Master's Thesis of City Planning

The association between urban form and perceived safety of urban environment:

– A case study in New York City, USA –

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Abstract

Understanding human perception in urban areas especially perceived safety of urban environment is important in a number of aspects of urban planning and design for sustainable cities. Recent research introduced Google Street View (GSV) and big data analysis to study more people in various cities than traditional methods. This study aims to examine the association between urban form and perceived safety in urban built environment using GSV Image data in New York City. Also the study validated whether classical urban theories can be adapted to empirical research in nowadays or not. The study collected various variables of urban form using Arc GIS and measurement data of perceived safety from MIT media lab. The research used Ordinary least squares model, especially multi regression model for analyzing the relationship between variables of urban form and perceived safety in urban areas. The results indicated that variables of urban form affect perceived safety of urban streetscape. The variables with proper urban form, such as high population density, mixed-use, diverse building types, and tree canopy, were more prone to make people feel safer about urban environment. The impacts of urban form to human safety perception were significant to urban planners and designers for making a better urban place for people.

Keywords: Human perception, Perceived safety, Urban form, Google street view, Big data analysis

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Chapter 1. Introduction

1.1. Background

Jane Jacobs (1961) indicated how the modernism ideologies in urban planning neglect to consider users of the city. After she published an influential book *The Death and Life of Great American Cities* in 1961, many researchers have attempted to develop a new discourse of human centered cities. Jan Gehl (2010) also emphasized an eye-level perspective for these cities. The study of human perception has become an important aspect of urban planning and design for better cities.

Perceived safety is considered one of the most important issues on the perception of urban environment. It is directly connected to people's daily experience in urban areas. Perceived safety affects people's behavior and influences people to avoid places they consider to be dangerous (Lis, Pardela, Can, Katlapa, & Rabalski, 2019). Furthermore, the perceived danger could cause many people to get much fear of crime and emotional stress (Schweitzer, Kim, & Mackin, 1999a). In urban planning and urban design for human centered cities, it is important to understand how people feel safe in different urban areas and how the perception of safety is affected by urban factors.

Among the large number of studies on perceived safety in the urban environment, many of them were based on survey data or interviews that were limited in both the quality and coverage. The results from studies were often limited by the data source as surveys and interviews on such a topic often cover small number of people and limited urban areas due to high costs in conducting them.

Recent advances in technology, however, allow research related to perceived safety to accept the latest methods using Google Street View (GSV) and Machine Learning. It can be possible to quantify perceived safety in large scale owing to new technologies.

A few recent studies were conducted to quantify and predict perceived safety in the urban environment by using GSV images and computer vision (Glaeser, Kominers, Luca, & Naik, 2018). Some of them focused on the relationship between urban socio-economic influences to perceived safety. Naik et al (2017) adapt three social science theories to analyze the relationship between socio-economic factors and people's perceptions including perceived safety. So the new technologies make it possible to evaluate a larger number of population and areas with various perspectives (Glaeser et al., 2018).

1.2. Research Purpose

In the literature, many studies introduced advanced methodologies such as Google Street View image data and machine learning for analyzing human perception of urban environment. Previous research, however, has not fully considered variables of urban environment such as land use on perceived safety. Also, there are few studies focusing on human-scale research for analyzing people's perception of safety. Further investigations are needed to fill theses research gaps.

The purpose of this study is to examine how physical urban form affects perceived safety in the urban environment using Google Street View data. With the big data techniques described above, the study can measure people's perceived safety in a larger area. This study also analyzes which factors affect perceived safety with comprehensive approach in human-scale. It allows the study can compare and figure out various parameters affecting perceived safety by the same set.

This topic is important to urban planners and designers in understanding perception of safety in urban environment. With this approach, the following research questions are addressed:

(1) How and to what extent do the factors of urban form affect perceived safety?
(2) If so, which factors are most influential to perceived safety?
(3) How do these results help to better understand perceived safety in the urban environment and its implications for the planning and design of urban area?

This thesis is structured as follows. Chapter 2 describes the theoretical background on human perception and perceived safety. In chapter 3, a research structure is constructed to define hypotheses and collect data with statistical methodology of this analysis. Empirical parameters are then tested in Section 4. Finally, Section 5 offers some limitations and implications about this study.

Chapter 2. Literature Review

2.1. The importance of perceived safety

When Downs and Stea analyze the cognitive mapping for investigating human perception, they find that human perception is always different from actual maps or aerial photos which are mainly reflected in urban planning and design (Downs and Stea, 1973: 18; Moore, G.T., 1979). According to Brown, "Cognition is seen as giving meaning to the world," which means human perception can be considered to conceive something to the world (Brown, 1972; Moore, G.T., 1979). The literature indicates why human perception is important in urban planning and design.

Perceived safety is considered a core concern for sustainable urban environment among human perceptions (Cozens, 2011). For many years, many researchers have investigated the relationship between perceived safety and urban environment because this issue is strongly related to people's daily life in urban area. For example, when residents may perceive crime or lack of safety in their neighborhood, they may get much psychological distress and stay in their homes. Perception of danger, especially fear of crime, negatively affects people's psychological status and physical behavior (Schweitzer, Kim, & Mackin, 1999b).

Perceived safety is also seen as an important factor for shaping high-quality urban environments (Jacob, 1961; Newman, 1973; Llewelyn-Davies, 2000; Cozens, 2002; Carmona et al., 2003; Office of the Deputy Prime Minister, 2004; Cozens, 2011). When people feel safe, they are more likely to actively use urban space. On the other hands, people seems to be restricted in indoors and specific areas while they perceive lack of safety in urban environment. This patterns of people can contribute to the creation and maintain of vibrant and sustainable urban environment (Cozens, 2011).

More recent attention in perceived safety has been drawn on the connection between urban sustainability with crime rate (Du Plessis, 1999; Cozens, 2002, 2007a, 2008a; Knights et al., 2002; Dewberry, 2003; Armitage, 2007; Glasson & Cozens, 2011). The criminal cases affect behaviors of residents and pedestrians in neighborhood. This suggests that urban planners and designers should have a broader understanding of the relationship between perceived safety and built environment for sustainable urban environment. To build sustainable city, it is important to examine perceived safety in urban areas.

2.2. Theoretical background on perceived safety

1. Objective safety and perceived safety

There are two types of safety: objective safety and subjective (perceived) safety (Mambretti, I. M., 2011; Lis et al., 2019). Objective safety refers to the real risk related to actual crime, risk, safety measuring by facts and figures. Subjective safety means individual emotions based on the personal experience such as the fear of crime, perceived safety, perceived risk, and perceived threat though shaped in a broader context, resulting from social conditions as well as personal experience (Sreetheran, M., & Van Den Bosch, C. C. K., 2014; Lis et al., 2019).

Fear of Crime is defined as the emotional response to potential victimization (Rader, 2017). It is a broader concept than perceived safety/risk/danger and refers not only to an emotional assessment of security but also to more diverse emotions including anxiety, depression, and social avoidance (Spicer, 2012; Lis et al., 2019). The fear of crime may more affect people living in urban area than actual crime figure. While urban residents perceive fear of crime, many of them go through psychological problems and stay in their home (Schweitzer et al., 1999a).

The concept of perceived risk/danger (safe), on the other hand, is a closer relation with a real situation than fear of crime. It has more concrete operational definition and indicates the analysis of results in related to people's behavior. This concept also demonstrates specific information that might help solve the problem.

Indeed, the perspective of perceived risk/danger (safe) has more attention in research area (Gau, J. M., & Pratt, T. C., 2010; Lis et al., 2019). Some authors indicated that the emotion (fear of crime), likelihood of risk (perceived risk), and precautionary behaviors (constrained behaviors) may work together, and generally perceived risk/safety and constrained behaviors predict fear of crime (Mesch, 2000A; Rader, 2004; Rader et al., 2007; Rader, 2017). In summary, perceived safety is strongly related to human's behaviors and might predict fear of crime.

The subjective safety is strongly related to human's behavior and emotional responses according to other scholars. Few studies also demonstrated that subjective safety could affect objective safety such as a figure of real criminal (Salesses et al., 2013). This present study, therefore, focuses on the research of perceived safety owing to fact that perceived safety is the most important things among related notions. This perspective could be generally seen as a factor bridging urban environment and people's behavior.

2. Previous research of perceived safety

For many years, urban planners, sociologists, and economists have investigated why people perceive danger or fear of crime in urban areas. Traditionally, many researchers have been interested in the relationship between physical settings and people's perception of built environment in diverse fields (Kaplan & Kaplan, 1989; Lynch, 1960; Nasar, 1997; Tuan, 1977; Zhang, Zhou, et al., 2018). There are a number of previous studies related to perceived safety which are affected by physical characteristics of urban environment.

Building and Street

The building and street are considerable factors for analyzing perceived safety in urban areas due to these variables are essential factors in urban environments. Jacobs (1961) finds narrow streets along with low-rise buildings in the Greenwich Village neighborhood of New York City is safer than other areas owing to residents and storekeepers can keep *"eyes on the street"* from their buildings.

The study by Blumenfeld supports a maximum width between buildings is 72 feet (22 m) for the distance where people can recognize each other. And he proposes 48 feet (15m) for the distance at which expressions are recognizable and communication is realizable with loud surroundings (Blumenfeld, 1971; Harvey et al., 2015). The another study demonstrates that buildings should be less four stories tall for promoting interaction between building and the street (Alexander et al., 1977; Harvey et al., 2015).

Based on classic research, several studies exam these hypotheses, which the height of building affect perceived safety, are valid in urban area. Asgarzdeh et al (2012) indicate that scenes of taller height buildings are perceived more suppressive than those of shorter height buildings. The study by Harvey et al (2015) also finds narrow streets with high building densities are considered safer than wider streets with low building densities.

On the other hand, Oscar Newman coined a concept of *Defensible Space* that suggests open spaces are advantageous for detecting and discouraging criminal activities (Newman, 1972). The theory of defensible space emphasizes the importance of physical setting in urban environment affecting perceived safety. Prospect-refuge theory likewise suggests that humans feel safest in places that provide a balance of opportunity for movement and visibility to adjacent spaces (prospect) and protection (refuge) (Appleton, 1975; Harvey et al., 2015). Harvey demonstrated that streetscapes with highly enclosed, continuous street walls are

less apt to attract potential criminals and can be a refuge space using prospect-refuge theory (Harvey et al., 2015).

Although it is important to consider height of building and width between building, these variables have a strong relation because streets (width) always along with buildings (Height). The height to street's width ratios can considers both variables as a fundamental urban design principle. It also is used to measure sunlight, urban heat energy as well as enclosure in the streetscape (Bakarman, M. A., & Chang, J. D., 2015).

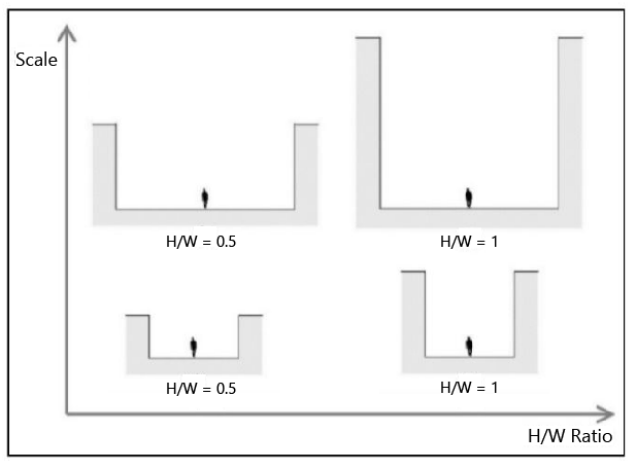


Fig. 1. Combination of H/W ratios and scales revised from (Kim, J., 2017).

