GREEN BUILDINGS AND GREEN USERS: AN ASSESSMENT OF USING GREEN BUILDING ENVIRONMENTS TO COMMUNICATE SUSTAINABILITY TO USERS

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ABSTRACT

GREEN BUILDINGS AND GREEN USERS: AN ASSESSMENT OF USING GREEN BUILDING ENVIRONMENTS TO COMMUNICATE SUSTAINABILITY TO USERS

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The objective of this work is to assess how green building and green building design communicate sustainable messages to the building users and affect their awareness, perception, and knowledge toward sustainability, as well as their pro-environmental behaviors. A corresponding new concept of influential design is proposed to fulfil the research needs. Two research challenges—the theoretical and the methodological challenges—are raised to study the influential design, complemented by three studies. The first study adopted Ajzen's theory of planned behavior and extracted the building communication mechanism as: 1) active instruction from people; and 2) passive instruction from the building. The second study differentiated the green design elements into visually available or conceptual only green designs and applied hierarchical regression modeling to ensure the analysis at a finer lever and address spatial variations within each building and among different buildings. Finally, using a LEED certified campus residential hall as the study site, the third study empirically tests whether the studied building affords successful communication of sustainable messages to its users. The results suggested that the building could afford to promote the awareness among users, while it could not afford the users' general knowledge about green building. And users' perceptions about green designs are experienced at different spatial scales. Key contributions of this work are: 1) transferring a message on the construction of an ecologically aware society; 2) applying the spatial perspective of the building and building design identified to further theoretical research; 3) separating different design elements and performing the analysis at a finer level to extract

causality from the built environment; and 4) providing practical evidence for the green building management and insights for understanding the design-environment-use feedback loops. For future work, a specific hypothesis regarding the dichotomous spatial perspectives of a person can be explored as to whether it is more effective to use the green design at building product or space scale to communicate sustainability. It is also suggested to consider factors such as different types of buildings and user groups.

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KEY TO ABBREVIATIONS

BUS	Building Use Studies method
CBE	Center for Built Environment at UC Berkley
EAI	Environmental Attitudes Inventory scale
EB	Environment-Behavior
GEB	General Measure of Ecological Behavior scale (GEB)
HLR	Hierarchical Linear Regression
IEQ	Indoor Environmental Quality
LCA	Life Cycle Assessment
LEED	Leadership in Energy and Environmental Design
NEP	New Ecological Paradigm scale
PBC	Perceived Behavioral Control
POE	Post-occupancy Evaluation
SN	Subjective Norm
TPB	The Theory of Planned Behavior
USEPA	U.S. Environmental Protection Agency
USGBC	U.S. Green Building Council

1. INTRODUCTION

1.1 Green Building and Communication of Sustainability

Green buildings have become increasingly popular due to their healthier and more resource-efficient models of design, construction, operation, renovation, maintenance, and demolition (USEPA 2016). Buildings designed in the past century exemplify the then prevailing modernism view - the Dominant Social Paradigm (e.g., the assumption of human dominance over nature and human separation from nature) (Dunlap and Van Liere 1978, Lynam 2007). However, the past few decades had witnessed fundamental changes in the prevailing social world-view alongside the environmental movement (Lynam 2007), which had also manifested itself in the emergence of green buildings (Wu et al. 2015).

Environment-Behavior research answers questions such as “What street layout, sign system, and landmark location in a new town will make it easy for residents to feel at home? Why do teenagers vandalize isolated buildings in parks that they themselves could otherwise enjoy? Does high-density living make people friendlier or meaner?” (Zeisel 2006). It has been demonstrated that people might be more susceptible to a building’s architectural influence than they might realize (Yiannas 2015). In this work, an emphasis is about the spatial dimension, such as determining users’ perceptions about the environmental setting at different spatial scale. Specifically, the role of space is a dimension in situational surroundings in which human activities are enacted and experiences are felt (Amedeo et al. 2009).

A wide range of studies on the physical environment (e.g., buildings) and their associations with user’s behavior and/or experience exist. The physical environment that supports healthy behaviors is receiving escalating interest (Thompson 2013). Researchers strive to apply appropriate urban planning and building design as a component for actions related to the prevention of crime (Zeisel 2006). The syntactic properties of layouts of buildings and cities are important determinants of wayfinding behavior (Peponis et al. 1990). Kim and Kaplan (2004) used a new urbanism community development case and found that natural features, open spaces, the overall layout of the community and traditional architectural style played important roles in determining the residents' sense of community (i.e. place attachment, community identity, social interaction, and pedestrianism). Cloutier et al. (2014) related the achievements on sustainable practices regarding energy/water/waste/food management, urban design, green building development with residents' happiness at city level.

Sustainability is defined in this work according to the ISO 15392 – *Sustainability in Building Construction* as "a state in which components of the ecosystem and their functions are maintained for the present and future generations, whereas components of the ecosystem includes plants and animals, as well as humans and their physical environment." For humans, sustainability requires a balancing of key elements of human needs: the economic, environmental, social and cultural conditions for societies' existence (ISO 2008, Wu et al. 2016).

The building users mentioned in this work include the following two types of individuals: 1) regular building occupants, including both full-time-equivalent (i.e. representing a regular building occupant who spends 40 hours per week in the building) and part-time occupants (with FTE values based on their hours per weeks divided by 40), examples include residents in apartment, overnight hotel guests, full/part-time employees; and 2) visitors, such as retail customers, restaurant customers, higher education students other than residents of dorms (USGBC 2016a).

Two themes that are becoming increasingly popular in the sustainability sector are effective communications and behavior change (Kaluarachchi and Jones 2013). In the green building sector, it has been identified that the attitudes and behavior of occupants play a critical role in promoting green buildings, and achieving desired performance of green buildings (Zuo and Zhao 2014). The focus is that people, their attitudes, and behavior towards sustainable living are the ultimate critical factors to achieve a low-carbon, green built environment.

Up to date, only a few studies have evaluated the development, emergence, and performance of a green building in relation to human minds, values, perceptions and behaviors (Wu et al. 2015). Based on the Environmental Determinism, which states that there is a link between the behavioral patterns of people and the geographical area they inhabit, Architectural Determinism, suggests that the environment facilitates or inhibits behavior, providing opportunities that influence the probability that behaviors will or will not occur (Lynch 1960, Psychology Dictionary 2016). Lynch (1960) argued that behavior observation should be an essential part of the design in order to understand what people actually do on a site to inform new planning. This kind of thinking has been acknowledged, for example, the Post-Occupancy Evaluation (POE) seeks whether the implemented designs meet the original intentions, to seek unintended consequences from users' interaction.

Two decades ago, Lister and Stevens (1996) suggested buildings as an active teaching tool to communicate sustainability. Lynam (2007) tested the potential to educate building users about sustainability through immersion in a green building. Using buildings as a teaching tool has a distinctive feature, that is, buildings as visual objects themselves can vividly communicate messages to people. Previous studies have already shown that the visualization of sustainability is effective in sustainable education/communication (Ma 2008, Mann 2011, Wu et al. 2016).

Under the current transformation to sustainable urbanization and the emergence of green buildings, few studies existed on researching the effects of sustainable physical environment (used interchangeably with green building design throughout the paper) on users' behavior. Most relevant studies compared the environmental attitudes of occupants from green buildings with those from control buildings (Hostetler and Noiseux 2010, Deuble and de Dear 2012, Daniel et al. 2014). The fundamental questions, however, remain uncertain, such as "What are the communication mechanisms and through which communication channels do green building designs convey their meanings to building users?"

1.2 Research Questions

The overall objective of this research is to study how green buildings and green design elements communicate sustainable messages to people and affect their awareness, perception, knowledge toward sustainability, as well as their pro-environmental behaviors. I conducted my research from both theoretical and methodological aspects and finished with an empirical study.

The theoretical and methodological challenges will be laid out based on current understanding after a comprehensive review of previous studies. A solution to theoretical challenges is proposed through the lens of the theory of planned behavior (TPB), and it serves to answer the following questions: 1) to what extent do green buildings communicate green messages to their occupants? And 2) how do buildings influence occupants' pro-environmental behaviors?

Then, a solution to methodological challenges is proposed through applying hierarchical linear regression to evaluate the potential of a green building design on influencing the occupants' pro-environmental behavior, especially the effectiveness of its visual persuasion. The hierarchical linear regression model with Bayesian inference is proposed and tested with simulated data, which extracts: 1) the effectiveness of the visual or conceptual-only green building design on influencing occupants to behave more pro-environmentally at the building-level; and 2) the effects due to the occupants' awareness and perception of the green design at the individual/personal level.

Finally, a survey study in a Leadership in Environmental and Energy Design (LEED) certified residential hall on campus is carried out to answer following questions: 1) how can the affordance theory be applied to the green building? 2) using the concept of "x-ability" from the affordance theory, how does the building afford three major aspects: 2.1) "aware-ability", how the users become aware of the building being a green building, 2.2) "know-ability", how the users become knowledgeable about general green building topics, and 2.3) "perceive-ability", how users perceive different green design elements. A special emphasis on spatial dimension is investigated when studying perceive-ability.

1.3 Relationships to Sustainability

The emergence of the green building goes along with technical standards and certification schemes such as LEED, Energy Star. To ensure the sustainable operation of green buildings, technical sustainability (i.e. in terms of building products, construction methods, daily operations (Williams and Dair 2007)) alone, without users' involvement is not enough. The question remains not so much about the adoption of green building technologies as to that of: 1) communication of green design philosophy; 2) appreciation of green designs; 3) generation of green building and sustainability knowledge; and ultimately; and 4) the adoption of sustainable behaviors.

The connection of this work with sustainability is multi-fold. First, a synergistic effect might be ascertained: if people are positively influenced by green concepts, they will support green buildings and thus provide a virtuous cycle. Second, if these positive synergies are confirmed, the barriers to implementing green building practices once identified by Hoffman and

Henn (2008) could also be tackled, which include factors such as egocentrism, and environmental literacy at the individual level. Third, people can become more conscious about green buildings and the natural environment. Fourth, the results can be learned, shared, adopted by further green building designs in similar settings, thus reducing the design-use gap in a building development. On the contrary, if a green building, and/or its design elements cannot express themselves properly and if people are not aware of its green features, do not perceive it as a green building, or it cannot facilitate people's sustainable behaviors, such findings can also have major implications for the future design and management of green buildings.

1.4 Intellectual, Practical, and Industrial Contributions

The worldwide booming of green buildings has several foundations: 1) the positive impacts on the external environment (e.g., through sustainable site, reduction of material and energy) and the society (e.g., saving building life-cycle cost, creating a green job market); and 2) the positive impacts on occupant health through providing occupants better indoor environmental quality. A systematic way of quantifying such impacts is Life Cycle Assessment (LCA). While LCA is widely recognized and adopted, one of the biggest challenges remains: modeling the impacts from building use stage. Previous studies either chose not to study/report the impacts from use stage (Lazzarin et al. 2008, Connor et al. 2012), or use pre-defined assumptions (e.g., from the building designer) to estimate the impacts from use stage (Singh et al. 2011). Such pre-defined static assumptions have been increasingly criticized and some study tried to establish dynamic occupancy profile and applied to whole building LCA (Collinge 2013). This study introduces a feedback loop within different stakeholders along the life cycle of a building and fills in the gap between the initial design and user experience within the loop. Insights gained in this study can be integrated into future whole building LCA.

The 2009 Passive and Low Energy Architecture Conference reinforced the importance of human agency in the built environment, denounced the disconnection between the occupants and the building, confirmed the consideration of dynamic and responsible interaction between inhabitants and architecture, and applauded rehumanizatison of architecture through inhabitants' increased autonomy rather than automation (Cole et al. 2010). A 2014 review of the current status and future agenda for green building research also explicitly identified the behavioral and cultural factors as crucial factors to achieve the desired performance of green buildings. Besides, attitudes and behaviors of occupants play a critical role in promoting green buildings (Zuo and Zhao 2014). The human factors along the life cycle of a building have been reinforced in this work.

This work could potentially add a new dimension within user experience in relevant technical standards. Examining current industry technical standards available for assessing the sustainability of construction works and buildings, it seems that most of their focus is paid to the technical sustainability. One suite is the ISO standards for sustainability in buildings and construction works: the ISO 15392 Sustainability in building construction are general principle guidelines to assess the environmental performance of a building's construction and the environmental declaration of building products. They both has a focus on environmental life cycle assessment of building products. Another suite of EU standards is the EN 15643 series, which covers the "sustainability of construction works" at different scales. Unlike the ISO suite, the EU series puts extra effort in assessing social and economic impacts. One example is the adaptability (clause 7.3 in EN 16309), which aims to assess the building's ability: 1) to accommodate individual user requirements; 2) to accommodate the change of user requirements; 3) to accommodate technical changes; and 4) to accommodate the change of use.

2. CURRENT UNDERSTANDING

To identify research gaps and detail research questions, literature reviews were conducted to better understand the background and current understanding of these research topics. Available studies were reviewed and grouped into following categories: 1) impacts that green buildings have on users; 2) green buildings and users' pro-environmental attitudes and/or behaviors; 3) the relationships between green building design and users' sustainable behaviors; 4) the meaning and communication roles of architecture and education of sustainability from green buildings. The first section (Chapter 2.1) provides a brief background in recent scholarly thinking on relevant topics, while the next three sections provide more in-depth reviews of relevant studies and concluded with analysis from this study's perspective.

2.1 Impacts of Green Building on Users

Studies on the impacts of green buildings on occupants are most widely carried out as Post-Occupancy Evaluation (POE) studies. Topics covered include office layout, furnishing, workspace, thermal comfort, air quality, lighting, acoustics, cleaning & maintenance, accessibility, IT/data projection, security (Blyth and Gilby 2006, CBE 2015). Evaluation methods vary from interview, focus group, workshop, to questionnaires (Blyth and Gilby 2006). Center for Built Environment (CBE) at UC Berkley maintains a large commercial database on occupant indoor environmental quality survey. Another POE methodology is the UK's Building Use Studies (BUS) methodology, it also maintains a commercial database of 650 non-domestic buildings from 17 countries and 50 domestic projects from the UK (Arup 2015). Many specific studies have looked at occupants' satisfaction on green buildings (Abdul-Muhmin 2007, Lee and Kim 2008, Altomonte and Schiavon 2013, Hua et al. 2014, Liang et al. 2014). Ouf et al. (2013) composed a set of indicators measuring occupant satisfaction, health, and productivity, and the satisfaction indicators include beauty, serenity, and color, which are not commonly measured by other methodology. Another group of studies looked at the impacts that green buildings have on the well-being of occupants, including mental and physical health, productivity at the green workplace (Lee 2007, Singh et al. 2010, Gou et al. 2014). Biophilic architects proposed that integrating natural contents (e.g., calm water features and vegetative elements) in the built environment could counter the negative effects on human functioning (e.g., reducing stress) due to reducing opportunities for contact with natural contents in modern urban life (Joye 2007).

The relationships between the green buildings and occupants are mostly studied by focusing on how the occupants' behaviors impact on green building performance (Kashif et al. 2013, Lee and Malkawi 2014), instead of the other direction – the influence that green buildings have on the occupants' behaviors. Many have identified that, due to the actual behavior of occupants, the actual performance (e.g., electrical consumption) of green buildings could not meet the initial forecast (Browne and Frame 1999, Hoes et al. 2009, Masoso and Grobler 2010). A new building science called occupancy analytics was proposed by Bacon (2013), recognizing the need to understand the poor performance of current building stocks when society has invested significantly in improved asset specification. Zeiler et al. (2013) proposed a human-in-the-loop strategy to integrate the occupants into the buildings' performance control loop, to solve the occupants' complaints on comfort and unnecessary high-energy consumption of HVAC system.

2.2 Green Building and Users' Pro-Environmental Attitudes and/or Behaviors

Several studies used office buildings as the research setting to identify whether occupants in green buildings embrace more pro-environmental attitudes and/or behaviors. The study by McCunn and Gifford (2012) was carried out in Canada with 77 employees surveyed from 15

LEED certified buildings. The occupants' environmental attitudes were measured by New Ecological Paradigm (NEP) scale (Dunlap, Van Liere et al. 2000), they were also asked about their pro-environmental behavior using the General Measure of Ecological Behavior scale (GEB) (Kaiser 1998). With correlation analysis, the results showed green design attributes in offices do not have a significant effect on either employee environmental attitudes or behavior.

The study by Rashid et al. (2012) was carried out in the U.S. with 175 employees surveyed from a single LEED-certified building. Based on correlation and regression analysis, it was found that no direct effects of green office design features on occupants' environmental awareness. The independent variable were named as green design features by the author in the study, including measurement on following variables: 1) having sufficient storage and furniture in the workspace, 2) enjoying the outside view, 3) having enough privacy, 4) socializing in the lounge/break room, 5) having easy access to equipment and to coworkers. In contrast, the study by McCunn and Gifford (2012) measured a more comprehensive list of green design features. The dependent variable in Rashid et al. (2012)'s study – named environmental awareness measured eight items (including, for example, asking if this building has a positive effect on the environment, helps conserve energy, provides a healthy work environment, increases company reputation). These items, in my point of view, are more of a personal evaluation of the building instead of a measurement of personal environmental awareness.

Azizi and Wilkinson (2015) carried out a comparative study in two green (both a certified and non-certified) and one conventional office buildings in Malaysia to examine whether occupants' motivation to practice energy-saving behavior are different in green and conventional buildings. The NEP scale was deliberately not used as it was considered too long, instead, simple questions were asked (e.g., rating the importance of knowing that energy scarcity is a global issue). Through Man U Whitney test, no significant difference in the response between green and conventional buildings was found regarding motivational factors such as knowing that energy scarcity is a global issue. On the other hand, occupants feel more motivated to practice energy-saving behaviors in the certified green buildings provided that they know the building is designed green.

Other than using office buildings, some researchers used academic buildings. One study compared a green and a conventional academic building in Canada to study differences in environmental attitudes of the students (Lynam 2007). A mixed method research approach was used by collecting both questionnaires on environmental attitudes of students within two buildings (by NEP Scale) and qualitative interviews (Lynam 2007). Grounded theory was used to analyze the qualitative data and one-tail t-test was used to compare mean NEP scores of students in green vs. conventional building (whereas the null hypothesis was no difference in the NEP scores) (Lynam 2007). The results from the interviews showed that green buildings carried a stronger pro-environmental messages to occupants so long as the green building occupants have some awareness of the building's green status (Lynam 2007). However, the results from quantitative examination came as a surprise where the students in conventional buildings hold more pro-environmental attitudes, which, actually might be explained from the interview, because groups, organizations, as well as staff/ faculty members in the conventional building conveyed stronger pro-environmental messages than those in the green building.

Using academic buildings in Sydney, Australia, a questionnaire survey was distributed to two academic buildings, one natural ventilated (NV) and one mixed-mode (MM) building (whereas NV is considered as a green building) (Deuble and de Dear 2009). The questionnaire measured the POE by the BUS methods and environmental attitude by NEP scale. Using a linear regression model, the study confirmed occupant satisfaction levels on the POE were positively associated with environmental attitudes. An earlier study carried out in the same two buildings showed the occupants from NV building has a significantly higher mean NEP score than MM building.

Other than the above studies on non-domestic buildings, studies focusing on residential buildings/communities in the U.S. and Australia were found. An empirical study in Florida aimed to compare the environmental knowledge, attitudes and behaviors of homeowners in four master-planned golf communities: two green communities (one certified by the Florida Green Building Coalition and one non-certified) and two conventional communities (Hostetler and Noiseux 2010). Measuring of environmental knowledge was based on previous survey, attitudes were measured by NEP scale, and behaviors were measured using the questionnaire developed by Youngentob and Hostetler (2005). ANCOVA analysis was carried out to account for the significant differences of demographic variables and their significant correlation with survey questions. Chi-square test, Fisher's Exact test; and Wilcoxon-Mann-Whitney, ANOVA was used for categorical and non-categorical responses, respectively. The results showed green homeowners reported more environmental knowledge and behaviors in only a few questions and no differences in attitudes were found.

The studies by Hyde and his research group focused on residential buildings in Queensland, Australia. Upadhyay et al. (2010) proposed a framework for assessment of sustainable housing from environmental quality of life (QoL_e) approach, in order to evaluate both design and attitude impacts concurrently, to test if there is an alignment between occupant environmental attitudes, satisfaction and sustainable architectural design, and to study whether environmental preservation attitude correlates with high QoL_e in sustainable housing (Upadhya et al. 2010). The underlying justification is that “sustainable development requires not only technological sustainability, but also behavioral sustainability, mainly focusing on pro-environmental attitudes and behavioral aspects” (Upadhyay et al. 2010, p.4).

O'Callaghan and Hyde (2011) applied the multiple regression to understand whether sustainably designed homes truly achieve lower levels of impact on the environment and also to what extent occupant attitudes play a role in any improvement. The independent variables include sustainable design and environmental attitudes, except other demographic factors, whereas the dependent variable is the utility usage. The interaction between sustainable design and environmental attitudes are possible taking into account the potential rebound effects. That is to reveal if those with high environmental attitudes and more sustainable homes produce lower utility usage and if the opposite is true. Proposed measurement of independent variables includes National Australian Built Environment Rating System for sustainable design; NEP scale or Environmental attitudes inventory (EAI) scale for measuring environmental attitudes (O'Callaghan and Hyde 2011).

Following their proposed framework, empirical data were collected from both a sustainable and a conventional community in Queensland (O'Callaghan et al. 2012). Environmental attitudes were measured by EAI (Milfont and Duckitt 2010). Hierarchical multiple regression was used, whereas the next step independent variable (e.g., environmental attitudes) were entered into the regression only after the previous step independent variable (e.g., sustainable design) had been statistically accounted for (O'Callaghan et al. 2012). The results showed a significant difference in energy consumption between sustainably designed and contemporary homes, and more positive attitudes to environmental conservation correlated with lower energy use (O'Callaghan et al. 2012). Though environmental attitudes were not found to be a statistically significant predictor of energy use when analyzed with other predictor variables, suggesting that technological factors have a much higher weighting relative to occupants' attitudinal factors in estimating the resource usage of housing (O'Callaghan et al. 2012). The study used the attitudes towards the environment as an indicator of behavior, which I will show in the next section that attitudes are most often treated as antecedent of behavior in many environmental behavior studies.

Overall, at a whole building/community scale, studies about the potential effects of a green building/community on the occupants' attitudes and/or behaviors showed different findings and could be grouped into: 1) more positive pro-environmental attitudes/behaviors in green than in conventional built environment (Deuble and de Dear 2009 & 2012, O'Callaghan et al. 2012); and 2) generally no difference regarding pro-environmental attitudes/behaviors between green and conventional built environment, including Hostetler and Noiseux (2010), McCunn and Gifford (2012), and Rashid et al. (2012) (Table 9 in Appendix B).

2.3 Relationships between Green Building Design and Sustainable Behaviors

A possible theoretical explanation for the relationships between green building designs and pro-environmental behavior is the perceived behavioral control–one of the antecedents in predicting behavioral intention and behaviors. Perceived behavioral control measures how the person perceives the easiness of conducting a certain behavior. In the green building context, this question applies to whether a particular green design can facilitate a corresponding behavior. The relationships between typical green designs and their corresponding sustainable behaviors are illustrated. To identify relevant studies, an eco-centric viewpoint is considered when referring to sustainable behaviors, following several main focus of existing green building programs on energy, water, transport, waste, indoor environmental quality issues. Specifically, sustainable behaviors include for example: those aiming at contributing to a reduction in energy and water consumption; reduction of automobile dependency; promotion of the 3R principle (reduce/recycle/reuse) of waste treatment, except correctly categorize waste; and maintaining their satisfaction of indoor environmental quality while not increasing energy cost indirectly.

Different names for physical environment were used in previous studies: contextual factors (Wu et al. 2013), situation factor (Tang et al. 2011), microscopic factors (Lee et al. 2015). For the review in this section, sustainable physical environment regarding structure and elements that are part of a building and its surrounding site that are designed to work together with the corresponding sustainable behavior are identified.

