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Sustainable | Sustaining City Streets

Edited by
Ken Tamminga and Thomas Knüvener

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Editors

Ken Tamminga
Thomas Knüvener

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Editors
Ken Tamminga
Department of Landscape Architecture, The Pennsylvania State University
USA

Thomas Knüvener
Knüvener Architekturlandschaft,
Brüsseler Straße 89-93 D
Germany

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

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Cover image courtesy of Ken Tamminga.

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About the Editors

Ken Tamminga is Distinguished Professor of Landscape Architecture at Penn State University. He teaches urban and ecological design and uses constructive approaches for engaging his students with community partners. He has conducted action research on applied sustainability and resilience-building in North American and west European cities and sub-Saharan African and south Asian rural communities. He is currently co-leading a research consortium that is exploring convivial greenstreets phenomena in dense urban cores.

Thomas Knüvener is an architect and landscape architect and Principal of Knüvener Architekturlandschaft. The office works at the interface between architecture and open space, city and landscape, interior and exterior. He has held different teaching positions, most recently as Visiting Professor of Landscape Architecture at HS Koblenz. He is currently planning and building projects according to the principles of circular construction and is an expert advisor on the board of the Regional Resource Transition in the Building Economy.

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Editorial

On Sustainable | Sustaining City Streets

Ken Tamminga [1,*] and Thomas Knüvener [2]

1 Department of Landscape Architecture, The Pennsylvania State University, University Park, PA 16802, USA
2 Knüvener Architekturlandschaft, Brüsseler Straße 89-93 D, 50672 Köln, Germany; mail@architekturlandschaft.net
* Correspondence: krt1@psu.edu

City streets have long been the subject and context for research. In this *Sustainable | Sustaining City Streets* volume, streets and their vast array of activities are examined by sustainability scientists and urbanists from many backgrounds. We hope that these papers promote an understanding of the reciprocal nature of the phenomenon of streets and their relationships with urban inhabitants. The more we reveal and activate sustainable approaches to streets, the greater the likelihood that our streets will help sustain life in cities.

In a late-1950s issue of *Fortune*, visionary urbanist Jane Jacobs wrote, "The street works harder than any other part of downtown. It is the nervous system; it communicates the flavor, the feel, the sights. It is the major point of transaction and communication. The real potential is in the street" [1]. A generation of scholarship and professional application on city streets followed, largely focused on morphology, infrastructure, policy, and program: the physical forms, spaces and patterns, and related human activities and rules, that characterized "good" streets. As the new millennium approached, there were broader calls for multi-disciplinary and evidence-based investigations of the dynamic processes that streets and urban corridors accommodated—or discouraged, as the case may be.

Meanwhile, the global population lodged in cities continued to expand, with especially serious challenges in the Global South. In particular, since the mid-20th century, policy-makers' abetting of the automobile's dominance has impacted cities and city life around the world. By the turn of the century, however, critique of the unsustainable streets-belong-to-cars paradigm gained momentum, and today cases of more balanced approaches are surging.

While diverse in scholarly background and geography, the authors introduced below are quite unified in seeing streets for the complex, impactful, and malleable urban phenomena that they are. Each paper shows 'street smarts' as it reveals ways to manage and craft more sustainable street systems. As a whole, this collection offers an interdisciplinary, multi-methods discussion on:

1. What makes for safe, healthy, efficient, convivial and inclusive city streets.
2. Why streets are vital to the well-being of urban inhabitants.
3. How scholars and practitioners can collaborate on effective interventions along the street as key factors in urban sustainability.

This collection features 13 papers on an array of subjects, although there are topical clusters. The plus-50 authors hail from 23 research organizations and 13 countries. Five of the six populated continents are represented—only Australia is missing from the list. Streets and street-based phenomena are investigated in western Europe and the United Kingdom; central Africa; east, southeast, and south Asia; and the United States. Almost 20 distinct disciplines collectively represent the social sciences (psychology, geography, economics, logistics, development science), engineering (civil, transportation, systems), design and policy professions (landscape architecture, urban design, city planning, architecture), and health and physical sciences (epidemiology, environmental toxicology, atmospheric science).

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In terms of the spatial scope of the inquiry, five papers explore sustainability at the scale of a precinct in a single city; four papers look at multiple sites in a single city; two address a single entire metropolis; and two are multi-city in scope.

Of course, there are gaps. For example, there is only passing reference to electric-assisted micro-mobility, which is quickly becoming entrenched in some cities. The shift toward more sustainable modes of moving people and materials in the city calls for timely study and dissemination by a wide cadre of urban scholars. Moreover, no papers deal substantively with ecology and changing urban climate along the street corridor and the intriguing opportunities for more robust ecosystem services in the heart of the city.

Eight papers address pedestrian activities and perceptions related to streets and adjacent land uses, perhaps recognizing that streets are as much vessels for human life as they are conduits for machines in motion. There is a growing understanding that active mobility—walking, biking, and a whole range of other muscle-driven or hyper-efficient modes of urban transport—has positive effects on cities and their citizens. Even partial liberation from the automobile is resulting in more equitable, healthier, and climate-responsive shared public spaces and transport modes, along with a variety of green infrastructure possibilities at local and urban regional levels.

Two papers discuss the use of eye-tracking technology to assess respondents' reactions to visual stimuli along the city streetscape. Simpson, Thwaites, and Freeth blend environmental psychology and landscape architecture methodologies in using mobile eye-tracking glasses to gauge pedestrians' visual engagement with street edges in Sheffield, UK.

Kim and Park, in a contrasting research context, employ eye-tracking within a virtual street-view environment to determine respondents' fixation on signboards as a way of informing municipal regulation of street-based advertising in Seoul, Korea. Both papers show the efficacy of eye-tracking in documenting visual interactions on the street. Further, both produce tangible results that could help guide policy and design seeking to improve pedestrian experiences within the street canyon.

Perović and Šestović address socio-spatial sustainability in the southeast European city of Podgorica, the capital of Montenegro. Through theoretical and case study analyses, they affirm the role of a traditional public open space in helping bolster social identity, and their design guidelines make a case for shaping human-scale spaces that enhance socialization and personal well-being.

Wakil et al. address sensory engagement along the streetscapes of Lahore, Pakistan. They test a novel methodology for the systematic development of a visual pollution assessment tool for streetscapes. Their expert-based tool teases out consensus on the characteristics of various visual pollution objects, as applied to a series of street-based locations.

The focus on pedestrian accommodation on the street continues with the paper by Campisi et al. Using a multi-criteria analytical hierarchy process analysis, the authors evaluate walkability in busy pedestrian areas of Rijeka, Croatia. Although their street-side surveys were administered pre-COVID-19, they make a solid case for pedestrian behavior analyses to inform tactical planning that enhances walker mobility while promoting social distancing and air quality.

Rodriguez-Valencia and Ortiz-Ramirez examine green infrastructure trends on streets in three American cities: Portland, Seattle, and Philadelphia. Using a qualitative case study methodology grounded in multi-agent interviews, documentary analyses, and site observations, they trace the evolution of traditional street design approaches and document emerging green street design protocols that focus on sustainable stormwater management in tight urban spaces.

Im's paper also explores the theme of urban green streets, this time by examining select civic green street manuals and constructed stormwater-oriented streetscape projects in select American cities. The author's collation of green street benefits results in a proposed design typology that is then affirmed through multi-expert review.

Lee and Kim address the hazards of walking along the narrow "organically shared" streets of the dense residential core of Seoul, South Korea. They investigate the effectiveness of the city's pedestrian priority street (PPS) strategy for shared space using on-site videography and a questionnaire survey to assess perceptions of traffic safety along local streets. Their findings should prove useful for informing government officials and residents about the value of PPS design protocols.

Tchinda and Kim examine fear of crime in public urban spaces in Yaoundé, the central African capital of Cameroon. They conduct street corner sampling of pedestrians' fear of crime perceptions at five key street intersections. Survey results are then referenced to spatial data acquired through drone aerial photography of real-time pedestrian density. Their work confirms the hypothesis that, in the case of Yaoundé, fear of crime rates rise as street-side congestion increases.

