm@uwm.edu 010-9053-6400 (한국) / jrhee@uwm.edu
연구 참가자의 권리에 관한 질문	IRB (연구 윤리 위원회; 연구 윤리 감독) *	1-414-229-3173 (미국) / irbinfo@uwm.edu
불만사항 혹은 문제제기	이지헌	010-9053-6400 / jrhee@uwm.edu
	IRB *	414-229-3173 / irbinfo@uwm.edu

* 브라이언 셔머 교수와 IRB 에 연락하실 때는 영어로 연락하시기 바랍니다.

서명

만약 연구에 관련된 모든 궁금한 점들이 해소되고, 본 연구에 참여하고 싶다면 아래에 서명해 주십시오. 당신의 참여는 완전히 자발적이고, 당신은 언제든지 자유롭게 연구참여 결정을 철회할 수 있음을 기억해 주세요.

____
연구 참여자 이름 (정자로)

____ ______________
연구 참여자 서명 날짜

____
동의서를 받는 연구자 이름 (정자로)

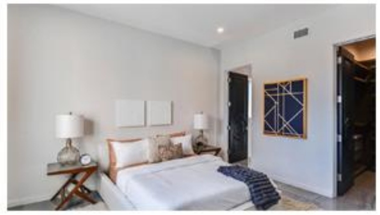
____ ______________
동의서를 받는 사람의 서명 날짜

APPENDIX F:

Image Sets

Image Set #1 - 1 (0% Vegetation)

0%

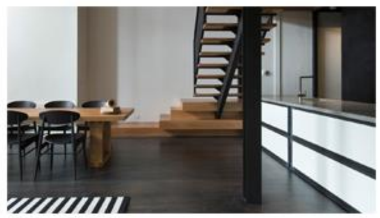


0%

0%

0%

0%



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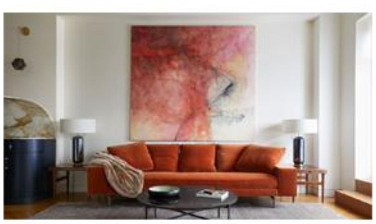
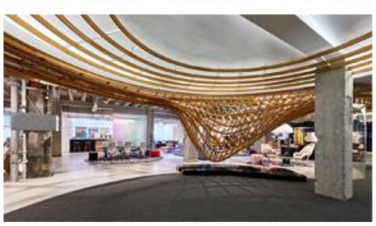


0%

0%



0%

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Image Set #1 - 2 (0% Vegetation)

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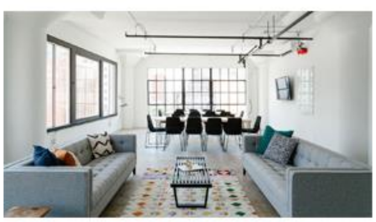

0%

0%

0%

0%

0%

0%

Image Set #1 - 3 (0% Vegetation)

0%

0%

0%

0%

0%

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0%

Image Set #2 - 1 (0 - 12% Vegetation)

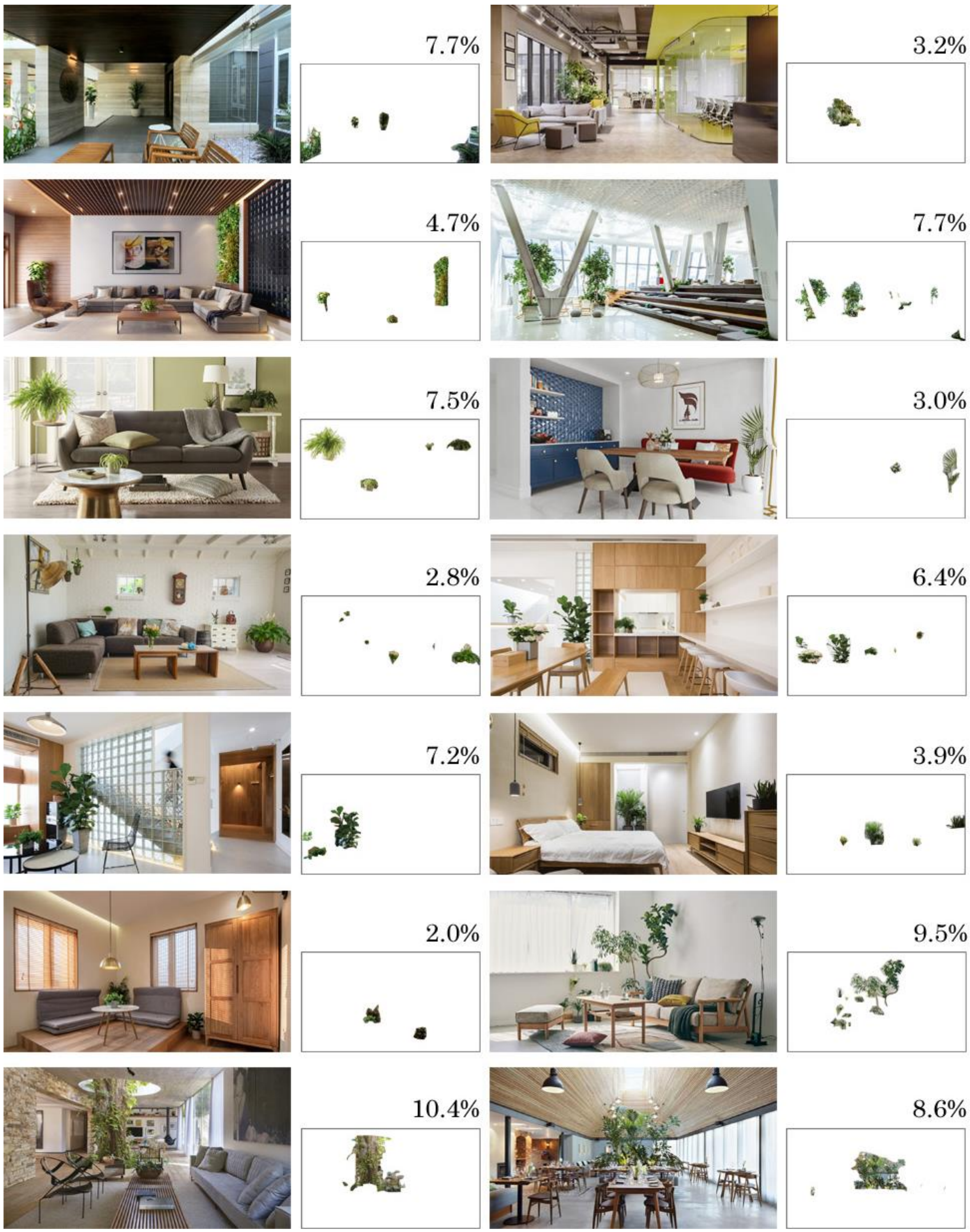


Image Set #2 - 2 (0 - 12% Vegetation)

Image Set #2 - 3 (0 - 12% Vegetation)