2.3.1 Energy and Water

O'Callaghan et al. (2012) showed that sustainable housing design was a significant indicator in determining utility consumption in energy and water. The study used both the sustainable housing design (technical side) and the occupants' pro-environmental attitudes (non-technical side) as independent variables to predict utility consumption. The housing design variables were indicated by a dummy variable and were not further categorized into different aspects. The interaction effects between the two independent variables might be more of interest to investigate. A further correlation analysis carried out in the study showed that pro-environmental attitudes of occupants were significantly correlated with the sustainable housing design O'Callaghan et al. (2012). This multicollinearity issue was not further explored though, which could be studied through the mediating effect of sustainable housing design on attitudes of occupants. Other studies included the physical environment as control variables. For example, the apartment type (studio, 1/2/3 bedrooms) was found to have predictive power for electricity consumption (Hewitt et al. 2016). Andersen et al. (2009) found that the presence of a wood-burning stove had a large impact on the control of the heating in Danish dwellings.

2.3.2 Indoor Environmental Quality

Earlier studies indicated that design features such as a spacious common room and access view to the natural environment reduces occupants' stress level and increases work productivity (Azizi et al. 2015). Heerwagen and Diamond (1992) examined the three types of behavior adjustments (personal, environmental, psychological) in green buildings. Advocates for personal adjustments believe that it not only helps reduce energy consumptions in buildings, but also creates healthier personal actions for the occupants since there is more muscle movement (Healey and Webster-Mannison 2012). The findings showed that the green buildings encouraged more personal adjustments than environmental adjustments, thus indirectly reducing the energy consumption from the environmental adjustment. Azizi et al. (2015) found that within the same building, more personal adjustments were made in spaces where occupants had limited access to the control systems, such as in open plan space; whereas in private offices, the occupants made more environmental adjustments than personal adjustments.

2.3.3 Transportation

A wide range of sustainable transportation technologies and alternative fuel options have been proposed by previous studies (Paudel and Kreutzmann 2015). Lee et al. (2015) studied the physical environment that could boost pedestrian volume for the development of sustainable cities; it was found that the planning factors at a neighborhood scale, such as domain attributes (diversity), the network attributes (global and local integration) and the accessibility (distance to and number of public transportation) affected pedestrian volume. Building attributes such as the form of the ground level and façade of the building also had a significant effect on pedestrian volume (Lee et al. 2015).

2.3.4 Waste Treatment

Wu et al. (2013) reported that people chose the correct disposal bins more often in a sustainable building than in a conventional building. However, the detailed green building design was not measured and related to the disposal behavior. Instead, Wu et al. (2013) raised a hypothesis that taking the availability of bins into account would result in a larger gap between proper disposal rates between green building and the conventional building. The behavior observation implies further design of waste bins could encourage the correct disposal of waste. An example is provided by Greaves et al. (2013), where transparent bins are implemented in an office building to make clearer and visual instructions on users' waste categorization behaviors.

The available space to store recyclables in a household is found to be a significant predictor for recycling participation both in western societies (do Valle et al. 2004) and in rural Chinese villages (Tang et al. 2011). The physical proximity of containers (e.g., to provide curbside collection for the household) is a determinant that justifies the recycling behavior (Ludwig et al. 1998). On the contrary, Rhodes et al. (2014) found that proximity to the recycling depot did not relate to behavior. Although they found that those who lived closer to the depot had larger planning-behavior relations than those who lived further away.

These studies concerning relationships between green designs and sustainable behaviors were grouped (Table 10, Appendix B). Combining these studies, a sample checklist for facilitating sustainable behaviors through green designs are prepared (Table 11, Appendix B). Only green designs with a corresponding behavior are identified. A wide range of passive technologies defined during the design phase such as appropriate orientation, ventilation path, and raised roof will not be included. More examples include such as installation of photovoltaics (PV) panel, which is also not listed since the PV operation relies less on user's behavioral inputs. Another example is the installation of rainwater harvesting systems that might have a less behavioral input while the successful implementation of low-flow showerheads and toilets requires a corresponding behavioral response (e.g., whether people are taking longer showers or flush toilet multiple times as counter-effecting). On the contrary, the presence of solar shading could be a potential green design as building users directly control (behave on) the solar shading.

2.4 Sustainable Communication and Education of Green Building

While the relationships between green building/design and sustainable behavior are discussed in Chapter 2.3 with support from empirical studies, at a deep philosophical level, Neisser discussed the meanings of a certain environment and how they are experienced – "In the normal environment most perceptible objects and events are meaningful. They afford various possibilities for action, carry implications about what has happened or what will happen, belong coherently to a larger context, and possess an identity that transcends their simple physical properties. These meanings can be, and are perceived." (Neisser1976, p.71).

Many scholars have argued that green buildings can and even should be used as educational tools to increase environmental awareness (Cranz et al. 2014). Goodsel (2000) repeated three levels of mnemonic meaning from the built environment and they will be detailed in Chapter 5. Buildings are viewed as communicative and a visual persuasion by Ragsdale (2011), whereas persuasion, refers to "messages that are designed to change attitudes, beliefs, values and behavior" (Ragsdale 2011, p21). Ragsdale grounds his theory based on several classical works to demonstrate that architecture influences the human mind, attitude, and behavior (Ruskin 1989, Roth 1993). A framework was proposed to assess the likely effectiveness of the visual persuasiveness of architecture, for a wide variety of architectures such as museums, cathedrals, performing halls, government buildings, universities, but not green buildings in particular (Ragsdale 2011).

The green building communities realize the importance of using the building as a communication medium, though they are still striving to find the most appropriate expression of a green building. Architects are also not united on the way to express the sustainability of a building (Cranz et al. 2014). Ken Yeang, a green architect, specifically argued that a green building should not “look like a modernist building; it should be something new” (Cranz et al. 2014, p.5).

There are different sensory cues that a user can feel and perceive the sustainability of a green building even if he/she may not be formally educated and/or aware of the sustainable design. One study investigated the relative impact of visual and auditory information on the perception of running tap water, finding that auditory information can play a significant role in the everyday experience of running tap water even though participants are normally unaware of the effect of audition (Golan and Fenko 2013).

Among all the sensory cues that a building can be felt by its users and those passing by, the focus of this work is to use building and building elements as visual objects to communicate its meaning and educate people. A visual object is anything that has to do with vision, it is communicative, symbolic, culturally representative, and deductive by the viewer (Barnes 2007). It could be mediated visuals (e.g., graphic designs, paintings, photographs, and films) or unmediated lived-in visuals: viewers stay within the visuals such as natural landscape and/or the man-made built environment. Visual impacts mean the power of the visual object to move feelings and produce behaviors (Barnes 2007). Idler (2014) stated that visual appeal can–more than anything–attract attention. Selective attention enables us to gather relevant information and guides our behavior (Carrasco 2011). Joffe (2008) highlighted the “vividness effect” – that visual material appears to be especially memorable and the salience that this confers may make it particularly forceful.

Case studies on how to make green design more visible include using signage and labels to demonstrate green design in Riverview Elementary school Washington (Shiever and Boettcher, 2011). The architects placed schematic drawings of the high insulation wall construction, daylight design, green roof, and the geothermal heat exchange system (Cranz et al. 2014). Another green commercial building in California tried to make its green design visible, with all its construction materials (e.g., from insulation to wood and finishes) selected for their educational value and were left exposed where possible (Cranz et al. 2014).

This chapter provides key findings from empirical studies on relevant. It is found that the pro-environmental behavior of the users due to exposure of green products/technologies and initiatives are diverse and no single trend can be detected. While empirical studies on the influence of green buildings/communities on people’s pro-environmental attitudes and behaviors yielded different findings, the relationships between green building design and people’s pro-environmental behavior were reviewed in more detail. It can be seen that different aspects of sustainable behaviors are closely tied to their corresponding physical environment. Finally, the communication and meaning of architecture have been reviewed and it is ascertained that the influential design of a green building is a research topic worth to be discovered.

The next chapter discusses two challenges in studying influential green design, its communication and influence on building users’ awareness, perception, knowledge, and behaviors, from both theoretical and methodological stands.

3. RESEARCH CHALLENGES AND APPROACHES

The research questions illustrated in Chapter 1.2 can broadly fall into the study of architectural determinism. It is a stream of environmental determinism, first raised and criticized by Broady in his 1966 paper, entitled “Social Theory In Architectural Design” (Broady 1966). Broady castigates architects and planners for being too idealist in believing that architecture has the power to redeem men or transform society (Lee 1971). Formally stated, architectural determinism, in Broady’s writing, holds that physical structures determine social behavior, and that the relationship between these two factors is one-way, where the social behavior is the dependent variable.

Lee (1971) opposed Broady’s criticism against architectural determinism and argued that it is a valid formulation of the relationship between a human and its environment, and that social planning determines the probability of a behavioral occurrence. The Psychology Dictionary adopted a similar definition of architectural determinism. While promoting the concept of architectural determinism, Lee (1971) stated two key points: (1) built environment influences behavior but is not the only enforcing factor on behavior; and (2) human behavior not only responds to, but also interacts with the environment. The focus of this work is to extract the effect of buildings upon people’s mind, perception and behaviors. The other direction will not be examined here.

I uphold Lee’s point of view that the architecture and the building design do not have the power to determine the way people behave. However, they can encourage, facilitate, reinforce, or impede certain types of behaviors, and they provide cues to remind people to behave in a certain way. At the same time, it is admitted that architecture is not the only factor that determines actual behaviors. To avoid the use of “determinism”, which implicates a strong and sometimes confusing tone, I will use a new term—"influential (building) design"—meaning that building elements and characteristics could have the potential to influence people's perception and behavior. Architecture as a whole is a cultural product of a society and potentially yielding deeper influences across a broader geographical scale and wider temporal scale, which is not studied here.

3.1 Theoretical Challenges

The studies reviewed in Chapter 2 showed that how buildings expresses meaning, distributes messages, and influences human minds, attitudes, and behaviors. Nevertheless, few credible mechanisms exist by which architecture can invade people's minds and have strong and systematic effects on their behaviors, individually or collectively (Hillier 2015). Such theoretical difficulty can be generalized into philosophical debates, such as whether and how physical objects could affect the mind (Hillier 2015). On the other hand, the extreme opposite of architectural determinism can be formulated as following: it does not matter how a building is designed, how the streets are laid out, and how people are placed within the space, and that the physical environment is attitudinally and/or behaviorally neutral. Such a proposition, however, is even less credible, based on the over four decades of research in environment-behavior. Previous studies found that the physical setting offers a useful unit of analysis for understanding how certain types of places elicit certain types of recurring (Barker 1976) and predictable (Thompson 2013) behaviors.

The influential design provides a third path out of the two extreme points of view. And the TPB originated by Ajzen (2005) is proposed to provide explanations on the mechanism regarding green building design and its influence on people's pro-environmental behavior. Another theory that has a potential to study influential design is Gibson's affordance theory

(Gibson 1979), which has been further applied in product design. Koutamanis (2006) first investigated the applicability of affordance theory to architecture and buildings, with the distinction between the affordances of building's elements and spaces.

The TPB is proposed as an explainable model regarding the effects of green building design on peoples' pro-environmental behaviors, consisting the first conceptual study (Chapter 4). The affordance theory is explored in Chapter 6 in the empirical study, in regards to the two affordances a green building should bear: the provision of sustainable education to users and the facilitation of its occupants' sustainable behavior.

3.2 Methodological Challenges

The skepticism against architectural determinism is also grounded in a main methodological issue: the causality and the variable problems. There is difficulty in determining the cause and effect factors: if a study finds an association between a design and a social outcome, how can one be sure that the former is determining, or even contributing, to the latter? As found by the empirical study of Deuble and de Dear (2012), while more environmentally-concerned occupants tolerate their buildings featuring green design, the causality remains moot.

There is a challenge in establishing the linkage between architecture and any social outcome due to the variable definition and selection. Leaman and Bordass (1999) argued that buildings are complex systems made up of physical and human elements with many associations, interactions, interfaces, and feedbacks. It is often fruitless to try to separate different variables and treat them as independent as many statistical methods require. What factors are responsible for the increasing productivity in a new office building, is it the new furniture, the indoor plants, or more natural light? Or simply because any type of change has been made (Leaman and Bordass 1999). Most studies on a building's effects have selected and defined architecture-related factors as independent variables, though they are likely to operate as dependent variables of the social process in which architecture is embedded. The variable problem, if unsolved, then lead to the causality problem such as how to allocate the causes of a certain social outcome to architectural variables.

Hillier (2015) argued that the solution to the variable and causality problems lies in a key difficulty: controlling the architectural variables. Architectural variables include factors that are related to the building design and operation. For example, design elements include overall and detailed layout, landscaping, density, indoor daylight and views, and building façade; and operational factors include thermal conditions, regular maintenance, and adjustability of personal space. The difficulty in separating design elements applies particularly in a cross-sectional study, that is, how to arrive with sufficient precision, at descriptions of the differences between two different built environments. The failure to control the architectural variables with sufficient precision was challenged in studies linking architecture and social outcomes (Hillier 2015). These studies tend to treat physical environment at a gross level, e.g., a courtyard, a section of walkway, and such gross level descriptions have failed to distinguish architectural effects from other social process (Hillier 2015).

The solution then is to select a finer level of analysis, with physical and social data collected at that level (Hillier 2015). The validity of the study could be reinforced through proper study design and analysis. To differentiate and scale down the level of analysis, I propose to separate green design into two categories to extract the possible effects on peoples' sustainable behaviors from these two different architectural variables. Namely, the visual green design and the conceptual-only green design. A hierarchical linear regression (HLR) model was proposed to address the effects of spatial layout on behavioral variables, consisting of the second conceptual study (Chapter 5).

3.3 The Proposed Research Framework and Research Scope

Through insights gained from current research's understanding and with the research needs outlined in the sub-chapter 3.2, an overall research framework has been developed (Figure 1). The framework begins from the center (the research topic) and formulates the two challenges described in the previous section. The two conceptual studies that provide solutions to the research challenges are depicted in the two dark gray blocks, connecting the central research question. The empirical study (Chapter 6) serves as an extension of exploring the affordance theory, with two affordances of green buildings identified: affording sustainable education and the sustainable behavior (the light gray block).

The second study (Chapter 5) investigates one of the two communication channels identified in the first study (Chapter 4) – the passive instruction from the building and the building design. And the influences of green building designs are separated into two categories. The third study (Chapter 6) connects with the two conceptual studies at two points. First, the affordance of sustainable behaviors that a green building shall possess can be connected with one antecedent in the TPB model—the perceived behavioral control—whether certain green design facilitates any corresponding sustainable behavior. The affordance of sustainable behaviors is not empirically tested in Chapter 6, though. Second, the third study asks the users about their perceptions on different green design elements. While their perceptions are mostly intrigued by the visual sensory cues, the study further scrutinizes the perception at different spatial scales.

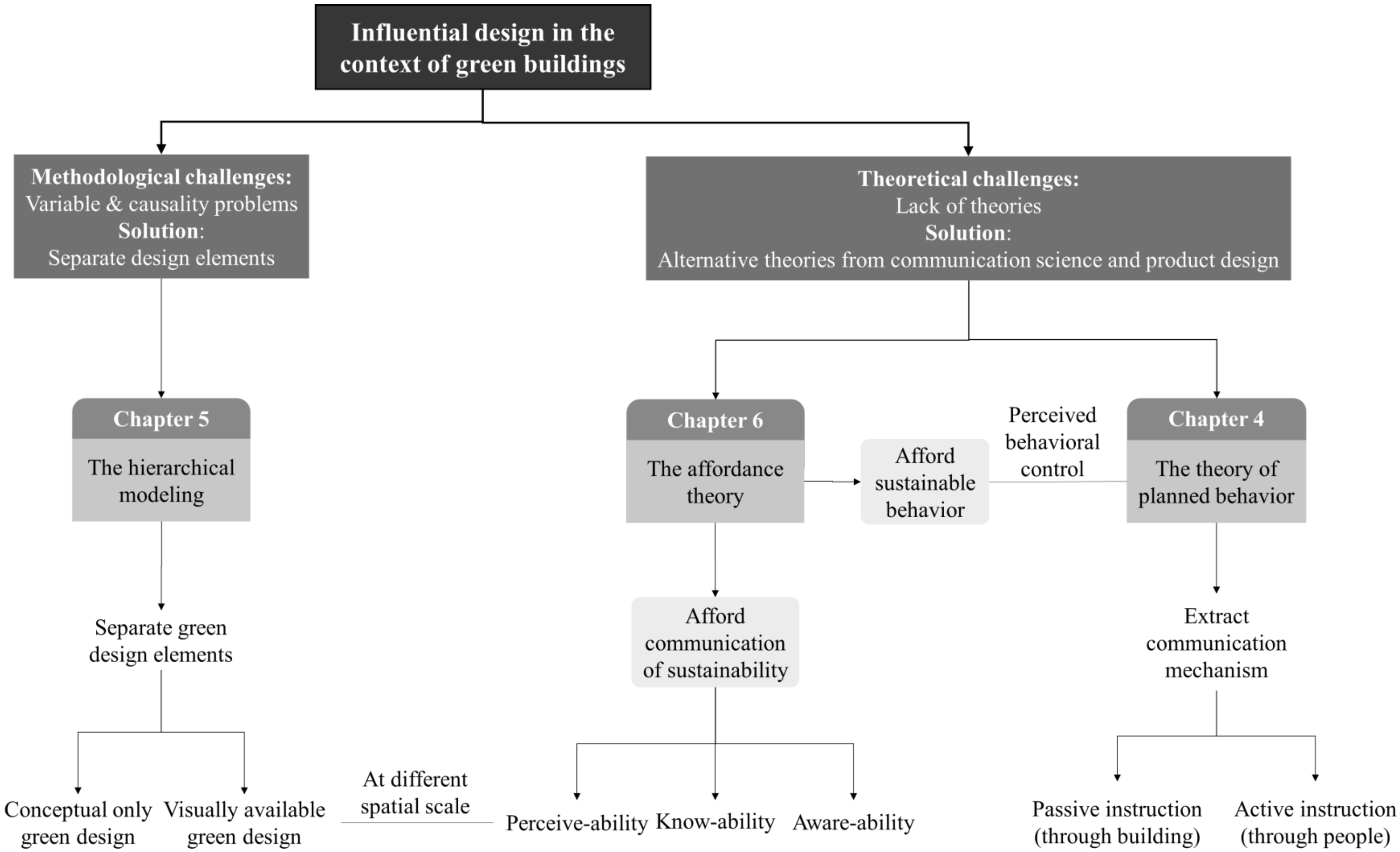

Figure 1. The conceptual framework for the research, including three individual chapters, with Chapter 4 and Chapter 5 providing possible solutions to the research challenges and Chapter 6 as an empirical extension.

Within the life cycle of a building, there are different stakeholders and feedback loops involved (Figure 2). The scope covered in this study includes the user stage along the whole life cycle of the building. The reasons to focus on users among all the stakeholders are due to the research goal and questions asked. Though not studied here, the feedback loop includes: 1) building users and the building itself (e.g., directly changing the interiors according to users' needs); 2) building users express their needs to internal property management/maintenance group/building managers; 3) building users and external third party auditors and/or researchers on any topics regarding POE; and 4) the internal/external parties and the groups of decision makers (designers and paying clients) who are responsible for new building design and/or existing building renovation.

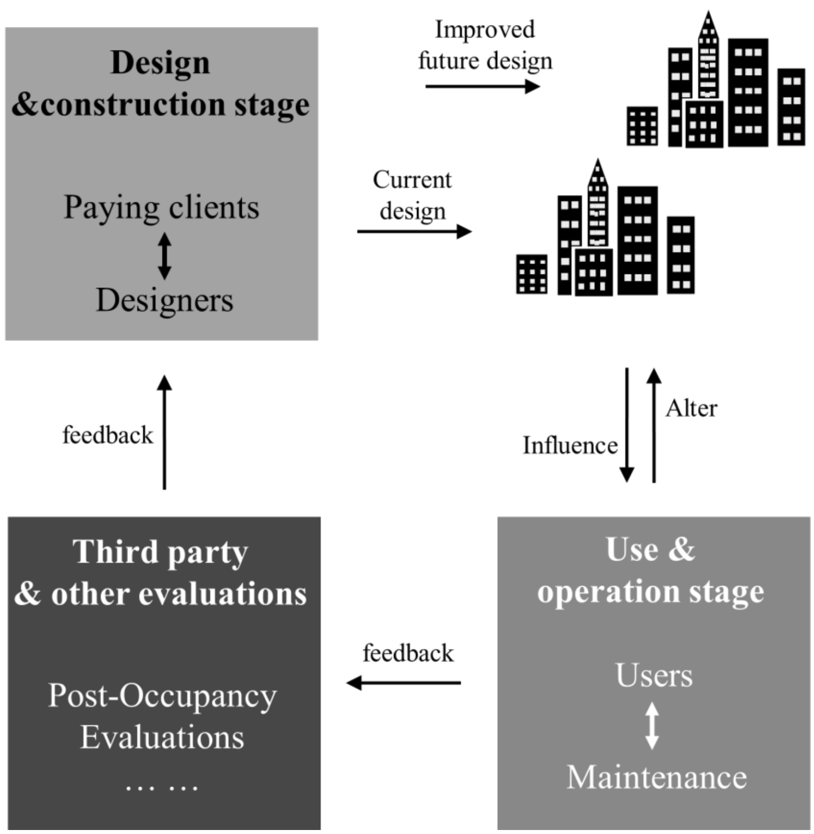

Figure 2. The feedback loops in studying the influential building designs and the stakeholders covered in this research.

The questionnaire survey involved in this research was approved by the IRB office at Michigan State University. The hard-copy of questionnaires will be stored in the dry-lab of the Landscape Ecology & Ecosystem Science lab in the Geography building at Michigan State University for three years and the electronic copy of the data entry will be stored on the hard driver of the lab computer without any identification of participants' ID during or after the survey.

While this chapter presents the research needs and proposes the overall research framework, the next three chapters present three studies regarding the framework and scope outlined here.

The first study (Chapter 4) has future implications to solve the lack of theories regarding influential design. Essentially, the debate on whether and how architecture might influence people's mind and behaviors can be answered by studying how the architecture communicates its messages to the audiences. The TPB, as a classical behavioral model in communication science, is the explicit theoretical basis for 1,264 studies listed in the Web of Science core collection from 1985 to April 2015. The proposed study demonstrates the potential of using TPB as an approach to solving the theoretical challenges.

The second study (Chapter 5) has future implications to solve the methodological challenges. Hierarchical Linear Regression helps to differentiate the effects of architectural variables from other social-economic factors through a varying intercept model for different buildings. It extracts the effectiveness of the buildings themselves by estimating the coefficients for group-level predictors, i.e., building-level characteristics. The finer level of analysis is realized in Hierarchical Linear Regression through the separation of green building designs into either visual green design or conceptual-only green design. Furthermore, Hierarchical Linear

Regression is innovative in addressing the variation through spatial differentiations of occupants from different buildings.

The third study (Chapter 6) extends the two conceptual studies in Chapter 5 and 6, and explores the affordance theory empirically. Similar to the approach chosen toward solving the methodological challenge, this study particularly separates different categories of green designs at a finer level of analysis. It investigates how people perceive different design elements, and whether and through which channel they become aware of a building's green status and what are their knowledge about green buildings, depending on their awareness.

4. GREEN BUILDINGS NEED GREEN OCCUPANTS: USING THE THEORY OF PLANNED BEHAVIOR TO STUDY COMMUNICATION OF SUSTAINABILITY FROM GREEN BUILDINGS

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4.1 Introduction

In this chapter, a green building is defined at a more general scope, as any new, existing, or renovated building that is either certified, or plans to be certified, by an authorized green building certification body; or, that is planned, designed, constructed, maintained and/or renovated according to an established guideline, which shall address sustainability as defined in the first chapter.