Lim et al. also address street crime, this time in Kuala Lumpur, Malaysia. Based on data gleaned from a large survey questionnaire of street-based respondents in the high-crime Dang Wangi commercial district, the authors conclude that the "Safe City Program works only when a combination of initiatives from the perspectives of guardians, victims, and offenders are integrated well."

The consideration of social factors and civil incivilities on and around city streets is broadened by Marzbali, Safizadeh, Tilaki, and Abdullah's contribution. Applying social disorganization theory to a neighborhood in Penang, Malaysia, they suggest, among other things, that the human–place bond may lessen the impacts of incivilities on residents' health in city neighborhoods. They conclude by discussing practical implications for enhancing place attachment and social identification.

Jia, Ma, and Hu are the sole team that address a complex public transportation system, in this case in the Chinese city of Xi'an. Their experimental study leverages complex network theory to investigate the topological properties of Xi'an's busing network, and then proposes an optimization model based on betweenness centrality and policy guidance.

Finally, Tönisson et al. present the most transdisciplinary paper of the collection, with physical, health, and social scientists collaborating as a choreographed unit. Their mixed-methods approach analyzes quantitative and qualitative data to propose mitigation strategies for black carbon emissions afflicting the streets of Manila, Philippines.

If there is a meta-concept that holds this compendium together, it is the street's chameleon-like capacity to simultaneously accommodate flows of life, material, and energy, while also providing spatial volumes and edges along which urban placefulness, civil society, and metro-scale economies may develop.

Indeed, during the COVID-19 era, city streets have taken on renewed meaning as public places of camaraderie, protest, and other forms of expression. The pandemic has also heightened our collective appreciation of the basic role of streets in the deceptively simple task of hosting safe and agreeable passage from point A to point B. The street's dramatic interplay of infrastructure, environment and humans in motion call for new collaborations—including fuller engagement with city inhabitants. As these papers suggest, the time is ripe for city leaders, scholars, planners, and residents to rethink the street as a key driver of sustainable urban futures.

To conclude, we would like to thank our author colleagues for contributing to this Special Issue, as it indicates a step forward in the understanding of sustainable streets and street systems. We also extend our sincere appreciation to peer reviewers. This volume would not have been possible without their rigorous critique and generous insight during the manuscript review process. Finally, we express gratitude to the MDPI Sustainability Editorial Office for their enthusiasm and support throughout the process.

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Reference

1. Jacobs, J. Downtown Is for People (*Fortune*, 1958). Reprinted in Fortune Classic 2011. Available online: https://fortune.com/2011/09/18/downtown-Is-for-people-fortune-classic-1958/ (accessed on 10 January 2021).

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Article

Understanding Visual Engagement with Urban Street Edges along Non-Pedestrianised and Pedestrianised Streets Using Mobile Eye-Tracking

James Simpson [1,*], Kevin Thwaites [1] and Megan Freeth [2]

[1] Department of Landscape Architecture, University of Sheffield, Sheffield S10 2TN, UK
[2] Department of Psychology, University of Sheffield, Sheffield S1 2LT, UK
* Correspondence: j.c.simpson@sheffield.ac.uk

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Abstract: Existing knowledge of street edge experience has often been constructed using methods that offer a limited opportunity to gain empirical insight from the first-hand perspective of pedestrians. In order to address this, mobile eye-tracking glasses were used during the current investigation to provide a detailed understanding of pedestrian visual engagement with street edges along both non-pedestrianised and pedestrianised urban streets. Through this, the current study advances empirical knowledge of street edge experience from a perspective that has previously been challenging to capture and quantify. The findings demonstrate that people visually engage with street edge ground floors more than their upper floors, that visual engagement is distributed more towards the street edge on the walked side of non-pedestrianised streets than the opposite side, and that visual engagement with street edges of pedestrianised streets is balanced across both sides. The study findings also highlight how the everyday activities of pedestrians and different streets being walked often influence the amount of visual engagement within these street edge areas. These insights provide a new understanding that develops existing knowledge of pedestrian street edge experience. Significantly, they also provide an empirical foundation from which to examine how design intervention can become more considerate of peoples' routine use of and experiential engagement with street edges along non-pedestrianised and pedestrianised urban streets.

Keywords: street edge; visual engagement; mobile eye-tracking; ground floors; pedestrian streets; non-pedestrianised streets

1. Introduction

Street edges span the interface between indoor and outdoor realms along urban streets. It has been argued that they significantly impact the everyday pedestrian experience [1–3]. Understanding the nature of such experience is important against a backdrop of contemporary issues, such as high street decline [4–6] and the reduction in the variety of street edge functions [7–9]. These factors have impacted how experientially engaging and stimulating today's street edges are for pedestrians, subsequently reducing their capacity to positively influence peoples' day-to-day quality of life [10–12]. Even though this is understood, there still remains a limited systematic understanding of the general principles that characterise the way in which people visually engage with street edges [3,13,14]. This makes it challenging to guide socially and experientially responsive street edge design intervention. The current investigation addresses this lack of first-hand empirical insight through the use of mobile eye-tracking. Specifically, it assesses the extent to which pedestrians visually engage with street edge ground and upper floors, as well as street edges on different sides of non-pedestrianised and pedestrianised streets. To provide greater insight, it also examines how optional and necessary pedestrian activities and differing streets walked influence the amount of visual engagement with these street edge areas.

Through this study, the current investigation provides a highly detailed insight into peoples' visual engagement with street edges from a pedestrian perspective that has previously been challenging to capture and comprehend. The findings obtained are then used to explore how design decision-making can become more considerate of peoples' routine experiential engagement with street edges.

Over many years, an understanding of what visual qualities and attributes of environmental scenes people engage with and value has been attained, often with a focus towards influencing design decision-making [15–18]. Alongside this, new data collection methods have provided a greater opportunity to capture insight into how these environments are engaged with by people while they are immersed within them [19–21]. However, even though advancements have been made, the application of new techniques to the systematic assessment of how pedestrians visually engage with urban street edges remains limited. To date, existing knowledge of street edge experience has often been attained through observations and interviews [22,23]. Interviews require the verbalisation of often difficult to describe and regularly fleeting experiences [24]. Observations regularly focus upon overt human–environment interactions and are susceptible to observer bias [25]. As a result, these methods often restrict the opportunity for individual experiential influences to be systematically analysed. This is significant when reflecting upon calls for built environment design intervention to become more evidence-based through an empirical understanding of peoples' routine use and engagement with urban environments [26–28]. In order to overcome these methodological issues, mobile eye-tracking glasses are used during the current investigation. This data collection technique captures quantified information on gaze distribution, through tracking eye-movements, allowing a detailed understanding of specific influences on cognition and perception [29]. Recently, there have been a number of mobile eye-tracking studies in outdoor urban situations [14,21,30], as well as indoor eye-tracking studies that assess how people distribute their gaze upon images of urban settings [31–33]. This highlights a steady increase in the number of eye-tracking studies assessing how people visually engage with various urban stimuli. However, none of these studies have so far sought to use eye-tracking in real-world situations to investigate which areas of street edges people visually engage with along non-pedestrianised and pedestrianised streets. Such an assessment is undertaken during the current investigation, with the information captured providing empirical insight that develops existing understandings from a direct pedestrian perspective.

1.1. Visual Engagement with Street Edge Ground and Upper Floors

It has been argued that pedestrians predominantly engage with street edge ground floors in comparison to upper floors [34,35]. For Gehl [1], ground floors are a key feature of a successful *city at eye level*. Glaser et al. [2], in an attempt to quantify ground floor experiential significance, claim that "*the ground floor may only be 10% of a building, but it determines 90% of the building's contribution to the experience of the environment*" (p. 12). From this assertion, they propose the concept of *street plinths,* with the re-appropriated use of the term *plinth* aiming to refocus attention upon ground floor social and experiential significance. Related to this is the proposition that street edges need to be understood across multiple scales [2,36,37]. Through this, there has been the opportunity to consider ground floors as being distinctly scale embedded within the wider built morphology of street edges [2,34,38]. This again highlights an attempt to focus attention upon ground floor significance, as well as to provide a greater chance for design decision-making actions to be more considerate of their specific requirements in response to peoples' engagement with them [2,38,39]. However, across the ideas introduced, there is a lack of empirical insight, from the first-hand experiential perspective of pedestrians, that evidences the arguments made. The current investigation will address this through a systematic assessment of pedestrian visual engagement with street edges using mobile eye-tracking.