The concept of height to width ratio also is related to building's enclosure at streetscape. Some scholars argue that enclosure can enhance perceived safety owing to fact that building façades form street walls, offering shade, protection from wind and rain, and a secure edge (Jacobs., 1993, Harvey et al., 2015). Street walls produces comfortable atmosphere as if people are staying in outdoor rooms (Alexander et al., 1977; Harvey et al., 2015). Recent study by Harvey et al (2015) demonstrates that narrow streets with high building densities are perceived as safer than wider streets with few buildings.

Table 1. Variables of height and width impact on literature review.

Variables	Impact on perceived safety	Related Literature
Height of the building	−	Jacobs (1961) Bluemenfeld (1971) Alexander et al (1977) Asgarzadeh et al (2012)
Width between buildings	−	Bluemenfeld (1971)

Height to Width ratio	+: enclosure	Newman (1972) Alexander et al (1977) Jacobs (1993) Harvey et al (2015)

+ : positive, − : negatvie

Land Use

Land use usually affect physical and functional attributes of buildings in urban environment owing to fact that it controls physical urban environments and usage of buildings under urban planning and design rules. Therefore, it is important to consider the land use as main influential factors on perceived safety in urban areas.

Previous studies generally indicate that mixed land uses are safer than exclusively residential area (Jacobs, 1961; Grant, 2002; Burton & Mitchell, 2006; Cozens, 2011). Jacobs (1961) suggests the concept of *eyes on the street* indicates that perceived safety assumptions such as permeability, mixed uses, and high densities for sustainable city environment. She recognizes that vibrant street provided more 'eyes on the street' which refers to surveillance and this could potentially reduce opportunities for crime (Cozens, 2011).

Jacobs commented:

"... there must be eyes on the street, eyes belonging to those we might call the natural proprietors of the street ... the sidewalk must have users on it fairly continuously, both to add to the number of effective eyes on the street and to induce a sufficient number of people in buildings along the street to watch the sidewalks." (Jacobs, 1961, p. 35)

Mixed use developments are considered to have more natural observation of people refers to "*eyes on the street*." It is likely to strengthen personal and community safety and weaken crime rate (Cozens, 2011). Mixed-use developments promote more pedestrian-friendly street and *"eyes on the street,"* which enhances perceived safety from crime. Mixing land use, which is usually composed of residential and commercial, more affect increasing diversity in neighborhood than homogenous land use area such as full of only residential areas.

Some studies, on the other hand, indicate that non-residential land uses are associated with higher crime rates (Stucky & Ottensmann, 2009). Jacobs (1961) insists that unpopulated area is more dangerous than other places due to the fact that there are no "*eyes on the street*."

Although there are many research about the influence that mixed use positively impact neighborhood crime, some empirical research revealed that mixed use development is always not valid. A study measured mixed land use and indicate there are no significant effects of mixed land uses on crime (Sampson & Raudenbush, 1999; Stucky & Ottensmann, 2009). The other study also advocated that mixed land uses in residential areas does not affect crime rate (Schneider & Kitchen, 2007; Cozens, 2011).

Mixed use development might also encourage and provide other kinds of crime such as pick-pocketing. The study by Sorensen examined increased pedestrian volume can encourage to risk related to the number of target (Sorensen, D., 2003; Cozens, 2011). Some studies argued mixed use cause to more crime rate on the grounds that a lot of people usually attract more criminals in complex area such as schools, shopping centers, and transportation facilities (Brantingham, P. J. & Brantingham, P. L., 1993; Cozens, 2011).

These claims have been strongly contested in recent years by a number of researchers. In spite of the fact that mixed land use incurs more crimes, mixed use development still is considered to create vibrant and sustainable city. Mixed use can induce more people on the street, which makes vibrant and safe urban environment.

Table 2. Variables of land use impact on literature review.

Variables	Impact on perceived safety	Related Literature
Mixed land use	+	Jacobs (1961) Cozen (2011)
Mixed land use	−	Brantingham et al (1993) Sampson et al (1999) Sorensen, D (2003) Schneider et al (2007) Cozen (2011)
Non-residential land use	−	Stucky et al (2009)

+ : positive, − : negatvie

Population Density

The feature of high densities is significant attributes of sustainable urban development (Urban Task Force, 1999; Cozens, 2011). Jacobs (1961) argues that higher densities are likely to be more *"eyes on the street"* and enhance personal safety of urban environment. This argument indicates while there are many people

in the street, it makes natural surveillance because people can watch each other's activities.

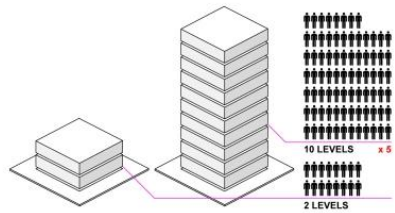


Fig. 2. The definition of Population density (Baldea M., 2013).

However, some research find high densities can promote more crime in urban areas. A study indicated high densities may attract a number of potential criminals and opportunities for offenses. Calhoun (1962) suggested *"crowding theory"* indicating that more densities provide more crime (Cozens, 2011). Other study analyzes the relationship between reported offense and population densities in Baltimore County, Maryland, USA. This study found there are more opportunities various types of crime with more population in the urban area (Harries, 2006; Cozens, 2011).

Even though there are some empirical studies, several theories support the relationship between population density and perceived safety. Previous mentioned *"eyes on the street"* still advocates people's natural surveillance in urban area. And the New urbanism suggests that higher population density makes a vibrant urban environment.

Table 3. Variables of population density impact on literature review.

Variables	Impact on perceived safety	Related Literature
Population densitiy	+	Jacobs (1961)
Population densitiy	−	Calhoun (1962) Harries (2006)

+ : positive, − : negatvie

Urban Greenery

To date, several studies have investigated that urban greenery influence a sense of peacefulness and quietness by Ashihara theory about the scenery of landscape in streets (Ashihara, 1983; Zhang, F et al., 2018), and by Rachel and Stephen Kaplan in their theory about restorative environments (Kaplan & Kaplan,

1989; Zhang, F et al., 2018). These studies indicate the importance of urban greenery for perceived safety and peacefulness in urban environment.

The urban greenery is important indicator for human perception research. This object affects perceived safety owing to contribute additional enclosure and complexity in urban environment (Arnold, 1993; Jacobs, 1993; Harvey et al., 2015). Indeed, tree canopy contribute additional enclosure by providing a partial roof on the street. Trees may complement shortage of enclosure where buildings are nonexistent or widely spaced (Arnold, 1993; Harvey et al., 2015).

Other scholars also support that visible greenery in urban area positively associated with perceived security. For instance, open spaces with few trees are the most safety place in human perspective (Herbert W, Schroeder and L, 1984). And another study show there is a strong inverse association between tree canopy and criminals. The result proves that 10 percent increase in tree canopy affect 12 percent decrease in crime (Troy, A et al., 2012). Other study also examines that people feel more safety in more greenery in the street (Harvey et al., 2015).

Thus far, there are controversial debates on the relationship between urban greenery and crime and perceived safety (Nasar et al., 1993; Foster et al., 2016). Some studies demonstrated urban greenery can conceal criminals from people and make easy to run away from crime site. This vegetation seemed to enhance fear of crime by limiting visibility in the immediate sight (Nasar and Jones, 1997; Foster et al., 2016).

Despite several studies argued the negative effects of urban greenery, other studies suggest street trees affect a more pleasant and safety environment for people now that these trees reduce speed of vehicle and manage more unforced observation from cars on the street (Cervero & Kockelman, 1997; Foster et al., 2016).

Table 4. Variables of tree canopy impact on literature review.

Variables	Impact on perceived safety	Related Literature
Tree canopy	+	Herbert et al (1984) Arnold (1993) Jacobs (1993) Cervero et al (1997) Troy, A et al (2012) Harvey et al (2015) F. Zhang et al (2018)
Tree canopy	−	Nasar et al (1997)

+ : positive, − : negatvie

2.3. Empirical studies of urban form and perceived safety

1. Studies with traditional surveys and interviews

Most studies on human perception of urban environment have historically depended on interviews, visual perception surveys, and manual evaluation of images like above studies (Glaeser et al., 2018). Kevin Lynch's literature has been recognized as the starting point among early scholars of urban environment perception (Moore, G.T., 1979). Lynch conducted a qualitative survey on the factors that strengthen the identity and structure of city imageability on a community level. The study found out that people's perception is affected by five physical attributes (Nasar, 1990).

Nasar asked people to visually designate areas they liked and disliked, and explained the physical characteristics of their perceptual assessment. These raters overlaid these maps to create a combined map for illustration for city's evaluative images. The combined map suggested that physical features might affect the preference of place depending on people's perception (Nasar, 1990).

Those methods, however, could only collect crude statistics and small-scale data on a few neighborhoods owing to the time-consuming fieldwork survey and interview. It prevents research proposals from reaching more generalized conclusion (Tang & Long, 2019).

2. Studies using big data

The advance of technology can provide high quality and abundant data about space and cities in the past decade (Glaeser et al., 2018). In 2011, the Massachusetts Institute of Technology (MIT) Media lab examined the project called Place Pulse, which collected a massive crowd sourced dataset on urban perception by using Google Street View.

Google street view is important to consider visible attributes of urban environment in human-scale. People actually perceive urban environment from surroundings that can be directly seen (Shen et al., 2018). The spatial perception of human mostly relies on vision among human senses. Other senses enhance and enlarge human perception of the space (Tuan, Y.F., 1977). This characteristic of human perception can be more reflected in Google Street View image than aerial image (Fig. 4) owing to fact that GSV images are taken by vehicles or people equipped specialized camera similar to height of eyesight (Fig. 5). This image data

shows the side view of the urban streetscape similar to view of people and depicts urban physical environment comprehensively (F. Zhang, Wu, Zhu, & Liu, 2019).

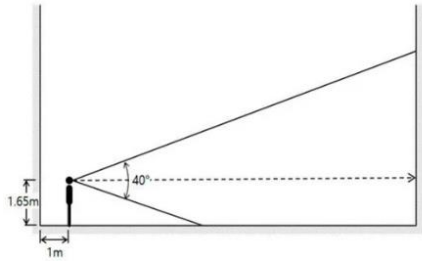


Fig. 3. Vertical fields of view at the average height of eye (Kim, J., 2017).

Fig. 4. The methods of taking google street views (Source: JOAO NOGUEIRA, Google AI Blog).

Place Pulse team asked people to select images from pairs in response to evaluative question such as “Which place looks safer?” (Fig. 2) Naik et al (2014) examined Place Pulse data to train a computer vision algorithm for predicting perceived safety (Fig. 3). These advances allow researcher to collect a large scale data of people which previously unmeasured and even predict urban perception in world wide.

Fig. 5. The question of Place Pulse research (Salesses, Schechtner, & Hidalgo, 2013).

Street view also can estimate general perception of people about urban environment. In Place Pulse data processing, participants from all over the world rated which area looks safer. They did not know the location of street view and other information such as economic status and social background. It indicates that Place Pulse data can measure purely people's perception depending on physical urban environment.

To date, a number of studies begun to examine the urban perception using Google Street view and computer vision technologies. Salesses et al analyze the relationship between social outcome and human safety perception through Google Street View and machine learning. The study proves the link between perceived safety of the city and the number of homicide in New York City. The number of homicide is lower in the areas where people perceived safer than in other areas (Salesses et al., 2013).

The study by Nadai notes the association between perceived safety of urban built environment and activeness and liveliness of city. They use social and demographic variables such as a population density, ratio of women and ratio of elderly people. The study suggests when the neighborhood looks safer people will be more active in this area. In particular, the ratio of women and the elderly have the most influential to human safety perception (De Nadai et al., 2016).