Studies on the performance of green buildings have been widely conducted through the POE with a wide range of topics covered. Studies on the relationships between green buildings and occupants' behaviors have mostly focused on investigating the impacts of the occupants' behaviors on building performance (Kashif et al. 2013, Lee and Malkawi 2014). However, considering the potential of green design to educate building occupants about sustainability through exposure and immersion in a green building (Lyman 2007), it is critical to understand the influences of green buildings on the occupants' behaviors. Such understanding will add a new dimension to existing topics of the POE.

This new dimension also matches with the two themes that are increasingly popular in sustainability science: effective communication and behavioral change (Kaluarachchi and Jones 2013). Behavior is the aggregated response of a person resulting as a consequence of complex interactions between internal and external factors (Gill et al. 2010). In the context of green buildings, Williams and Dair (2007) argued that technical sustainability alone, without behavioral sustainability (i.e. the sustainable actions of those living, working, and/or staying in a building), will not ensure the initially designed parameters (e.g., energy consumption reduction) of green buildings (Browne and Frame 1999, Hoes et al. 2009, Masoso and Grobler 2010).

In communication science, Bamberg et al. (2003) stated that an introduction of new information may change the cognitive foundation of intentions and behaviors. New information is an external factor that interacts with internal (e.g., emotional, moral) factors to create a consequent behavior, which, in the green building context, can be understood as green messages communicated to the occupants. Green messages are defined here as the green design ideas embedded within the building, with a potential to be communicated to and realized by the building users. Previous studies have demonstrated that architecture influences human minds, attitudes, and behaviors: "All architecture proposes an effect on the human mind" (Ruskin 1989); "architecture constantly touches us, shapes our behavior, and conditions our psychological mood" (Roth 1993, p.1).

In order to investigate the influences of green buildings on the occupants' changing pro-environmental behaviors, this chapter provides a framework to answer the following questions: Do green buildings communicate green messages to their occupants? If they do, how so? Lastly, how do they influence occupants' pro-environmental behaviors?

4.2 Background Understanding from Communication Science

The theory of planned behavior (TPB) from communication science was used as the theoretical foundation in this study. The TPB is a widely accepted behavioral model for explaining and predicting behaviors through considering three core constructs: attitudes, subjective norms, and perceived behavioral control. It is arguably the most widely researched behavioral model (Armitage and Conner 2001) and is the theoretical basis for 1,311 studies from the Web of Science core collection between 1985 to August 2015. The TBP has been extensively applied in empirically based, environmental behavior studies (Chang et al. 2014, Greaves et al. 2013, Kumar 2012). One study (Lee et al. 2013) in the field of architectural science explored the behavioral intentions of interior designers when they chose sustainable materials.

It is essential to identify the communication channels of a building to answer the first two research questions - whether and how green buildings communicate green messages to their occupants. In the persuasive communication (i.e. influential communication that affects people's attitudes and behaviors), different medium factors are used to communicate the messages including 1) mass media (print, digital, and visual); and 2) face-to-face interpersonal transmission (Oskamp 1991, p.175-177). According to different communication medium involved, it is assumed that green buildings communicate messages through two communication channels: active instruction and passive instruction.

Active instruction is defined here as those deliberate interventions incorporating communication medium of "face-to-face interpersonal transmission" (Oskamp 1991, p.175). Examples include education programs, incentives, feedback interventions and engagement events used to actively educate and influence building users. For example, the basic idea of comparative feedback is to evoke a feeling of competition, social comparison or social pressure which then leads to changed behavior to correspond more closely to the norm (Mulville et al. 2013). Comparative feedback interventions considering the consumption of an individual or a group in relation to an average have been successful in reducing energy consumption in households (Abrahamse et al. 2005). Except self vs. others comparison, self vs. self-comparison is shown to be effective as well (Brandon and Lewis 1999). Active messages are conveyed through verbal and/or non-verbal communication by human interactions, including stakeholders involved during the occupancy stage (e.g., owners, building managers, occupants).

In contrast, passive instruction incorporates all other kinds of non-human communication mediums. Examples include a mural advertising green building concepts, a digital dashboard showing building energy consumption, posters suggesting sustainable practices, and waste categorization bins facilitating recycling behaviors. Passive messages are conveyed from the building itself (e.g., the overall design, site, structure, construction materials, decorations, furniture, and vegetation), through green design implemented during the building planning, construction, occupancy, and renovation. Any passive instruction can be reinforced to become an active instruction in the presence of face-to-face interpersonal transmission, such as volunteers distributing flyers and talking with occupants about tips to save energy. Importantly, the major characteristics in distinguishing the passive instruction from active instruction are the absence of deliberate interventions. Buildings that instruct passively are not intended to communicate a message but often do so none-the-less (Mitchell 2006).

The passive instruction utilizes the building itself – a form of lived-in visual (Ragsdale 2011), as a communication medium when seeing at a whole building scale. Though, at a smaller scale (i.e. building elements), the green design that manifests the green status of a building, can be separated into the visually-evident green design and conceptual only green design. Conceptual herein means that the design provides no visual evidence of its green features. Many of the designs, such as those contributing to the building energy efficiency, have no visual attributes to make them visually evident (Lyman 2007). The persuasive power of visual green design might be an important area of research as previous studies have shown that the visualization of sustainability is effective in sustainable education and communication (Ma 2008; Mann 2011).

4.3 Relevant Studies

This sub-chapter provides current understanding to answer the first and second research questions and to identify the potential of visual persuasion of green buildings and designs. And the focus is given to building occupants, among all building users, in other words, those full-time building occupants. As the pro-environmental behaviors of full-time occupants (instead of short-term users such as visitors) are more important in building performance. Reviews are grouped into:

(1) Influences of green buildings on occupants' pro-environmental attitudes and behaviors: to understand the potential effectiveness of active and passive instructions, if any. These studies were named as green building–green occupant studies. While the name implies a multidirectional relationship, the focus of this study was to identify the influences of green building on green occupants.

(2) The TPB and its explanatory potential on green building–green occupant studies: to diagnose the mechanisms of behavioral changes, and to explain findings from previous green building–green occupant studies through this behavioral model.

(3) Visual persuasion of green building design: to learn how previous studies have used buildings, in particular, green building and green design, as a visual persuasion tool to influence people.

4.3.1 Green Building-Green Occupant Studies

Detailed reviews of individual studies on green building–green occupant are provided in Chapter 2.2. This section provides further analysis, specifically according to the definitions on active/passive instruction.

Most of the studies listed in Chapter 2.2 have incorporated passive instructions of green buildings. They focused mostly on the general environmental attitudes of occupants, instead of the attitude(s) toward a specific behavior and did not measure behavioral intentions and/or actual behaviors. These studies concluded with different findings (Figure 3). Studies examining the active instruction included Kaluarachchi and Jones (2013) who investigated the effectiveness of several engagement events in a year-long initiative in the UK, aiming to promote low-carbon home adaptations and stimulate behavioral changes among the elderly. Lynam (2007) aimed to examine whether green academic buildings communicated a more pro-environmental message to occupants in comparison to conventional academic buildings. An unexpected result of the study was that the conventional building occupants held stronger pro-environmental attitudes than those in the green building, apparently due to a more active involvement from the staff and their interaction with students concerning the environment (Lynam 2007) – which is an active instruction. This study indicated that there might be a stronger potential of persuasive power through active instruction than merely passive instruction through green building alone.

All of the green building–green occupant studies differed in geographic location, the scale of the study, data collection methods, analysis approach and statistic modeling. Most studies were carried out in developed countries, without a single one in a country where green buildings are rapidly developing such as Brazil, China, or the United Arab Emirates (USGBC 2015). Both non-residential and residential buildings/communities were studied. All residential studies embraced a broader geographical scale (i.e. in terms of green communities, or all homes within a city (Daniel et al. 2014)), than studies on the non-residential buildings (i.e. in terms of individual buildings). All studies except Kaluarachchi and Jones (2013) collected cross-sectional data instead of longitudinal data. These studies were either conducted on green building occupants only or used a comparative approach (green vs. conventional). Most studies used quantitative data analysis with statistical methods, falling into two approaches: 1) linear regression analysis, and 2) two (or multi-group) mean scores comparison on environmental attitudes of occupants from green vs. conventional buildings.

4.3.2 The TPB for Explaining Green Building–Green Occupant Studies

According to the TPB, intentions and behaviors are a function of three basic determinants: 1) the personal factor – the individual attitude toward the behavior (A_b), i.e., the person's positive or negative evaluation of performing the particular behavior of interest; 2) the subjective norm (SN) – reflecting social influence, i.e., the person's perception of social pressure to perform or not perform the behavior of interest; and 3) the perceived behavioral control (PBC) – dealing with issues of control, i.e., the sense of self-efficacy or ability to perform the behavior of interest (Ajzen 2005). Each of the three determinants, A_b, SN, and PBC, can be formulated according to the beliefs people hold and an evaluation factor for each determinant (equations 1 - 3 in Table 1). As a general rule, the more favorable the attitude and SN, and the greater the PBC, the stronger the person's intentions to perform the behavior of interest should be (Ajzen 2005).

In addition to the three determinants, the background variables might influence the beliefs people hold, which can be divided into three categories: personal (e.g., values, emotions, intelligence), social (e.g., age, gender, education) and informational (e.g., experience, knowledge, media exposure). Unlike the three direct antecedents of behavioral intentions (i.e. A_b, SN, and PBC), for background factors, Ajzen stated that "…there is no necessary connection between background factors and beliefs. Whether a given belief is or is not affected by a particular background factor is an empirical question" (Ajzen 2005, p.134).

The TPB model can be used to help explain the different findings from previous green building–green occupant studies. Such as, why studies that focused on passive instruction showed different results; and why, on the other hand, studies that focused on active instruction showed positive findings in influencing occupants' attitudes and behaviors.

The active and passive instructions are interventions at different positions along the causal chain in the TPB model (Figure 3). The active instruction is designed to alter A_b, SN, and PBC directly through deliberate intervention. Active instruction included: 1) intervene/strengthen the normative beliefs (n_i), where teachers in conventional buildings always ask students to recycle class paper (Lynam 2007); 2) intervene evaluation (e_i) and behavioral beliefs (b_i) to increase the positive attitude toward pro-environmental behaviors (Kaluarachchi and Jones 2013); and 3) intervene/increase control beliefs (c_i) that lead to stronger PBC where occupants think they are capable of performing sustainable practices (Kaluarachchi and Jones 2013). The passive instruction through daily exposure to a green building can be considered as a background factor under the informational category. Different empirical studies came to different conclusions because background factors do not necessarily influence beliefs (Ajzen 2005).

While the TPB predicts intentions and behaviors from attitudes, numerous research showed that people's behavior also has a reciprocal effect on their attitudes (Oskamp 1991). This adds another causal link in the TPB: behaviors at time 1 (t_1) cause attitudes at t_2, which is different from the initial attitudes at t_0 that are used to predict intentions (and behaviors) at t_1. Unfortunately, the causal links could not be empirically supported through the reviewed studies without behavioral data at $t_{1.}$

Besides the multidirectional relationship between attitudes and behaviors, the green building–green occupant relationships are also multidirectional when introducing temporal differentiation. This is conceptualized through adding a link from the constructs of behavior and/or intention to the background factors (e.g., information category). The new link indicates that the attitudes and behaviors at a certain time might influence the future green building development and design. Furthermore, when considering a relatively short temporal scale, the multidirectional relationships between green building and occupants are also manifested in the fact that occupants' pro-environmental attitudes and behaviors extensively influence the actual building performance during the operation, especially in residential buildings where occupants have more decision power. Some of the studies reviewed here (e.g., Azizi and Wilkinson 2015, Daniel et al. 2014) have shown such multidimensional relationships.

4.3.3 Visual Persuasion of Green Building and Green Design

A visual object is anything that has to do with vision, it is communicative, symbolic, culturally representative, and deductive by the viewer (Barnes 2007). It could be mediated visuals (e.g., graphic designs, paintings, photographs, films) or unmediated lived-in visuals, such as natural landscape and/or man-made built environments. Joffe (2008) highlighted the 'vividness effect' – where visual materials appear to be especially memorable and the salience that this confers may make it particularly forceful. McKenzie-Mohr (2000) applied vivid communication in promoting sustainable behaviors by using community-based social marketing.

It is argued that buildings are a form of lived-in visuals and communicate themselves with a visual persuasion. Persuasion refers to 'messages that are designed to change attitudes, beliefs, values and behavior' (Ragsdale 2011). A framework was proposed by Ragsdale (2011) to assess the effectiveness of the visual persuasiveness of a wide variety of architecture, such as museums, cathedrals, performing halls, government buildings, and universities, but not green buildings.

Two kinds of green design were identified in section 4.2: the visually-evident green design and the conceptual-only green design. Visual green design vividly speaks of a building's green status (e.g., on-site renewable energies, interior design elements, interpretive signage, transparent waste bins, green-roofs/spaces, calm water features and vegetation (Joye 2007)). The conceptual-only green design is more difficult to be recognized, does not have the vividness effect, and might be weaker in the persuasive effect. The conceptual-only green design may be implemented throughout any stages of a green building's life cycle, such as implementing a waste management plan, using low-emitting materials during construction, or controlling indoor pollutants during operation (USGBC 2010). Lyman (2007) showed that the more visual elements used, the more evident a green building would become. Both visually-evident and conceptual-only green designs discussed here are passive instruction. On the other hand, with the wide adoption of multi-media techniques, active instruction tends to combine visual aids frequently.

The persuasive power of a visual object was demonstrated in few studies, though not combining green design with visual persuasion. O'Brien and Gunay (2014) identified the visibility of energy use as an important factor that adjusted the occupants' behavior in office. Bartram et al. (2010) showed the potential of visualization real-time feedback of energy use in influencing occupant conservative behavior. They piloted informative art into existing designs by using ambient canvas to visualize energy use. These studies demonstrated the value and necessity in further understanding visual persuasion in green building–green occupant relationships.

The basic layout of the TPB is originated from Ajzen (2005). Following the definition of active and passive instruction given in this study, dashed-lines indicate that the informational background factor (i.e. passive instruction) studied here does not necessary influence beliefs.

Solid bold lines indicate an established causal relationship in the TPB. The active instruction (i.e. deliberate intervention) is designed to alter the beliefs – the necessary antecedents of Ab, SN, and PBC. bi: behavioral belief; ei: subjective evaluation; ni: normative belief; mi: the motivation to comply; ci: control belief; pi: the power/importance. A detailed description of the three equations is provided in Table 1.

Table 1. A detailed description of the three equations for measuring A_b, SN, and PBC in the TPB.

	Description
Equation 1 Attitude $\propto \sum (b_i e_i)$	For each behavior leading to outcome i, the behavioral belief (b_i) (i.e. degree of confidence about the evaluation) is multiplied by the subjective evaluation (e_i) (i.e. positively or negatively evaluation) and the resulting products are summed (Ajzen 2005).
Equation 2 SN $\propto \sum (n_i m_i)$	For each referent i (e.g., a person's co-workers, close friend), the normative belief (n_i) (i.e. does the referent think I should perform the behavior) is multiplied by the motivation to comply (m_i) (i.e. to what extent I should comply with the referent) and the resulting products are summed (Ajzen 2005).
Equation 3 PBC $\propto \sum (c_i p_i)$	For each behavior there are presence or absence of a given factor i (e.g., the availability of recycling bins to perform recycling), the control belief (c_i) (i.e. is the factor present or not) is multiplied by the power (p_i) (i.e. how important the presence of the factor is to facilitate or inhibit performance of behavior) and the resulting products are summed (Ajzen 2005).

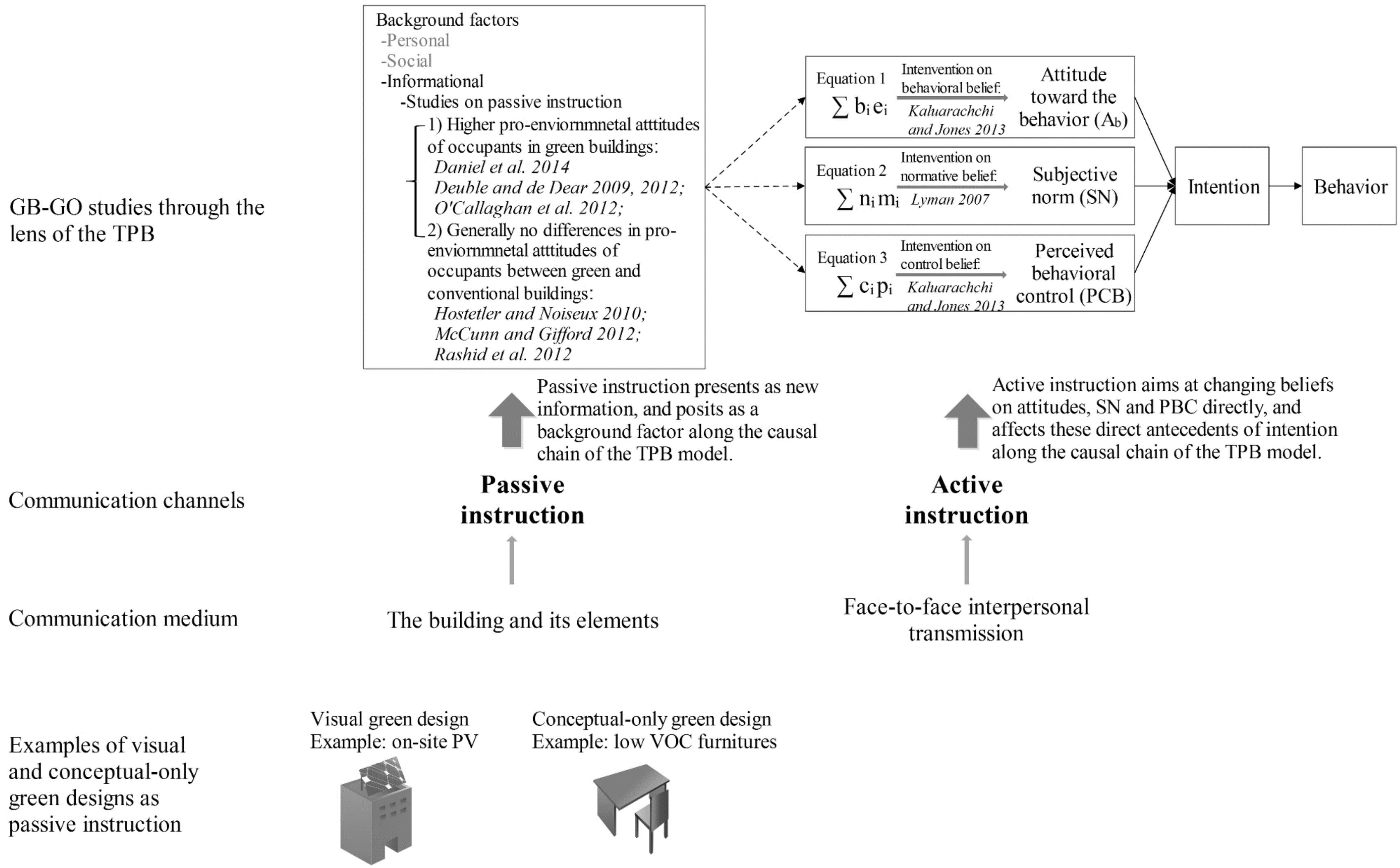


Figure 3. Results of the literature reviews on green building–green occupant studies through the lens of the theory of planned behavior.

4.4 A Framework Incorporating the TPB for Green Building–Green Occupant

Following concepts in communication science and through previous green building–green occupant studies reviewed, the first and second research questions could be answered: green buildings can communicate green messages to their occupants through two communication channels – active and passive instructions. A specific framework is needed to address the third research question. The green building–green occupant studies carried out within the study area of architectural science provided insight for the research framework proposed in Figure 4, which was designed to advance knowledge in green building–green occupant studies through incorporating the TPB with following four perspectives.

Frist, the TPB model is integrated as a theoretical foundation, as it can help to 1) disclose the behavioral change mechanisms – the effects, if any, of how a green building might communicate messages and cause behavioral changes in occupants; and 2) reveal the consistencies between the attitude and behavior – a subject of debate for decades (Oskamp 1991, pp266). It is the behavior, not the attitude, which determines the technical performance of the green building. Thus, it will be advantageous if one can measure both attitudes and behavioral changes.

Second, it is necessary to collect longitudinal data to reflect the changing beliefs, attitudes, and behaviors of occupants. This will detect the effectiveness of active instruction while occupants are involved in an intervention, such as when they are personally asked to follow recycling guidelines; and similarly, detect the effectiveness of passive instruction when occupants are exposed to a changing physical environment.

Third, it is suggested to use actual behavioral measurement schemes in addition to self-reported measurements on the behavior. Examples include behavioral observations, such as counting the unnecessary lights/computers turned on. Physical measurements of changes in resource consumption, waste generation, and recycling rates can also be used to validate the quality of self-reported data and examine the effectiveness of active/passive instruction more accurately.

Finally, the use of a building and its elements (e.g., green design) for visual persuasion as a communication medium shall be studied to fill in the current research gap on the visual persuasion of green building design.

4.4.1 The Framework

The above four perspectives were taken into consideration when developing a framework to address the question – how do green buildings influence occupants' pro-environmental behaviors? The TPB model is used to examine changes in the pro-environmental behaviors of occupants, with two different communication channels. Two illustrating questions (Q.A and Q.B) are provided to demonstrate the framework. Q.A assesses the effectiveness of active instruction and answers the question: Whether deliberately designed intervention methods to encourage a targeted behavior can enhance the occupants' positive attitude, SN, and PBC toward the specific behavior? Q.A does not require the presence of green building design. Q.B, on the other hand, assesses the effectiveness of passive instruction and answers the question: Does exposing visual or conceptual-only green designs to occupants enhance their positive attitude, SN, and PBC toward more pro-environmental behaviors in general; and do visual and conceptual-only green design engender comparative differences in their persuasive power? Q.B requires the presence of green building design.

This framework can be applied in an intervention study design with a longitudinal cohort of building occupants in the real world. To assess Q.A, a cohort of building occupants can be surveyed in the same building, before and after an active instruction implementation (pre- and post-intervention survey), with the same set of questions (Figure 4a). To assess Q.B, a prospective cohort of building occupants can be surveyed in a conventional building (pre-move survey), and again after their move into a green building or after a green renovation in the same building (post-move survey), with the same set of questions. The questions to measure the constructs in the TPB can be self-reported, with the net change scores obtained as the differences between pre- and post-move surveys (Figure 4b).

The frequency of distributing pre- and post-surveys, and the intended duration of the intervention studies should be formulated according to individual study goals. For example, the pre-move survey can be taken multiple times before the occupants move out; and the post-move survey can be repeated at specified intervals (e.g., every 1, 3, 6 months) after moving into the green building. The temporal differences from the initial moving-in period to a longer term residence can be examined through measuring at different times along the cohort study.

Figure 4.a on the top of Figure 4 discloses the effectiveness of active instruction. If the active instruction is effective, mean scores for constructs of the TPB model from post-intervention survey (indicated by black bold subscript 2) should be higher than that from pre-intervention survey (indicated by light grey subscript 1); The TPB model as a whole should be able to explain more variance for model 2 (post-intervention) than for model 1 (pre-intervention). The Figure 4.b on the bottom discloses the effectiveness of passive instruction, the effectiveness should be differentiated for visual or conceptual-only green design (as indicated by v/c starting from the background factor).