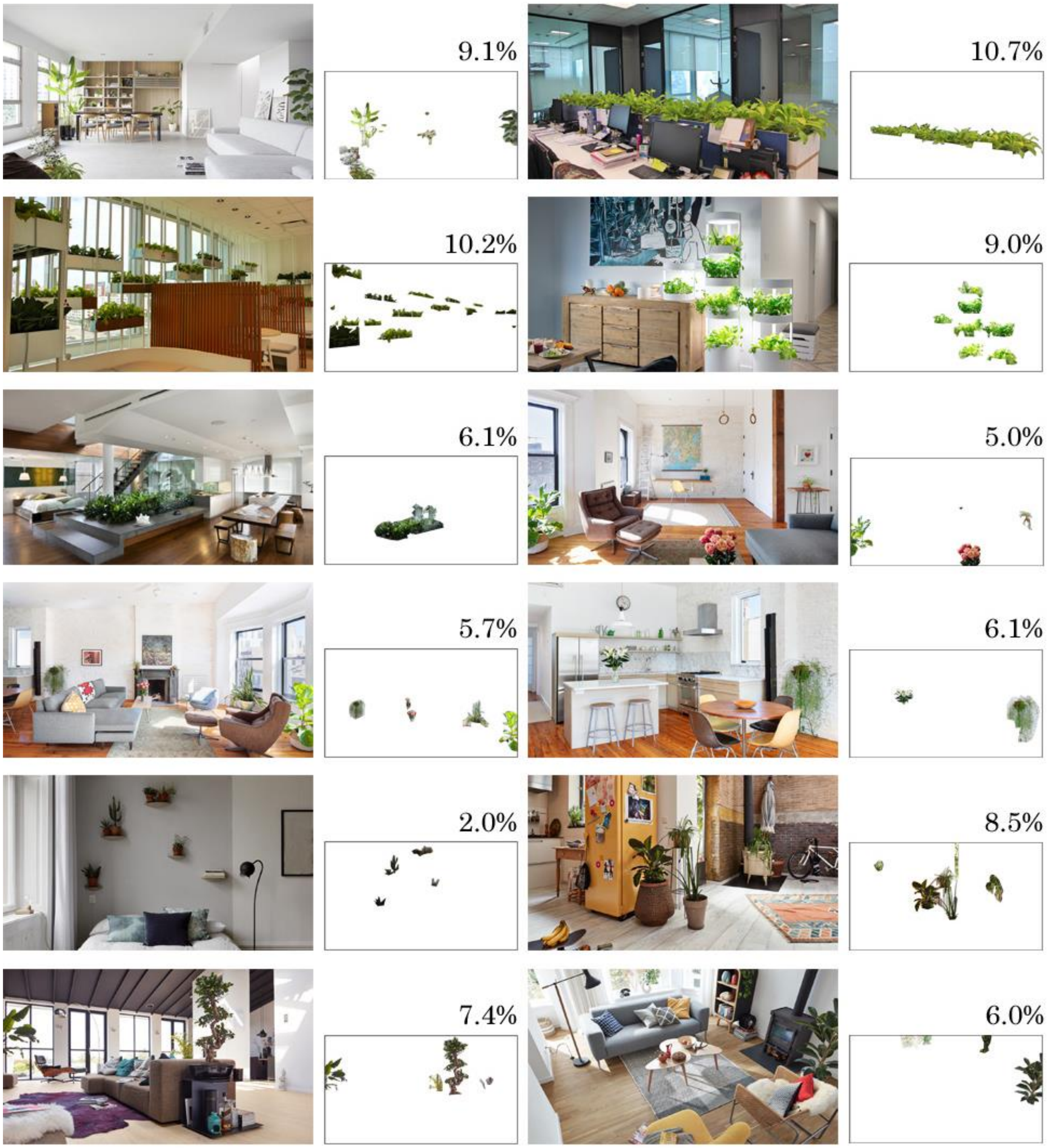


Image Set #3 - 1 (12 - 24% Vegetation)

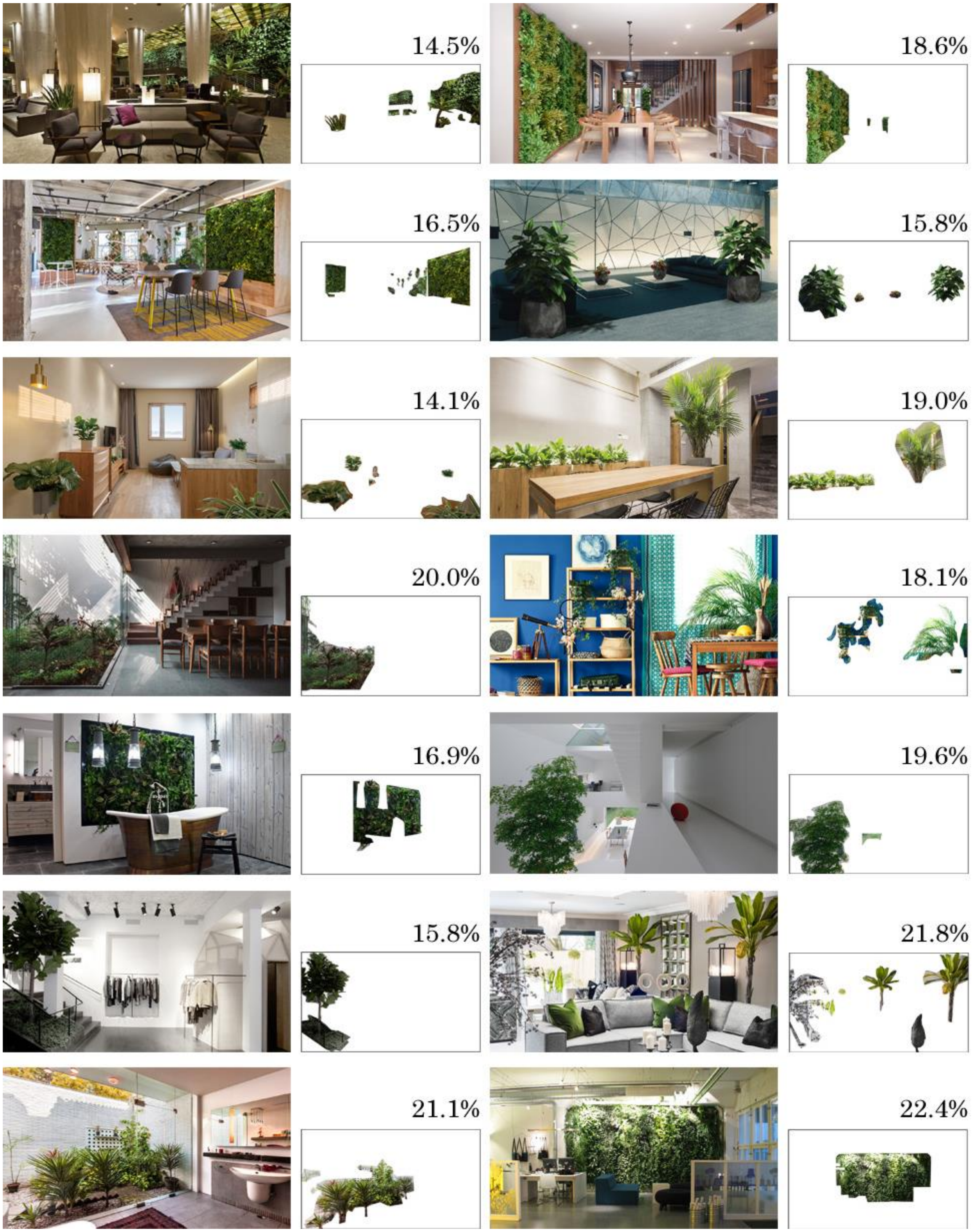


Image Set #3 - 2 (12 - 24% Vegetation)