Naik et al demonstrate the connection between the socio-economic factors and the changes of the urban appearance. The study use social demographic data and Street change data which is acquired from the image of the two years 2007 and 2014. The result of analysis shows that population density and education level are strongly correlated with Street change. (Naik et al., 2017).

3. Research gaps in the field

There are several research gaps in the field. First, although a number of previous studies devoted to demonstrate the relationship between perceived safety and socio-economic background or outcome, people actually perceive urban environment from surroundings that can be directly seen (Shen et al., 2018). The spatial perception of human mostly relies on vision among human senses (Tuan, Y.F., 1977). In Place Pulse data which used GSV, this data show only image data depicting physical urban environment. There is none of information such as social background, economic status of this neighborhood in the GSV image. People including participants of Place Pulse data, perceive urban environment based on their visual perception.

Second, previous studies examined various physical characteristics for

analyzing the influence on criminal rate and fear of crime. Although, some of research tried to examine the relationship physical attributes of urban environment and perceived safety, none of these studies fully consider physical attributes in urban area regarding perceived safety. There are no studies considering the influence of land use on perceived safety and comprehensive approach. Physical characteristics of urban environment are all concatenated with each other (Dempsey, N et al., 2010). For example, there are many people in mixed-use complex such as shopping mall with residential buildings.

To bridge the gaps between studies, the features that differentiate the present study from previous research are as follows:

- To analyze people's perception, this research aims to focus on use visual attributes of urban physical environment on Google Street View. In addition, this study verifies classical theories of perceived safety in urban area and illustrates the value of computer vision methods and street-level imagery to understand the perceived safety of cities.

- In this paper, this study presents research on an aspect of urban form that is rarely discussed in the perceived safety debate: that of the ability to comprehensively consider urban physical attributes. Urban form includes many physical characteristics and nonphysical attributes such as size, shape, density, land uses, building types, and distribution of green space. The study by Dempesy et al comprehensively classify as broad and inter-related elements that constitute urban form in a city (Table 5). Theses elements of urban form are material to understand sustainability and human behavior in urban environment (Dempsey, N et al., 2010). The study use the concept of urban form for comprehensive analysis between physical element of urban environment and perceived safety.

Table 5. Element of urban form (Dempsey et al., 2010).

Urban Form	Variables
Density	• Person per area • Dwelling per area
Housing/Building Type	• Building type • Housing type • Street characteristics
Land Use	• The number of particular services and facilities • The extent of specific land use in site

It would seem, therefore, that this investigation is needed in order to approach using human-scale urban forms which can consider both physical characteristics and a scale of human view.

2.4. Conceptual framework

As depicted in Fig. 6, urban form is one of the basic elements affecting perceived safety. The framework proposed in this paper is used to formalize the research structure. This one suggests the research structure about perceived safety through Google Street View. Before understand the conceptual framework, it is important to consider the Place Pulse data, which is collected by using Google Street View images and machine learning.

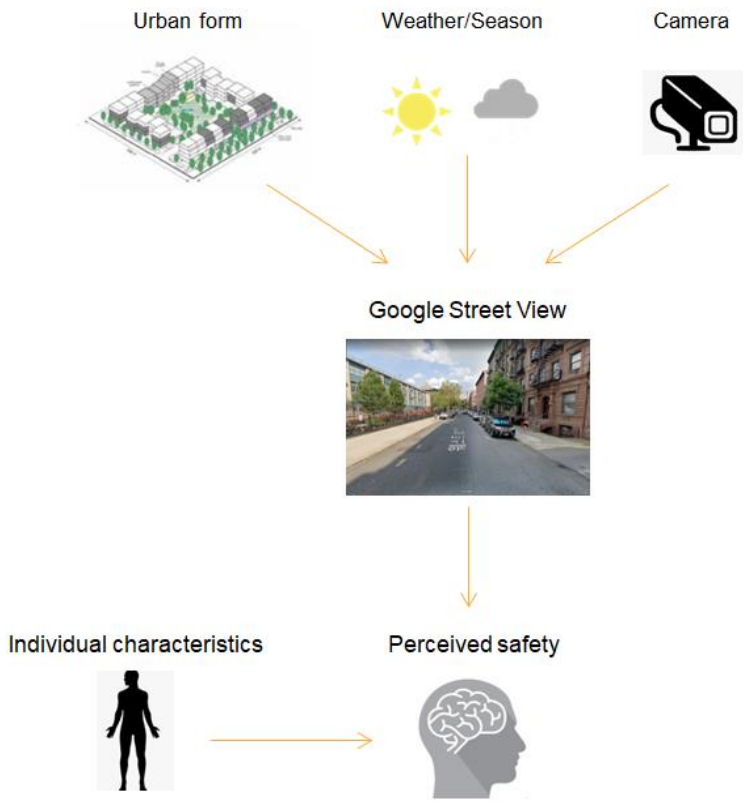


Fig. 6. Classification of perceived safety in Place Pulse data.

To use Place Pulse data, it is essential to understand which factors affect perceived safety through Google Street View image data. These images usually depict streetscapes at a moment when special cameras equipped vehicles captured.

It can display only visible features such as buildings, roads, vehicles, people and sky. Seeing that these images only can represent physical things of streetscapes not socio and economical background, Google Street View images are appropriate to analyze the relationship physical attributes of urban environments and perceive safety.

There are three main indicators which can affect Google Street View; urban form, weather and season, and camera condition. The concept of urban form can include most of urban physical elements including buildings, blocks, density, and land use. The concept enables taking quantitative measurements among places and contributes to analyze perceived safety at human-scale. Unfortunately, there are not enough data about weather and season, and individual characteristics. This study also could not control the camera conditions due to the fact that these images are already taken.

Urban form is the most important features among them owing to fact that physical factors are more visible in the Google Street View t. To sum up, the study mainly focuses on the relationship the features of urban form and perceived safety except other causes. Figure 7 is a conceptual framework which reflects overview image figure 6. This framework shows that the research structure.

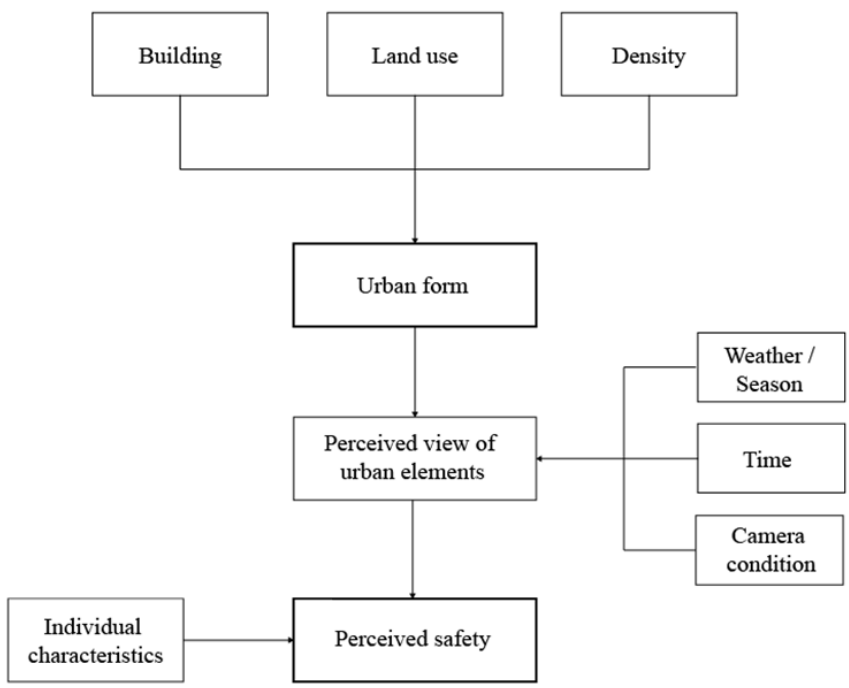


Fig. 7. The Conceptual Framework.

Chapter 3. Methods

3.1. Hypotheses

This paper uses urban form variables to investigate whether one's physical characteristics influence on the perceived safety in human-scale urban form by stating the value of the previous studies. Specifically, the study tests five hypotheses in three subjects:

Hypothesis 1: *Higher height to width ratio enhances perceived safety in the urban environment*. This study assumes height to width ratio as a variable to measure enclosure in the street according to previous studies. This ratio refers to the height to street's width ratios as a fundamental urban design principle.

Hypothesis 2: *Mixed-use development influence on safer human perception in the built environment.* Mixed use can induce more people on the street, which makes vibrant and safe urban environment. Thus the study hypothesis mixed use development positively affects perceived safety in urban neighborhood.

Hypothesis 3: *Industry and parking land use negatively affect perceived safety in the built environment.* Industry and parking land use are likely to be considered unpopulated place among land uses. The study also assumes that industry and parking land use negatively affect perceived safety.

Hypothesis 4: *Higher population density makes safer perception in the urban area.* Previous mentioned *"eyes on the street"* and New urbanism show that higher population density makes a vibrant urban environment. To sum up, this study hypothesis higher population density positively influence on perceived safety in urban environment.

Hypothesis 5: *As more tree canopy in the street, people can perceive safer than other areas in the urban environment.* The urban greenery is important indicator for human perception research. Trees among urban greenery objects are visually prominent at streetscapes. Traditionally, it has been argued that urban greenery variables are highly correlated with perceived safety. Based on previous research, this study hypothesis tree canopy can positively affect perceived safety on streetscapes.

3.2. Methodology

To test the hypotheses, the study was conducted with three different steps including data collection, test spatial autocorrelation, and multiple regression analysis. First of all, the research collected data from data base and geocoding using ArcGIS 10.2.1. A street score data and nine variables of urban form were compared. In each data, there were 588 different values depending on each site which street score was measured.

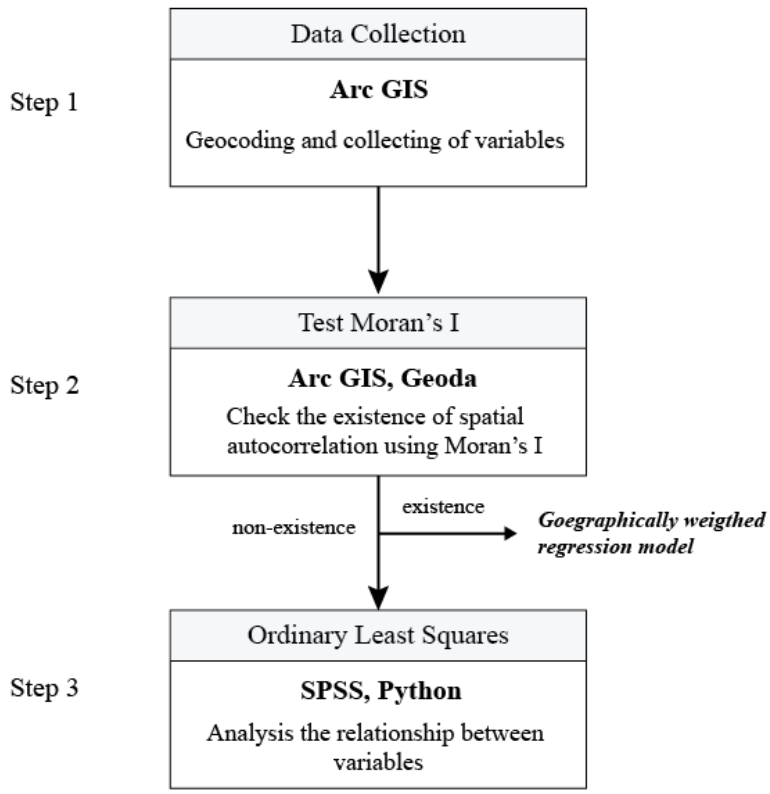


Fig. 8. Research method framework.