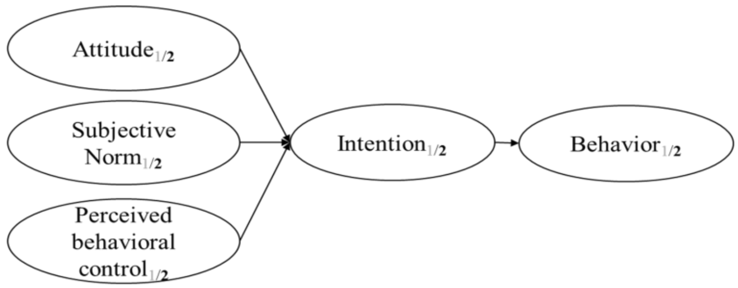


Figure 4.a

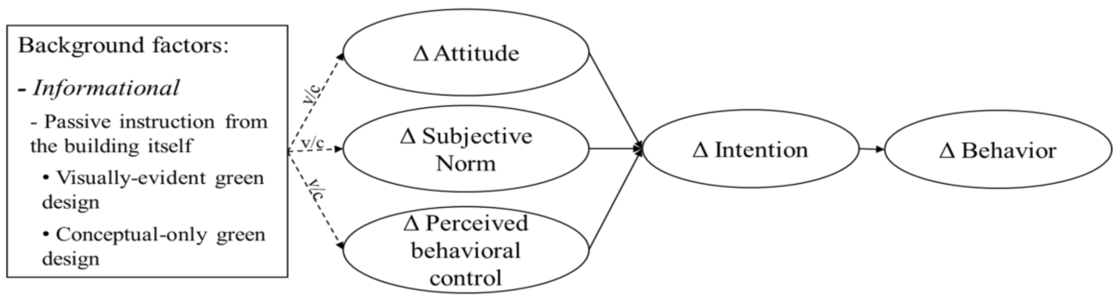


Figure 4.b

Figure 4. The modified theory of planned behavior framework to disclose effectiveness of active instruction (Figure 4a) and passive instruction (Figure 4b). The subscript 1/2 represents the pre- and post-intervention measurement for each construct. Δ indicates the net change after the exposure to the green building, to capture the effects of passive instruction – the informational background factor under the TPB model.

4.4.2 Sample Questionnaires

Based on Ajzen (n.d.), self-reported sample questionnaires for measuring all the constructs of the TPB were developed for Q.A and Q.B (Table 2 and Table 3). For the final construct of the TPB, the actual behavior can also be measured with in-situ observations and/or physical measurements on building performance. The seven-point Likert scale is employed and questions are to be answered before and after active instruction (i.e. deliberate intervention) to detect the differences. The sample questionnaires need to be modified, validated, and pre-tested for future studies.

To develop a full questionnaire, one can follow the recommendations of Francis et al. (2004), who provided example questions and explicitly listed procedures in constructing the TPB questionnaire (e.g., the identification of a reference group through elicitation study). In the sample questionnaire in Table 2, co-workers were used as an example for the reference group (i.e. those who are likely to apply social pressure toward others with respect to the studied behavior). According to Francis et al. (2004), the psychological (internal) constructs of the TPB model – the attitude, SN, PBC, and intention – can be measured directly by asking about the overall attitude (Table 3); or measured indirectly by asking for behavioral beliefs and outcome evaluations (Table 2), as indicated in equations 1 - 3 in Table 1 .

All measures in a questionnaire should refer to the same level of generality to meet the principle of compatibility(Ajzen 2005). The sample questionnaires were developed at different generalities for the two questions (Q.A & Q.B), targeting specific or general beliefs and behaviors. Unlike passive instruction which does not intentionally communicate a message, the active instruction works most efficiently when specific intervention method(s) are designed for a targeted behavior (Ajzen 2005). The questions for assessing active instruction are developed at a specific scope (Table 2). Waste categorization was used as a targeted behavior in the sample questionnaire, assuming a corresponding intervention of educating people on correct waste categorization. On the other hand, it is developed at a general scope for assessing passive instruction (Table 3) by asking occupants questions within the building as well as on general daily routine.

Other aspects that need to be considered include: the sampling method with randomized selection in experimental study designs; the mode of the survey (e.g., mail, online, or face-to-face); the disclosure of the survey objectives before- and/or post-survey; and the appropriate design of the survey to avoid the Hawthorne effect (i.e. where occupants report what they think the researcher want to hear).

Table 2. Sample questionnaire designed for measuring the effectiveness of active instruction, using the example of waste categorization as a targeted behavior.

Construct	Indirect measures	Possible questions
Attitude	Behavioral belief (b_i)	By doing waste categorization I can help to reduce environmental impacts from this building. Likely 7 : 6 : 5 : 4 : 3 : 2 : 1 unlikely
	Outcome evaluation (e_i)	Reducing environmental impacts from this building is: Good 7 : 6 : 5 : 4 : 3 : 2 : 1 bad
Subjective norms [1]	Injunctive normative belief (n_i)	My co-workers think that I should do waste categorization whenever possible. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
	Motivation to comply (m_i)	When it comes to matters of waste categorization, I want to do what my co-workers think I should do. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
	Descriptive normative belief [3]	Most of my co-workers do waste categorization in the building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
	Identification with the reference group	When it comes to matters of waste categorization, how much do you want to be like your co-workers? Very much 7 : 6 : 5 : 4 : 3 : 2 : 1 not at all
Perceived behavioral control [2]	Control belief (c_i)	This building already provides me, or will very likely in the near future (e.g., within the forthcoming month) provide me with the necessary provisions (e.g., waste categorization bins) for me to do the waste categorization. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
	Power of control factor (p_i)	Having the necessary provisions would enable me to do waste categorization whenever possible. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
Intention		I intend to do waste categorization whenever possible in this building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
Behavior		Currently, I am frequently engaging in waste categorization in this building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree

Note:

1. Suppose the reference group is coworkers in a green office building.
2. Suppose an example control factor for the waste categorization behavior is the provisions of waste categorize bins.
3. The descriptive normative belief (what others do) are included other than injunctive normative belief (what you are supposed to do).

Table 3. Sample questionnaire designed for measuring the effectiveness of passive instruction, differentiating visual and conceptual-only green design.

Construct	Direct measures	Possible questions
Informational background factor - Passive instruction	Visually-evident green design	Do you feel the green features added to the building and surrounding site are visually persuasive in representing the green icon of the building? (Visual green features such as: on-site renewable energies (e.g., solar panel), landscape artwork, outdoor views, indoor vegetation, green-space/green-roof, and interior design elements promoting sustainability.) Very persuasive 7 : 6 : 5 : 4 : 3 : 2 : 1 not persuasive at all
	Conceptual-only green design [1]	To what extent are you familiar with the green designs implemented within the building? Very familiar 7 : 6 : 5 : 4 : 3 : 2 : 1 not familiar at all
Attitude	Within the studied building	I think engaging in pro-environmental behavior [2] within the building I reside in is; Good 7 : 6 : 5 : 4 : 3 : 2 : 1 bad
	General daily behavior	I think engaging in pro-environmental behavior daily is: Good 7 : 6 : 5 : 4 : 3 : 2 : 1 bad
Subjective norms	Injunctive norm – within the studied building	Most people who are important to me in this building think that I should engage in pro-environmental behaviors in this building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
	Injunctive norm – general	Most people who are important to me in my life think that I should engage in pro-environmental behaviors. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
	Descriptive norm – within the studied building	Most people who are important to me in this building engage in pro-environmental behaviors in this building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
	Descriptive norm – general	Most people who are important to me in my life engage in pro-environmental behaviors. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
Perceived behavioral control	Within the studied building	I can easily have access to necessary equipment, provisions, and resources (e.g., easy access to recycling facilities, experts to ask) in order to behave pro-environmentally in this building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree I am fully capable of engaging in pro-environmental behaviors in this building if I want. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree It is up to me whether I engage in pro-environmental behaviors in this building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree I am in full control over whether I engage in pro-environmental behaviors in this building. Agree 7 : 6 : 5 : 4 : 3 : 2 : 1 disagree
Intention	Within the studied building	I intend to engage in pro-environmental behaviors within the building. Likely 7 : 6 : 5 : 4 : 3 : 2 : 1 unlikely
	General daily behavior	I intend to engage in daily pro-environmental behaviors. Likely 7 : 6 : 5 : 4 : 3 : 2 : 1 unlikely
Behavior	Within the studied building	Currently, the frequency of me engaging in pro-environmental behaviors in the building that I am residing is: Frequently 7 : 6 : 5 : 4 : 3 : 2 : 1 un-frequently
	General daily behavior	Currently, the frequency of me engaging in daily pro-environmental behaviors is: Frequently 7 : 6 : 5 : 4 : 3 : 2 : 1 un-frequently

Table 3 (cont'd)

Note:

1. A more complex and categorized version to measure 'conceptual-only green design' is presented in Table 4. Similarly, visual green elements can be extended to more complex questions.
2. Whenever 'pro-environmental behavior' is used in the question, it does not mean any specific/targeting behavior.

In the building context, using an office building for example, pro-environmental behaviors can include: 1) regarding resource conservation: turning off computers and lights when they are not in use; not wasting water and reporting a leaking; printing as less as possible and printing on both sides whenever applicable; 2) regarding waste & recycling: reusing office supplies whenever possible (e.g., refilling pens); involving in recycling programs; categorizing waste whenever possible.

For the general daily behavior, pro-environmental behaviors could include: 1) regarding resource conservation: waiting a full load before doing laundry; taking a short shower to conserve water; switching the light off when not in use; 2) regarding waste & recycling: bringing empty bottles to recycle; collecting and recycling used paper; not putting dead batteries in the garbage; refusing paper/plastic bag whenever possible; 3) mobility & transportation: trying not to drive my car if public transportation, walking, and bicycling is efficient

Table 4. Alternative questions to be asked according to the LEED scheme for a more complex and categorized version to measure conceptual-only green design.

Indicators	Example questions, according to LEED (USGBC 2014)
Conceptual-only green design (example questions on water efficiency (WE), energy saving (ES), materials and resources (MR) and indoor environmental quality (IEQ))	PI_C_WE-Q1: Are you aware the building minimizes or eliminates the use of potable water for landscape irrigation? PI_C_WE-Q2: Are you aware the building use innovative wastewater technologies PI_C_ES-Q1: Are you aware the building has increasing levels of energy performance PI_C_ES-Q2: Are you aware the building's relevant systems (e.g., HVAC) do not contain HCFCs or halons to reduce ozone depletion? PI_C_MR-Q1: Are you aware the building use salvaged, refurbished or reused materials, products, and furnishings? PI_C_MR-Q2: Are you aware the building materials have recycled content? PI_C_IEQ-Q1: Are you aware the building installed a permanent carbon dioxide (CO_2) monitoring system? PI_C_IEQ-Q2: Are you aware the building uses low-emitting materials? PI_C_IEQ-Q3: Are you aware the building introduces daylight and views into the regularly occupied areas of the building.

4.5 Discussion

It is clear that green buildings can communicate green messages to their occupants through two plausible communication channels: active and passive instructions. Through the lens of the TPB, active and passive instructions are found to differ in the persuasive power since they are interventions located at different positions along the causal chain in the TPB model. Active instruction shows a stronger persuasive power since it is designed to directly alter the A_b, SN, and PBC – the three antecedents of the behavior in the TPB.

To advance green building–green occupant studies, a framework was proposed with two illustrating questions through incorporating the TPB. This framework separately investigates the effectiveness of active and passive instructions on changing beliefs and behaviors. The combination of the two instructions in a building (i.e. interaction effects) was not considered in the proposed framework. Possible results include green building–green occupant links or green building–gray occupant links (Table 5). The proposed framework and associated sample questionnaires can be incorporated into existing POE methods. The identification of changing behaviors inspired by the active/passive instruction is essential, as behaviors toward sustainable living are critical to achieving the success of a green building (Zuo and Zhao 2014). It reinforces the importance of human dimension in the built environment, especially with consideration of the dynamic interaction between human and architecture (Cole et al. 2010).

Table 5. Possible results of studying the effects of active or passive instruction, or an interaction between active and passive instruction.

Possible results	Passive instruction only	Active instruction only	Passive × Active (interaction)
Green building - green occupant	Green design alone may boost the environmental awareness and attitude of people and lead to pro-environmental behaviors.	If designed correctly, the active instruction should be effective, as being said "If you give me any normal human being and a couple of weeks… I can change his behavior from what it is now to whatever you want it to be, if it's physically possible" (Oskamp 1991, p.207).	It is very likely that the combination of green physical space and the intervention will lead to synergistic effects since the technical sustainability provide necessary opportunity to adopt 'behavioral sustainability'.
Green building - gray occupant	Green design alone cannot promote the 'behavioral sustainability' of occupants, and future design and management of green buildings may need to incorporate other factors (e.g., from active instruction) to ensure the behavioral sustainability.	The active instruction is not effective, maybe due to the fact that the technical side of the green building does not match with the local customs, culture?	Something wrong with the design of the intervention, or people do not appreciate the technical sustainability part of the building.

Note:

These possible insights are not confirmed by empirical studies.

The connection of conventional building-green occupant was left out as the aim of the study is to find out possible influence from the green building on occupants' changing pro-environmental behaviors.

A longitudinal approach was suggested for the framework to capture the changing behaviors resulting from the active/passive instruction. Multidirectional green building–green occupant relationships discussed in this chapter might also be studied with the longitudinal approach. A proper study design is important to isolate the effects of buildings in passive instruction, which could be isolated from other background factors by controlling for personal and social-demographic factors whenever possible. One could control the intra-study differences by collecting data from the same cohort to a certain extent. Though any other changes occurring, especially those building-related along the time, will potentially introduce bias and affect the overall results. This can be controlled by introducing other mediating variables, for example, satisfaction with the building.

The framework was designed with reference to the findings of studies which demonstrated a positive correlation between attitudes toward the environment and the actual environmental behaviors and/or behavioral intentions (Abdul-Muhmin 2007; Kaiser et al. 1999; Polonsky et al. 2012; Tan 2011). Contrarily, a criticism raised by other studies is that concerns for the environment do not always translate into pro-environmental behaviors (Steg and Vlek 2009; Stern 2000). Empirically, low correlations between attitude and actual behavior were found (Hines et al. 1987; Mainieri et al. 1997; Valkila and Saari 2013). These findings open up questions for future work include the following perspectives to be considered.

First, knowledge about green building: previous studies showed the positive relationships between environmental knowledge and attitudes (Molla et al. 2014, Polonsky et al. 2012) or behavior (Edgerton 2009). Future research can include this as a background factor in the TPB model under the informational category, similar to the passive instruction.

Second, satisfaction with the building: Rashid et al. (2012) found that the occupants' satisfaction with the workspace-related features affected their environmental awareness. It may be reasonable to assume that the satisfaction toward the green building alters the occupants' positive/negative evaluation of the building, which mediates the influences from the building.

Third, the scale and background: previous studies on the behavioral changes were conducted at a broad scale (e.g., the whole residential communities) or fine scale (e.g., the individual building). The proposed framework targeted at building-scale and did not examine how people could be affected by the surrounding sustainable physical environment at different scales. Furthermore, the influences of green buildings may differ significantly based on local culture and social norms. The contextual adjustment at different scale may affect both the development of green buildings and the behavioral changes.

Fourth, types of building: the proposed framework and the questionnaires did not target a particular type of building, but can be used in both commercial and non-commercial structures. Andersson et al. (2005) pointed out that people behave differently in their home and the workplace. In reality, occupants can be differentiated as either passive green building occupants (e.g., who happen to work or live in a green building) versus active green building occupants (e.g., green home-owners who decide to install the PV, the thermal mavericks who conserve more energy due to their lower expectations on thermal comfort (Daniel et al. 2014)).

Finally, the intensity of the active and passive instructions: while some plausible routes of the two instruction of a building were identified, the intensity of instruction was not investigated. For example, green certified buildings have different certification levels (e.g., silver, gold, or platinum under the LEED system). Whether different levels of exposure to green design may result in different levels of changes in the occupants' pro-environmental behavior is an important area of future research.

4.6 Chapter Conclusions

Ideas from communication science were synthesized in seeking answers to the questions: Do green buildings communicate green messages to their occupants? If they do, how so? Lastly, how do they influence occupants' pro-environmental behaviors? It was evident that green buildings can communicate green messages to their occupants through two plausible communication channels – active instruction and passive instruction. By the definition of active/passive instruction given in this study, most previous green building–green occupant studies focused on studying the effects of passive instruction when looking at how green buildings might influence occupants. Possible explanations for the different findings from previous studies were provided through the lens of the TPB model. The active/passive instructions posit differently along the causal chain in the TPB model. As a potential persuasive medium, the visual persuasion of green buildings has not been studied. A research framework was proposed, along with sample questionnaires for two illustrating questions to investigate the last research question. The adoption of the framework to add a new dimension to existing POE methods holds great potential and is a research priority in the future.

5. THE INFLUENCE OF GREEN BUILDING DESIGN – SEPARATING TO CONCEPTUAL VS. VISUAL ELEMENTS

The following chapter contains material reproduced from an article presented at the 49th International Conference of the Architectural Science Association 2015 and published in the conference proceedings, with the citation:

[Wu, S.R., M. Green, J. Chen, A. Yang, and Y. Tang. 2015. Green building design and visual persuasion on occupants' pro-environmental behaviors. In proceedings of the 49th International conference of the Architectural Science Association, pp. 133-142, December 2-4, 2015, Melbourne.]

5.1 Introduction

Buildings visually represent themselves, demonstrating a distinctive feature as a communicating medium. Previous studies have already shown that the visualization of sustainability is effective in sustainable education and communication. Using residential buildings in Hong Kong as study sites, Ma (2008) demonstrated the importance of transmitting sustainability through visual means and revealing interrelationships among the persuasive power of design and the experience of people. Mann (2011) suggested communicating sustainability by visualizing sustainability through visual aids. To utilize this distinctive feature, the visual persuasion of a green building is worthy of study.

The aim of this chapter is to identify the potential influence of green building design on changing occupants' pro-environmental behavior, especially, at two finer level of analysis – the conceptual only and visually available green design. A preliminary survey of people who work in the Melbourne Council House 2 (CH2) is presented, identifying the potential of green design's visual persuasion in influencing people's pro-environmental behaviors. Supported by findings from the preliminary survey, a hypothetical dataset is simulated, using a hierarchical regression model with Bayesian inference, to demonstrate a potential solution to the methodological challenges raised in Chapter 2.

5.2 Visual Persuasion of Architectural Elements

Idler (2014) stated that "visual appeal can – more than anything – attract attention." Selective attention enables us to gather relevant information and guides our behavior (Carrasco 2011). Joffe (2008) highlighted the emotional power of visual forms and the "vividness effect" – where the visual material appears to be especially memorable, making it particularly forceful. While numerous literature studied such visual impacts of mediated visuals, fewer studied the unmediated lived-in visuals.

Ragsdale (2011) pointed out that the elements of architecture influence our attitudes and behavior, and answered the question on why are some buildings more persuasive than others and how do architecture convey meaning, which, in turn, results in social influence. In a green building context, one can ask whether and how the meaning conveyed by green design is persuasive and whether the occupants adopt pro-environmental behaviors as a result.

According to Rapoport (1990) and Goodsel (2000), there are three levels of mnemonic meaning from the built environment: low, middle, and high/cosmological level. The low level communicates basic everyday ideas. The middle level indicates a more subtle meaning embedded in the environment including such as power, status, and identity. The high level cosmologically evokes an emotional response to ideas of culture. Examples of the three level meanings include doors of the building indicating where to enter; exterior architectural sculptures depicting mythological figures and interior paintings portraying heroes and legends; and capitols' domes whose rising rounded point repeats an accenting expression of sacred importance (Goodsel 2000). Hershberger (1974) identified two categories of meaning that can be derived from architectural structures – representational and responsive (Figure 5). Assuming that the concept of sustainability is a deliberately embedded meaning in the green building design, could it communicate such a middle-level meaning to its occupants and trigger consequent behavioral responses? The possibility of green designs conveying high-level meaning (e.g., Gaia) is not illustrated in the Figure.

The distinctive power of buildings as visual objects and use for visual persuasion have been discussed in some general architectural studies. However, to date, no single specific study on the visual persuasion of green building design exist. The following preliminary survey was carried out in Melbourne Council House 2 (CH2) to fill in this research gap.

The study site CH2 is Australia's first Green Star rated building to be awarded 6 Stars to demonstrate an "international leadership" status. It is a 10 story office building with ground floor retail spaces has a net lettable area of 8,870m^2. Innovative designs of the building include Chilled ceilings, using phase change materials thermal storage, a shower towers for cooling and integrating wind turbines (GBCA 2008).

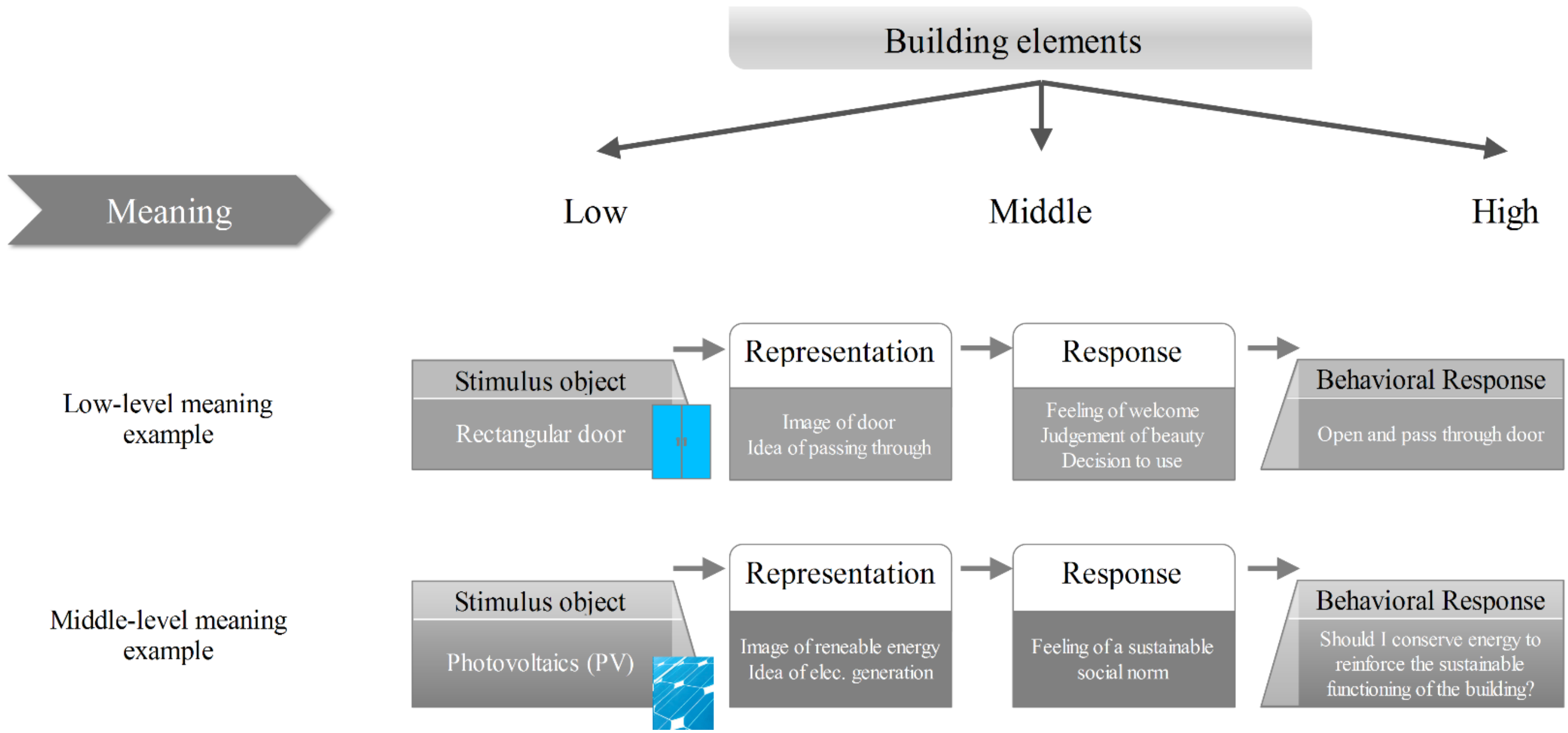


Figure 5. The three levels of meaning conveyed from the building elements, and two types of elements under the green building context – the visually available and conceptual only green design. An example of low-level meaning (adapted from Hershberger (1974)) and an example of middle-level meaning using a green design example.