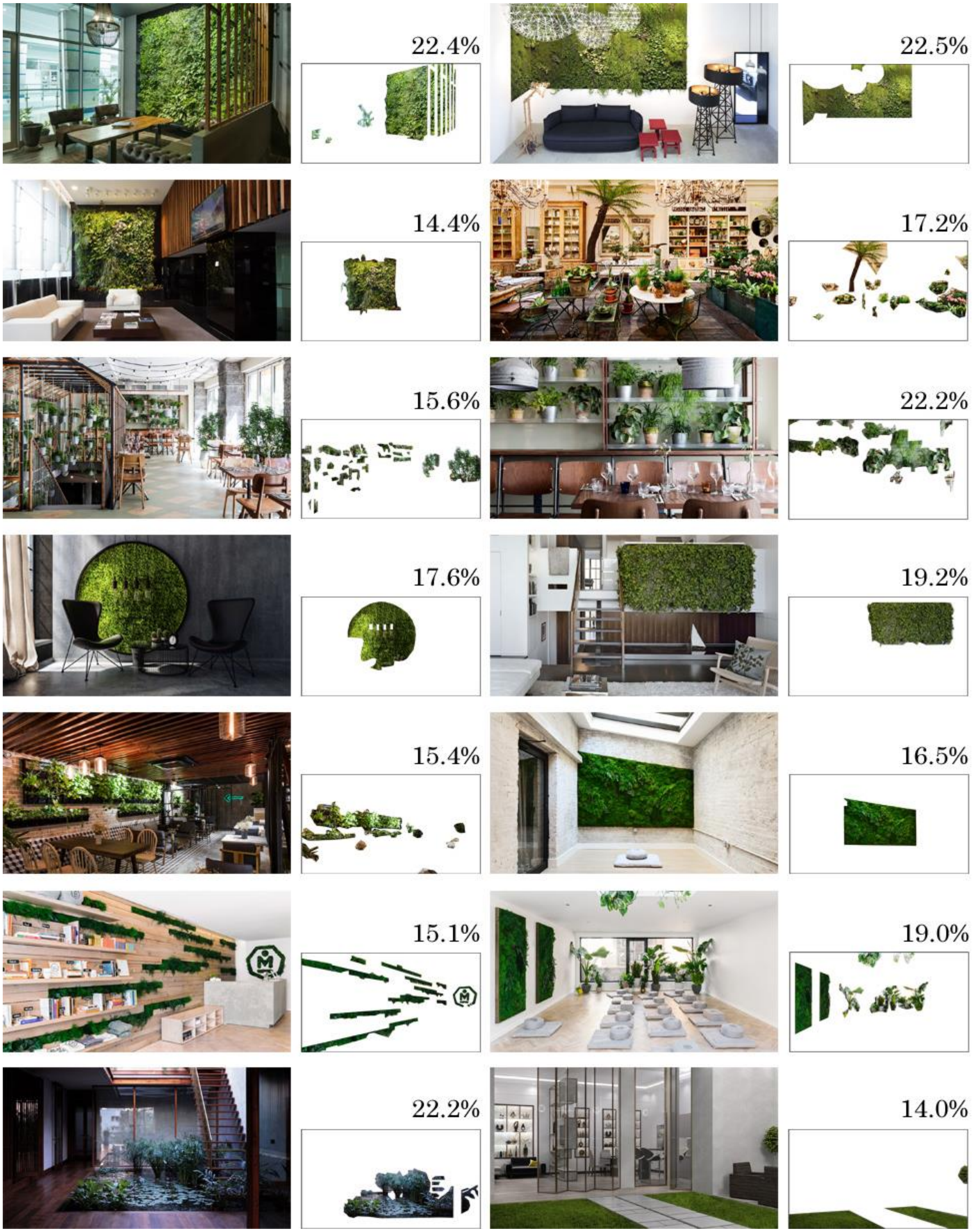


Image Set #3 - 3 (12 - 24% Vegetation)