After processing data in the map, the study used Moran's I to test spatial autocorrelation of variables. The type of data under urban environment is possible to have spatial autocorrelations between variables. In statistics, Moran's I is a measure of spatial autocorrelation developed by Patrick Alfred Pierce. It measures how one object is similar to others surrounding it. If objects are attracted by each other, it means that the observations are not independent. This violates a basic assumption of statistics — independence of data. In other words, the presence of autocorrelation renders most statistical tests invalid, so it is important to test for it.

This study tested Moran's I in ArcGIS 10.2.1 and Geoda 1.12.1.161 to test autocorrelation of this spatial data.

Whether there are spatial autocorrelation in this data or not, it decides to how the data would be examined. The result of Moran's I indicated that these data is randomly located without spatial autocorrelation (Appendix 3). Therefore, the research moved to next stage for analysis the relationship between nine variables of urban form and perceived safety. To test these associations, the research chose multiple linear regression analysis.

Multiple linear regression analysis is the extension of ordinary least-square (OLS) regression that involves more than one explanatory variable. The study used multiple linear regression for analysis the relationship between multiple independent or predictor variables and one dependent variable. A dependent variable is modeled as a function of several independent variables with corresponding coefficients, along with the constant term. It requires two or more predictor variables, and this is why it is called multiple regression analysis. The multiple regression equation explained above takes the following form:

$$y = b_1x_1 + b_2x_2 + \ldots + b_nx_n + c.$$

Here, b_i's (i=1,2…n) are the regression coefficients, which represent the value at which the criterion variable changes when the predictor variable changes. Using this test one can estimate the appropriate relationship among these factors. This paper used multiple regression analysis in IBM SPSS Statistics 25 and Jupyter Notebook. This result can show the relationship between variables of urban form and perceived safety.

3.3. Study area

The study area is the New York City (NYC) in the United States (US). This city is the most populated city in United States and one of the most populous metropolises on the world (U.S. Census Bureau, 2019). Its area is more than 750 km2 of land area and consists of five boroughs such as Manhattan, Brooklyn, Bronx, Queens, and Staten Island, each of which has its distinct visual appearance (W. Zhang et al., 2017).

There are diverse urban form and street scenes from skyscrapers to low-rise block, which is a reason why we chose this area. The city is dense and vertically oriented unlike other cities in United States. There are also diverse built environments in many urban contexts owing to city development since early and mid-20th century (Harvey et al., 2015).

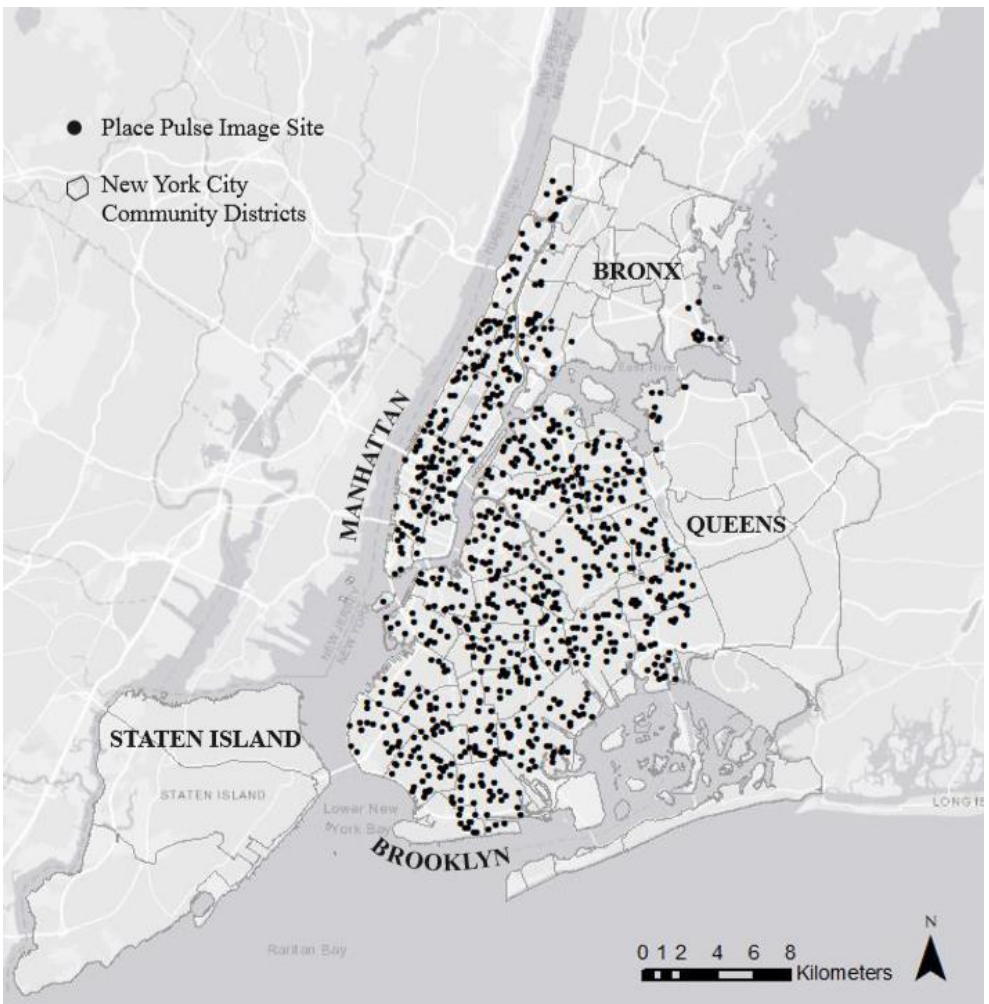


Fig. 9. New York City districts with Place Pulse Image site.

In New York City, there are five boroughs and 59 community districts. Every boroughs and community districts have different characteristics of architecture, density, and land use. And there are a lot of accessible data regarding to urban built environment by NYC department, thus making it a proper site for this study.

The MIT Media Lab collected perceived safety scores at over six hundreds sites in New York City, conducted an internet survey called Place Pulse (Salesses et al., 2013). The study collects urban form attributes of the built environment over six hundreds urban blocks, proposed locations through Place Pulse. This data of GSV images is mostly located in Manhattan, Brooklyn, Bronx, and Queens except State Island. To sum up, the study comprehensively carries out the relationship urban form and perceived safety in New York City in the view of street view.

3.4. Data Collection

1. Street score data

The Place Pulse 1.0 dataset was collected geo-tagged images in four cities (# of images) such as New York City (1,706), Boston (1,236) in the United States, and Salzburg (544) and Linz (650) in Austria by MIT Media Lab. The streetscape images from New York City and Boston were obtained by using Google Street View (GSV). The image data from Salzburg and Linz were manually acquired, considering time, weather and accessibility (Salesses et al., 2013). This dataset were collected between August and November 2011.

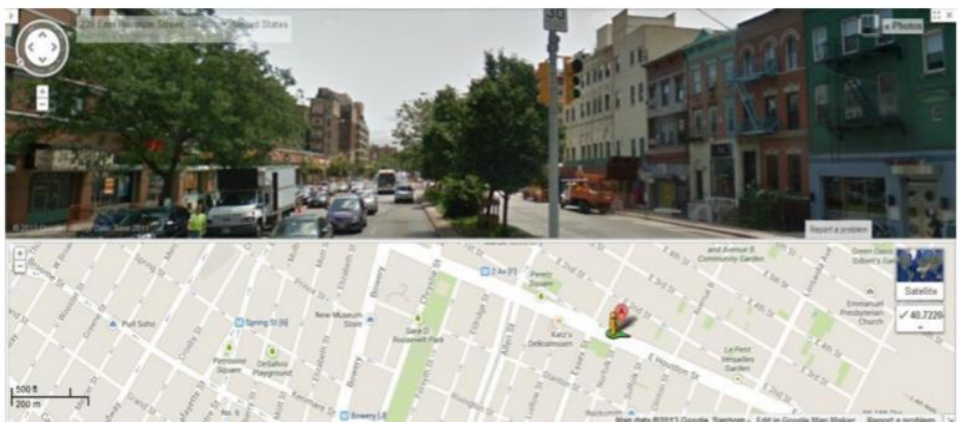


Fig. 9. GSV Panorama image in Manhattan East Village, New York City (Li, X et al., 2015).

GSV images are collected by using various methods such as specially equipped vehicles that can be driven streets, and backs equipped with cameras (Google, 2015; Less, E. L et al., 2015). The research team made a list of 1,000 randomly generated coordinate pairs and asked requests to Google for the nearest Street View panorama within 50 meters. While there was no panorama, researcher skipped that area. If Street View image was found, research team curated results by manual work and sometimes declined inappropriate images such as images only depicting a brick wall or poor qualities (Salesses et al., 2013).

The street images were used to conduct surveys for research on online website. Participants look at two randomized images and choose one image for answering one of three questions: “Which place looks safer?”, “Which place looks more upper-class?”, or “Which place looks more unique?” Then research team collected responses of participants to measure human perception of each image. The 7,872 participants from 91 countries contributed to 208,738 votes. Participants identified themselves 76.0% as male and 21.1% as female and the median age was 28 years.

The researchers examine the influence of gender and location on perceived score. They also find the variables of demographic have not significant correlations after analysis few examines (Salesses et al., 2013).

Table 7. Top 20 countries ordered by number of participants (Salesses et al., 2013).

Country	Number of Participants
United States of America	8574
Spain	1798
United Kingdom	1064
Canada	905
Switzerland	492
Poland	419
Germany	388
Australia	320
France	293
Netherlands	235
Mexico	199
Argentina	183
Sweden	147
Brazil	144
Austria	129
Italy	120
Chile	106
Denmark	103
Portugal	99
Belgium	95

To measure perceived safety as a street score, the researchers made a relative scale that is called *Q*-score. *Q*-scores are generated based on the voting dataset provided online surveys. These scores cannot be compared with *Q*-scores obtained from other cities. For instance, while the research team calculates the *Q*-score in New York City, they supported only images in the same city. And *Q*-score is a relative score between 0 and 10 by using True Skill ranking algorithm (Naik et al., 2014).

These images and True Skill ranking algorithm generated the data set for training a computer vision algorithm to predict the perceived safety of new streetscapes based on image features. This predicted one is called Street score (*Q*-score), means score for perceived safety of an image (Naik el al., 2016). Street score is a predicted algorithm result for measuring perceived safety of a streetscape

by suing training dataset from online survey with over 7,000 participants all over the world.

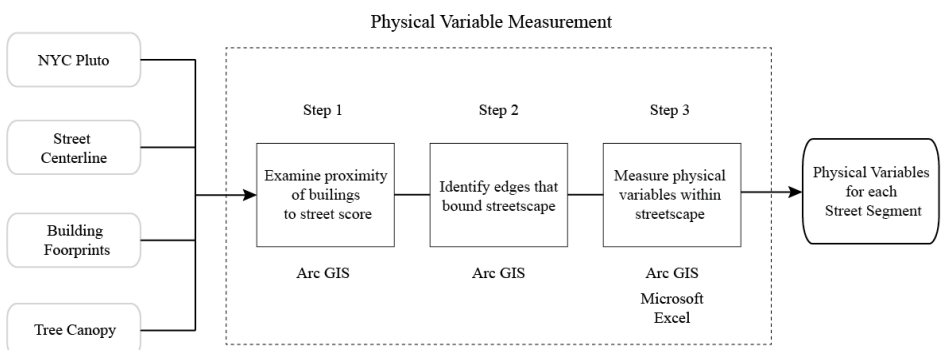
In this paper, the study used street scores of Place Pulse data for measuring a perceived safety in urban environment. There were 1,706 street scores with street images in the original Place Pulse data in the New York City boroughs of Manhattan, Bronx, Brooklyn, and Queens (Fig. 9). Some of them, however, have both the foreground and background of street score in the same point or located more two data in the same street.