Building upon the points made, little is known about the way that streets, spanning both different non-pedestrianised and pedestrianised streets, influence the extent to which visual engagement is predominantly focused upon street edge ground floors. Previous mobile eye-tracking research has highlighted that pedestrians visually engage with the totality of surrounding street edges to variable extents along different streets [14]. However, it is not fully understood if this insight is transferable when considering ground floors along differing non-pedestrianised and differing pedestrianised streets. Currently, there is also limited knowledge of the way in which variable pedestrian activities within streets influence ground floor visual engagement. There has recently been a growing understanding that people are situated and embodied agents experiencing their surroundings in an enactive manner that is responsive to variable social and spatial influences [40,41]. However, the extent to which specific social factors, such as varying everyday activities, influence street edge and specifically ground floor engagement is still not fully understood. Previous research has highlighted how contrasting activities affect how people behave in urban settings, providing opportunity to categorise peoples' everyday actions into optional and necessary activities [1]. Mobile eye-tracking has subsequently shown how these activity groups influence wider street edge visual engagement [14]. However, no studies have focused on examining the impact that these pedestrian activities have upon ground floor visual engagement along non-pedestrianised and pedestrianised streets. From these foundations, the current investigation asks the following:

Research Question 1a: Do people visually engage with street edge ground floors more than upper floors along (i) non-pedestrianised and (ii) pedestrianised streets? 1b: Do different everyday activities and different streets walked influence the amount of visual engagement upon street edge ground floors along (i) non-pedestrianised and (ii) pedestrianised streets?

Existing discourse provides an opportunity to hypothesise that pedestrians will visually engage more with street edge ground floors compared to upper floors along both non-pedestrianised and pedestrianised streets, [1,2,34,35]. Building upon previous eye-tracking research, that was not ground floor specific and did not systematically assess differences across non-pedestrianised and pedestrianised streets [14], it is anticipated that everyday activities and differing streets walked will influence the amount with which ground floors are visually engaged.

1.2. Visual Engagement with Street Edges on Different Sides of the Same Street

It has been suggested that pedestrians engage with street edges on opposing sides of a street differently [1,34,37]. Along non-pedestrianised streets, the street edge on the walked side is experienced at a closer, more-detailed range and as a result, is able to capture and hold pedestrian engagement to a greater extent. The opposite street edge cannot be engaged as closely and objects in the street often hinder prolonged engagement. Even though this is understood, there is limited empirical evidence from a pedestrian perspective highlighting the disparity in engagement between the walked and opposite side street edges of the same non-pedestrianised street. Street edges along pedestrianised streets cannot be delineated as walked and opposite, with pedestrians often able to occupy much more of the street space between the edges [42,43]. These street edges are instead left and right sided from a pedestrian perspective. Significantly, we currently lack empirical knowledge of the way in which these street edges of the same pedestrianised streets are visually engaged with. Similar to understandings of ground floor visual engagement, it is currently not known how visual engagement with street edges on different sides of non-pedestrianised and pedestrianised streets varies in response to everyday pedestrian activities and different streets walked. The current investigation will use mobile eye-tracking to address the lack of knowledge in this area, while asking the following:

Research Question 2a: Are there differences in the amount of visual engagement upon street edges on different sides of the street along (i) non-pedestrianised and (ii) pedestrianised streets? 2b: Do different everyday activities and streets walked influence the amount of visual engagement upon street edges on different sides of the street along (i) non-pedestrianised and (ii) pedestrianised streets?

It is predicted that visual engagement will be focused towards the street edge on the walked side of non-pedestrianised streets [1,34,37]. In contrast, visual engagement with street edges of pedestrianised streets will be more balanced across both sides. Building upon the understanding that differing activities and streets walked impact street edge visual engagement overall [14], it is predicted that such factors will also influence the amount that street edges on the walked and opposite sides of non-pedestrianised streets, as well as edges on the left and right sides of pedestrianised streets, are visually engaged with.

1.3. The Influence of Pedestrianisation upon Visual Engagement with Urban Street Edge Areas

The broad benefits of pedestrianisation have been detailed by many [1,35,42,43]. However, it is not understood how such intervention impacts pedestrian engagement with street edges. Specifically, there has been no systematic exploration of how visual engagement with areas of street edges along pedestrianised streets contrasts with that of street edges areas of non-pedestrianised streets. Therefore, the current investigation asks the following:

Research Question 3: Are there differences in the amount of visual engagement upon (i) street edge ground floors between non-pedestrianised and pedestrianised streets, and (ii) street edge sides between non-pedestrianised and pedestrianised streets?

The experiential significance of street edge ground floors has been described, often regardless of context [1,2,34]. It is therefore hypothesised that there will be no significant difference in the amount of visual engagement with ground floors between non-pedestrianised and pedestrianised streets. It is anticipated that visual engagement will be more balanced across both street edges of pedestrianised streets, in contrast to non-pedestrianised streets, where it will be focused on the edge on the walked side [1,34,37]. This provides the opportunity to hypothesise that there will be a noticeable difference in the amount of visual engagement upon the different street edge sides between non-pedestrianised and pedestrianised streets.

2. Materials and Methods

2.1. Participants

Opportunity sampling, through a volunteers list held by the University of Sheffield, was used to recruit 24 adult study participants (n = 12 female; n = 12 male) with a mean age of 35 years (range = 21–61 years, standard deviation = 10). Academic staff were omitted from invitation to attain a sample without bias towards higher education levels. All participants had normal to corrected-to-normal vision via contact lenses, did not know the intentions of the study at the time of participation, and had previous experience of the streets investigated.

2.2. Apparatus

A SensoMotoric Instruments (SMI) Glasses 2.0 Mobile Eye-tracker was used within the current investigation. Inside the frame of these glasses are one forward-facing camera recording a video of the environment in front of the wearer and two backward-facing cameras in the rim of the glasses recording the wearer's eye movements. The video data captured was processed using SMI BeGaze to give a single video output, comprising the video of the environment in front of the wearer with the gaze location superimposed on top. Each participant was fitted with the mobile eye-tracker and wore a peaked cap to help limit the influence of sunlight on data quality, which is consistent with previous real-world eye-tracking studies [44].

2.3. Design

The current study examined the percentage of pedestrian visual engagement with different urban street edge areas of interest (AOIs). These AOIs were ground and upper floors along non-pedestrianised streets (Figure 1A), ground and upper floors along pedestrianised streets (Figure 1B), street edges on the walked and opposite side of non-pedestrianised streets (Figure 1C), and street edges on the left and right sides of pedestrianised streets (Figure 1D). The study also examined the effect of two independent variables—street (levels = street id; non-pedestrianised and pedestrianised streets were considered separately) and pedestrian activity (levels = optional and necessary activities)—on the dependent variable, which was the percentage of visual engagement upon the street edge AOIs discussed.

Non-pedestrianised streets within the current investigation were considered as streets with thoroughfares that actively delineate pedestrian and vehicular movement. Pedestrianised streets comprised a single space that pedestrians have priority of movement and activity within, even though street materiality and furniture may still delineate opportunity for vehicular access.