5.3 A Preliminary Survey

To uncover the visual persuasion of buildings, it is necessary to separate the green design elements into (Figure 5). the visual green design element; and 2) the conceptual-only green design elements Visual green design such as on-site renewable energies, interior design elements like wall paintings, interpretive signage, green-roofs/spaces, calm water features, and vegetation (Joye 2007) all vividly speak of a building’s green status. On the other hand, conceptual-only green design such as low VOC materials applied, and energy efficient appliances installed do not have the vividness effect. The occupants’ awareness on conceptual-only green design might be weaker compared to those eye-catching visual elements. It is reasonable to assume that visual green design is equal to a layer of conceptual green design plus a layer of vividness effect.

A simple two questions survey was distributed randomly to people who work in the CH2 during a weekday in April 2015. A total of 11 people answered the questionnaire. The first question asked was, “Do you feel that you are becoming more pro-environmental since you moved to this green building (pro-environmental behaviors such as minimize water/energy use when possible, recycle and categorize waste, use public transportation instead of car)?” Four answers can be chosen, namely “no changes”, “slight”, ”moderately”, and ”strongly more pro-environmental”. If the answer was other than “no changes”, then the second question being asked was, “Do you think the exposure to different types of green design (visual vs. conceptual) resulted in your different level of pro-environmental behavior (visual exposure such as the building has solar panel, and other exterior/interior visual features (e.g., the wood shading in the west façade in CH2), conceptual exposure such as that you know the building uses recycled water, but they do not express themselves visually and vividly)?”. Four answers can be chosen, namely “no differences”, “conceptual exposure is slightly more persuasive”, “visual exposure is slightly more persuasive”, and “visual exposure is certainly more persuasive”.

Out of the 11 people, three answered “no changes” on the first question, thus, the second question was not applicable to them. Six answered “moderately more pro-environmental” (Table 6). This showed that majority of the occupants might be positively influenced by the CH2 and behave more like a green occupant, to some extent. Among the eight people who were becoming more pro-environmental since moving into the CH2, four answered that visual green design is slightly more persuasive than conceptual green design in influencing their pro-environmental behaviors, two answered visual green design is certainly more persuasive. The overall trend matches with the hypothesis that visual persuasion is a more powerful tool in influencing occupants’ pro-environmental behavior (Table 6).

Table 6. The result of the preliminary survey from Melbourne Council House 2. The contingent 2 by 2 table shows the answers on the first and second question.

		2nd question: Persuasive power of visual vs. conceptual green design on changing pro-environmental behaviors				
		No differences	Conceptual exposure is slightly more persuasive	Visual exposure is slightly more persuasive	Visual exposure is certainly more persuasive	Sum
1st question: Pro-environmental behaviors since moved into the CH2	No changes	3	0	0	0	3
	Slightly more pro-environ.	0	1	0	0	1
	Moderately more pro-environ.	0	1	4	1	6
	Strongly more pro-environ.	0	0	0	1	1
	Sum	3	2	4	2	11

5.4 Hypothetical Data Simulation

Though with a small sample from only one green building, the above preliminary results ensured the necessity of separating the green designs to conceptual vs. visual elements. A hypothetical example and simulated data were used to demonstrate one possible analysis approach to answer: While controlling for personal background factors, what is the effects of: 1) the presentation of objective building characteristics (i.e. visual and conceptual green design); and 2) the subjective viewpoints of individual occupant (i.e. awareness and perception of visual and conceptual green design) in influencing the occupants' pro-environmental behaviors.

Ideally, longitudinal data should be collected from the same cohort of building occupants before and after moving into the green building. In real cases, cross-sectional data are more feasible, thus, an analysis method for a comparative study of different buildings was proposed in the following.

Leaman and Bordass (1999) argued that buildings are complex systems made up of physical and human elements and their many associations, interactions, interfaces, and feedbacks and it is often fruitless to try and separate out different variables and treat them as `independent' as many statistical methods require. Nevertheless, statistical analysis is a powerful tool in answering a wide range of research questions. In previous studies reviewed in Chapter 2.2, some of them used two (or a multi-) group comparison on environmental attitudes scores (Daniel et al. 2014, Deuble and de Dear 2009, Hostetler and Noiseux 2010). Others used classic regression analysis (Deuble and de Dear 2012, O'Callaghan et al. 2012, Rashid et al. 2012). The hypothetical data simulation with the hierarchical regression model is demonstrated in this chapter, as a possible solution to the methodological challenges.

One of the most distinctive feature of a hierarchical regression is that when the study sample are collected from different clusters/levels (e.g., buildings in this example), it is a method for compromising between: 1) excluding a categorical predictor (e.g., building index) from a model (complete pooling); or 2) estimating separate models within each level of the categorical predictor (no pooling, e.g., a separate regression for each building) (Gelman and Hill 2006). In the data simulation, a varying intercept hierarchical model was used to extract following effects. First, to extract the effectiveness of the buildings themselves by estimating the coefficients for the group-level predictors, i.e., the building-level characteristics (i.e. whether or not the building has the visual/conceptual green design or both). From the statistical perspective, group-level predictors play a special role in hierarchical modeling by reducing the unexplained group-level variation and thus reducing the group-level standard deviation (Gelman and Hill 2006). Second, to extract the effects due to the awareness and different perception that individual occupant holds within the same building, while controlling for personal factors. These two individual predictors were selected due to the fact that, while occupants are exposed to the same green design in a building, their awareness of the green design and perception of the green design are different, which may result in their different responses to behavioral changes.

Specific questionnaires (e.g., on how to measure the pro-environmental behaviors) were not provided. For the simulation, it is assumed the scores on independent variables are either 1) binary (for objective building characteristics, and occupants' awareness on green design), or 2) seven points Likert scale (occupant's subjective perception, e.g., from not persuasive at all to very persuasive) assuming a normal distribution. One personal background factor was assumed for demonstration purposes, i.e., the educational level. Fifteen buildings with different characteristics were simulated, some with visually green design only, some with conceptual green design only, and others with both features (Figure 6). Different sample sizes were simulated for each building, ranging from 6 to 29, with a total of 273 samples.

Hierarchical regression is, in essence, a Bayesian inference (in comparison to frequentist inference), the parameters estimation is non-point estimation by Markov Chain Monte Carlo (MCMC) simulation. Following steps were carried out for the simulation: 1) set-up fake dataset; 2) specify “true” parameters; 3) specify the hierarchical model in Winbugs and call from R using R2winbugs package (Gelman et al., 2015). Two hierarchical model were simulated, the first model without including the group/building-level indicators (Figure 7) and second model including group indicators. The model setup and the simulation results for the second model are provided in Appendix C.

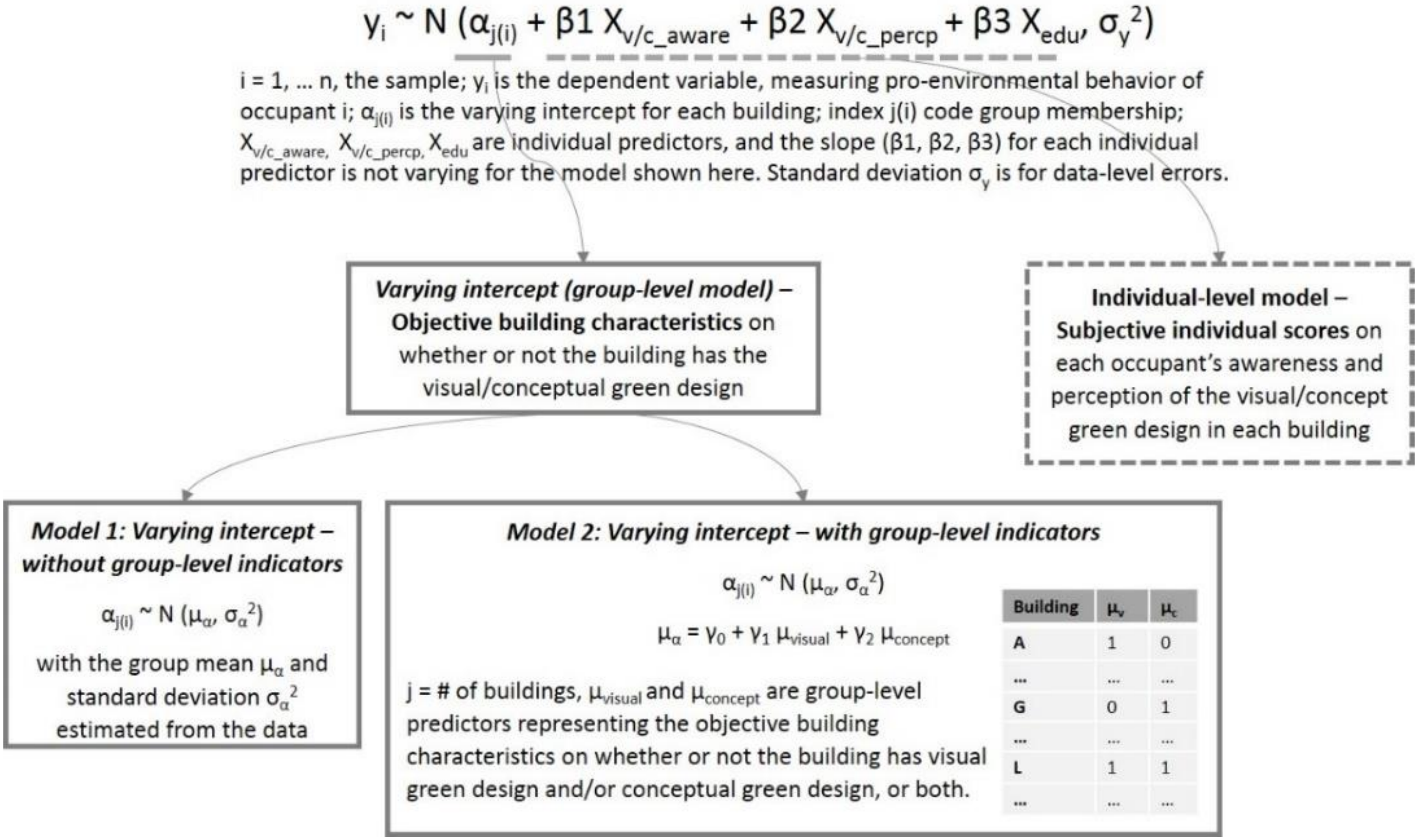


Figure 6. The hierarchical regression model simulating the individuals clustering in 15 buildings with different characteristics – a building either having conceptual-only green design or visually available green designs.

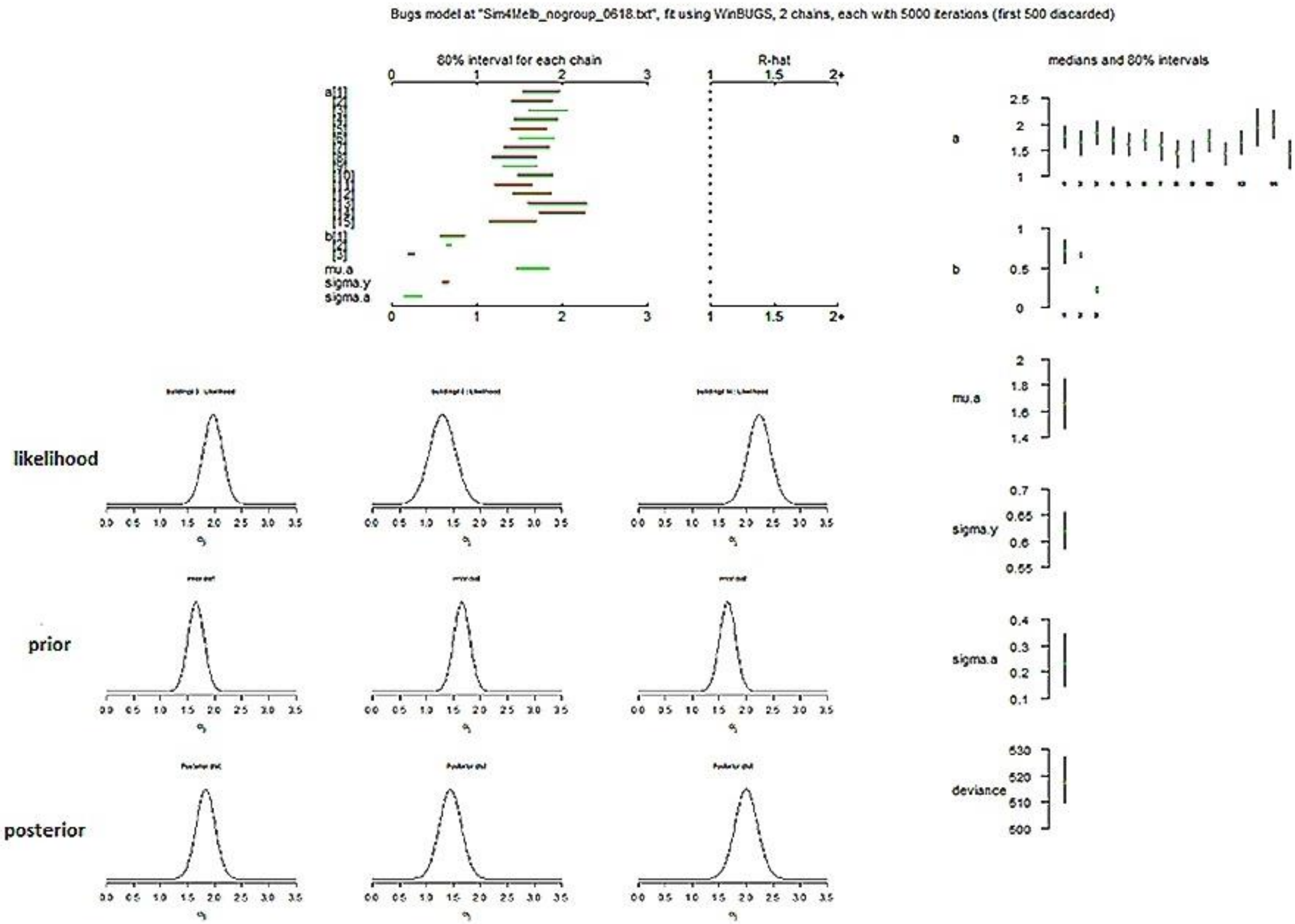


Figure 7. The simulation results with likelihood, prior, and posterior shown for the hierarchical regression model – a screenshot showing results for the estimated parameter of the model without group-level indicators.

5.5 Discussion

To identify how a green building may encourage occupants' pro-environmental behaviors, previous relevant studies were reviewed, all which came to different results and conclusions. Studies on visual persuasion and communication roles of buildings were also reviewed, as a potential powerful persuasive medium, the visual persuasion of green buildings has not yet been studied.

A simple preliminary survey was carried out in the CH2 to find out the possible influence from the green design on influencing occupants' pro-environmental behavior, and in particular, the effectiveness of the visual green design. The results showed it is likely that occupants could be influenced by the green design and behave accordingly, and the visual green design might have a higher persuasion power than conceptual-only green design. The preliminary survey with a small sample size restricted us in using a statistical analysis to come up with more scientific rigorous conclusions. Besides, the small sample size could not serve the representativeness of a larger population; the single study site also limited us from generalizing the findings to other locations.

Bear in mind that with the limitations of the preliminary survey, its results nevertheless ensured a future full study is necessary to detail the research questions in more depth. Unlike the analysis method applied to previous studies, the use of hierarchical regression model is proposed to match the sampling procedure that occupants are clustered within each building. A fake data simulation with varying intercept model including objective building characteristics as group-level predictors and subjective viewpoint of occupants as individual-level predictors were demonstrated. The fake data simulation certainly does not hold any empirical values, and the validity of any study design and analysis could only be achieved through a real study in the future. The hypothetical example shown, however, is innovative in that it addressed the variation through spatial differentiations of occupants from different buildings.

There are several important factors that can be scrutinized by future studies. First is the level (intensity) of the green design exposed to the occupants. For example, green certified buildings have different certification levels. This can be solved by using a scale (e.g., 0 to 5) to represent the intensity instead of using binary variables to represent the existence of visual/conceptual green design, as did in the fake data simulation. Second is occupants' satisfaction with the physical and non-physical environment. Rashid et al. (2012) found that the occupants' satisfaction with the workspace related features affects their environmental awareness. Leaman and Bordass (1999) found that some employers in a building always kept the light on just to annoy the manager. Third, only the potential of visual green design is explored, other sensorial cues (e.g., auditory information provided, feeling of different material texture, e.g., brick vs. steel) are not explored here and shall be part of future studies. This study looks at the effect of the green building itself (i.e. the physical environment), instead of looking into the administrative and behavioral environment within the building, such as influence from the social norms. Future studies can incorporate different perspectives to find out the potential effectiveness of different means (physical vs. administrative and behavioral) of green built environment on influencing occupants' behaviors.

5.6 Chapter Conclusions

It is of interest to know whether and how green building design can communicate green messages to the occupants and lead to their pro-environmental behaviors. The distinctive power of building elements as visual objects and their use for visual persuasion have not been studied in the context of green buildings. A preliminary survey was carried out in Melbourne CH2 and the results showed the potential of using green building design as a persuasion tool to influence the occupants' behaviors. This finding ensured the necessity of a future full-study to extract: 1) the effectiveness of the (visual) green building design on persuading occupants to behave more pro-environmentally at the building-level; and 2) the effects due to the occupants' awareness and perception of the green design at the individual-level.

6. HOW GREEN BUILDINGS AFFORD COMMUNICATION OF GREEN DESIGN TO THE USERS? A SURVEY STUDY ON A LEED CERTIFIED BUILDING

6.1 Introductions

Throughout this study, green buildings refer more specifically to those certified under the Leadership in Energy and Environmental Design (LEED) system by the US Green Building Council (USGBC). The real benefits of green buildings have been studied extensively, mostly using Post-occupancy Evaluation, covering a wide range of topics (Lee and Kim 2008, Hostetler and Noiseux 2010, Deuble and de Dear 2012, Altomonte and Schiavon 2013, Kaluarachchi and Jones 2013). Most of these studies can be asked in a similar way as to "whether the green building can afford x", where "x" can be anything from a better indoor environment, improved satisfaction of the building users, to the provision of sustainable education for users.

I suggest that the affordance theory, originated by Gibson (1979), has great potential in guiding the development, design, and evaluation of green buildings. Gibsonian natural environment's affordance was enriched through integrating affordance concepts for man-made objects in the product design field (Norman 1988, Tweed 2001, Galvao and Sato 2005, Hsiao et al. 2012). Normanian *perceived affordance* is adopted by this study, which is a result of the mental interpretation of things—the perceived properties of the thing that determine how the thing could possibly be used (Norman 1988).

Pertaining to architecture and urban planning, several studies have proposed the affordance-based design approach (Clark and Uzzell 2002, Maier et al. 2009). At a building scale, two affordances have been proposed: one concerning the building product, and another on the building space (Koutamanis 2006). The affordance of a building product is similar to that defined in Norman, such as doors afford entrance. The affordance of space involves a higher degree of abstraction as space generally lacks the interfaces allowing direct interaction with objects (Koutamanis 2006). Practically, the concept of affordance can be understood through "x-able" (Maier et al. 2009), such as "walk-able, step-able, sit-able, lean-able, eat-able" of different spaces in a building (Kim et al. 2011).

Using the idea of "x-ability" provided by a building, the goal of this study is to identify whether and how a green building affords successful communication of green design to its users. Previous studies have compared the pro-environmental attitudes and/or behaviors from occupants in a conventional vs. a green building (Deuble and de Dear 2012, Brown and Gorgolewski 2014, Azizi et al. 2015). It is argued that through studying how the green designs are disseminated and communicated, their effects can be more clearly extracted for the attitudinal and behavioral changes of users. Thus, the focus of this study is to extract following three "x-ability" of a green building, with an extension to future importance:

1) The "aware-ability"—*testing the awareness*—whether the building users are aware of the building being green? In detail, the study answers:

1.1) what is the general awareness level among the building users and through which communication channels do they gain awareness; and

1.2) how do personal background factors affect the awareness?

2) The "know-ability"—*testing the knowledge*—whether the green building facilitates the generation of green building knowledge among the users? In detail, the study answers:

2.1) what is the knowledge level about green buildings among the users; and

2.2) whether it is independent from the awareness?

3) The "perceive-ability"—*asking the perception*—which green design features are mostly perceived by the building users? Similar to the two affordances proposed in (Koutamanis, 2006),

people can perceive the green design from the building product and/or the building space. The perceive-ability indicates the order of how different green designs catch one's attention, in other words, which green design(s) are more perceivable among all those selected by the users. In detail, the study answers:

3.1) what are the most perceivable green designs and how users perceive them differently according to their spatial scales within the building—product-related vs. space-related green designs; and

3.2) whether people perceive green designs differently according to their awareness?

4) In regards to "perceive-ability", which studies the status quo of an existing building, the relative importance of different green designs for future implementation—*asking the importance*—is also examined from the users' perspective. In detail, the study answers:

4.1) what are the most important green designs that users think should be implemented in future design; and

4.2) whether users prioritize green design features differently according to their knowledge about green buildings?

6.2 Methods

6.2.1 The Research Setting

With the emergence of green buildings, and green campus activities across the US and the world, it is argued that such advance can be part of the larger cultural project of sustainability, above and beyond technical innovations. In the US, universities can voluntarily participate in the Sustainability Tracking, Assessment & Rating System™, which is a transparent, self-reporting framework for colleges and universities to measure their sustainability performance (AASHE 2015). There is also the annual Princeton review of green colleges, with testimonies such as

“Colleges train the next generation of leaders who will ultimately be responsible for putting green ideas into practice.” (Princeton review 2015, p3).

The young generations (as one of the targeted population for this study) is the foremost important groups in preparation for a sustainable future. It is hoped that studying the campus buildings and providing feedback for future improvements can partly educate students about sustainability issues. These young people will join different industries after graduation, and will be the next generation of industrial leaders, who will make decisions and collectively change the current unsustainable practices within industries, technically, behaviorally, and psychologically.

A residential dining hall (named as Brody hereafter) at Michigan State Universiy (MSU) was selected as the study site. Until August 2016, MSU has a total of 10 buildings on campus that are LEED certified, and 1,559,273 square feet of MSU-owned space has been LEED registered (MSUIPF 2016). There is a USGBC student chapter on campus promoting continuous improvement of building performance. MSU is one of the nation’s top sustainable campuses and has been recognized by “The Princeton Review’s Guide to Green Colleges” (MSUtoday 2014). MSU also uses the least electricity per square foot among the Big Ten universities (MSUsustainability 2016).

The building itself is a stand-alone addition to the original building and was built in 2011, at a size of 33,832 sq.ft. The building is certified at the silver level of LEED and is a multi-functional building used for housing, lecturing, and studying. It has the largest dining hall on MSU campus on the second floor. It is hoped that studying the campus building can indirectly educate students about sustainability. Indeed, several respondents mentioned in the commentary page that they had learned about the green design through completing the survey. There are several other LEED buildings that might have been chosen as the study site, although it was found that they are smaller is size, mainly used for academic purposes, and also under a high-level security that discourages external users. Brody, however, has a well-mixed user groups, including students, staff, faculty, local residents and external visitors who visit for a variety of reasons (e.g., classes, food, conferences).

A site visit was offered to the researchers by the campus sustainability manager to introduce the buildings' green features. The lighting system is automatic and whenever the pre-defined indoor luminance level is reached, the artificial lighting is not used. People are provided with natural light and outside views in most spaces of the building, with daylight and outdoor views provided for over 75% of the space (USGBC 2016b). Due to its unique culinary service provided, the daily operation incorporates relevant sustainable features such as sourcing food from local organic farms, organizing a "healthy food for you" section by the chef. The building achieves 4 out of 5 credits in the water efficiency category in LEED, and the kitchen employs 100% food waste recycling system (USGBC 2016b). Other than the green building technologies employed, the layout and the furniture are specifically designed for catering different purposes and improving user experiences. There are sofa tables for group chatting, and tall tables and chairs for individual study. The sustainability manager mentioned the overall layout as a green design as it mimics several smaller restaurants within a bigger restaurant, with each section separated by internal decorative walls, or wood screens. Such a design does not earn direct credits from LEED certification, though, it features the concept of design for the real people and real world.