To satisfy the assumption of independence between attributes, the study aggregate and make an average street scores within 164 ft (50m). The study also skipped few data locating at non appropriate area which is hard to get physical environment variables such as intersections and near port. This study used 588 street scores owing to some limitations. After all, the study yielded a final sample of 588 sites with perceived safety scores and spatially appropriate for collecting physical attributes of built environment.

2. Variables of physical environment

Physical attributes of urban environment were collected and calculated based on the GIS data obtained from open data portal by the Department of City Planning of New York City. The study derived spatial data such as building footprint, tree canopy, street centerline, land use, and population density from The Primary Land Use Tax Lot Output (PLUTO) of NYC. After that, this spatial data was processed geocoding and merged together at one map using Arc GIS 10.2.1 as the platform for data processing (Fig. 11).

Fig. 11. Methods for measurement physical variables.



In first step, this present research examined adjacent buildings for each image sites. Then the study verified edges that ranged in streetscape using ArcGIS. To understand this process, there is an important assumption that people perceive an edge where façade alongside a set back line in a streetscape (Harvey et al., 2015). The edge was a standard for measuring street width and building height in the streetscape following this premise. Physical attributes of built environment were measured for each sampled streetscape which has street score data.

Table 6. The descriptive information of variables.

Variables	Scale	Time	Source
Street score	Location	2011	MIT Media lab
Residential use	Street segment	2016	NYC Pluto v.16
Mixed use	Street segment	2016	NYC Pluto v.16
Commercial use	Street segment	2016	NYC Pluto v.16
Industial use	Street segment	2016	NYC Pluto v.16
Parking use	Street segment	2016	NYC Pluto v.16
Population density	Block group segement	2014-2018	U.S. Census Bureau
Height	Street segment	2016	NYC Pluto v.16
Width	Street segment	2016	NYC Pluto v.16
Tree canopy	Street segment	2010	NYC Open data

Notes: PLUTO: Primary Land Use Tax Lot Output

Height is an important variable for measuring human perception due to building is visible and prominent in streetscape. People are affected by building's height according to several scholars such as Jacobs and Newman. In this study, this variable was measured as an average height of every building in the street for each image site (Fig 12). It can suggest an average building's height in the street.

Width was the distance between opposing edges, indicating space between buildings in a streetscape by a street-level user (Fig. 12). This distance can affect human perception owing to fact that street width influence streetscape. It was considered as the distance between edges bound buildings along street. The study used centerline data and building foot print for estimation of width.

This paper also measured *Height to Width ratio* by dividing average height by width. It can describe more accurate user's experience at the human-scale level due to these variables intertwined each other. The ratio can explain the interactive effects depending on street scale.

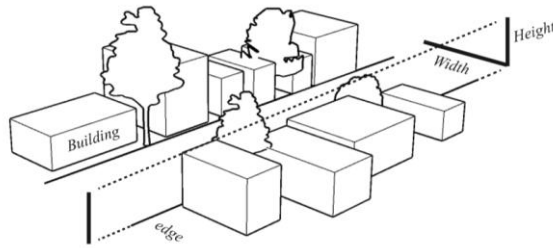


Fig. 12. Physical variables of urban environment at Isometric View
revised from (Harvey et al., 2015).

Tree Canopy Coverage shows how much street trees cover the streets at human scale. *It* was derived by measuring the tree canopy ratio in the street for each image site. It can be only measured tree canopy in the street not beside to buildings because people usually cannot perceive trees next to buildings. To calculate tree canopy coverage, the study measured street space which multiplied width by edge. Then, tree canopy coverage was calculated by measuring ratio how much tree canopy occupies in the street space (Fig. 13).

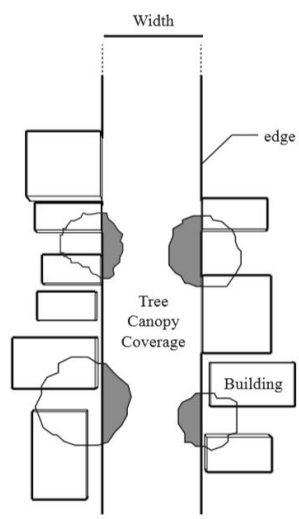


Fig. 13. Physical variables of urban environment at Overhead View
revised from (Harvey et al., 2015).

Population density is a vital factor for perceived safety according to Jacobs. She argued that people can play a role as a natural observation for each other in the

street referring to "*eyes on the street*." This present study measured population density which indicates how many people are living per square mile for each block group in New York City. The study measured population density for each block group not street scale owing to fact that there are no accessible data for measuring population density by street

Land use can regulate physical and functional characteristics of buildings in urban environment. Urban designers should follow the rules following land use. Therefore, it is a fundamental attributes for understanding physical environment of city. In this study, land use was measured as a proportion of building's land use along the both side edges for each street score site from 0 to 1. The study analyzed every building's land use whole buildings on the street then calculated how many each buildings have different land use.

For example, there are ten buildings along the both side for each image site. There are six residential buildings and four mixed use buildings; residential ratio is 0.60 and mixed use ratio is 0.40. The study merged land uses in new land use ID and selected some land uses which mainly affect perceived safety (Table 8).

The study examined eleven land uses in for each image sites. Then these variables are merged and chosen in order of importance. There are two characteristics of chosen variables such as populated land use and unpopulated land use for verification previous studies and theories. There are land uses of residential, mixed use, and commercial related to populated area, whereas two variables such as industrial and parking land use are chosen representing unpopulated area.

Table 7. Unit of variables

Variable			Unit of a variable
Dependent variable	Perceived safety	Street score	log *Street score*
Independent variable	Land use	Residential use	Number of land use type lots / number of entire lots
		Mixed use	
		Commercial use	
		Industrial use	
		Parking use	
	Density	Population density	Number of people (unit: 10,000) / square mile
	Building and Street	Height	unit: meters
		Width	unit: meters
		Height to Width ratio	Height (unit: meters) / Width (unit: meters)
	Urban Greenery	Tree canopy	Tree canopy area (m^2)/ Street space area* (m^2)

* *Street space area*: multiply width by the distance of edge

Table 8. Land use categories in the study area

Land use class (before merging)	Land use ID (before merging)	Land use class (after merging)	Land use ID (after merging)	Description
One & Two Family Buildings	1	Residence	L1	One family dwellings, Two family dwellings,
Multi-Family Walk-Up Buildings	2	Residence	L1	Walk up apartments, Condominiums
Multi-Family Elevator Buildings	3	Residence	L1	Elevator apartments, Apartment hotels
Mixed Residential & Commercial Buildings	4	Mixed-use	L2	Mixed use building that has spaces for both commercial and residential use
Commercial & Office Buildings	5	Commercial & Office Buildings	L3	Office buildings, Merchandise, Hotels, Shopping malls, Restaurants, Car stores
Industrial & Manufacturing Buildings	6	Industrial & Manufacturing Buildings	L4	Warehouses, Factory and industrial buildings, Loft buildings
Transportation & Utility	7	-	-	Garages and gasoline stations, Transportation facilities, Utility bureau properties
Public Facilities & Institutions	8	-	-	Dormitories, Hospitals and health, Churches, Synagogues, Educational structures, Cultural condominiums, Fire department, Police department,
Open Space & Outdoor Recreation	9	-	-	Beach club, Amusement Place, Outdoor recreation facilities, cemetery
Parking Facilities	10	Parking Facilities	L5	All parking garages, Parking lots, Public parking area
Vacant Land	11	-	-	Vacant land

Chapter 4. Results and Discussions

4.1. Descriptive statistic

The results section shows outcomes of the statistical analysis. First, table 9 shows the descriptive statistics of variables for 588 image sites in this study. There are perceived safety, which is an independent variable, and eight variables of urban form such as land uses, population density, urban greenery, and height to width ratio. Fig 14 and 15 show that the association between variables of urban form and street score.

Table 9. The result of descriptive statistic (N=588)

Variables	Mean	Minimum	Maximum	Standard deviation
Perceived safety (log)	1.485	0.526	2.014	0.287
Residence	0.700	0	1	0.351
Commercial	0.062	0	1	0.151
Mixed-use	0.098	0	1	0.177
Industry	0.049	0	1	0.168
Parking	0.025	0	0.75	0.079
Population density (10k)	5.816	0.078	38.765	4.348
Greenery canopy	0.294	0	0.988	0.23
H/W	0.685	0.138	9.454	0.768

Fig. 14. The heatmap of the associations between variables.

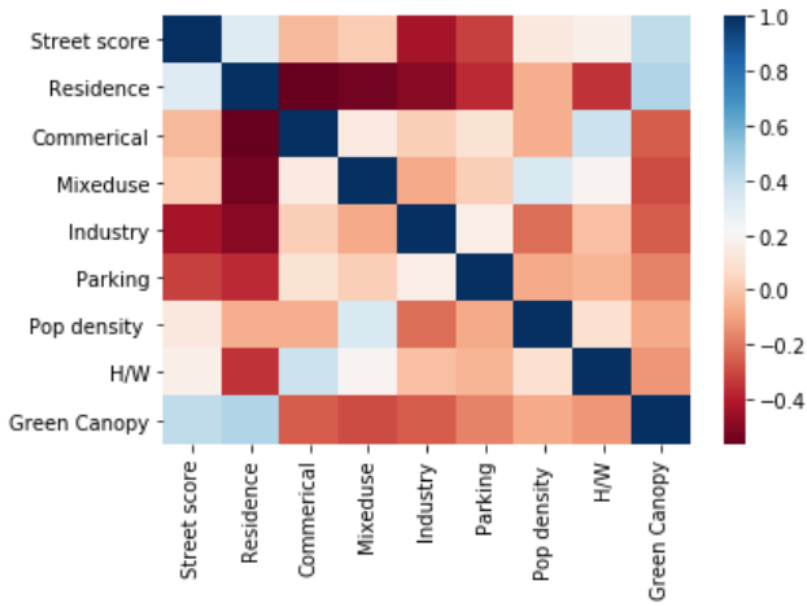
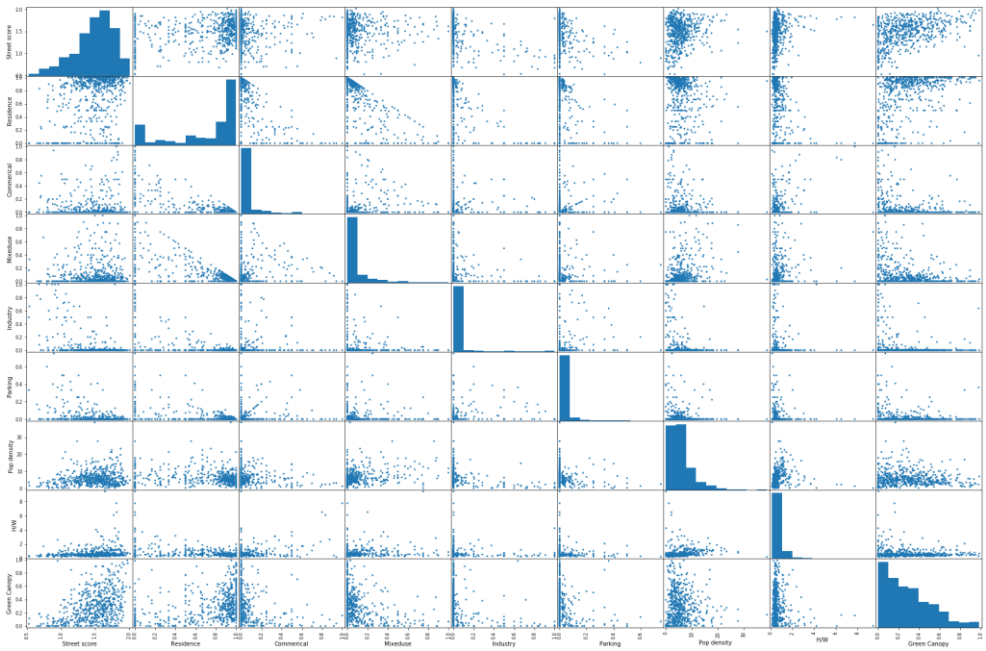


Fig. 15. The scatter matrix between variables.