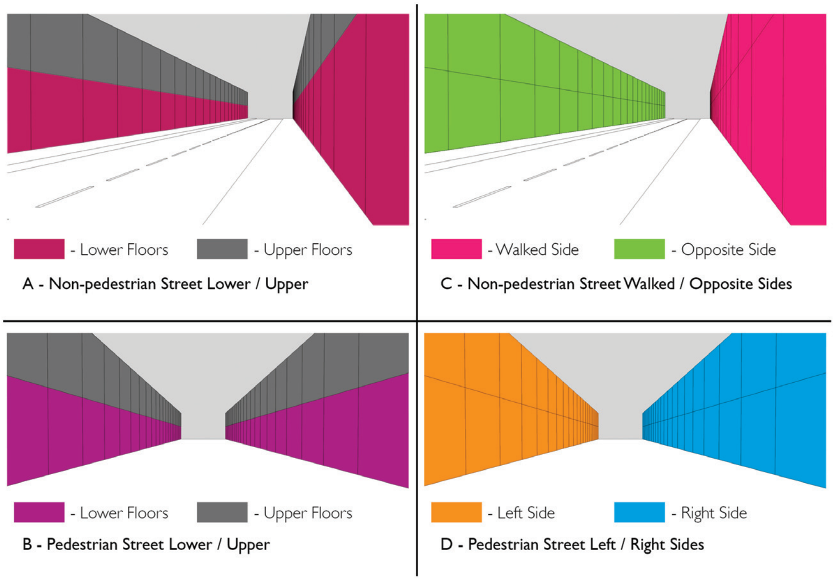

Figure 1. Diagram of Street Edge Areas of Interest (AOIs).

2.4. Procedure

Figure 2 presents an overview of the methodological procedure employed during the current investigation to collect, process and code the mobile eye-tracking data. After fitting the participant with the mobile eye-tracker, a three-point calibration was undertaken. Subsequent checks for tracking accuracy were undertaken and, if required, calibration was repeated. Data collection took place during the day and not at night, as this could have influenced the data captured [45]. It also took place during fair weather conditions in order to reduce the effect of poor weather, such as rainfall, on participant behaviour within the study streets. A cap was worn by the study participant in order to allow data collection within sunny conditions [44].

Two walked routes were used during the current study, with each route comprising six streets within Sheffield's city centre, UK. Following the initial study setup (see Figure 2, points 1–3), participants were requested to walk one of these two routes. The battery-life of the eye-tracker restricted the duration of data collection to six streets per participant, so two routes were used in order to provide eye-tracking data of street edge visual engagement from a range of different streets. Both routes comprised non-pedestrianised and pedestrianised urban streets, were discrete, and were devised so that each street had a well-defined start and end point. This was in order to reduce the need for wayfinding, which may have influenced how participants visually engaged with their surroundings.

Before walking along a street of a specified route, study participants were required to read a task card. This introduced an everyday activity for the participant to undertake when walking that street (see Figure 2, point 4). This process took place for each of the six streets of the route walked and provided the opportunity to assess the extent to which everyday activities impacted the distribution of visual engagement upon the different street edge AOIs. The activities were derived from the on-site observation of peoples' routine behaviours, establishing a degree of real-world and context-specific validity. In total, six activities were selected across two categories: optional activities (break-time stroll, going for coffee with a friend, window-shopping) and necessary activities (rushing to work, dropping an item off with a friend, walking to the bus). The activities were distributed evenly amongst the streets, with each study participant carrying out an activity once (three optional and three necessary activities across six streets along a single route, see Figure 2, points 4–6).

Data collection across the two routes was undertaken twice; however, eye-tracking data for one street was omitted from the subsequent analyses due to it only having a street edge on one side. This resulted in the data from six non-pedestrianised and five pedestrianised streets being assessed (see Figure 2, points 7–9 and Figure 3 for eye-level images of the study streets). Such a process provided a total dataset of pedestrian visual engagement with the street edges of 132 walked streets, i.e., 24 study participants walking eleven different streets undertaking different activities that were either optional or necessary.

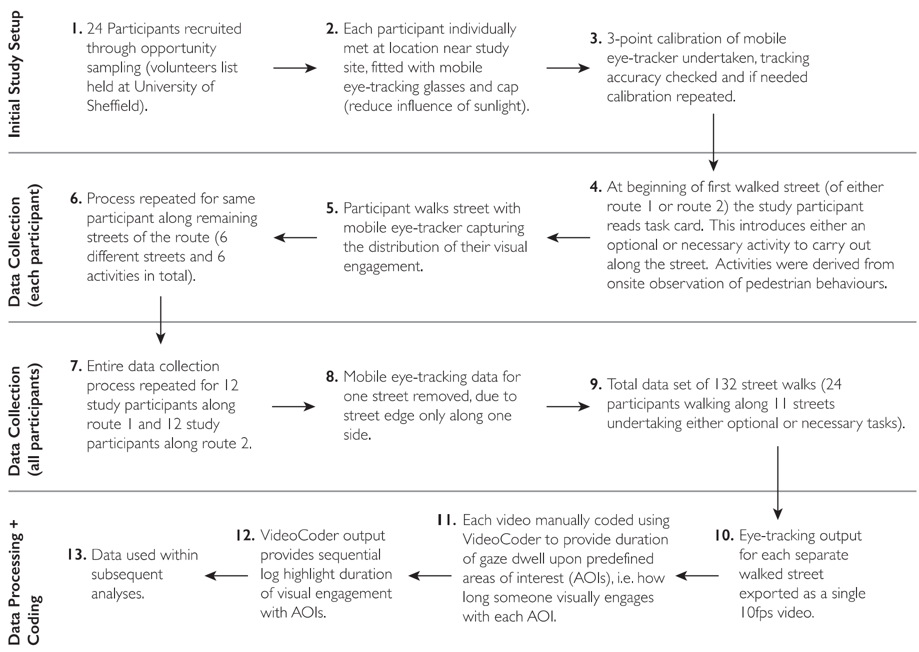

Figure 2. Methods Workflow Diagram.

2.5. Data Processing and Coding

Following the completion of data collection (see Figure 2, points 4–9), each participant's eye-tracking data for each separate street was exported as a single video. VideoCoder [46] was then used to code the gaze dwell duration upon street edge AOIs based upon the knowledge that each video frame indicated the gaze location for a tenth of a second (see Section 2.2 Design for the AOIs used when coding). Processing the data in this way overcame issues with eye-movement definition, with the raw eye-tracking video output being used prior to the automated classification of eye-movements as either fixations (when the eye is stationary and focused upon a stimulus), or saccades (when the eye is moving and re-adjusting itself) [47,48]. After coding, a log of sequential gaze dwell durations on the AOIs was exported, which could then be used within the subsequent analyses. Depending on the question being posed, these analyses took into account 1) only street edge visual engagement data in order to compare the percentage of visual engagement upon a street edge AOI vs. another street edge

AOI (e.g., the amount of visual engagement with ground floors vs. upper floors), or 2) participant visual engagement with the entire street in order to assess the percentage of visual engagement upon a street edge AOI vs. visual engagement with the rest of the street (e.g., the amount of visual engagement with ground floors vs. the entire street).

With tracking accuracy in outdoor investigations being typically lower, when compared with laboratory-based eye-tracking, it was anticipated that there would be fluctuations in the data quality. Data loss was generally low, but did vary slightly, resulting in a mean tracking ratio of 93% (range = 68%–99%, standard deviation = 6%). All data captured and coded was used in the following analyses.