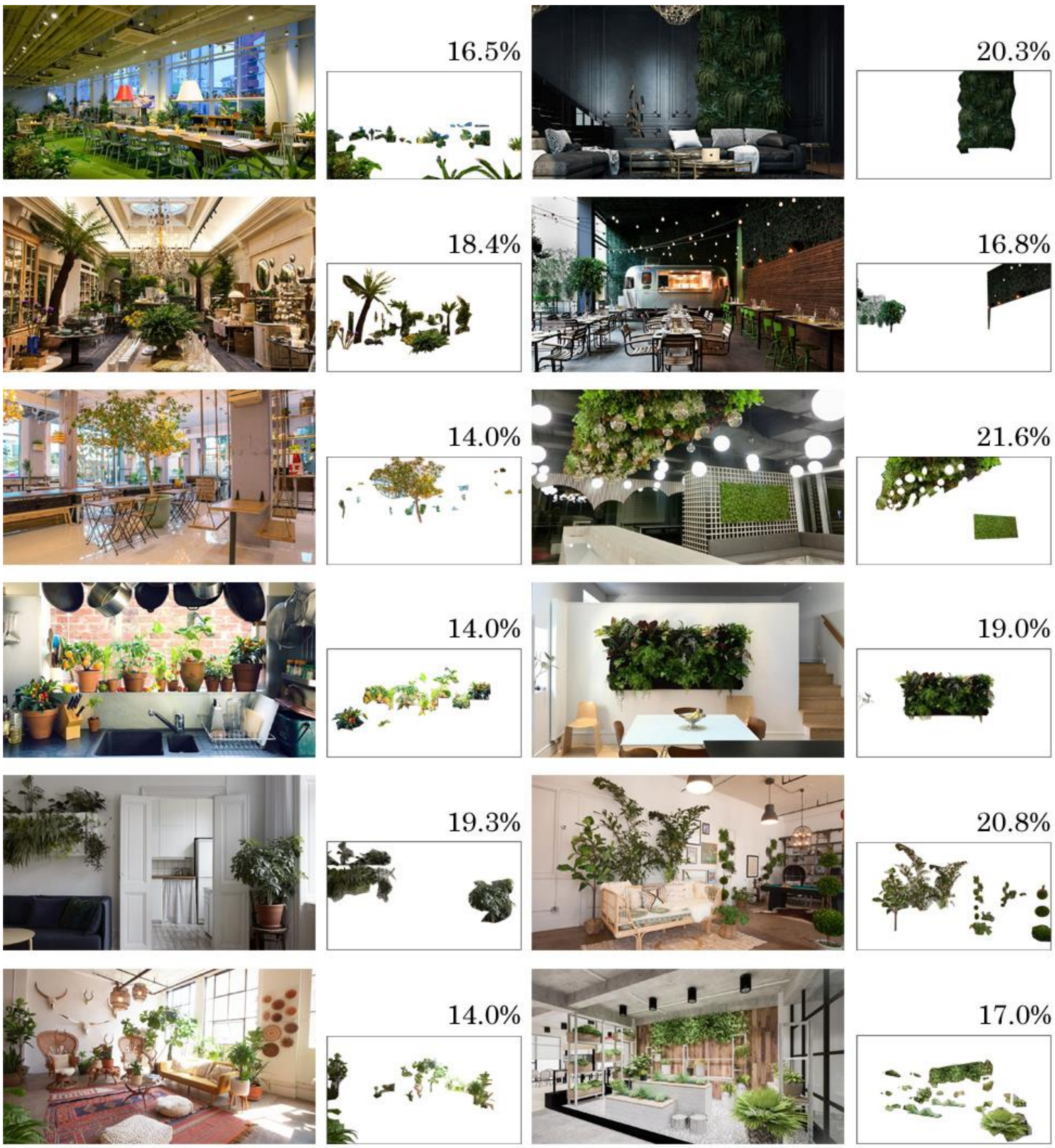


Image Set #4 - 1 (24 - 36% Vegetation)

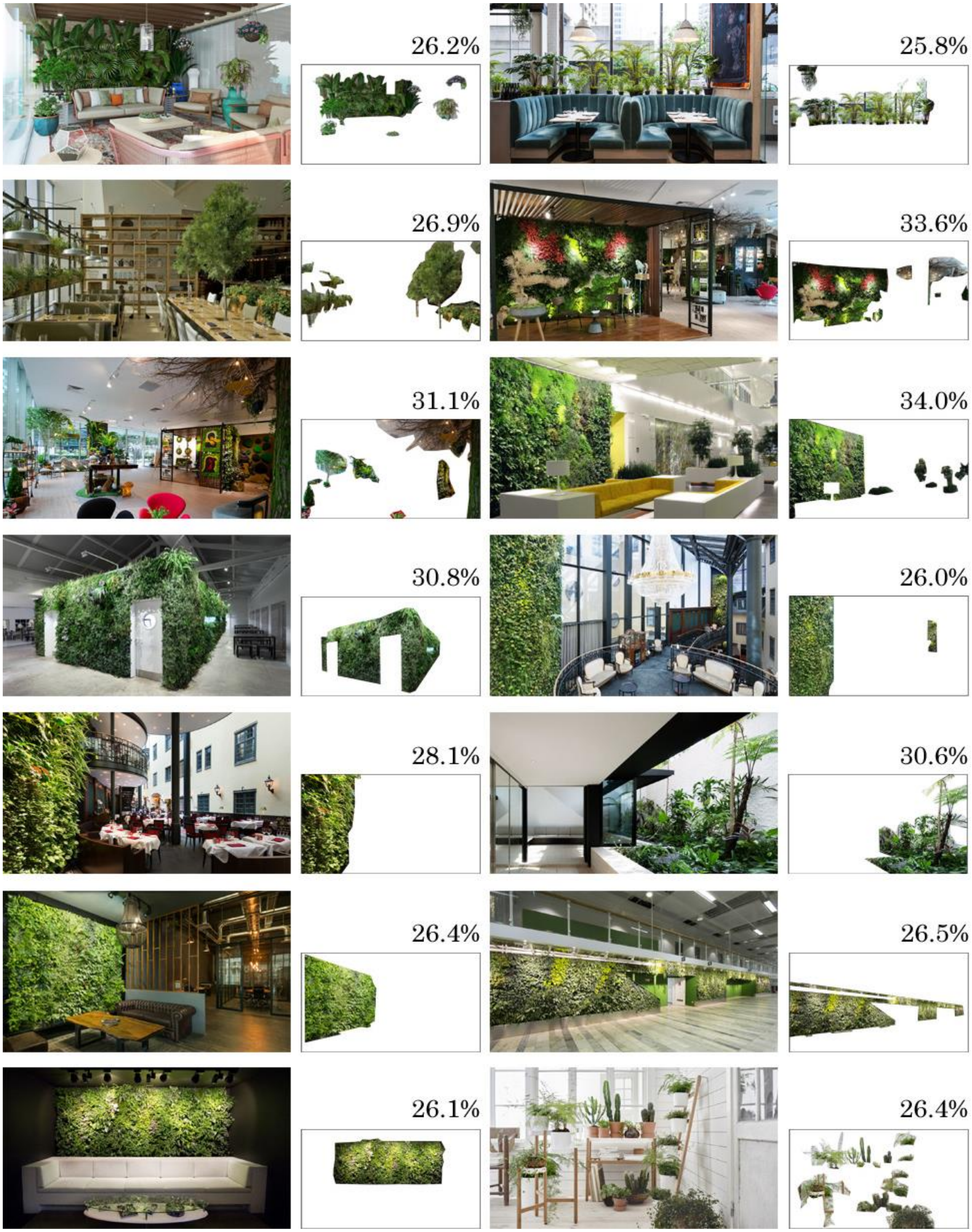


Image Set #4 - 2 (24 - 36% Vegetation)