4.2. Results

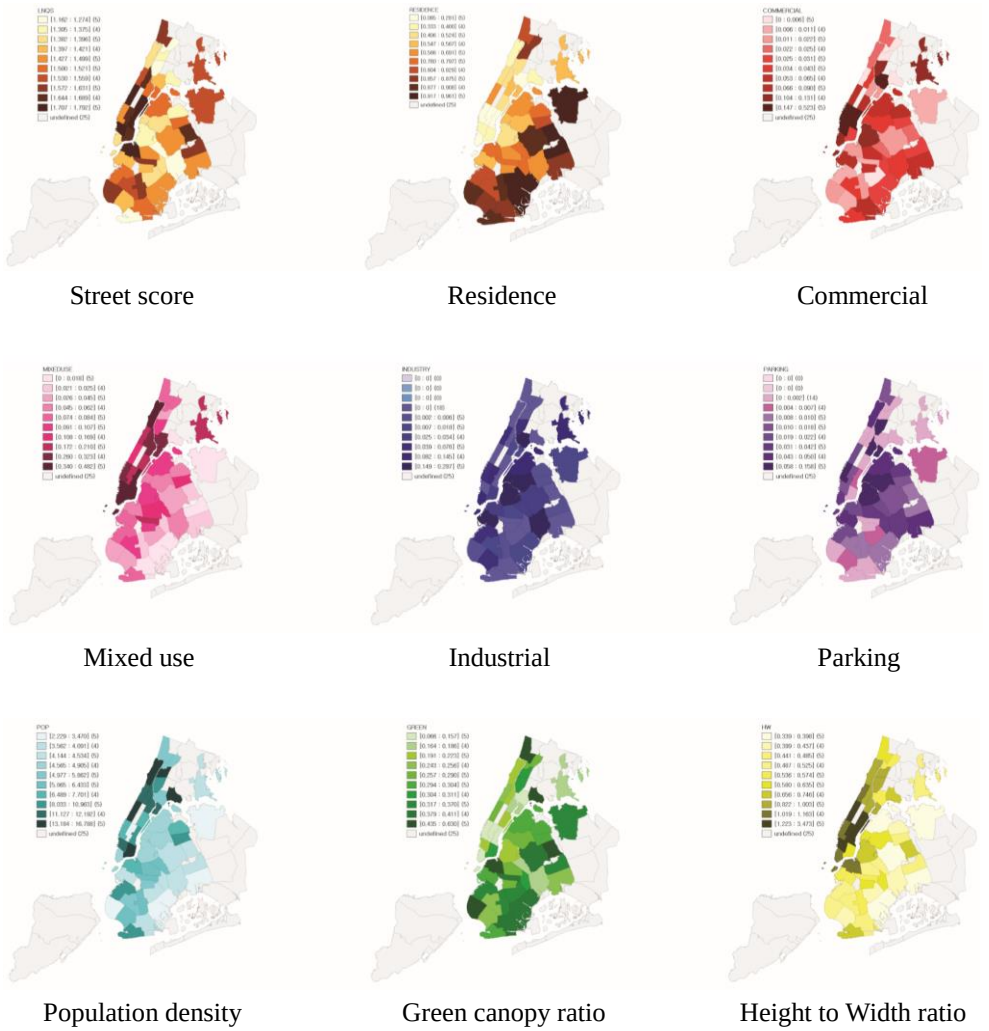
1. Result of spatial autocorrelation

The study illustrated spatial distribution of the variables in New York City community districts. It shows how variables of urban form and perceived safety distribute in New York City (Fig. 16). People are likely to perceive safer near Manhattan districts and some areas of Brooklyn. And there are more commercial and mixed use buildings near Manhattan whereas residences are mainly distributed in Brooklyn and Queens.

Height to width ratio seems to be higher in Manhattan than other areas. It means there are more dense buildings and shorter street in there. Population density is usually high in Manhattan whereas industry and parking land use similarly distributed in unpopulated areas. Green canopy seems to be lower in Manhattan than other areas.

These images of spatial distribution suggest there can be spatial autocorrelation. The study checked Moran's I for analysis of the existence of spatial autocorrelation in this data. After test Moran's I, the result showed that there are no autocorrelation in this data. Moran's I was calculated 0.009436 (p = 0.679) based on Euclidean distance between residuals at each image site (Appendix 3).

Fig. 16. The spatial distribution of the variables in New York City.



Street score | Residence | Commercial

Mixed use | Industrial | Parking

Population density | Green canopy ratio | Height to Width ratio

A Moran's I of 1 or -1 explain that residuals were either clustered or dispersed in a regular pattern, indicating the existence of spatial autocorrelation between variables. This result demonstrated there were little spatial autocorrelation that was insignificant at the 0.05 level. The study, therefore, focus on using OLS model for analysis of these variables.

2. Result of the multiple regression analysis

The multiple regression analysis predicted the relationship variables of urban form and perceived safety for test hypotheses in this research. The null hypothesis was there are no any associations between urban form and perceived safety. This

statistical model detected the existence of significant associations between variables of urban form and perceived safety at the 0.001 level. This analysis accounted for more than 38% of variability in perceived safety score (Table 10).

A value of Durbin-Watson was measured 1.605 between variables, nearly two not zero. It means these variables have independence each other. Also the results proved that there are normality of residuals and heteroscedasticity (Appendix 2, 3). Also, the maximum variance inflation factor (VIF) among predictor variables was 0.6953, considerably lower than the threshold of 10 that O'Brien considers problematic in regression modeling (Harvey et al., 2015).

Table 10. OLS regression result.

Variables	Coefficient		Standardized coefficient	t-value (p)	*TOL*	*VIF*
	B	SE	β			
Constant	1.096	0.072		15.209		
Residence	0.233	0.070	0.284	3.318**	0.144	6.953
Commercial	0.234	0.096	0.123	2.430*	0.410	2.436
Mixed use	0.299	0.088	0.184	3.412**	0.362	2.759
Industry	-0.261	0.092	-0.153	-2.831**	0.361	2.770
Parking	-0.482	0.141	-0.133	-3.413**	0.694	1.441
Pop density	0.004	0.002	0.062	1.725	0.814	1.229
H/W	0.081	0.014	0.216	5.822***	0.767	1.305
Green Canopy	0.433	0.046	0.346	9.378***	0.777	1.287
F(p)	45.996***					
adj. R^2	0.380					
Durbin-Watson	1.605					

*p<.05, **p<.01, ***p<.001

In all the variables of urban form, the directions of association did not change, but the correlation values varied. The strongest relationships were discovered in the case of the findings obtained in greenery canopy (r = 0.346), and the weakest ones in population density (r = 0.062). Although most independent variables had positive relationship with perceived safety, some of them such as industry and parking land use negatively affected perceived safety. The variable of population density, however, was insignificant at the 0.05 level. Hypotheses of this research were supported by variables of urban form except population density. This result can predict multiple regression equation following below form:

$$Y = 1.096 + 0.233(X1) + 0.234(X2) + 0.299(X3) - 0.261(X4) - 0.482(X5) + 0.081(X6) + 0.433(X7)$$

These results suggest the type of urban form for safe urban environment. Overall, there are much of trees and residential buildings with mixed use and commercial areas. Also, these buildings are densely high and the width of streets is pretty short. And there are no industrial areas and parking places in the urban environment. These conditions are related each other and effect together. It makes comprehensive influence on perceived safety in urban environment.

4.3. Analysis results and Discussions

The discussion section provides findings and verifies hypothesis of this study based on data analysis. Although there are five hypotheses related to four variables, one hypothesis — population density — could not be proved owing to the fact that this variable is not significant at 0.05 level. Therefore, the study focuses on verify the relationship three variables of urban form and perceived safety in urban environment.

1. Effects on Height to Width

The present study supposed that height to width ratio affect perceived safety. Table 10 shows coefficient value of height to width ratio variable on the 588 sites for impact on perceived safety. This ratio has the positive association with perceived safety (β= 0.216 in 0.001 level). It has the third strong relationship with perceived safety among other variables of urban form. In a sense, people perceive an area with high buildings and narrow streets as safer than other areas. On the other hand, a street which has relatively low buildings with vast streets is likely to be perceived as an unsafe area by people.

This finding is contrary to previous studies which have suggested that tall buildings make people uncomfortable. In the previous studies, scholars argued that people feel more dangerous in front of tall buildings. It is related on natural surveillance and communication of people in urban environment (Jacobs, 1961). People could not observe and communicate with each other well while the building is tall (Blumenfield, 1971). Other scholars also demonstrated that tall height of buildings can give a feeling of oppressive to people (Asgarzdeh et al, 2015).

This different result from previous research can be assumed that people

perceive urban streetscape as a safe place while they are surrounded by buildings in urban environment. The defensible space theory by Newman (1972) supports this assumption that the defensibility of space enhances perceived safety in urban environment. The building façades form street walls supporting enclosure of urban environment. The prospect-refuge theory similarly demonstrates that people feel safest in a place where they have enough opportunities of visibility to adjacent spaces and protection. Jacobs, A. B. (1993) also argues the importance of height to width ratio by mentioning that the wider street has taller height buildings.

To sum up, the result verifies the first hypothesis of this research which is related to the effect of height to width ratio on perceived safety. This demonstrates that people can perceive safety in urban environment when they are surrounded by tall building walls with not wide streets (Fig. 17).

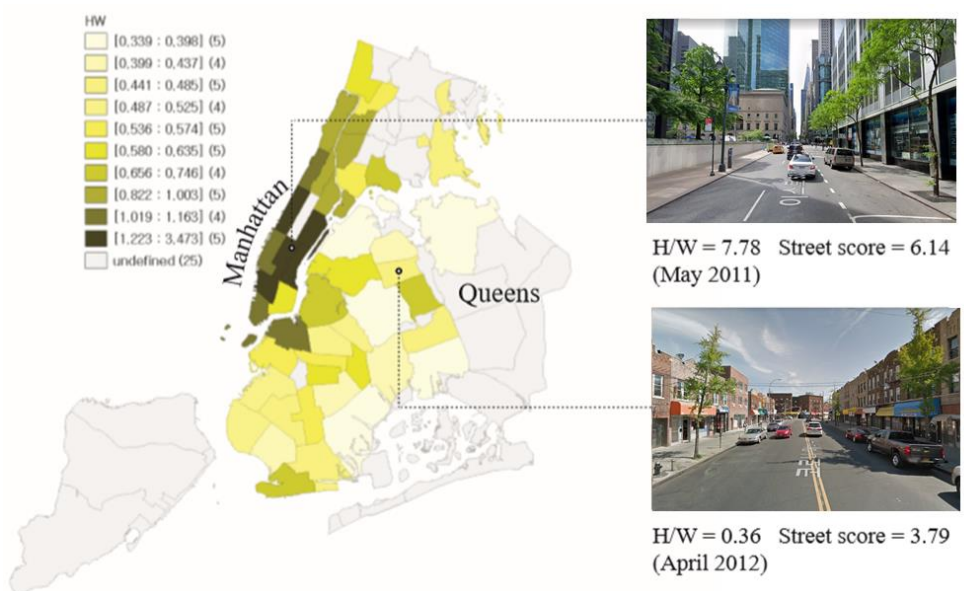


Fig. 17. Google Street view with high H/W ratio and Street score.