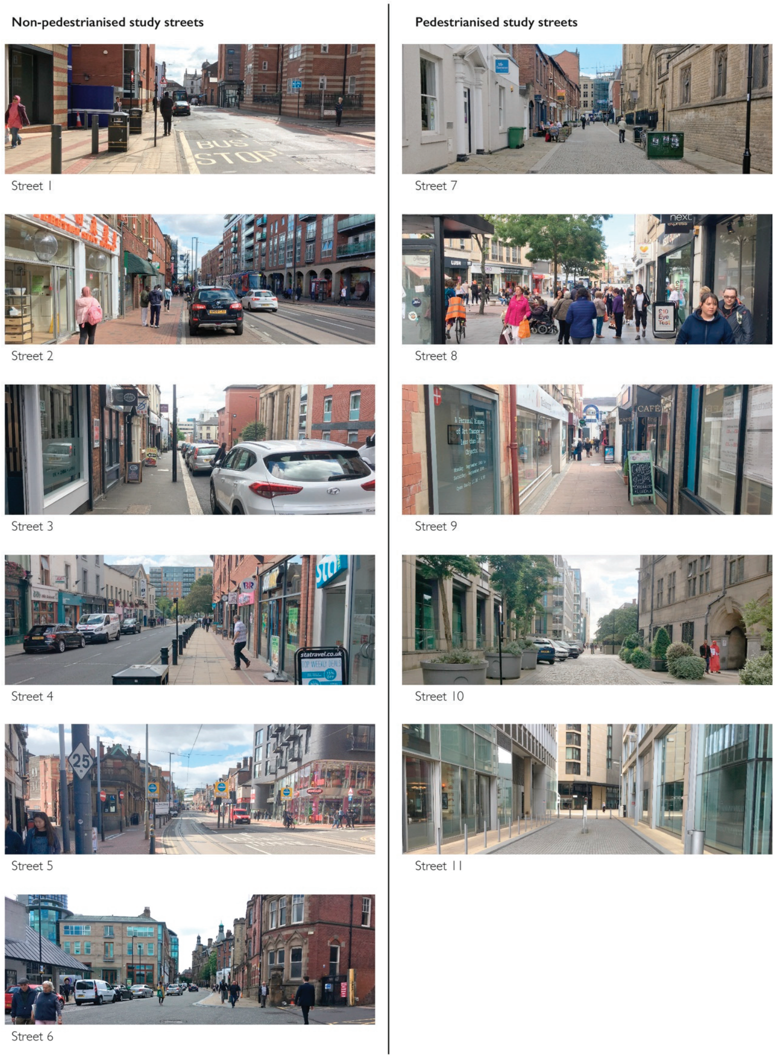

Figure 3. Eye-Level Images of Study Streets.

3. Analysis and Results

3.1. Research Question 1a: Do People Visually Engage with Street Edge Ground Floors more than Upper Floors along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

To determine if participants visually engaged more with street edge ground or upper floors along both non-pedestrianised and pedestrianised streets, Welch two-sample *t*-tests were performed. This *t*-test was chosen because of unequal variance between the two samples. Visual engagement was focused overwhelmingly upon ground floors in comparison to upper floors along both non-pedestrianised streets and pedestrianised streets (Table 1).

Table 1. The amount of visual engagement with street edge ground and upper floors along non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Type	Amount of Visual Engagement with Street Edge Ground and Upper Floors (Only Street Edge Visual Engagement)			Amount of Visual Engagement with Street Edge Ground and Upper Floors (Entire Street Visual Engagement)		
	Ground Floor	Upper Floors	*t*-Test Results	Ground Floor	Upper Floors	*t*-Test Results
Non-pedestrianised street	90.1% ± 2.0%	9.9% ± 2.0%	t (142) = 46.52, $p < 0.001$	34.2% ± 2.4%	3.6% ± 0.5%	t (78.35) = 12.55, $p < 0.001$
Pedestrianised street	91.7% ± 2.5%,	8.3% ± 2.5%	t (118) = 33.36, $p < 0.001$	34.8% ± 2.8%	2.8% ± 0.5%	t (62.67) = 11.41, $p < 0.001$

3.2. Research Question 1b: Do Different Everyday Activities and Streets Walked Influence the Amount of Visual Engagement upon Ground Floors along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

The effects of activity and street on participants' visual engagement with street edge ground floors were determined using linear mixed-effects models in the R statistical computing environment [49] ('lme4' package [50]). The fixed effects were 'activity' (optional or necessary) and 'street' (street id: 1–6 for non-pedestrianised and 7–11 for pedestrianised). To account for inter-participant variation in gaze behaviour, 'participant' (participant number 1–24) was entered as a random effect, which allowed different intercepts for each participant (i.e., a differing baseline level of engagement for each participant). *P*-values were simulated by comparing this model to a grand mean model using a parametric bootstrapping method ('pbkrtest' package; [51]) with 10,000 simulated generations. The goodness of fit for all mixed effect models was assessed using the 'R.squaredGLMM' function ('MuMin' package [52]) and marginal R^2 values (those associated with the fixed effects only) were high (non-pedestrianised street analyses: $R^2 = 0.58$, pedestrianised street analyses: $R^2 = 0.55$).

The activity being undertaken influenced the amount of visual engagement with street edge ground floors along both non-pedestrianised (see Figure 4A) and pedestrianised streets (see Figure 4B) (Table 2). The different streets walked influenced the amount of visual engagement with street edge ground floors along both non-pedestrianised (see Figure 4B) and pedestrianised streets (see Figure 4D) (Table 2).

Table 2. The influence of everyday activities and street walked upon visual engagement with street edge ground floors along non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Type	Amount of Visual Engagement with Ground Floors when Undertaking Different Activities (Entire Street Visual Engagement)			Amount of Visual Engagement with Ground Floors along Different Streets (Entire Street Visual Engagement)	
	Optional Activity	Necessary Activity	LRT Result	Streets Walked (Range)	LRT Result
Non-pedestrianised street	46.2% ± 3.2%	22.1% ± 2.2%	46.49, $p < 0.001$	19.9% ± 3.0% 50.0% ± 7.4%	35.02, $p < 0.001$
Pedestrianised street	44.2% ± 4.1%	25.5% ± 2.9%	23.87, $p < 0.001$	15.7% ± 3.1% 56.7% ± 5.1%	40.15, $p < 0.001$

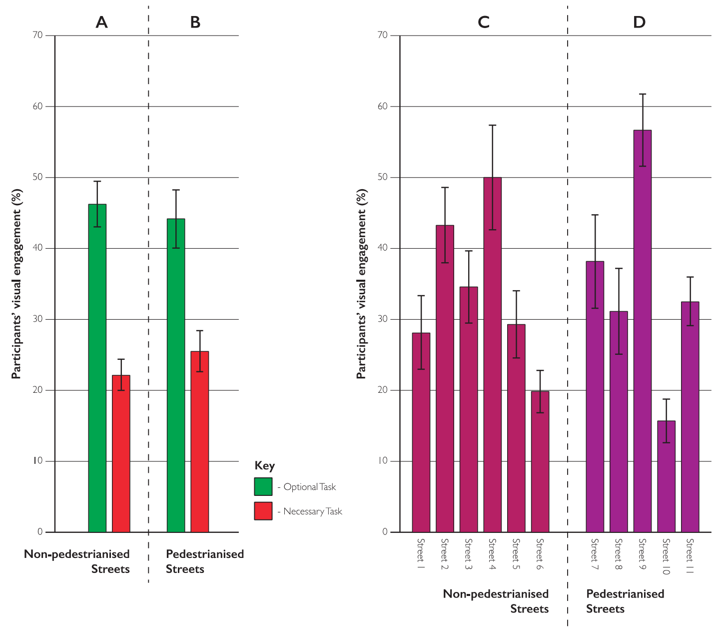

Figure 4. The influence of activity and street on the percentage of participants' visual engagement with street edge ground floors along non-pedestrianised and pedestrianised streets. Error bars represent 1 standard error.

3.3. Research Question 2a: Are there Differences in the Amount of Visual Engagement upon Street Edges on Different Sides of the Street along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

To determine if the amount of participant visual engagement with the different sided street edges varied along both non-pedestrianised and pedestrianised streets, Welch two-sample *t*-tests were performed. Visual engagement with street edges along non-pedestrianised streets was predominantly with the street edge on the walked compared with the opposite side (see Table 3a). The amount of visual engagement with street edges along pedestrianised streets did not vary across the street edges on the left and right sides (see Table 3b).

Table 3. (**a**) The amount of visual engagement with street edges on different sides of non-pedestrianised streets (mean ± standard error). (**b**) The amount of visual engagement with street edges on different sides of pedestrianised streets (mean ± standard error).