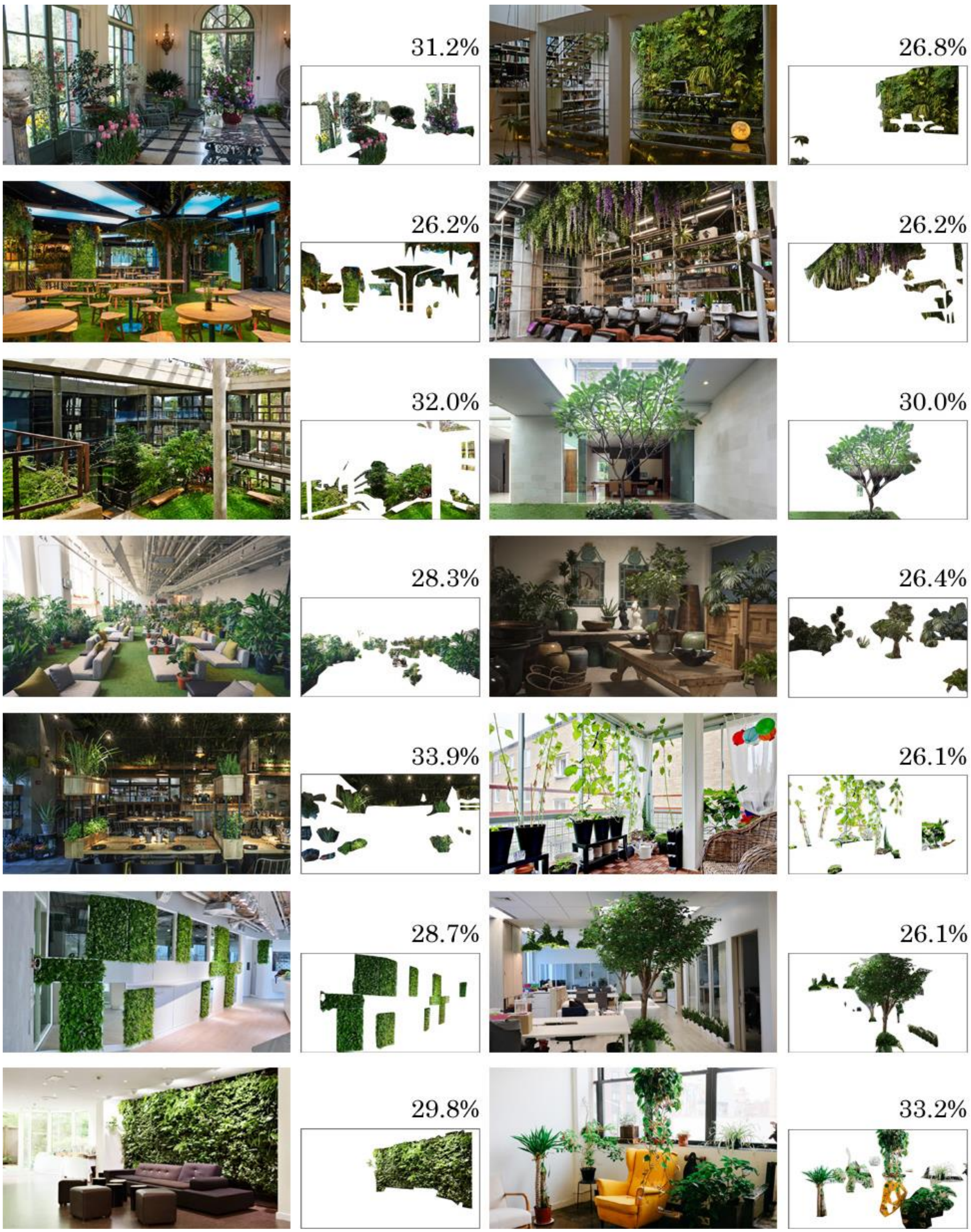


Image Set #4 - 3 (24 - 36% Vegetation)

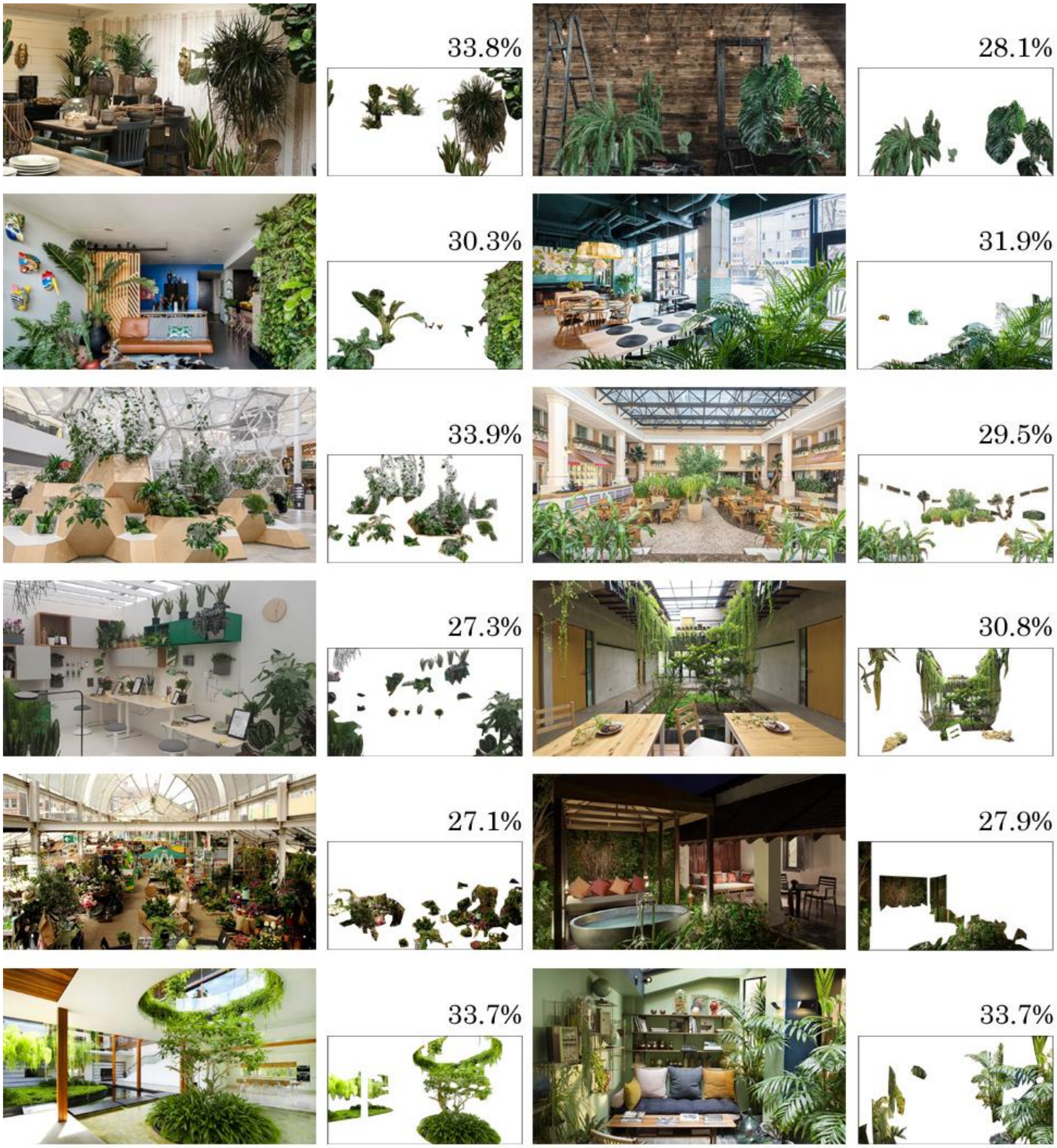


Image Set #5 - 1 (36 - 100% Vegetation)