6.2.2 The Working Procedures

The research procedures and logics are illustrated (Figure 8) to provide schematic views. The focus of this study investigates sustainable communication and how people perceive the green design, as well as testing people's knowledge regarding the green building design.

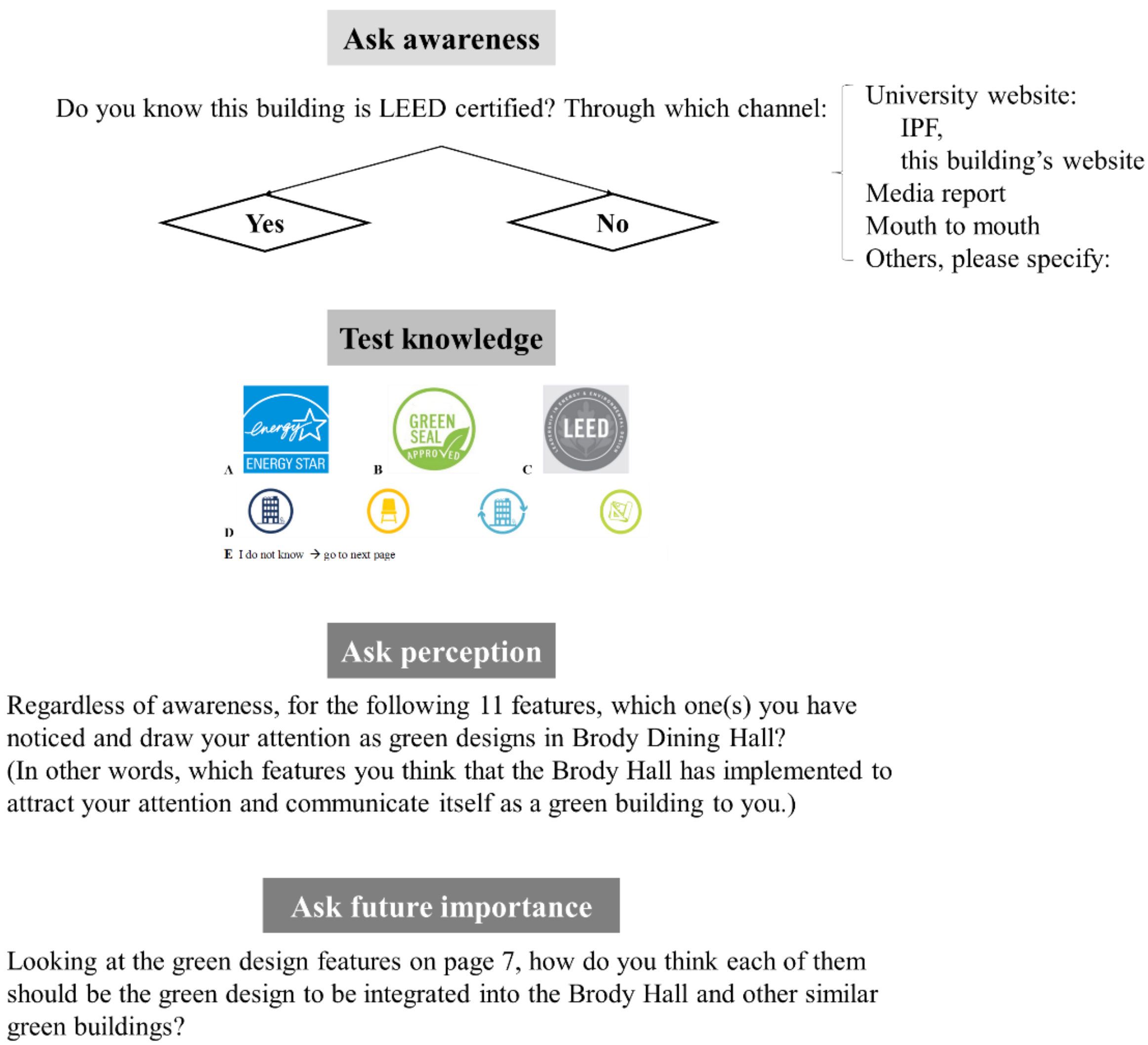


Figure 8. The working procedures and logics for understanding major aspects that the green building shall afford, including the aware-ability, the know-ability, and the perceive-ability, as well as how people prioritize each design for future implementation.

This study is explorative and observational in nature as it uses a survey study on a particular building, with mixed research methods, to identify associations among variables without extracting casual relationships. A survey questionnaire was prepared on the four aspects:

testing the awareness, testing the knowledge, asking the perception of selected green designs and their future importance. Finally, personal background factors were answered.

The scope of this study assumes the built environment is static during the study. Figure 2 in Chapter 3 illustrates the overall feedback loops with a temporal scale, and environment-user dynamics incorporate both how the environment impacts the users as well as how the users can change and alter the environment, which is not studied in detail in this empirical study. Such mutual dynamics could be investigated with a longitudinal approach using the research framework proposed in Chapter 4.

Before preparing the questionnaire, the background information on the study site was searched through the archival method (e.g., searching the building’s website, the university’s Infrastructure Planning and Facilities website, relative media reports, and the USGBC project archival). Following the site visit and a semi-structured interview with the sustainability manager, a total of 11 green designs that have a potential to be perceived by the users were listed (Figure 9).

The survey was carried out around the final exam week of the spring semester in 2016. The sampling method was convenience sampling where several researchers were presented at the entrance of the building every day from 11AM to 6PM for three days, approaching each person as they entered the building. Convenience sampling was selected as the sampling method since the researchers could not proactively seek out the population that uses the building, which is dynamic and changing over time. Not every single person coming into the building could be approached, especially during peak times. The questionnaire was handed out in person and the respondent could either sit at the provided table to finish it or take it elsewhere and return it later on. Researchers particularly mentioned to the respondents that they should complete the questionnaire on their own. It is assumed that the samples are independent of each other, and that there is independence within each sample.

6.2.3 The Questionnaire

The questionnaire sent out include the four major sections (6.2.3.1 to 6.2.3.4) as well as a background information section (6.2.3.5). The study's purpose and definitions on terminologies are provided on the cover page. Such an explanation is considered appropriate to familiarize the respondents with relevant information. The questions were coded before analysis. A total of 177 questionnaires were returned and those with low-quality data are discarded, defined as those with over 80% of the data entry missing for either one of the four sections (Figure 8). After discarding the low-quality questionnaires, a total of 153 were used for analysis later on. Other than the low-quality questionnaires discarded, there were occasional missing data among those 153 samples, and they were treated as the following. There were four samples among the 153 with missing data on the section of future importance (two samples with one missing value and another two samples with two missing values among the 11 elements). In these four cases, a score 0 (least importance) was substituted for missing values for conservative estimation. There were nine samples with missing data on the section of perceive-ability (with either one or two missing values) and the mean value was replaced.

Aware-ability—awareness about the building being a green building: Respondents self-reported whether or not they were aware that the Brody is a green building, if they were aware, then the respondents answered through which channel(s) they had become aware: the university website, this building's own website, media reports, word of mouth, the educational signs in the building, and/or others as they specified. The respondent who was aware that Brody is green was later on coded as awareness = 1, and awareness = 0 for those who were not aware.

Know-ability—knowledge about green buildings: The respondent's knowledge of the green building was tested by two questions. First, they were asked whether they can recognize the certification logo that represents the green building certification schemes most widely adopted in the U.S., three other logos were presented together with the correct answer—LEED logo: the Energy Star logo, the Green Seal logo, and the Green Star logo (representing the Australian green building certification scheme). Alternatively, they can have chosen "I do not know" without further answering the second question, which tested whether they knew the certification level of the studied building. The first question was short-named as "LEED" for further analysis, coded with 1 for the correct answer and 0 for all other answers. The second question was short-named as "level", coded with 1 for knowing the level and 0 otherwise.

Perceive-ability—perception about different green design features: Among the total 11 green designs listed, the respondents were encouraged to choose no more than five items that they thought were most perceivable and caught their attention as green designs. This would keep a relatively short time for the respondents to answer the questionnaire to remain accuracy, as well as to focus on the most perceivable items. The coding schemes made sure that no matter how many features were chosen, all the features were summed up to a total of 15 points. If five features were chosen (as the majority respondents), then 5, 4, 3, 2, and 1 point(s) were attributed to each of them in order. If over eight (including eight) were chosen, the first eight features were selected (discarding the last three, which were comparatively less perceivable), with the following scores attributed to each feature: 3.275, 2.875, 2.475, 2.075, 1.675, 1.275, 0.875, and 0.475 point(s). The coding ensured the same gap between each selected design with a total of 15 points. Similar schemes were applied when different numbers of items were chosen. The different points attributed to each feature were used for calculating the relative perceive-ability.

According to the two affordances of a building (Koutamanis 2006), the 11 green design features can be presumably categorized as either building product-related or space-related, underlying different spatial scales. The feature Vw, St, and L/O are exclusively related to building space, while Ltg, En, Mtl, Edu, and Veg are features that specifically related to building products. The remaining features lie in between, which are the building product with a larger spatial scale.

Future importance of selected green design: The respondents filled in a 0 to 5 scale regarding how each green design feature should be integrated into the future design in a similar type of building. Here, 0 means the feature is not at all important to a green building, and 1 to 5 means slightly, somewhat, moderately, very and extremely important, respectively.

Background factors: Respondents answered questions regarding: the frequency of using the building, the length of using the building from the first time they used it, the usage (i.e. for what reasons they use the building), their age, gender, role/occupation, the prior knowledge on green building/design topics, and the self-reported environmental consciousness on a 0 to 5 scale. For non-numeric factors, they were coded for further analysis. The frequency was coded as: 1 = 1st visit, 2 = occasional, 3 = monthly, 4 = weekly, and 5 = daily. The usage is transferred to: for food only = 1, for other reasons = 2. Gender was transferred to: female = 1, male = 2, and others = 3. The prior knowledge was transferred to: layman = 1, familiar with the topic = 2, and the expert = 3.

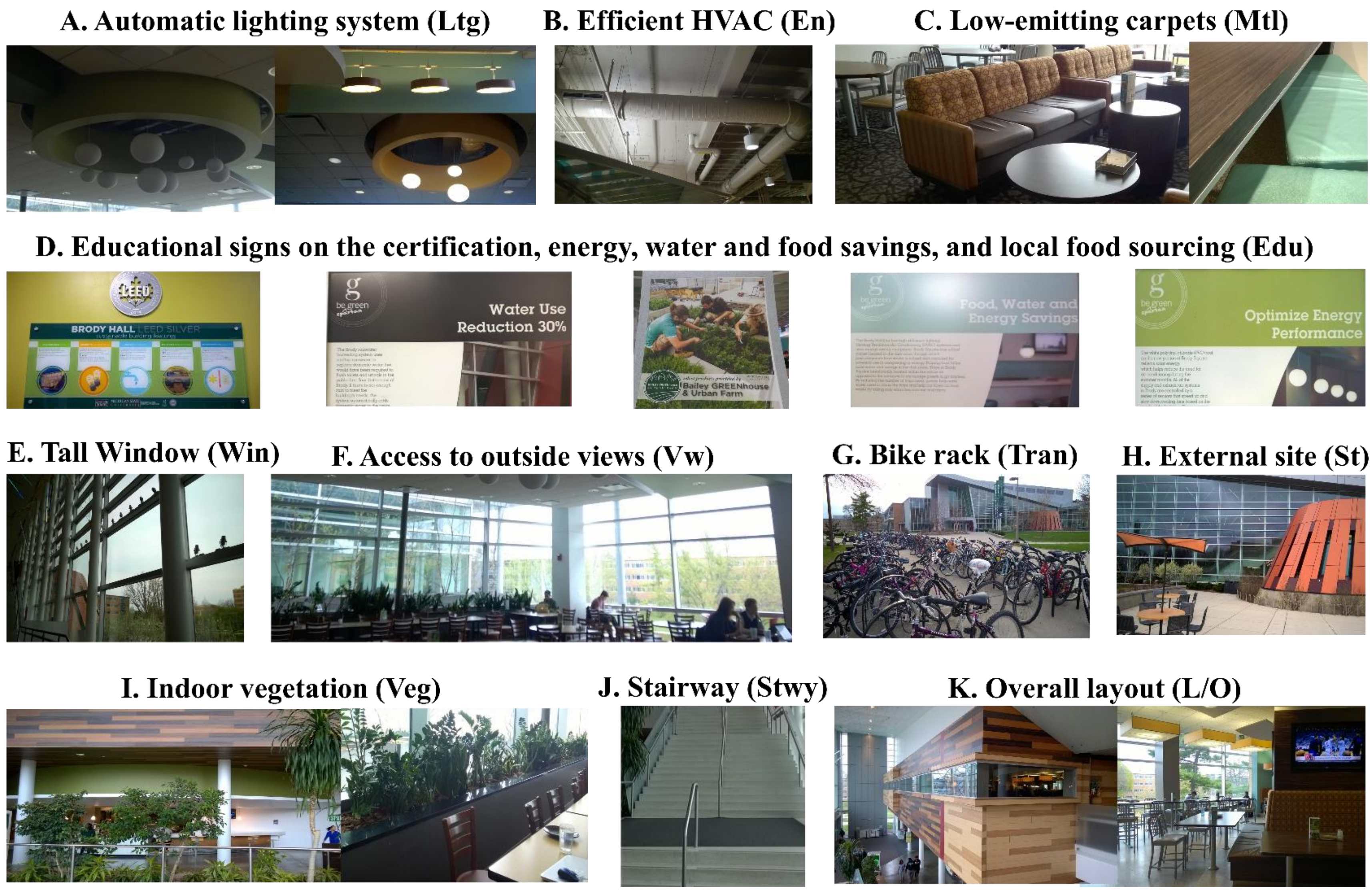


Figure 9. The photo elicitation shown to the respondents regarding the selected green design features implemented in the study site. The short-name for each feature follows the full name in the bracket.

6.2.4 Analysis

The R programming language was used for statistical analysis (Rdevelopmentcoreteam 2008). For descriptive correlational analysis, all coded categorical data are treated as factors, the mixed.cor() function and pairs.panels() function provided by "psych" package (Revelle 2014) were used for calculating correlation between variables.

The analysis on perceive-ability and future importance were stratified according to awareness and the knowledge, respectively, for the following reasons. Being aware that Brody is green does not require deliberate acquirement of knowledge, whereas the knowledge on green buildings requires more active and intentional acquisition of knowledge on the topic. In corollary, the perception about the green designs is instinctive and is subconscious measures regarding people's impressions about the building's green designs. The weight placed on certain design's future importance, however, involves more rational thinking and reasoning about what should be implemented to achieve a green building, which, might be affected by one's understanding and knowledge about green buildings. Thus, it is aimed to find out the differences in how people perceive about the current design according to the awareness—a type of perceptual knowledge; and differences in how people prioritize different green design according to their actual knowledge on green buildings —a type of rational knowledge.

Aware-ability: The communication channels were counted to identify the effectiveness of each channel. To extract the effects of background factors on the awareness, the descriptive correlation matrix was constructed first, then those factors with relatively higher correlation with awareness were explored further. Two-way independence test (i.e. Chi-square test) between awareness and the extracted factors was carried out first. Then conditional associations were performed on those factors that were not independent from awareness: given $factor_1$, what are the conditional associations between awareness and $factor_2$, so on so forth. The background factors that were highly correlated with awareness were studied together with the communication channels to extract their potential interactions. Practically, for analysis and graphic output, the original frequency with 5 categories were combined into three categories as: 1 = 1^{st}-time visit + occasional user (2 + 21 samples), 3 = monthly and weekly users (19 + 21 samples), and 5 = daily users (90 samples).

Know-ability: The knowledge level was counted as the percentage of people who could answer the questions correctly. To study the relationships between awareness and the knowledge (with two variables—knowing LEED logo and certification level of Brody—“LEED” and “level”), conditional independence tests were performed on the three-way tables. Furthermore, log-linear models were fitted against all possible combinations of independence, using loglm() function from the vcd package in R (Meyer et al. 2015), including: the mutual independence, the joint independence, the conditional independence, the all two-way associations, and the saturated three-way associations (Friendly 2016). The best-fitted model was then identified through ANOVA(), through analysis of Deviance for model selection (Sakate and Kashid 2014).

Perceive-ability: The most perceivable green designs (top five) were identified through frequency analysis (i.e. how many times each feature has been selected), as well as calculating the mean score of each feature regarding its relative perceive-ability. Exploratory factor analysis was carried out on the 11 green design features to study how people perceived green designs at different spatial scales. Two factors were to be extracted – the product or the space-related green designs. Two algorithms were performed, one with the traditional factanal() function with varimax rotation, returning factors that were orthogonal; and the other using fa.poly() function from the psych package with oblimin rotation, allowing the factors not to be orthogonal. The fa.poly() function is specifically useful for the factor structure of categorical items (Revelle, 2011).

With the reduced dimension of perception data from the exploratory factor analysis, the question of whether people perceive green design features differently according to their awareness was tested using two-sample test of proportion (using the prop.test() function in R), and Mann-Whitney U test (using wilcox.test() function in R). The proportion test was used to compare the frequency (i.e. the proportion of people who select a specific feature). The Mann-Whitney U test was used to compare the distribution shape and the locations of the perceive-ability scores. The 11 green designs were re-grouped according to the reduced dimension, using average score from the original variables when forming a new variable.

Future importance of selected green design: The most prioritized green designs for future buildings were identified through comparing the mean scores (on a scale of 0 to 5 that each feature receives). The descriptive correlation matrix was constructed for: 1) the current perception and future importance of each green design; 2) within future importance for each green design; and 3) the knowledge on green buildings and on prioritizing future green design.

Unlike perception, which involves two different measurements—the frequency and relative perceive-ability, for future importance, no frequency was measured. It was tested with Kruskal-Wallis test (using kruskal.test() function) to identify whether people prioritize each green design differently according to their knowledge. There were three groups of knowledge—not knowing the correct answers for either of the knowledge test, knowing one of them, and knowing both. Kruskal-Wallis test was used to test the null hypothesis that multiple population distribution functions are identical against the alternative hypothesis that they differ by location (Hollander and Wolfe 1973).

6.3 Results

The raw data were coded according to the analysis plan outlined in the previous section. No data transformation was performed and due to non-normality of most categorical variables, non-parametric statistical methods were employed (e.g., Mann-Whitney U Test, Kruskal-Wallis test). Overall, no abnormal patterns are found within the demographic and background factors. The majority of respondents are undergraduate students (n=122). Most of them used the building on a daily basis (n=89). Most people (n=117) come here for food only, while others also visit the building for other purposes such as using the lecture rooms on the first floor. Five people claimed to be experts regarding prior knowledge about green buildings before taking this survey, 89 were of laymen, and the remaining claimed to be familiar with the topic. Most people stated they were moderately environmentally conscious (n=76), followed by very conscious (n=36), and somehow conscious (n=22). The differentiation between the user groups and their potential effects to the aware-ability, know-ability, perceive-ability, and future importance were not statistically tested, due to the significantly unequal sample size of each group (Table 7). The potential effects of background factors were investigated under each “x-ability” (sections 6.3.2 to 6.3.5). Descriptively, the percentage of respondents according to their user groups had been calculated according to their awareness (Table 7).

Table 7. Background characteristics and the percentage of respondents who are aware or not aware about the Brody being green based on different user groups.

		Total (# of people)	Aware (%) (92 are aware)		Not aware (%) (61 are not aware)	
			Frequency	%	Frequency	%
Frequency of using the building	1st time user	2	1	1.1	1	1.6
	Occasionally	21	6	6.5	15	2.5
	Monthly	19	15	16.3	4	6.5
	Weekly	21	11	12.0	10	16.4
	Daily	90	59	64.1	31	51.0
Time spent using the building	≤ 1 yr	80	50	54.3	30	49.2
	> 1 yr, ≤ 2 yrs	37	21	22.8	16	26.2
	> 2 yrs, ≤ 3 yrs	19	10	10.9	9	14.8
	> 3 yrs	17	11	12.0	6	9.8
Occupation/role on campus	Undergraduate	122	77	83.6	45	73.8
	Graduate	5	3	3.3	2	3.3
	Faculty/staff	6	3	3.3	3	4.9
	Local residents	11	6	6.5	5	8.2
	External visitors	9	3	3.3	6	9.8
Why use the building	For food	117	73	79.3	44	72.1
	Other reasons	36	19	20.7	17	27.9
Age	≤ 25	128	81	88	47	77
	> 25, ≤ 40	7	3	3.3	4	6.6
	> 40	18	8	8.7	10	16.4
Gender	Female	84	51	55.4	33	54.1
	Male	68	40	43.5	28	45.9
	Other	1	1	1.1	0	0.0

6.3.1 Aware-ability

Out of the 153 samples, 92 respondents were aware that the building is a green building. Out of all the communication channels that people had become aware, over one-third of the respondents selected the educational signs in the building as the only channel that they become aware (36 out of 92), followed by word of mouth (21), while 11 choose both of them. The university websites appear to be a less effective channel, and the media coverage is the least helpful.

Among all the background factors, awareness was most correlated with the prior green building knowledge (the more knowledgeable about green buildings, the more chances a person is aware of Brody being green). The awareness was also weakly correlated with the frequency of using the building, as well as the environmental consciousness a person holds. The chi-square test between awareness and the above three background factors showed that the null hypothesis of independence was accepted between awareness and environmental consciousness, which was discarded in further analysis. For the frequency and prior knowledge, their independence with awareness was rejected (with both of the test p-value less than 0.001).

The analysis of the conditional associations between awareness, the frequency, and the prior knowledge showed that when the respondents were laymen about green buildings (i.e. prior knowledge =1), the awareness increased with the increase of frequency of using the building from very rare (=1) to more frequent (=3), but not further (frequency = 5) (Figure 10). Contrarily, for people who were either familiar or expert in the green building before this survey, their awareness of Brody being green and the frequency remained statistically independent (Figure 10).

The most effective channel—the educational signs—was tested against the frequency of using the building, and it was found that noticing the signs were not independent of the frequency. Their interactions yielded similar patterns as the prior knowledge (Figure 10). For those people who did not see the educational signs in the building: 1) when their frequency of visiting the building increased from 1 to 3, statistically, the probability of becoming aware of Brody being green increased at alpha = 0.05 level; 2) the awareness became independent from the frequency when it further increased from 3 to 5 (i.e. daily users).