2. Effects on Land use

The second hypothesis in this research is related to land use of urban environment. These results verify hypotheses about the influence of mixed use, industry, and parking land use on perceived safety. Importantly, the verification can support the relationship between land use and perceived safety. Previous studies mainly focus on evaluating criminal rate not perceived safety. This outcome suggests the importance of land use on perceived safety in urban environment.

Interestingly, residential land use has the second strong association on

perceived safety among other variables of urban form. It is also the most influential on perceived safety among land uses. There are positive relationships between residential, commercial, and mixed land use and perceived safety. The influence of residential land use (β= 0.284 in 0.01 level) is stronger than commercial land use (β= 0.123 in 0.05 level) and mixed land use (β= 0.184 in 0.01 level).

This finding is contrary to previous studies which have suggested that diverse land use such as mixed use can be safer than single land use like typical residential area. Jacobs (1961) indicated multi land use areas may attract more pedestrians and residents during whole day than single-functional areas, supporting natural surveillance. Although a variable of mixed land use affect perceived safety (β= 0.184 in 0.01 level), it is not stronger than residential land use (β= 0.284 in 0.01 level). Therefore, this result shows that people may perceive residential area is safer than multi-functional buildings and commercial district.

Although the variable of mixed use is less powerful than residential land use on perceived safety, this variable is still important and influential on people perception of safety in urban areas. In this results, multi-functional area including residential, commercial, office and other facilities positively affect perceived safety. This result supports previous literature, ensuring the importance of natural surveillance and vibrant street. In *"The Uses of Sidewalks: Safety,*" Jacobs (1961) argue narrow, crowded, and multi-functional street makes a community of neighborhoods and a city livable. The study confirms that mixed land use is positively associated with perceived safety.

On the other hand, land uses of industrial and parking negatively affect perceived safety. These results seem to be consistent with other research which argued some land uses of non-residential are related to higher criminal rates (Stucky, T. D. et al, 2009). And people usually feel unsafe in unpopulated places owing to that there is no natural surveillance such as "eyes on the street" (Jacobs, 1961).

The existence of people is likely to affect safety of urban environment based on these results. It proves that hypotheses related land uses are statistically significant in regression model. This study suggests urban planners and designers have to consider diverse land use for safe urban environment. And this indicates the importance of land use for safe and sustainable urban environment, which has been unable to demonstrate in previous studies.

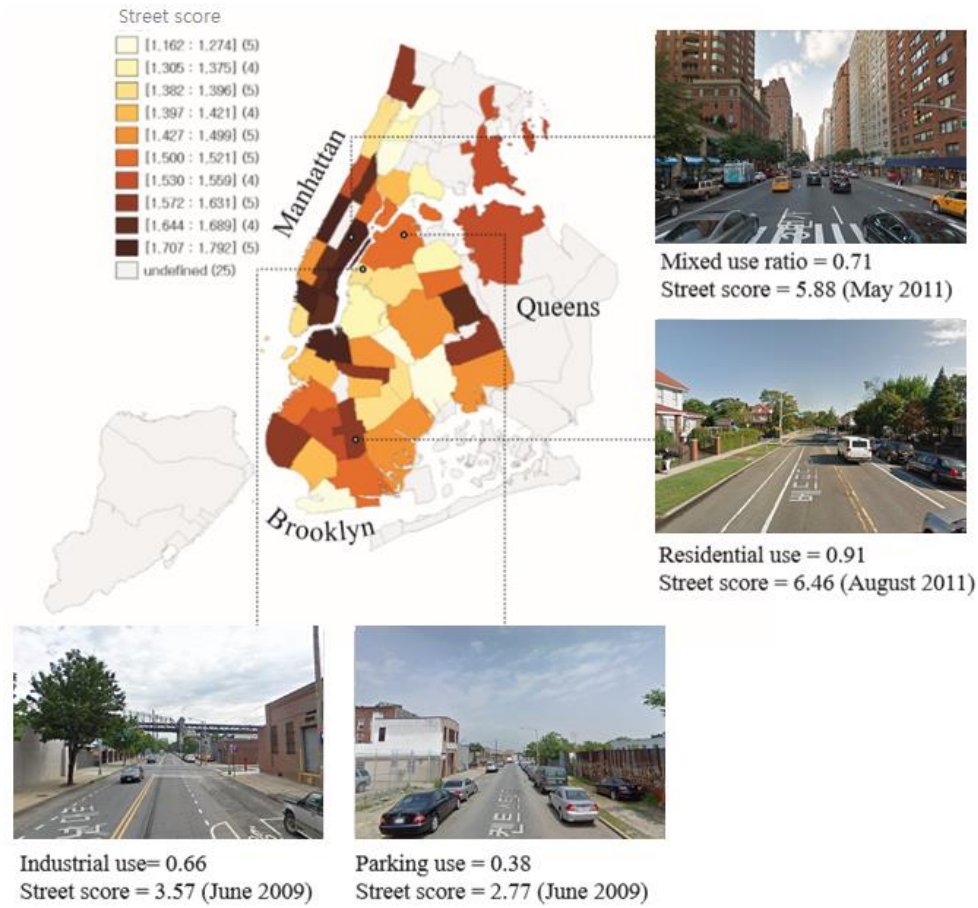


Fig. 18. Google Street view with Land use ratio and Street score.

3. Effects on Urban greenery

The last hypothesis of the research is about urban greenery of influence on perceived safety. What stands out in the table 11 is that green canopy is the most influential variables of among urban form variables (β= 0.346 in 0.001 level). This influence of tree canopy is about two times the force of mixed use variable. This indicates that tree canopy play the most important factors on perceived safety in the urban environment.

Overall, this outcome indicates that people usually feel safer when there are more trees on the urban street. It is related to previous studies which conducted the relationship between urban greenery and criminals. It is related the definition of enclosure by Newman (1972) on the ground fact that trees can contribute to form enclosure in the street. Trees also contribute to supplement enclosure of shortage where buildings are nonexistent or widely spaced (Arnold, 1993; Harvey et al.,

2015). Tree canopy also creates enclosure similarly street walls in the urban environment.

Furthermore, this analysis can support result of other studies. Some people argue that street trees slow down and make proper traffic speeds in urban areas. Street trees form vertical green walls along streets and divide lines between walkways and roads. This plays a role as a guide for appropriate traffic speed and reduces a speed of vehicles, so that pedestrian can secure safe pathways from vehicles. Also trees can block rain, sun, and heat using their coverage on the road. These effects of tree canopy positively affect psychological and physical condition of pedestrians especially on perceived safety (Burden, D., 2006).

This result demonstrates that street tree is the most influential factor among variables of urban form on perceived safety. It contributes to support a number of previous studies related to urban greenery about human perception of safety.

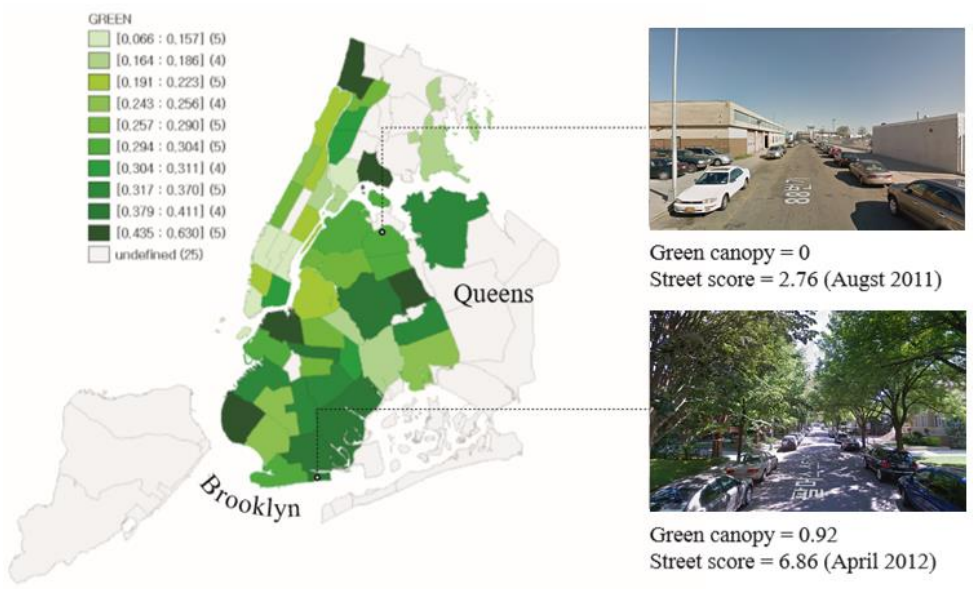


Fig. 19. Google Street view with Green canopy ratio and Street score.

Chapter 5. Conclusion

5.1. Conclusion

The aim of the present research was to examine the relationship between variables of urban form and perceived safety in New York City. The results of this investigation show that greenery canopy is the most positively influential variables on perceived safety in urban areas. Other variables of urban form such as land use, building height, and street width influence of human perception of safety in urban areas.

These results support several classic theories of urban design such as *"eyes on the street"* of Jacobs and *"enclosure"* of Newman. These findings have significant implications for the understanding of how people perceived safety in urban environment. It shows that these theories are still valid in the city today given sustainable urban environment.

These findings contribute in several ways to our understanding of the association between physical attributes of urban environment and perceived safety. First, the contribution of the study is that this research examined the concept of urban form which can comprehensively consider physical variables of urban environment for analysis influence on perceived safety. This analysis can comprehensively analyze and compare the influences of physical attributes on perception of safety in urban streets.

Also the study demonstrates that land use affect people's perception of safety in urban areas. This result has significant meaning at this field owing to fact that previous studies might not focus on the association between land use and perceived safety. This study makes possible to analyze the importance of land use on perceived safety.

Furthermore, the study contributes to understand people's perception in human scale through Google Street View images. This study focuses on analyze human perception using GSV image data, which is similar to people's sight. This method can practically help to design and plan sustainable urban environments.

In general, these results help to understand where people feel comfortable and safe in urban environments. It might contribute to form core premises for planning safe and sustainable city beyond naive design suggestions of urban environments. This research tried to give a significant meaning for forming livable city following prominent scholars including Jane Jacobs.

5.2. Limitations and Future works

The major limitation of this study is the Place Pulse data which used Google Street View image data. First, these image data can be varied depending on photographing condition such as weather, season, and the time of day. For example, street trees are usually more abundant in summer, not winter; perception of people can be varied with season. Also, these images mostly depict few people and empty roads due to that most of GSV images are taken in the early morning; thus, they cannot fully reflect actual urban environment at this condition.

Second, variables of urban form which influence on perceived safety can be affected by other parameters of urban form. For example, the more greenery might make safer perception of people when this vegetation is well managed in rich neighborhood not bush in crime-ridden district. It is necessary to consider interrelationship between variables of urban form.

Third, this present research cannot analyze the influence of participants' characteristics and social backgrounds. People who have different background such as gender, social status, socio economic background, and nationality may differently perceive urban environment. Although few studies analyzed the relationship between average median income and perceived safety in a neighborhood (Naik et al., 2017), this study cannot fully analyze characteristics of each person who rates these images.

Also, Place Pulse data 1.0 which this present study used trained little thousands photos from New York and Boston. This fact demonstrates that these data only contained limited scale which had similar architecture style, urban form and urban planning. This dataset cannot predict other cities except these two cities. Unfortunately, this image data is hard to analyze various cities where have different styles.

At last, it has important limitation that google street image cannot fully depict placeness and human perception. Although visual perception is the most part of human perception, people use several senses such as smell, feeling, and spatial atmosphere. These image data can only reflect physical settings of urban environment. The result from Place Pulse data can be different from actual perception of this site.