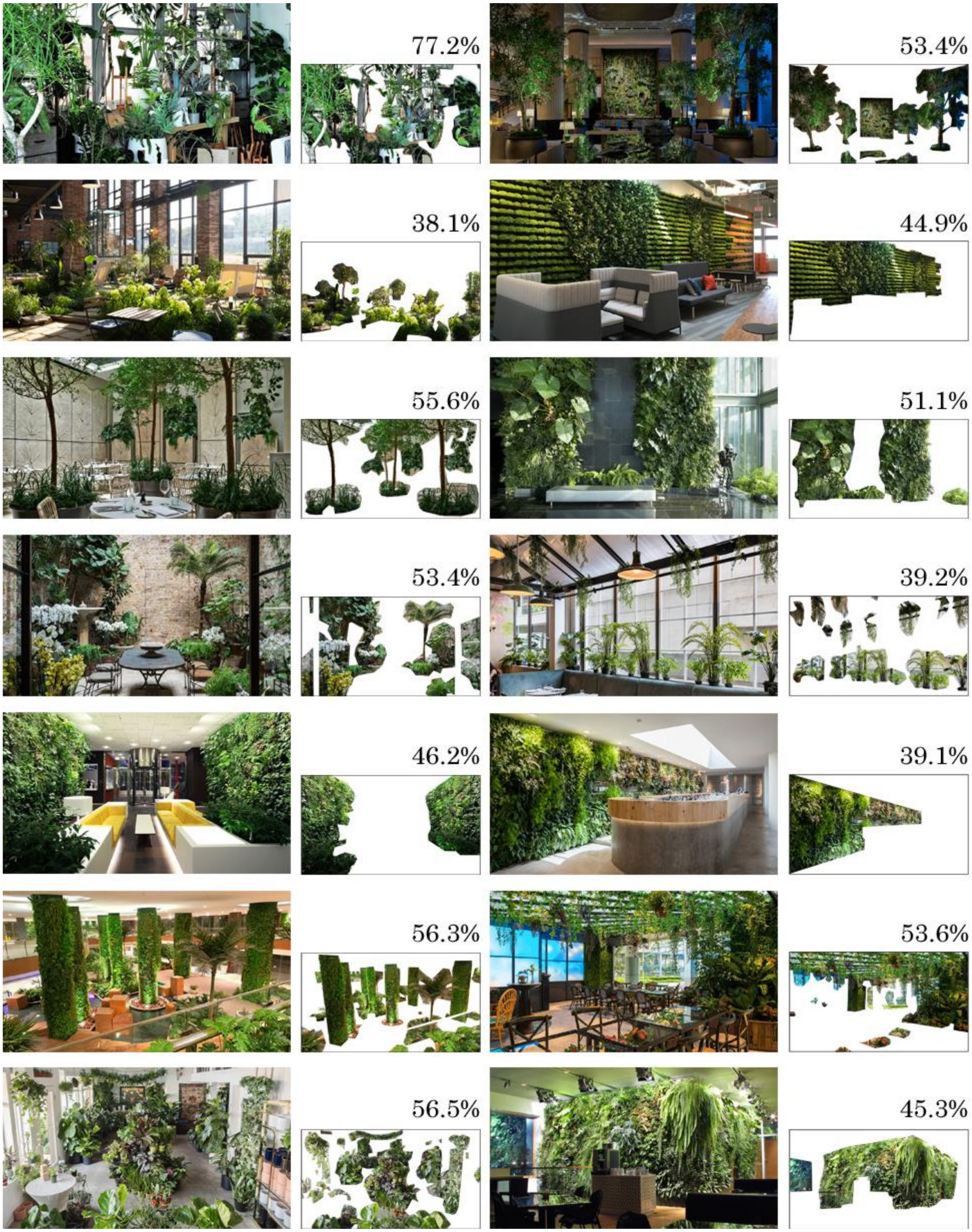


Image Set #5 - 2 (36 - 100% Vegetation)

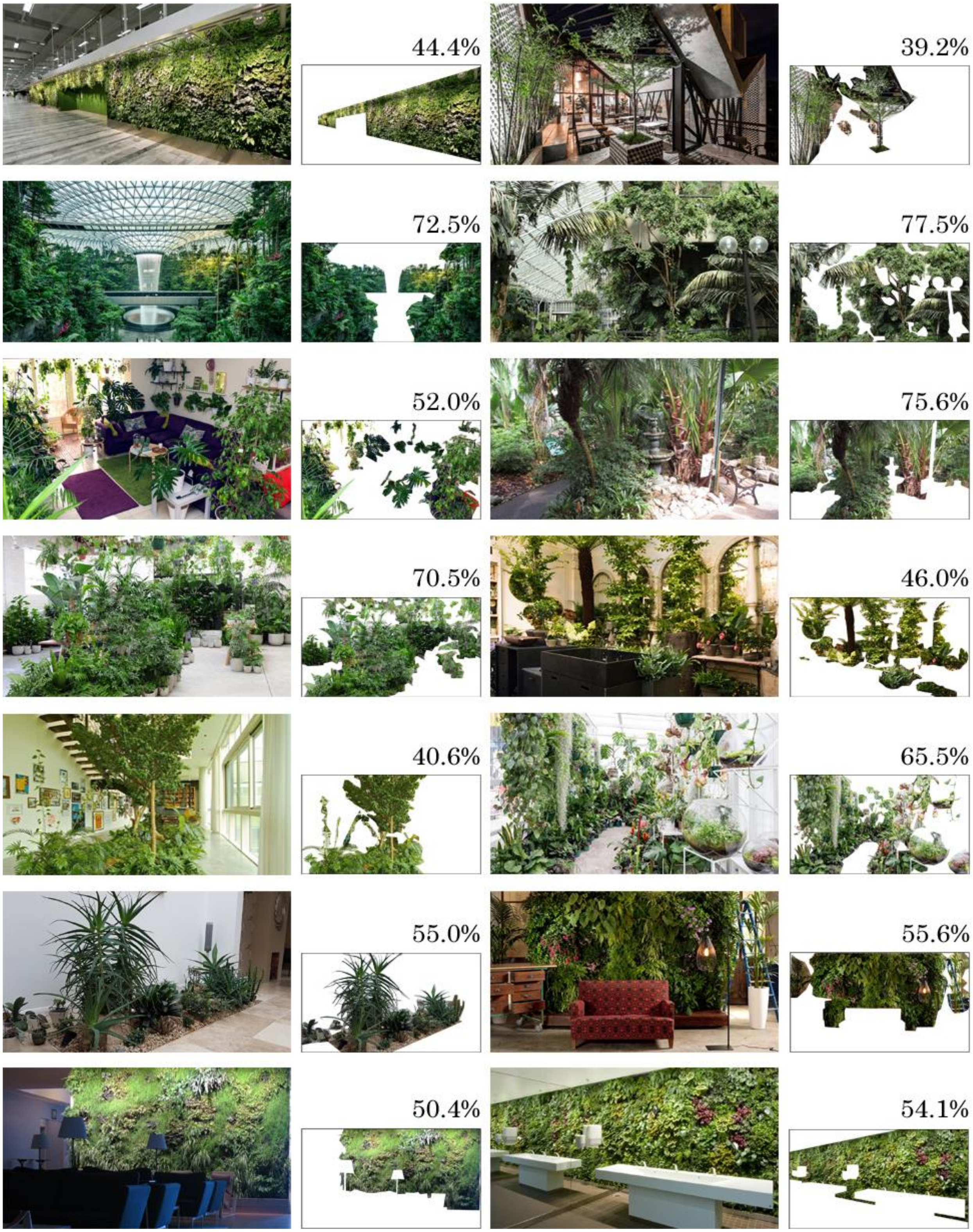


Image Set #5 - 3 (36 - 100% Vegetation)

Image Set #6 - 1 (100% Vegetation)