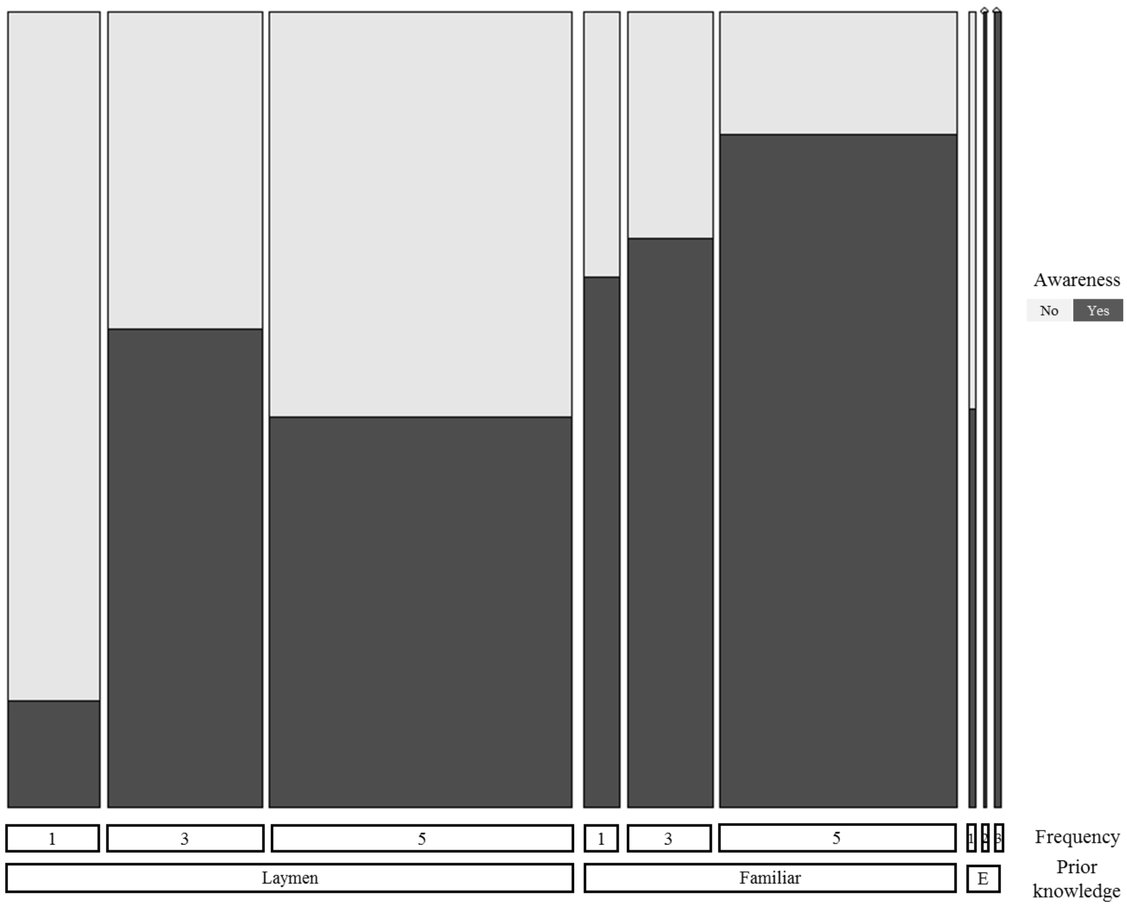


Figure 10. Conditional independence plot visualizing the relationships between the frequency (three levels: 1 = rare, 3 = monthly and weekly, 5 = daily) and the awareness (two levels: yes or no), given respondents' prior knowledge about green buildings (three levels: laymen, familiar, or experts).

6.3.2 Know-ability

Less than a third respondent could answer either of the two knowledge questions correctly: recognizing the LEED logo (K1) or knowing the certification level of the building (K2). Less than 10% of the respondents could answer both questions correctly. Among all 109 people who could not recognize LEED logo, 49 people answered "I do not know". Among the 60 people whose answers were incorrect, 45 chose the "Green Seal" logo () as LEED, and 9 were confused with the "Energy Star" logo.

The conditional independence test found that regardless of whether or not people can recognize LEED logo, being aware of Brody as a green building was independent from knowing its certification level. The log-linear models revealed that the joint independence model had the best fit, indicating there was an association between the two knowledge variables, whereas the awareness was independent of both of the two knowledge variables, as well as independent of their combinations. All two-way independence model also obtained a good fit.

The mosaic plots provided a "lack of fit" indication (Meyer et al., 2015), with each colored residual violating the null hypotheses of independence. Both the mutual independence model (Figure 11.a) and the conditional independence model (Figure 11.b) could not capture the interactions between the two knowledge variables (K1 and K_2) conditioned on people’s awareness (Figure 11).

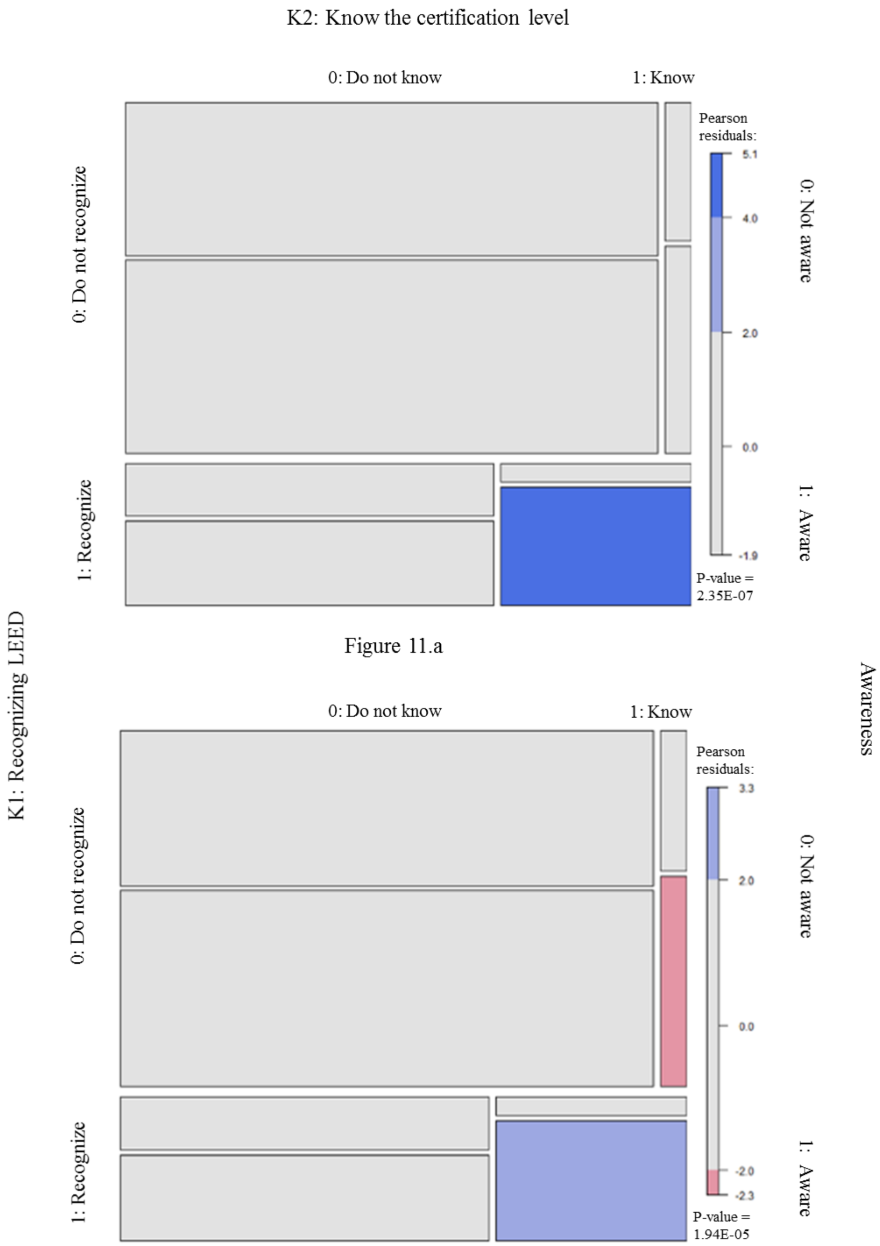


Figure 11.b

Figure 11. Mosaic plot showing the lack of fit for the two log-linear models (the mutual/conditional independence model) investigating independence between the two knowledge variables (K1 and K2) and the awareness. Figure 11.a indicates that when awareness = 1, K1 and K2 are positively associated (the blue color). Figure 11.b indicates that when awareness = 0, K1 and K2 are negatively associated (the red color).

6.3.3 Perceive-ability

The frequency analysis found that Edu (educational signs), Vw (outside view), and Veg (indoor vegetation) were the mostly perceived green designs with 101, 103, and 104 people choosing them. Ltg (lighting) and Win (tall window) followed, both with 81 people selecting them. About 60-65 people also chose En (efficient HVAC), Tran (bike rack), St (external site), and L/O (overall layout). The least selected were Mtl (low-emitting furniture) and Stwy (stairway). The top five selected features also scored the highest regarding their relative perceive-ability, with the order slightly changed.

The explorative factor analysis indicated that the pre-assumed spatial patterns were supported to some extent. Two algorithms show slightly different results, though the major trend was similar. The first factor extracted was related to building space: Win (tall window), Vw (outside views), St (external site), Stwy (stairway) and L/O (overall layout) fell under this factor under oblimin rotation, while Win, St, and L/O were also supported by the varimax algorithm. The second factor extracted was related to building product: Ltg (lighting), En (efficient HVAC), and Mtl (low-emitting furniture) fell under this factor with both algorithms. One product-related feature—Edu (educational signs), however, was not identified as a variable under the second factor. Tran (bike rack) was not grouped to either factor for both algorithms. Similar results were found for Veg (indoor vegetation) with the varimax rotation.

The original 11 green designs were re-grouped to five new variables for the test on the proportion and distribution (Figure 12). Tran (bike rack) was left out as it did not belong to either factor and the least perceived. Five new variables included: Edu (educational signs), Vw (outside views), Veg (indoor vegetation), S, and P. The first three used their original name and were among the most perceived features and not combined with any other features; S indicated the new variable combining space-related features (Win (tall window), St (external site), Stwy (stairway), and L/O (overall layout)); and P indicated the variable combining product-related features (Ltg (lighting), En (HVAC), and Mtl (low-emitting furniture)).

The two-sample test of proportion (with two-sided tests) indicated that, statistically, the proportion of people selecting Edu differed significantly according to their awareness at P-value = 0.0022. The respondents' preference on Vw , Veg, S, and P did not differ significantly according to their awareness at alpha = 0.1 level.

When comparing the distribution shape and center location using the Mann-Whitney U Test, Edu showed significant differences within the two different awareness groups, so did S, where both had a P-value less than 0.05 (Figure 12). Their pattern reversed: Edu received higher scores for people who were aware of Brody being green, whereas S received higher scores for people who were not aware of Brody being green. For Vw, Veg, and P, no differences were found among the two awareness groups.

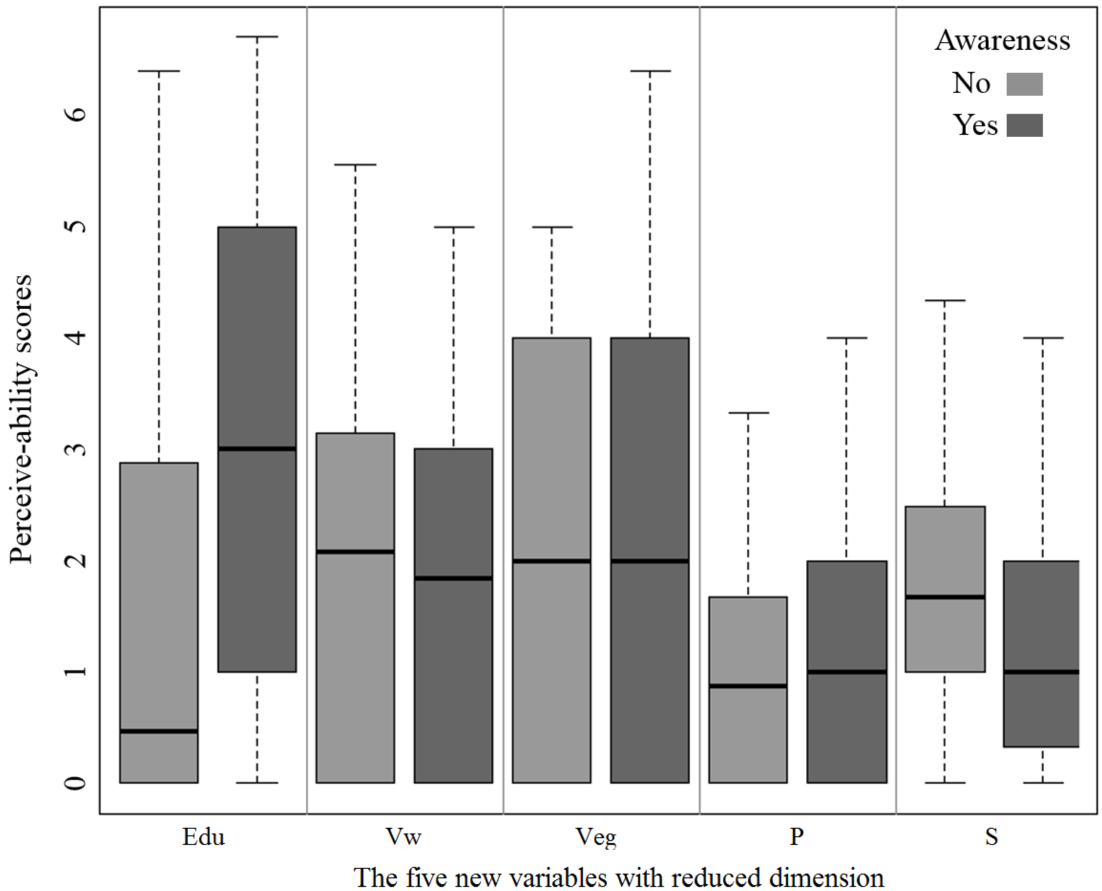


Figure 12. The perceive-ability on the new, reduced five variables according to people's awareness. The Edu (educational signs), Vw (outside views), and Veg (indoor vegetation) are the original features, P combines product-related variables, and S combines space-related variables.

6.3.4 Future Importance

The importance given to future design was not found to be significantly correlated with the current perception about the 11 green designs. The correlation within future importance themselves found that Win (tall window) and Vw (outside views) had the highest correlation at 0.68. The second highest correlation (0.60) was between Stwy (stairway) and L/O (overall layout). The highly correlated groups were either between features regarding building space, or between building products, but not between the two groups.

Different findings were observed on how people prioritize future designs from how they perceive current green designs in Brody. The most important green designs that should be implemented were En (efficient HVAC), Ltg (lighting), Veg (indoor vegetation), Tran (bike rack), and Edu (educational signs) (Table 8). Only Edu, Ltg, and Veg were overlapped with the top five perceived features.

When grouping the future importance into the three knowledge groups, people who could answer correctly on one of the two knowledge questions always weighted the highest priority to each of the 11 green designs (Table 8), instead of those who were the most knowledgeable (answering both questions correctly). Such differences were not statistically significant, though. The Kruskal-Wallis test found that, for all the 11 features, at alpha = 0.1 level, only E showed a different distribution among the three groups of knowledge (Table 8).

Table 8. The perceive-ability for each green design feature implemented in Brody, and the prioritizing of each of them for future design (Knwl = knowledge: knwl = 0 means knowing neither, knwl = 1 means knowing either one, knwl = 2 means knowing both questions).

The 11 green design features	Perceived green design		Future importance				
	Frequency (out of 153)	Perceive-ability score	Future importance	Knwl = 0 (n = 104)	Knwl = 1 (n = 34)	Knwl = 2 (n = 15)	Kruskal-Wallis test (p-value)
Ltg (lighting system)	81	1.75	3.61	3.36	4.29	3.87	0.93
En (efficient HVAC)	60	1.02	3.69	3.45	4.29	3.93	0.55
Mtl (low-emitting furniture)	40	0.61	2.78	2.67	3.15	2.73	0.75
Edu (educational signs)	101	2.22	3.11	3.06	3.32	3.00	0.84
Win (tall window)	81	1.39	2.84	2.78	3.24	2.33	0.09
Vw (outside view)	103	1.96	2.99	2.87	3.35	3.00	0.89
Tran (bike rack)	65	1.03	3.23	2.99	3.76	3.67	0.17
St (external site)	63	1.02	2.72	2.65	3.03	2.47	0.41
Veg (indoor vegetation)	104	2.13	3.27	3.22	3.44	3.20	0.58
Stwy (stairway)	47	0.74	2.37	2.29	2.79	1.93	0.89
L/O (overall layout)	63	1.14	2.92	2.92	2.97	2.80	0.57

6.4 Discussion

Due to an extremely unequal sample size for most of the user characteristics, no statistical test was performed on the several affordances studied, instead, the correlational analysis revealed that for know-ability, perceive-ability, and how people weigh future important, no significant correlation was found between the user characteristics and the studied affordances. Such findings suggest that using the building as a medium to communicate sustainability might not be affected by user’s gender, age, occupation. On the other hand, assuming that people become more familiar with the building when they visit the building more frequently, then this factor—users’ familiarity with the building could potentially yield interactions with the green design implemented within the building to affect their awareness and to promote their knowledge. And such interaction needs to be studied in future research with a larger sample size, which will enable more robust statistical analysis.

6.4.1 Aware-ability

The overall aware-ability that Brody affords was satisfying, and 60% of the respondents were aware of its green status. This finding is similar to a similar study conducted earlier (Cranz et al. 2014), with a different target population. Educational signs within the building were proven to be the most effective communication channel, reinforcing the integration of “a comprehensive signage program built into the building's spaces to educate the occupants and visitors of the benefits of green buildings” from the innovation category in LEED (USGBC 2016c).

The frequency of using the building was found to be an important factor to affecting awareness. When people did not have prior knowledge, the more frequent they visited the building, the higher the chance that they became aware of the building being green. This phenomenon can be explained by looking at the correlation between the frequency of building use and noticing the educational signs in the building. When one visits the building more often, the chance of him/her noticing the educational signs becomes higher, resulting in their awareness. For those who did not see the educational signs, their awareness increased along with frequency probably due to other communication channels (e.g., word of mouth).

Unsurprisingly, the three background factors that had relative more associations with the awareness included prior knowledge, the frequency of building use, and the environmental consciousness. Other individual factors not considered here, such as comfort and satisfaction might be explored in future. Deep-level cultural influence was not studied, similarly, the effects of social norms can be further studied. Since the process of how knowledge is learned, perception is felt, behaviors are conducted in a setting are generally in accordance with the norms of a given socio-cultural system.

6.4.2 Know-ability

The know-ability the building affords was unsatisfactory compared with aware-ability. Programs driving the green university movement in the U.S. exist (AmericanSchool&University 2008). The Center for Green Schools at USGBC also claims that education is the core reason for greening schools as "tomorrow's future leaders are in school today" (USGBC 2011). Nevertheless, the effective way of achieving the sustainable education needs to be further researched.

An unexpectedly large number of people confused the "Green Seal" logo with LEED, though it was initially expected that the "Energy Star" logo would be the most chosen incorrect answer as most people are aware of the logo in their daily life (USEPA 2015). When people know more about the "Energy Star", they could be more confirmative that it is not for green buildings alone. On the other hand, the “Green Seal” logo is less used in consumer products directly, and the word “green” might be misleading, resulting in more people choosing this logo.

Konwing the LEED logo did not affect the conditional independence between the awareness and knowing the certification level. This is probably due to the following reasons. Although the LEED badge on the first floor clearly indicated the building’s certification level, people might not have carefully read over the whole sign, instead, they might have glanced over it and seen the “LEED” instead of the smaller character “Silver” underneath the logo. Thus, how to implement a well-designed and successful “comprehensive signage program” suggested by LEED (USGBC 2016c) remains a future research and practical priority.

The log-linear models indicated that when people were aware of Brody being green, the independence between the two knowledge variables did not hold. There was an interaction between people who were aware of the building being green, as well as being the most knowledgeable. How awareness might stimulate people’s desire to learn more about a green building needs to be further studied.

6.4.3 Perceive-ability

The findings indicate that people’s appraisal of most green design features were not affected by their awareness of the green status of the building. Their attention to educational signs, however, differed significantly based on awareness. This might be explained by the fact that those who paid attention to the educational signs became aware of the building being green.

When a certain green design feature was perceived and selected, the perceive-ability order became a different type of decision. While the proportion of people who chose space-related factors did not differ significantly among the two awareness groups, the perceive-ability order, did show differences. Those who were not aware of the building being green tend to prefer space-related features more than those who were aware. The question remains whether higher priority given to the space-related features makes people neglect smaller-scale products, such as the educational signs, which was the most effective communication channels to raise the awareness.

Presumably, before conducting the survey, the Ltg, En, Mtl, and Edu were specifically related to building products. However, Edu was not identified as a variable under the product-related latent factor. This could be explained by the fact that Ltg, En, and Mtl are very specific green building technologies/materials, compared to Edu, which is for educational purpose, as well as to the space-related features, which are not specifically designed to improve a specific sustainable aspect. Another interesting finding also suggested a spatial dimension, where the most significant negative correlation found among all 11 designs was between the educational signs and the access to outside views.

The above findings indicate a hypothesis that can be explored in future regarding the different spatial perspective of a person: whether those who tend to notice features at an overall spatial scale might neglect small-scale products. Previous studies already demonstrated the spatial differentiations among occupants in one building when studying their satisfaction (Hua et al. 2014). At a larger geographical (i.e. regional) scale, the spatial pattern was supported conceptually and empirically by Cidell and Beata (2009, 2013), where the researchers concluded that the LEED credits are found to be grouped into spatially-specific credits (e.g., sustainable sites, water efficiency, and energy and atmosphere) and non-spatial credits (e.g., materials and resources, indoor environmental quality, and innovation and design) (Cidell and Beata 2009, 2013).

6.4.4 Future Importance

The correlation between the importance given to future design shows that people tend to either give priority to space-related features or product-related features without a crossover. This indicates that most people might be either a space perspective person or a product perspective person, but not both at the same time.

The knowledge level did not appear to affect people's views on future design. People who were more knowledgeable did not tend to think a particular green design shall be more important. Statistically, only the the Win (tall window) stands out at alpha = 0.1 level, and people who were most knowledgeable gave the lowest priority to this feature. Giving a more detailed look at the distribution of how the most knowledgeable people prioritized the feature, it showed a reversed bell shape. The reasons why the most knowledgeable people tended to hold strong feelings – either positive or negative views toward the large windows remain unexplained and will need further study to explain such patterns.

A noticeable finding was that people give exceptionally high weight to energy-related design (En), on the other hand, En received a low perceive-ability among all green design features in Brody. The possible explanation is that under the current policy emphasis on energy efficiency, people instinctively feel that a green building should incorporate such a feature. On the other hand, energy efficiency features are not as visible as other green design features, for example, the indoor vegetation, which received both high scores in perceive-ability in Brody and importance for future design. The un-visibility of energy efficient features might have prohibited them from being perceived directly by users, which indirectly demonstrates the importance of using appropriate signs to educate people.

The transportation-related design (Tran) also highlighted similar patterns as the feature En. While people might have acknowledged the importance of alternative and less emission-intensive transportations, they did not perceive it in the current building, probably due to following reasons: first, the bike rack is not located near the building, but within several hundreds of yards away from the building; second, people may not relate the transportation as an essential part of green buildings; finally, while people tended to acknowledge the importance of sustainable transportation, their current actual behavior did not choose such alternatives, possibly affecting their current perception.

6.5 Chapter Conclusions

Using a LEED certified building, this chapter explicitly studied several affordances that a green building shall convey: the aware-ability of the building being green, the know-ability of the users' knowledge about green building topics, the perceive-ability at different spatial scale of selected green designs, and their weighted importance for future implementation from users' perspective. The following users characteristics—gender, age, occupation/their role on campus, time spent since using the building, and reasons for visiting the building—did not contribute to significant differences in the outcome of the affordance studied. Though the frequency of using the building and users' prior knowledge on green building topics did affect the outcomes to some extent and resulted in interactions with different green design features, especially the educational signs presented in the building.

The results demonstrated that the aware-ability achieved was satisfactory and the educational signs were the most effective communication channel. The know-ability, however, achieved a low score and more effort is needed to promote knowledge distribution using a green building as a teaching tool. The spatial patterns (at building product scale vs. spatial scale) among different green designs were supported to some extent. The perceive-ability generally did not differ according to people's awareness. Regarding the future importance, people who were more knowledgeable about green buildings did not tend to think a particular green design was more important. The potential of using the affordance theory to guide and evaluate a green building and its designs has been demonstrated. When using the affordance theory for future green building design, a special attention is needed to specify the affordance through building product and/or building space. Similarly, a future research need is to inveistigate users' spatial perspective: whether those who tend to notice green design features at a building scale might neglect small-scale building products.

7. CONCLUSIONS

7.1 Summary

This work improved the understanding of how a green building can be used as a medium to communicate sustainability and influence the users' pro-environmental behaviors, as well as their awareness, knowledge, perception toward green building/design. The current understanding gained through relevant literature review showed that: 1) green buildings have the potential to promote people's pro-environmental attitudes and behaviors; 2) there exist links between how certain green design features are implemented and how they facilitate corresponding behaviors; and 3) the communicational and educational roles of buildings have been demonstrated among different building types, though less is studied in the context of green buildings. To systematically investigate the research topic, the concept of influential design was proposed and defined, raising two research challenges – theoretically and methodologically. An overall research framework was proposed incorporating the feedback loops between design-environment-use, with a focus on user experience.