Notwithstanding its limitations, this study does suggest new possibilities for analyzing perception of more people in various cities using Google Street View and machine learning. Future studies will expand to measure and predict human perception in other cities. This advanced methodology can lead to analyzing people perception of urban environment in the world.

Future studies would use computer vision technology for accurately analyzing Google Street View image data. The technology of computer vision can measure proportion of images using image segmentation. It makes possible to precise measure which factors affect human perception of environment. In summary, future work will be expected to expand the scale of research and accurately measure human perception. This study is likely to be applied to other cities except New York and Boston. Researchers can use street view data for analyzing people's perception of urban environments considering various contexts of each city.

5.3. Implications

These findings suggest several implications for understanding urban planning and design in human-scale. First, this present research reflected cutting-edge technology such as machine learning and big data analysis. It shows that how research in urban planning and design field adapt technological innovations to understand between people and urban environment for building sustainable city. It is important to use advanced technologies in research owing to fact that study have to keep up with trend of society. Also it can provide innovative research and new methodology which can improve problems of prior methods for analyzing people's perception.

Second, these results suggest the importance of urban planning and design to people living in urban areas. The physical attributes of urban environment which are affected by urban planning and design influence on people's perception and behavior. It means planning and design is indirectly affect human perception and their behaviors in urban areas. When urban environment is designed appropriately for human, people can be more activate and creative in urban areas. Therefore, it proves the research should study which physical factors of urban environment influence on people's perception for sustainable cities.

At last, this present study focuses on human perception of urban environment not bird view which has been used by traditional urban planners and designers. In twenty first century, it is important to plan and design city by human-centered perspectives. These findings suggest implications and guides for planning safer city for human-centered city. This perspective can reflect people's actual perception of urban environment and provide practical planning and design of sustainable cities. It pursues to follow recent movements of urban planning and design for *Cities for people*.

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Appendix

Appendix 1. OLS Regression Results

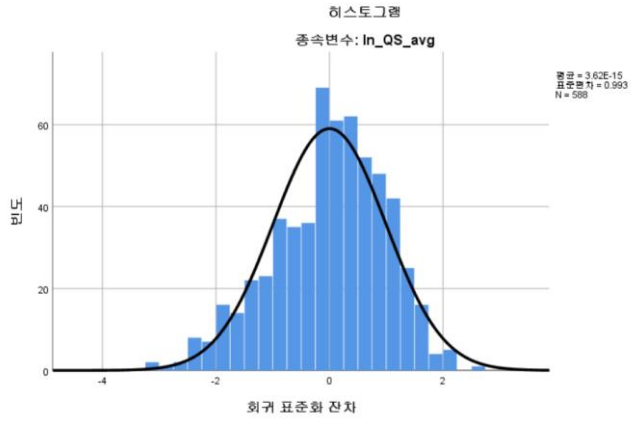
OLS Regression Results

Dep. Variable:	Street score	R-squared:	0.389
Model:	OLS	Adj. R-squared:	0.380
Method:	Least Squares	F-statistic:	46.00
Date:	Thu, 04 Jun 2020	Prob (F-statistic):	3.45e-57
Time:	00:21:03	Log-Likelihood:	43.163
No. Observations:	588	AIC:	-68.33
Df Residuals:	579	BIC:	-28.94
Df Model:	8		
Covariance Type:	nonrobust		

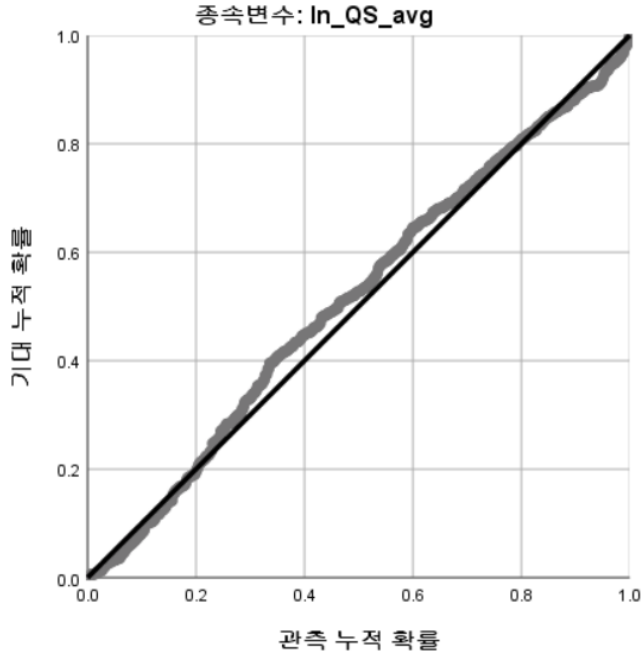
	coef	std err	t	P>|t|	[0.025	0.975]
const	1.0962	0.072	15.209	0.000	0.955	1.238
Residence	0.2326	0.070	3.318	0.001	0.095	0.370
Commerical	0.2338	0.096	2.430	0.015	0.045	0.423
Mixeduse	0.2990	0.088	3.412	0.001	0.127	0.471
Industry	-0.2612	0.092	-2.831	0.005	-0.442	-0.080
Parking	-0.4823	0.141	-3.413	0.001	-0.760	-0.205
Pop density	0.0041	0.002	1.725	0.085	-0.001	0.009
H/W	0.0809	0.014	5.822	0.000	0.054	0.108
Green Canopy	0.4325	0.046	9.378	0.000	0.342	0.523

Omnibus:	18.731	Durbin-Watson:	1.605
Prob(Omnibus):	0.000	Jarque-Bera (JB):	19.997
Skew:	-0.451	Prob(JB):	4.55e-05
Kurtosis:	2.972	Cond. No.	145.

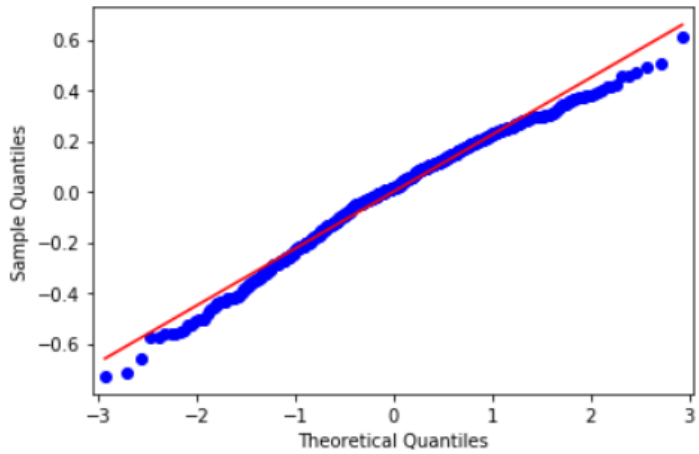
Appendix 2. The normality of this model



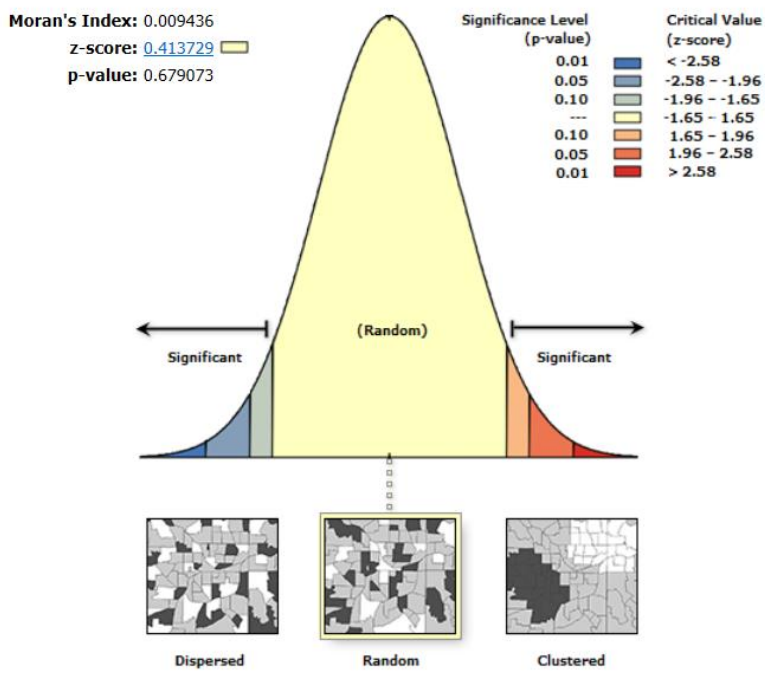
회귀 표준화 잔차의 정규 P-P 도표



Appendix 3. The analysis of heteroscedasticity



Appendix 4. The result of Morans' I



Abstract in Korean

최근 뉴어바니즘과 도시에 대한 권리 담론들을 통해 도시를 사람들의 관점에서 바라보는 것이 중요해졌다. 이 중에서 도시에 대한 사람들의 인식은 지속 가능한 도시 계획을 위해 필수적인 부분이다. 특히나 도시 환경에 대한 사람들의 안전 인식은 도시에서의 사람들의 활동에 영향을 끼친다는 점에서 중요한 가치를 갖는다.

기존에 도시환경에 대한 인식 연구를 위해서는 적은 수의 사람들에게 직접 설문조사를 진행하거나 이미지 맵핑 방식을 사용하였다. 최근 MIT Media lab 연구진들은 구글 스트리트뷰를 활용해 사람들의 안전 인식에 대한 연구를 진행하였다. 이는 빅데이터와 머신러닝을 활용해 기존의 방식보다 더 많은 장소와 사람들의 인식을 조사할 수 있다는 점에서 의미를 갖는다. 또한 제인 제이콥스를 포함한 여러 도시 학자들의 기존 이론들을 문헌 고찰하여 본 연구의 분석에 유효한지 분석하였다.

본 연구는 뉴욕시의 물리적 도시형태에 따라 도시 환경에 대한 사람들의 안전인식이 어떻게 변화하는지를 분석하였다. 이를 위해 ArcGIS를 통해 분석한 도시형태 데이터와 MIT Media lab 의 사람들의 도시환경에 대한 안전인식 관계를 다중회귀모델을 활용하여 분석하였다. 도시형태 데이터의 경우 기존 문헌을 참고하여 사람들의 인식에 크게 영향을 미치는 인구 밀도, 토지 이용도, 도로 폭과 빌딩 높이, 가로수 데이터를 사용하였다.

연구 결과는 도시 형태의 변수에 따라 사람들의 도시 환경에 대한 안전인식이 달라진다고 밝혀졌다. 특히나 가로의 가로수 현황에 따라 사람들의 안전인식이 가장 크게 변했다. 또한 토지 이용도가 혼합될수록 사람들은 안전하게 느꼈다. 그리고 도로의 폭이 좁고 건물 높이가 높을수록 사람들은 안전한 도시환경으로 인식했다.

이러한 연구 결과는 도시 계획과 설계에 있어 사람들의

안전인식을 고려할 수 있다는 점에서 중요한 시사점을 갖는다. 이는 활력 있고 지속 가능한 도시 환경을 설계하기 위해 사람들이 안전하게 인식할 수 있는 도시환경을 계획하여야 한다는 의미를 제시한다. 또한 사람을 위한 도시 설계를 위해 본 연구는 어떤 도시 형태의 요소가 사람들의 안전 인식에 어떻게 영향을 끼치는지 밝히는 데 중요한 의미를 갖는다. 이 연구는 추후 사람 중심의 지속 가능한 도시계획 및 설계를 위해 보다 더 다양하게 사용될 수 있는 가능성을 보여준다.

주요어: Human perception, Perceived safety, Urban form, Google street view, Big data analysis

학 번: 2018-23493

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