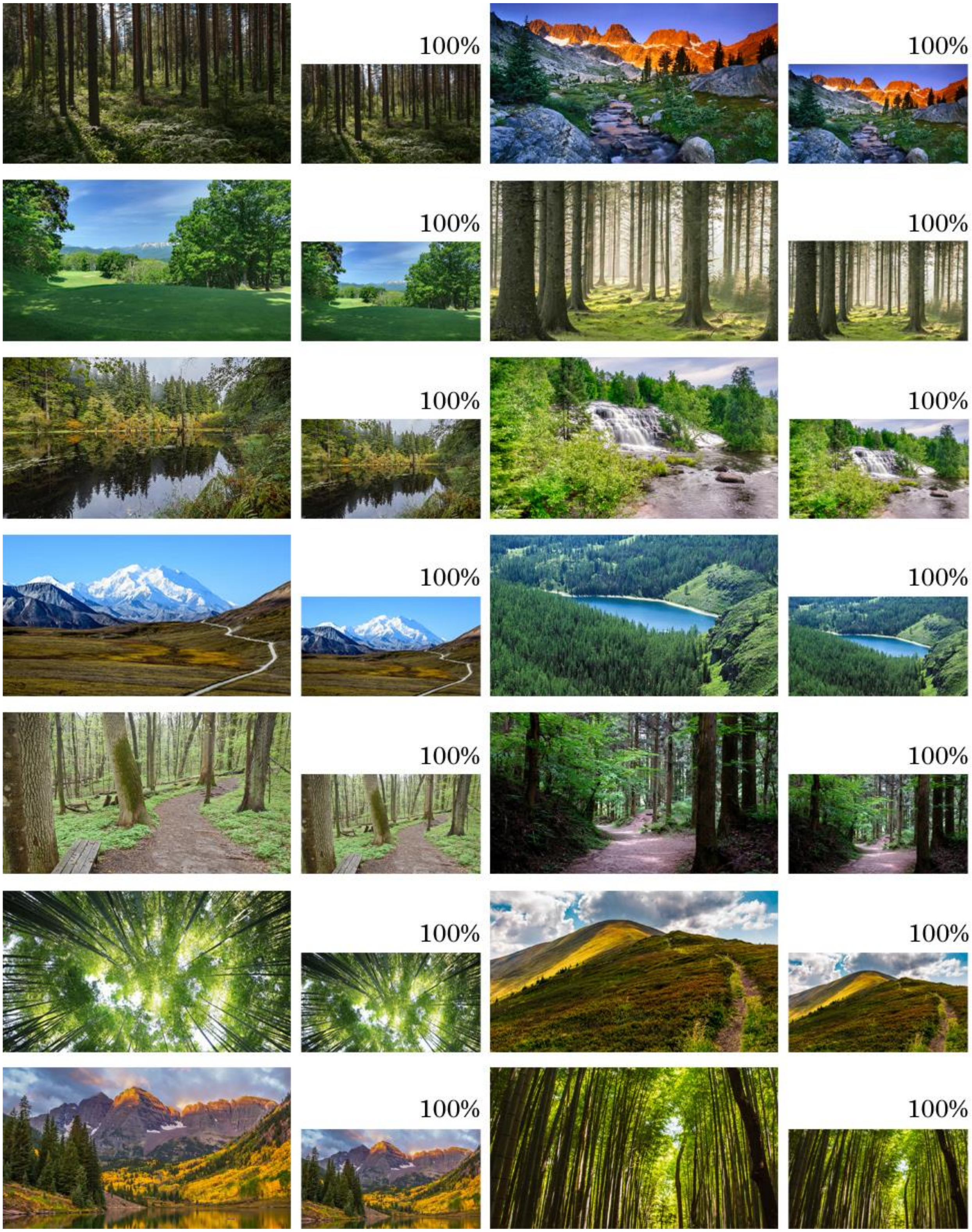


Image Set #6 - 2 (100% Vegetation)

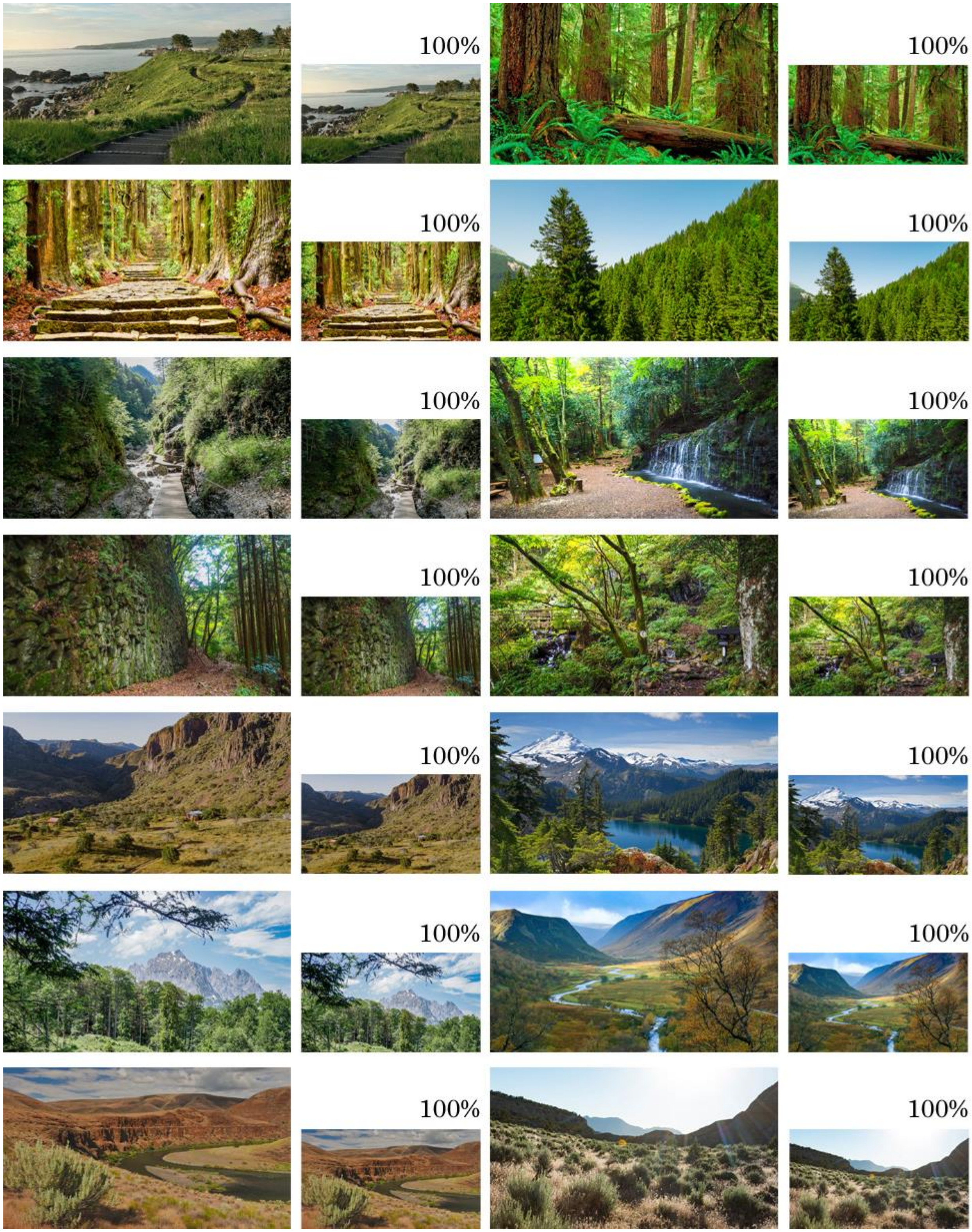
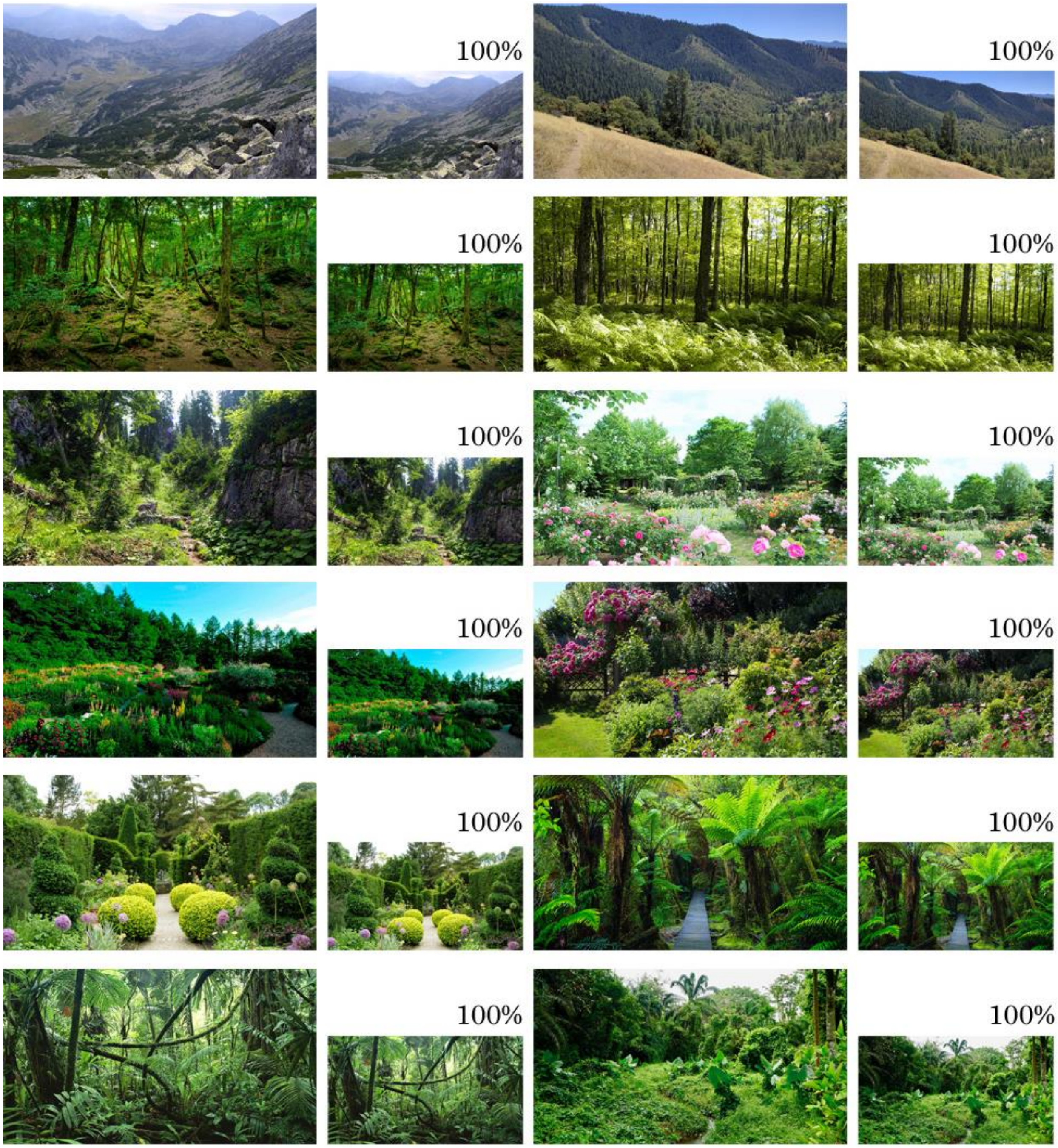