(**a**)						
Street Type	**Amount of Visual Engagement with Different Sided Street Edges (Only Street Edge Visual Engagement)**			**Amount of Visual Engagement with Different Sided Street Edges (Entire Street Visual Engagement)**		
	Walked Side	**Opposite Side**	***t*-Test Result**	**Walked Side**	**Opposite Side**	***t*-Test Result**
Non-pedestrianised street	72.1% ± 3.5%	27.9% ± 3.5%	t (142) = 15.14, $p < 0.001$	27.8% ± 2.2%	10.0% ± 0.9%	t (96.13) = 7.45, $p < 0.001$

Table 3. *Cont.*

(b)						
Street Type	**Amount of Visual Engagement with Different Sided Street Edges (Only Street Edge Visual Engagement)**			**Amount of Visual Engagement with Different Sided Street Edges (Entire Street Visual Engagement)**		
	Left Side	**Right Side**	***t*-Test Result**	**Left Side**	**Right Side**	***t*-Test Result**
Pedestrianised street	51.0% ± 4.2%	49.0% ± 4.2%	t (118) = 0.49, p = 0.62	19.9% ± 1.9%	18.0% ± 1.6%	t (114.61) = 0.75, p = 0.45

3.4. Research Question 2b: Do Different Everyday Activities and Streets Walked Influence the Amount of Visual Engagement upon Street Edges on Different Sides of the Street along (i) Non-Pedestrianised and (ii) Pedestrianised Streets?

To determine the effect of activity and street, linear mixed-effects models were again fitted to the data. The fixed effects were activity and street, with participant as a random effect. Marginal R^2 values (those associated with the fixed effects only) were high (analyses for walked non-pedestrianised edge R^2 = 0.54; opposite non-pedestrianised edge R^2 = 0.25; left side pedestrianised edge R^2 = 0.33; right side pedestrianised edge R^2 = 0.39).

The activity undertaken influenced the amount of visual engagement with both the street edges on the walked and opposite sides of non-pedestrianised streets (see Figure 5A and Table 4). Along pedestrianised streets, activity influenced the amount of visual engagement with both the street edge on the left and right sides (see Figure 5B and Table 4).

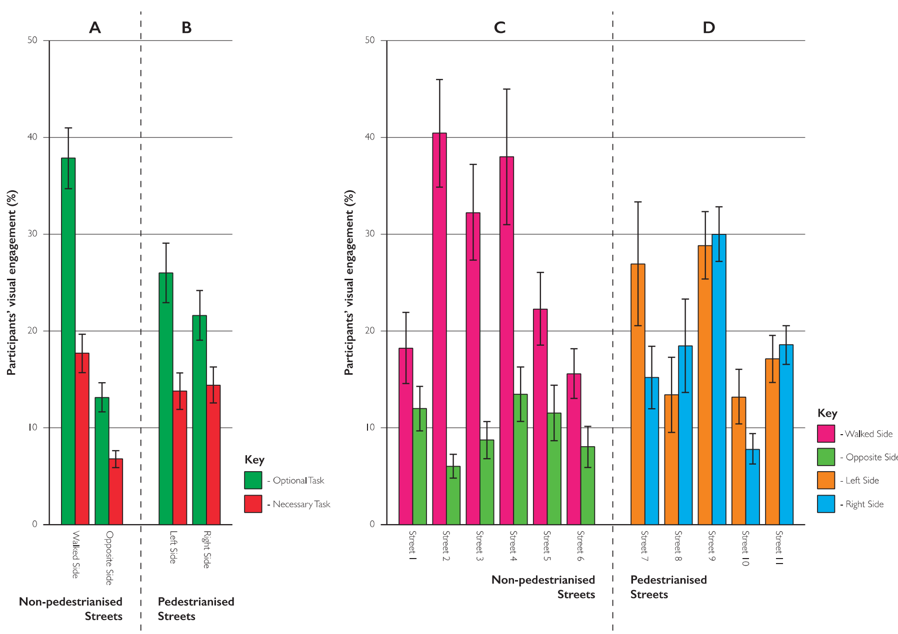

Figure 5. The influence of activity and street on the percentage of participants' visual engagement with street edges on different sides along non-pedestrianised and pedestrianised streets. Error bars represent 1 standard error.

Table 4. The influence of everyday activities and street walked upon visual engagement with street edges on different sides of the street along non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Type and Street Edge Side	Amount of Visual Engagement with Street Edges on Different Sides of a Street when Undertaking Different Activities (Entire Street Visual Engagement)			Amount of Visual Engagement with Street Edges on Different Sides of a Street along Different Streets (Entire Street Visual Engagement)	
	Optional Activity	Necessary Activity	LRT Result	Streets Walked (Range)	LRT Result
Walked side of non-pedestrianised street	37.9% ± 3.2%	17.7% ± 2.0%	36.61, $p < 0.001$	15.6% ± 2.6% to 40.5% ± 5.6%	34.05, $p < 0.001$
Opposite side of non-pedestrianised street	13.2% ± 1.5%	6.8% ± 0.9%	14.51, $p < 0.001$	6.0% ± 1.2% to 13.5% ± 2.8%	9.43, $p = 0.09$
Left side of pedestrianised street	26.0% ± 3.1%	13.8% ± 1.9%	15.44, $p < 0.001$	13.2% ± 2.8% to 28.8% ± 3.5%	20.18, $p < 0.001$
Right side of pedestrianised street	21.6% ± 2.6%	14.4% ± 1.8%	7.99, $p = 0.05$	7.8% ± 1.6% to 30.0% ± 2.8%	26.72, $p < 0.001$

The different non-pedestrianised streets walked influenced the amount of visual engagement with the street edge on the walked side, but not the street edge on the opposite side (see Figure 5C and Table 4). The different pedestrianised streets walked influenced the amount of visual engagement with both the street edges on the left and right sides (see Figure 5D and Table 4).

3.5. Research Question 3: Are there Differences in the Amount of Visual Engagement upon (i) Street Edge Ground Floors between Non-Pedestrianised and Pedestrianised Streets and (ii) Street Edge Sides between Non-Pedestrianised and Pedestrianised Streets?

To determine if the amount of visual engagement with street edge ground floors varied between non-pedestrianised and pedestrianised streets, Welch two-sample *t*-tests were performed. The amount of visual engagement with the street edge ground floors did not vary between the non-pedestrianised and pedestrianised streets (Table 5).

Table 5. The difference in visual engagement upon street edge ground floors and street edge sides between non-pedestrianised and pedestrianised streets (mean ± standard error).

Street Edge Area	Amount of Visual Engagement across Street Types (Only Street Edge Visual Engagement)			Amount of Visual Engagement across Street Types (Entire Street Visual Engagement)		
	Non-Pedestrianised Street	Pedestrianised Street	*t*-Test Result	Non-Pedestrianised Street	Pedestrianised Street	*t*-Test Result
Ground floor	90.1% ± 2.0%	91.7% ± 2.5%	t (108.24) = 0.72, $p = 0.48$	34.2% ± 2.4%,	34.8% ± 2.8%	t (122.86) = 0.17, $p = 0.86$
Difference in visual engagement between street edge sides	46.8% ± 3.7%	35.0% ± 3.6%	t (129.54) = 2.27, $p = 0.02$	18.7% ± 2.2%	12.4% ± 1.7%	t (126.45) = 2.27, $p = 0.03$

The difference in the amount of visual engagement upon street edges of the same street was calculated and Welch two-sample *t*-tests were performed to determine if these differences varied between non-pedestrianised and pedestrianised streets. The difference in street edge visual engagement between the sides of non-pedestrianised streets was greater than the sides of pedestrianised streets (Table 5).

4. Discussion

The current investigation provides detailed empirical insight into pedestrian visual engagement with different areas of urban street edges through the use of mobile eye-tracking. The study findings demonstrate, as predicted, that people visually engage with street edge ground floors more than upper floors, that visual engagement is distributed more towards the street edge on the walked side of non-pedestrianised streets than the opposite side, and that visual engagement with street edges of pedestrianised streets is balanced across both sides. However, as also anticipated, differing everyday activities and streets walked significantly influenced the amount of visual engagement upon all these street edge areas, except the street edge on the opposite side of non-pedestrianised streets, which was not predicted.