The first study adopted the theory of planned behavior (TPB) from the communication science and provided a possible theoretical basis for studying influential design. It answered the questions on how green buildings communicate messages based on ideas from persuasive communication. The results identified two communication channels of a building: active instruction through face-to-face interpersonal transmission and passive instruction from the building itself. Previous studies were explained through the lens of the TPB where the active/passive instructions were found to locate at different positions along the causal chain of the TPB. Furthermore, a framework incorporating the TPB was proposed as a theoretical foundation to differentiate the two communication schemes and to help understand the role of visual persuasion of green building designs.

The second study proposed the hierarchical modelling to provide a possible solution to the methodological challenge. After analysis of the preliminary survey of employees working in a certified green building, it was ascertained that: 1) people were positively influenced and became more pro-environmental after moving into the green building; and 2) the visually-available green design elements were more persuasive than conceptual-only green design. A hypothetical hierarchical model was then demonstrated with simulated data to take account for 1) building level variations separating the visual and/or conceptual-only green designs; and 2) individual variations within each building considering their awareness about the building being green, perception toward the green design, and other personal background factors.

Finally, the affordance theory was used to evaluate the affordance that a green building shall support using a survey study in a LEED certified residential dining hall—the Brody hall at Michigan State University. A post-occupancy survey was performed on four aspects: the aware-ability, the know-ability, the perceive-ability, and the future importance. The results suggested that the building was satisfactory in promoting awareness while not promoting the users' knowledge about green buildings. Whether and how people perceive different green design elements indicate that people are dichotomous in the spatial evaluation of those elements. They either tend to notice the building product at a smaller spatial scale or building space at a larger spatial scale. Similarly, people give more weights to either the product-related or to the space-related green designs when choosing the most important aspects to be integrated into future green building design.

7.2 Philosophical, Theoretical and Methodological Contributions

The philosophical root of this research about the promotion, communication, and education of sustainability from built environment indicates a cultural assumption of sustainable development originated from western society. While this sustainable viewpoint swept across the world, one might ask questions such as whose buildings and whose value are based upon for the scholarly thinking and who set up the criteria for determining the sustainability of the built environment. The justification for such commonly adopted (and accepted) sustainability concepts is not a topic studied here. This research, however, transfers a message of shifting attention from technical sustainability to the root of any environmental crisis—a crisis of mind (Palmer and Finlay 2003). Similarly, Roslin (1996) argues that an ecologically aware society "has as much, if not more, potential for the conservation of resources than technical innovation".

The empirical findings in the spatial perspective (either product-focused or spatially-focused) from the green building users indicate that people tend to be dichotomous in spatial thinking and cognition. The relationships between the green design and the user behaviors found in Chapter 2 also reinforce the importance, as well as the potential manipulation of space for influential design. The spatial perspective identified in this research can contribute to theoretical research in general. For example, it is necessary to involve the spatial scale for the two antecedents of behavioral intention from the TPB—the subjective norms and the perceived behavioral control. Similarly, the physical proximity and the spatial location and/or distance of certain facilities in promoting perceived behavioral control might be considered.

The simulated hierarchical model in Chapter 5 aimed at the methodological contributions. The variable and causality issues were scrutinized by: 1) separating different design elements; and 2) clustering the analysis according to the individual building, as well as individuals within a building. Furthermore, the feedback loops introduced in this research and empirically tested in Chapter 6 can be used by one of the systematic building assessment methods—the whole building Life Cycle Assessment (LCA). Specifically, future research can gain insights upon the user experience extracted in this work and add in the environment-user dynamics to the whole building LCA. At a practical level, it is suggested to incorporate the sustainable communication and education credit into the current green building rating systems, ensuring the achievement of a virtuous cycle of green buildings and green users.

7.3 Limitations and Future Work

Types of stakeholders not considered: Within the whole building life cycle, there are feedback loops. In this work, all three studies focused on the users in the study scope. This was decided according to the research goal, and the research questions. However, other scopes are also essential to be considered in future research in order to understand more about the research area of the influential design. For example, it is important to consider how designers initially encode their ideas (e.g., sustainability) through design element embedded within the building and how users decode and interpret them. It is essential to include different stakeholders, including designers, maintenance, and renovation groups to study the influential design.

Building user groups not included: In the empirical study, convenience sampling schemes were adopted, thus, not all the users and user groups could be covered. First, there is the non-observation problems where not every single user of the building could have been possibly covered. Second, there is the non-response bias, where around 20% of people who took the questionnaire have not finished it and/or returned. Furthermore, there are individuals who should have been on the sampling list but were missing and a large number of users were not covered temporally. Lastly, due to the heterogeneity among building users, those inherently more influential in distributing feedback on future design/improvement were not covered.

Non-generalization due to the nature of survey study: The empirical study is based on a survey study, where the particular building site is in a fixed geographical location and the survey population targeted particular user groups. Such non-probability sampling techniques cannot give generalized answers to other building sites and building users.

Causal relationships not extracted: As stated in Chapter 4.2, to study influential building design, essentially, the causes from the building elements to the social outcome is needed. This problem is not solved by the second study where the analysis was tested against a hypothetical data simulation without real experimental data. The causality also cannot be confirmed by an observational study used in this explorative study. Although a "control" group from the conventional building is formed when comparing pro-environmental behaviors among pre-existing occupants from different buildings, there are many differences between the groups that cannot be controlled and measured. Thus, the effectiveness/influence of green buildings to occupants cannot be formally stated, in other words, the differences found between buildings may or may not be due to the presence of green design to occupants. When the situation allows, a longitudinal approach shall be utilized as the consideration of the whole feedback loop requires long-term efforts across the whole building life cycle, which crosses different temporal scales.

Types of buildings not differentiated: Throughout the two conceptual studies, the types of buildings are not differentiated, and the targeted building in the empirical study is restricted to the residential hall on campus. Other types of buildings, both residential and non-residential, need to be further studied. LEED-certified residential buildings in the US witnessed a significant increase from 31 in 2006 to 18,481 in 2013 (USGBC 2014). With the increase in residential buildings being built/renovated as green buildings, it is urgent to further research on using the building as a teaching tool and communicate sustainability.

Green building achievement levels not differentiated: Green buildings have different levels of achievement, shown by certification levels for those certified buildings, e.g., silver, gold or platinum for LEED system. Although it is arguable that different levels of certification (thus different levels of experience with green design features within the building) might result in different levels of awareness, perception, knowledge, and behavior, this topic is not scrutinized in this work.

Geographical and cultural differences to be considered: It is not answered in this work as to how people are affected by the surrounding built environment and landscape at different scale. In previous studies that look into the behavioral changes after the adoption of green technologies, different results were found in different countries (Keirstead 2007, Andersen 2013). The influence of an individual green building may differ significantly in different places based on local culture and social norms, which could be considered as a confounding issue, meaning that the contextual background affects both the development of green buildings and the behavioral changes of people. Future studies from different geographical locations are encouraged, but not included in this study.

The spatial cognition within a building: The third study empirically observed people's perceive-ability about green designs at different spatial scales, or, in the geographical sense, perceive-ability relates to the cognitive process about spatial properties of objects. Spatial properties can be referred to the two fundamental and generic features: the structuring and the scaling effects (Amedeo 2009). This study only considered the scaling effects (e.g., relative size) of different green designs, while the structuring effects (e.g., the arrangement, the configuration, the connection, and separation) and the influence on perceive-ability can be studied in the future.

7.4 Outlook

This research studied the connection of design, in the green building context, to the building users. It extends previous scholarly thinking on environmental determinism, and a new study area has been proposed—the influential design. It is hoped that this work will shed light on influential (green) design. The studies and surveys performed in this research are expected to add a new dimension to existing POE methods. Relevant studies are encouraged in developing countries where large-scale (sustainable) urban transformation and/or renewal are in progress.

APPENDICES

Appendix A. Definitions of Terminologies

Active instruction

In this study, it is defined: deliberate interventions incorporating communication medium of ‘face-to-face interpersonal transmission’ (Orr 1999) to influence building users’ behaviors.

Affordance

The actionable properties that the environment offers to the people (adopted from Gibson 1979).

Affordance theory

People recognize opportunities for action in the environment by perceiving the affordances of either object within the environment or the environment itself (Gibson 1979).

Architectural determinism

The environment facilitates or inhibits behavior, providing opportunities that influence the probability that behaviors will or will not occur (PsychologyDictionary 2016).

Aware-ability

In this study, awareness is defined as the building users are aware about the fact that the building is (or is not) a LEED certified green building. In corollary, “Aware-ability” is used specifically in the empirical study and means the ability/affordance of the LEED certified building to promote awareness among users.

Behaviors

Behavior is the aggregated response of a person resulting as a consequence of complex interactions between internal and external factors (Kaluarachchi and Jones 2013).

Conceptual only green design

In this study, it is defined: the design provides no visual evidence of its green features. Examples include implementing a waste management plan, using low-emitting materials during construction, and controlling indoor pollutants.

Environment-Behavior research

Studies that try to understand the relationship between form (e.g., the building structure) and function (e.g., user behavior) (Memmott and Keys 2015).

Environmental determinism

The environmental determinism (also as climatic determinism or geographical determinism) states there is a link between the behavioral patterns of people and the geographical area they inhabit (Lynch 1960).

Green building

Buildings that are healthier, apply more resource-efficient models of design, construction, operation, renovation, maintenance, and demolition in comparison to conventional buildings. It is used interchangeably with sustainable buildings throughout the dissertation. Buildings that are not green are named as conventional buildings.

Green designs

Elements of a building that make it be green. It is used interchangeable with green building designs throughout the paper.

Influential (building) design

It means that building design has the potential to influence building users' awareness, perception, knowledge, and behavior. They can encourage, facilitate, reinforce, or impede certain types of behaviors, and provide cues to remind people to behave in a certain way. Meanwhile, it is admitted they are not the only reasons that determine the actual behaviors.

Know-ability

This word is used specifically for the empirical study and means how the LEED certified building is educating the users about green building knowledge and ideas through users' observing or experiencing the building, and/or intentionally studying and investigating about the topic.

Passive instruction

In this study, it is defined: passive instruction incorporates non-human communication mediums, specifically, utilizes the building itself to influence building users' behaviors.

Perception

The process of achieving awareness and comprehending sensory information, incorporating both the content of a scene and a very quick unconscious assessment of what it is possible to do in the setting (Kaplan & Kaplan 1989).

Perceive-ability

This word is used specifically for the empirical study and indicates the order of how different green designs catch one's attention, in other words, which green design(s) are more perceivable among all those selected by the users.

Persuasion (and visual persuasion)

Persuasion refers to messages that are designed to change attitudes, beliefs, values and behavior (Ragsdale 2011). Similarly, visual persuasion in this study is defined: the visual green design *that is designed* to change attitudes, beliefs, values and behavior. The meaning of "that are designed" refers to that when the building is designed in that particular way, it inherently entails an encoding process of designers choosing a particular design, element, materials and layout to express the green status of the building, regardless of whether it is decoded by the users.

Physical settings

In this study, physical settings remind people of what is expected of them through certain cues embedded into them, such as a certain type of behavior or response. This term is used interchangeably with built environment/physical environment throughout the dissertation. The above definition relates to the definition of **behavior setting** in the Environment-Behavior research, which is an ecological unit consisting of interactions between a person's behavior and objects, time, and the immediate environment (Memmott and Keys 2015).

Sustainable behaviors

In this study, it is defined: behaviors by individuals or groups taken at the scale of a building and its surrounding site. The behaviors could be supported or interfered by the physical environment. They aim at contributing to a reduction in energy and water consumption, reduction of automobile dependency, promotion of 3R principle (reduce/recycle/reuse) of waste treatment, encourage to correctly categorize waste, and maintaining occupants' satisfaction of indoor environment quality while not increasing energy cost indirectly.

Sustainability

Sustainability is defined according to the ISO 15392 – *Sustainability in Building Construction* as "a state in which components of the ecosystem and their functions are maintained for the present and future generations, whereas components of the ecosystem include plants and animals, as well as humans and their physical environment." For humans, sustainability requires a balancing of key elements of human needs: the economic, environmental, social and cultural conditions for societies' existence.

The theory of planned behavior (TPB)

The TPB is a classical behavioral model for explaining and predicting behaviors through considering three core constructs of attitudes, subjective norms, and perceived behavioral control.

Visual green design

In this study, it is defined: those design elements that speaks of a building's green status. Examples include on-site renewable energies, interior design elements, interpretive signage, transparent waste bins, green-roofs/spaces, and indoor vegetation.

Appendix B. Results and Analysis from In-depth Review of Previous Studies

B.1 Green Buildings and Pro-Environmental Behaviors

Table 9. Previous studies on relationships between green building and occupants' pro-environmental attitudes/behaviors and other general environmental attitudes/behaviors studies.

Study	Data collection	Analysis approach	Independent variables	Dependent variables	Location	Major findings
(McCunn and Gifford 2012)	Questionnaire survey	Correlation analysis	n.a.	n.a.	15 LEED office buildings, Canada	Neither engagement nor environmental attitudes were correlated with green design features
(Rashid et al. 2012)	Questionnaire survey	Ccorrelation analysis, multiple regression	Individual workspace, departmental spaces	Environmental awareness, organizational image	One LEED office building, the US	Individual workspace and department space affect satisfaction then indirectly affect environmental attitude and organizational image
(O'Callaghan et al. 2012)	Questionnaire survey	Hierarchical multiple regression	Sustainable design, environmental attitudes	Utility usage	One green and one conventional residential community, Australia	Positive attitudes to environmental conservation correlated with lower energy use. Attitudes were not found to be a statistically significant predictor of energy use when analyzed with other predictors.
(Lynam 2007)	Mixed method: questionnaire survey and qualitative interviews	Grounded theory method; t-test for quantitative survey data	n.a.	n.a	One green and one conventional academic building in Canada	Analysis from interview showed green buildings send out pro-environmental messages to occupants so long as the occupants have awareness of the building's green status. The results from quantitative showed students in conventional buildings hold more pro-environmental attitudes.
(Deuble and de Dear 2012)	Questionnaire survey	Linear regression	Environmental attitude (NEP)	Forgiveness factor	Two academic buildings, Sydney, Australia	Occupant satisfaction levels on the POE were positively associated with environmental attitudes, though, 'the question of causality remains moot'.
(Hostetler and Noiseux 2010)	Questionnaire survey	ANCOVA; Man U Whitney	n.a.	n.a.	Two green and two conventional residential communities, Florida	Green homeowners reported more pro-environmental behaviors in only a few questions while no differences in attitudes
(Azizi and Wilkinson 2015)	Questionnaire survey	Man U Whitney test	n.a.	n.a.	One certified green, one non-certified green, one conventional office building, Malaysia	Occupants were motivated to practice energy-saving behaviors in green buildings provided that they know the building is designed green.
(Daniel et al. 2014)	Questionnaire survey	Paired T-test	n.a.	n.a.	Low-energy dwellings in Melbourne and Darwin, Australia	Occupants of low-energy dwellings showed higher biocentric concern and lower anthropocentric concern compared with control sample from the general population.

B.2 Relationships between Green Building Designs and Sustainable Behaviors

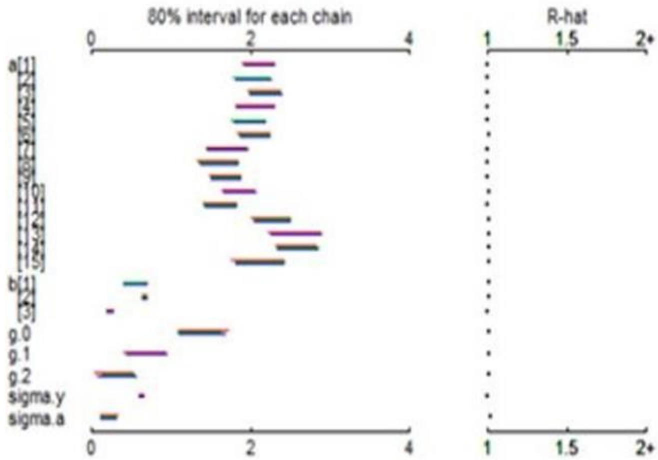
Table 10. Associations between green designs and sustainable behaviors from previous research.

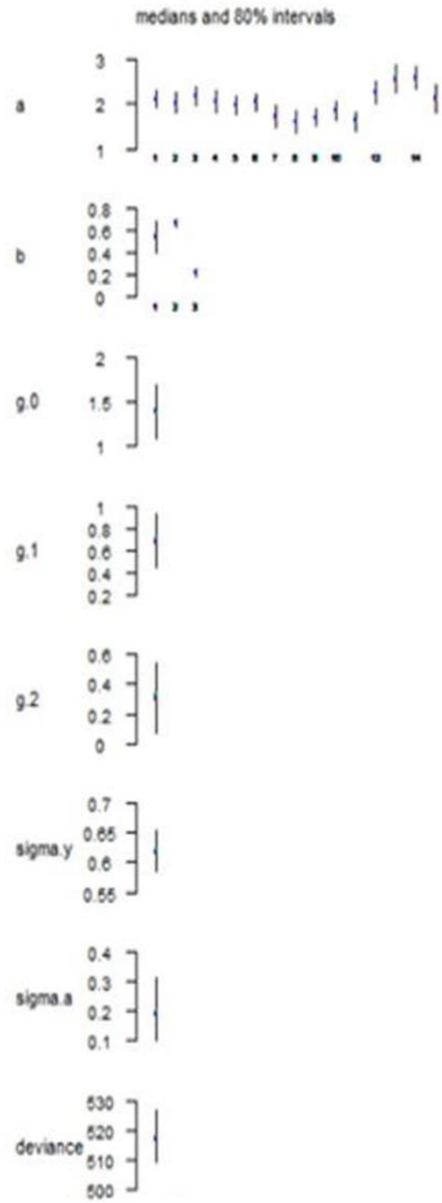
Category	Examples of desired sustainable behaviors	Relationships between Sustainable behaviors and green designs	Source
Energy	Promote the use of energy-recovery ventilation systems in four LEED-Gold residential towers in Toronto;	Occupants' comments include: "Tried to clean, way too difficult, did not bother", "The ventilation is really loud", "Noisy fan, have to adjust TV when it comes on in winter".	(Brown and Gorgolewski 2014)
	Promote the use of mechanical ventilation with heat recovery system in low-carbon houses in UK	Through interviews, occupants did not understand the controls and filter cleaning procedure of the MVHR.	(Carmona-Andreu et al. 2013)
Indoor Environment Quality (IEQ)	Encourage the occupants to practice pro-environmental and healthy adjustments in response to discomfort (e.g., overheating/overcooling) that is supported by design attributes in the green buildings: such as promote "personal adjustment" (i.e. clothing adjustment, walking around, consuming hot/cold drinks) instead of "environmental adjustment" (e.g., adjust temperature, open/close window)	Have spacious common spaces for occupants to retreat. Have space for occupants to walk more around in the building to heat up their body.	(Azizi et al. 2015)
		The appropriately designed physical environment can encourage occupants to make healthy adjustments such as by walking around more. Occupants in commercial buildings engaged in less personal adjustments (i.e. drink beverages; dress in layers, walk around more) than environmental adjustments and due to the lack of physical environment such as a place to buy coffee and a place to retreat.	(Moezzi and Goins 2011)
		Personal adjustments were made more than environmental adjustments in spaces which occupants have limited access to the control systems such as the open plan space. While in private offices within the building, the occupants made more environmental adjustments than personal adjustments.	(Heerwagen and Diamond 1992)
Transportation	Promoting pedestrian volume (at neighborhood scale)	Planning factors such as density, diversity, accessibility, distance to transit, network attributes affect pedestrian volume. Besides above factors, following building related attributes increase pedestrian volume: the existence of openings and transparency of the ground floor.	(Ewing et al. 2008) (Lee et al. 2015)
Water	N.A.	Rainwater and recycled water are used within sustainable houses and not connected to town mains, and the local area water restrictions do not apply to residents in the sustainable houses thus they have increased water usage.	(O'Callaghan and Hyde 2011)
Waste	Promote correct food disposal behavior (correctly choose disposal bins) in academic buildings	The cafe at the sustainable building employs both constraining (e.g., no bottled drinks are available for purchase) and suggestive approaches which could be shaping and influencing user behavior.	(Wu et al. 2013)
	Promoting recycling behavior in households	The physical proximity of containers is the fundamental reason that justifies the success of recycling behavior, e.g., to provide curbside collection for the household.	(Ludwig et al. 1998)
	Promoting recycling behavior in households	The existence of some available space in the household is a significant predictor of recycling participation.	(do Valle et al. 2004)
		Situation factor includes: 1) Recycling takes up too much time; 2) Recycling takes up too much room, and 3) Recycling is too complicated all prohibit recycling behaviors in rural households.	(Tang et al. 2011)

Table 11. A sample checklist of associations between green designs and sustainable behaviors that might be implemented in an office building.

Sustainable behaviors		Green design features
Energy	Reset thermostat to save energy	HVAC system that can be regulated by end users
	Turn off light when absent	Warning stickers around the switch
	Unplug cell phone chargers, computers etc. when not in use	Warning stickers around the switch
	Using natural light whenever possible	Certain distance within windows; Presence of daylight duct
	Taking less elevator	Appealing interior design around stairs
Water	Reducing flushing water	Dual-flush toilet
	Reduce bottled water consumption	Provision of water filtration bottle
IEQ	Clothing adjustment when feeling cold/hot	Provision of individual hangers and space
	Moving to a different location when feeling thermal, lighting, acoustic discomfort	Provision of open space, places of respite
	Having choice where to get work done when feeling dissatisfied with IEQ in personal space	Provision of comfortable open rooms with essential equipment
	Adjusting shadings when overheating is felt	Solar shading for windows
	Reduce A-C usage when feeling hot	Accessible windows for passive ventilation
	Walking outside when feeling stress/discomfort inside	Pleasant walking paths around the site
Transportation	Bicycling when weather allows	Bicycle facilities; Changing rooms and shower
	Using public transportation	Access to quality transit
Waste-reduce	Double page printing when applicable	Default setting on printers
Waste-reuse	Reusing for packaging	Box in common place for reusable packaging materials
	Reusing paper that has been printed only on one side	Provision of a paper box in printing room
Waste-recycle	Recycling paper	Recycling bins in the printing room
	Recycling cardboard	Recycling bins in places with more accessibility
	Recycling aluminum cans and plastic bottles	Recycling bins in common places
Waste – treatment	Composting organic waste	Provision of composting bins and easy access to on-site compost facility
	Separating hazardous waste such as batteries	Provision of collection box for hazardous waste
	Not mixing different source of waste, categorize waste and do it correctly	Provision of bins and clear guidance on waste categorization

Appendix C. Simulation Results of the Hierarchical Model





The hierarchical model set up in Winbugs

```
model{
  for (i in 1:n){
    y[i] ~ dnorm(y.hat[i], tau.y)
    y.hat[i] <- a[building[i]] + b[1]*x1[i] +  b[2]*x2[i] +  b[3]*x3[i]
  }
  tau.y <- pow(sigma.y, -2)
  sigma.y ~ dunif(0,100)

  for (k in 1:K) {
    b[k] ~ dnorm (0, 0.0001)
  }

  for (j in 1:J){
    a[j] ~ dnorm(a.hat[j], tau.a)
    a.hat[j] <- g.0 + g.1 * u1[j] + g.2 * u2[j]
  }
  g.0 ~ dnorm(0, 0.0001)
  g.1 ~ dnorm(0, 0.0001)
  g.2 ~ dnorm(0, 0.0001)
  tau.a <- pow(sigma.a, -2)
  sigma.a ~ dunif(0,100)
}
```

Figure 13. The hierarchical regression model setup with Winbugs and simulation results for the model with group-level indicators (g1 and g2).

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