Image Set #6 - 3 (100% Vegetation)



CURRICULUM VITAE

JEE HEON RHEE, Ph.D., M.Arch.

EDUCATION

Ph.D. in Architecture, University of Wisconsin-Milwaukee, USA, December 2020

Dissertation Title: Restorative Potential and Working Memory Capacity of Exposure to Vegetation in Indoor Built Environments

M.Arch., University of Illinois – Urbana-Champaign, USA, May 2008

B.E. in Architectural Engineering, Korea University, Korea, February 2006

TEACHING EXPERIENCES

Lecturer, Seoul National University of Science and Technology, 2017-2019.

Lecturer, Korea University, 2018.

Lecturer, Sookmyung Women's University, 2017.

Lecturer, Hanyang University, 2012.

Teaching Assistant, University of Wisconsin-Milwaukee, 2009-2010.

WORKING EXPERIENCES

Architectural Designer & Researcher, Hanbit Architects & Engineers, Seoul, Korea, 2018-2020.

Assistant Researcher & Research Assistant, Architecture & Urban Research Institute, 2016-2017.

Lieutenant, Corps of Engineers, Republic of Korea Army, 2013-2016.

Architectural Designer, Olson & Associates Architects, Campaign, IL, 2008.

PUBLICATIONS & PRESENTATIONS

Rhee, J. H. & Schermer, B. (2020). Biophilic Design into Neuroarchitecture: Influence of Vegetation within Indoor Spaces on Restorativeness. In *ANFA 2020 Fifth International Conference: Sensing Spaces, Perceiving Place Presented Posters, San Diego, CA & Online, September 14-25, 2020*. San Diego, CA: Academy of Neuroscience for Architecture.

Rhee, J. H. (2012). Let Older Adults Walk: Measurement Approach to Physical Environment and Neighborhood Walkability for Older Adults. *Korean Living Science Research*, 32(1).

Jorn, M., Shih, C., & Rhee, J. H. (2011). Comparing the Characteristics of Apartment Floor Plans and Their Evolving Processes in Korea and Taiwan. In *EDRA 42 Chicago: Make no little plans: Proceedings of the 42nd Annual Conference of the Environmental Design Research Association, Chicago, IL, May 25-28, 2011*. McLean, VA: Environmental Design Research Association.

RESEARCH

"A Study on the System for Ensuring the Safe Environment of Residential Welfare Facilities for the Elderly in an Ageing Society". Research Assistant, Architecture & Urban Research Institute, 2017.

"Creating Safe Communities: Project Management Brief". Assistant Researcher, Architecture & Urban Research Institute, 2016.

"Evaluating Research Questions and Design: Focusing Studies on Walkability and Older People", University of Wisconsin-Milwaukee, 2012.

HONORS AND AWARDS

Chancellor's Graduate Student Awards, Architecture Scholarship, University of Wisconsin-Milwaukee, 2009

Faculty Memorial Scholarship, University of Wisconsin-Milwaukee, 2008

Graduate Award Nominee, University of Illinois – Urbana-Champaign, 2007

Honors Scholarships, Korea University, 2002-2004

Freshmen Special Scholarships, Korea University, 2002

MEMBERSHIPS AND ORGANIZATIONS

The Academy of Neuroscience for Architecture, Member, 2020-present

Environmental Design Research Association, Member, 2007-present

Architectural Institute of Korea, Member, 2006-present

Korean Institute of Interior Design, Member, 2006-present