The study insights advance understanding of street edge visual engagement in a manner that has previously been challenging to attain. This subsequently provides opportunity to evidence existing understandings and assess how street edge design intervention can align to a greater extent with the way in which street edges are engaged with by pedestrians. This is outlined in the following discussion.

4.1. The Focus of Visual Engagement upon Street Edge Ground Floors

The current study shows that pedestrians visually engaged more with street edge ground floors than upper floors along both non-pedestrianised and pedestrianised streets. This insight supports previous work describing the experiential significance of ground floors [19,20], especially the concepts of Gehl [1] and his *city at eye-level* and Glaser et al.'s [2] *street plinths*. It is also notable that the current study findings correspond well with Glaser et al.'s claim that ground floors determine 90% of peoples' experience of buildings that flank streets. The current study highlighted that 90%–92% of people's visual engagement takes place with the ground floor of street edges. However, ground floor engagement was shown to be less, at 34%–35%, when taking into account visual engagement with the entirety of the whole street.

Highlighting the focus of visual engagement upon ground floors supports the understanding that street edges should not be understood as singular entities with pedestrian experiential engagement distributed equally across their entirety. Instead, they need to be approached across multiple scales [2,36,37]. Within this, ground floors require consideration as a distinct scale embedded within the overall built morphology of street edges [2,34,38]. Significantly, this mind-set has implications for the way in which design intervention is approached, especially when seeking to create street edges that are more experientially engaging for pedestrians. Delineating ground floors as an experientially salient street edge scale provides better opportunity and scope for decision-making attention to be focused on their specific requirements [38,39]. Ground floors are therefore not solely regarded as the point at which buildings make contact with the ground and the dominant focus of interest is not just the aesthetic qualities and overall form of entire buildings [1,2,53], the totality of which pedestrians rarely visually engage with. Instead, ground floors become a point of decision-making focus in their own right based upon the knowledge that people overwhelmingly engage with them.

4.2. Visual Engagement with Street Edges on Different Sides of a Street

The study findings highlight that pedestrians walking along non-pedestrianised streets visually engaged with the street edge on the walked side significantly more than the opposite street edge. This insight evidences the notion that street edges of the same street should be considered as experientially separate, even though both contribute to the spatial totality of a street [1,34,37]. It also brings into question the understanding that streets are experientially a *place between the edges* [37]. Instead, non-pedestrianised streets required greater consideration as a place between two experientially distinct edges, with pedestrian engagement focused towards the walked side street edge. Such a mind-set has subsequent implications for street edge design decision-making. Currently, streets and their edges are often approached in their totality. This is especially important when seeking to influence factors such as pedestrian walkability and the overall liveability of urban environments [35,42,43]. Even though, within certain situations, it is appropriate to think of streets in this way, intervention within street edges should also be considered on a side-by-side basis. This is along with the need for design decision-makers to anticipate that pedestrians on different sides of a street will not visually engage with street edge interventions to an equal extent.

The study findings show that there was no significant difference between the amount of visual engagement across the street edges on different sides of pedestrianised streets. The significance of this is examined in the section that follows when reflecting upon the impact of pedestrianisation upon street edge visual engagement.

4.3. The Influence of Pedestrianisation upon Street Edge Visual Engagement

There was no difference highlighted between the dominant amount of visual engagement with street edge ground floors of non-pedestrianised and pedestrianised streets. This further evidences the need to consider street edge ground floors as experientially significant, regardless of street type [1,2,34]. As examined in the earlier ground floor discussion, such insight highlights the need to focus attention upon ground floors as experientially distinct from the overall built morphology within which they are embedded [2,38].

The current study findings show that visual engagement was more balanced across both street edges of pedestrianised streets than the street edges of non-pedestrianised streets. Previously, there has been limited systematic exploration of the way in which pedestrianisation influences peoples' engagement with the surrounding street environment, particularly its edges. The current investigation addresses this limitation, with the insights obtained offering subsequent opportunity to inform design decision-making. As shown, pedestrianised streets afford more open and less-restricted distribution of visual engagement. As a result, they provide a spatial setting that encourages visual engagement with a greater proportion of opportunities within the surrounding street edges. This is significant when considering the fact that pedestrians direct a predominant amount of their visual engagement towards street edges as they build an understanding of what the surrounding setting offers them [1,2,14]. When seeking to establish urban streets that are more engaging, it is therefore beneficial to consider the way in which pedestrianisation significantly influences the extent to which people visually engage with the totality of what the surrounding street edges offer them.

4.4. Everyday Activities and Differing Streets Walked Influence Street Edge Visual Engagement

Optional activities encouraged a greater amount of visual engagement, in comparison to necessary activities, with the street edge ground floors and street edges on different sides of both non-pedestrianised and pedestrianised streets. This insight adds further detail, from a direct pedestrian perspective, to the observations of Gehl [1] and corresponds with previous mobile eye-tracking research [14]. It also provides new insight into the way that pedestrians can be considered as active perceivers, through the way in which their everyday activities significantly influence and mediate their engagement with the surrounding environment [26]. The current study findings thus further the argument that people engage with urban environments in an enactive manner, with combined social influences and spatial factors influencing the urban experience [40,41].

The differing streets walked influenced the amount of visual engagement upon the street edge ground floors of non-pedestrianised and pedestrianised streets. They also influenced the amount of visual engagement with both the left and right sided street edges of pedestrianised streets and the street edges on the walked side of non-pedestrianised streets. Such insight advances systematic understanding of the extent to which varying streets influence visual engagement with different street edge areas. Future research, again using mobile eye-tracking, could build upon this foundation through a focused analysis of what specific physical and material attributes of the environment influence street edge visual engagement. This would provide empirical insight into what specific characteristics of the environment visually engage pedestrians, subsequently providing opportunity to inform design decision-making.

The current investigation captured no difference in the amount of visual engagement with the street edges on the opposite side of non-pedestrianised streets. This insight was not anticipated. It does, however, provide opportunity to consider how the spatial composition of these streets, along with objects within the street, restricted visual engagement to the walked side to such an extent that there was no opportunity for significant variation in visual engagement with the opposite street edge. This provides further opportunity to evidence the potential experiential benefits of pedestrianisation, which afford more open visual engagement with the surrounding street edges, as shown during the current investigation. However, further systematic investigation is needed to examine such ideas in detail.

4.5. Study Limitations and Future Research

The current study provides a new empirical understanding of the way in which pedestrians visually engage with urban street edges. Even though this is the case, it is beneficial to acknowledge that there are a number of factors stemming from the current research that require further consideration. There is also opportunity to highlight future research opportunities.

The current investigation did not look at assessing how differences in the characteristics of the street edges examined, or the composition of the streets walked, might have influenced pedestrian visual engagement. Instead, the focus was on capturing general principles and clear patterns in the way that people visually engage with street edges. Beyond the fact that the study streets could be categorised as non-pedestrianised or pedestrianised, they clearly have distinct features and attributes that may have influenced where people looked in the street (see Figure 3). This highlights an opportunity for future research, which could more systematically examine the effect of specific street and street edge characteristics on street edge visual engagement.

We believe that findings from the current study are transferable to broader situations, with the findings obtained validating and building upon previous insight attained within differing urban contexts. It needs to be acknowledged, however, that data collection during the current study took place within a specific urban environment categorised by a certain type of European urbanism (see Figure 3). Further investigation would help to determine if the insights obtained during the current study can be seen when assessing visual engagement with street edges in other urban settings with contrasting types of urbanism. The current investigation also focused on the examination of pedestrian engagement with commercial city centre urban street edges. It would be interesting so see how visual engagement is distributed upon different street edge typologies, particularly residential street edges.

Mobile eye-tracking outdoors provides detailed insight into the way in which people visually engage with their surroundings at the same time as being immersed within the reality of real-world urban settings. However, when people are situated within such environments, it can be difficult to assess if their attention, along with second-by-second perceptual processing, is actually being directed towards what they are looking at within the often diverse and multi-sensory environment around them. This is due to their being heightened potential for them to be cognitively processing aspects of their wider surroundings or something they have previously engaged with (21). Future research could take this into consideration by attempting to link mobile eye-tracking with wider data collection methods, such as mobile electroencephalogram (EEG) (19,20). This has the potential to provide more robust insight through establishing a stronger link between gaze distribution and cognitive processing. However, the development of such an approach is still at a stage of infancy, with methodological issues needing to be overcome (20).

5. Conclusions

The social and experiential significance of urban street edges has long been understood. However, their potential to be engaging and stimulating for pedestrians has recently been impacted by issues such as high street decline and a reduction in the variety of functions they offer. These factors have triggered the need to gain greater insight into how contemporary street edges are experienced, building upon the broader consideration that there is currently a limited empirical understanding of the way in which street edges are experientially engaged with from the direct perspective of pedestrians. The current investigation addresses this limitation through the use of mobile eye-tracking along both pedestrianised and non-pedestrianised streets. The study findings demonstrate that people visually engage with street edge ground floors more than their upper floors along both non-pedestrianised and pedestrianised streets; that visual engagement is distributed more towards the street edge on the walked side along non-pedestrianised streets; and this contrasts with visual engagement upon the street edges of pedestrianised streets, which was balanced across the edges on both sides. The current investigation also highlights how everyday activities of pedestrians and differing streets walked both have the potential to impact visual engagement with the street edge areas examined. As a result, the study advances our empirical understanding of pedestrian street edge experience. With this in mind, the current investigation subsequently examined how such insight could inform the way street edge design intervention is considered and approached. This was pursued in an attempt to highlight how street edge decision-making can align to a greater extent with the way that pedestrians visually engage with these realms. Such alignment is essential in order to ensure that street edges remain socially and experientially engaging aspects of urban environments that can contribute to peoples' day-to-day quality of life long into the future.

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The Visual Effect of Signboards on the Vitality of the Streetscapes Using Eye-Tracking

Byungsuk Kim [1] and Jina Park [2,*]

[1] Department of Urban Planning, Hanyang University, Seoul 04763, Korea; bsk0728@nate.com
[2] Department of Urban Planning and Engineering, Hanyang University, Seoul 04763, Korea
* Correspondence: paran42@hanyang.ac.kr; Tel.: +82-2-2220-0332

Abstract: This study focuses on whether signboards attract people's visual concentration as a foreground element of the streetscape and check the difference in streetscape image according to the area of the signboard. For this purpose, 133 street-view photographs were taken at five major commercial districts in Seoul and 17 photos were selected for this study. The photos were then classified into the High Signboard Group (HSG) and Low Signboard Group (LSG) according to the area of the signboards and conducted eye-tracking experiments and surveys. Finally, data from 33 people were collected and a *t*-test was conducted to identify differences between the two groups. As a result, the number of fixations, the fixation time, and the revisits of fixation on signboards were measured higher in HSG, and the distance of gaze movement (saccade) was lower. The results of the image survey analysis showed that HSG groups had low streetscape satisfaction, signboard satisfaction, and streetscape aesthetic quality. However, Dynamic and Interesting factors were high. Taken together, the signboard can be seen as a landscape element that focuses attention by giving people an active and interesting image, which shows the importance and possibility of using signboards in future streetscape design.

Keywords: eye-tracking; signboard; commercial street; streetscapes

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1. Introduction

Signboards (outdoor advertisements) traditionally provide information about stores and help consumers make decisions on purchasing goods when consumers tour cities or engage in consumer activities. Consumers accept visually presented information through their eyes. At this time, if the visual elements of the signboard are made in conformity with the consumer's visual principles, the consumer at some point recognizes that the signboard has already been perceived and processed for memory [1]. As such, signboards are crucial elements of commercial streets and may be one of the most effective ways of delivering information.

The signboard is one of the characteristics of the streetscapes of Korean commercial districts. In particular, in places such as Seoul where there is an excessive population and commercialization density, the indiscriminate signboards for advertisements of stores located on commercial streets raise aesthetic issues. Yoon [2] found that experts in the project for street maintenance selected signboard arrangement as the most essential issue. To solve this problem, Seoul sought to improve the aesthetics of the city by implementing regulations on the quantity and size of outdoor advertising signs through its campaign, "Creating Beautiful Streets". However, regarding these regulations, the shop owners were concerned about negative impacts in terms of advertising effects, resulting in backlash.

So far, in various studies related to signboards in Korean cases, signboards have been generally discussed as a negative factor. Research shows that indiscriminately designed signboards have a visually negative effect on streetscapes [3]. As the number and types of signboards increase, the aesthetic value decreases, and a decrease in signboards seems to increase pleasantness [4–6]. The signboards of stores can be a negative influence on the aesthetic of the streetscape yet are essential to commercial streets. The importance of such signboards also appears in Kim et al. [7], where signboards are the most urgent negative factor that needs improvement, even while they are the most impressive factor to note. Many studies have thus sought to find improvements in signboard management.

Kim et al. [8] focused on the direction of signboard management for streetscapes. First, the size, surface, color, quantity, and lighting of signboards may not be suitable for street environments, so guidelines need to be improved. Second, the materials and lighting of signboards need improvement. Third, restrictions on new methods such as occupancy on the building surface regarding the installation of signboards in relation to the legal system are effective, as well as to focus on the design aspect rather than quantitative regulation and make use of local characteristics. In this context, many other studies indicated that it is important to establish a consistent management system to harmonize with the existing environment and to deliver a unified image reflecting the unique identity of each industry by region [9–12]. Meanwhile, the continuity and unity of the signboard in the streetscape are emphasized in the literature. Cho [13] said that the signs' size and spacing should be constant to give a sense of unity, suggesting several colors or using similar colors to give a sense of unity and rhythm. Additionally, the colors of the surrounding buildings must be considered to keep harmony with the colors of the signboards and colors that provide psychological stability and pleasure [12]. In terms of visual continuity, it is necessary to consider continuity between facades considering the behavior, color, and material of the facade in order to convey the pedestrian's horizontal use or effective advertising purpose. Lee and Song [14] found it is necessary to secure horizontal continuity that fits the movement and gaze of pedestrians rather than vertical continuity at the lower and upper floors.

Then why are signboards so important in commercial streets? Signboards serve as a medium for mutual communication and advertisements. However, in modern urban streets, signboards are an important factor in determining the streetscape beyond simple means of information delivery [11]. In this study, the importance of signboards is to be investigated whether or not they form an active image of the street visually rather than transmitting information. Commercial streets should be attractive, and visitors should feel that the street is active. Among the sensory organs of people, the dependence on vision is absolute, and visual vitality is generated through the perception of the physical environment of the streetscape.

According to Gestalt theory, perception in morphology is understood as a holistic process. In other words, the physical elements that form the streetscape are perceived as a single scene, rather than individually [15]. The main laws of Gestalt psychology concern proximity, similarity, continuity, closedness, simplification, equivalence, foreground and background, and familiarity. Among them, the foreground and background are mainly discussed in urban landscapes. Within given visibility, certain forms or objects stand out and others do not attract attention. The outstanding form is called the foreground, and other elements are called the background [15]. The foreground and the background also appear variously in street space. The first thing a pedestrian sees when walking along the street would be a building that is consecutively built along the side of the street. If you look at the building as the foreground, the sky and the floor will naturally become the background. After that, if you observe the interior in detail, the building becomes the background, the signboards, windows, and show windows in the building become the foreground, or the green space such as a street tree in the street may be the foreground and other things will be the background. As such, the signboard in the streetscape has a strong character of being a foreground element. The foreground element induces people's attention and interest and can inspire vitality in the street. Chen [16], as a result of simulation of pedestrian behavior, found signboards attract pedestrians' interest and induce behavior.

The signboard itself can be an attractive element that attracts people's attention, serves as a foreground, and infuses people's interest and street vitality as part of the streetscape. Therefore, this study examines whether there is a difference in interest or vitality felt in the streets according to people's gaze patterns on signboards for representative commercial streets in Seoul and provides implications for the future function and importance of signboards in streetscape management of the commercial street.

2. An empirical Approach to Landscape Analysis

People are affected by the physical environment of the city. The environment is perceived and the relationship between the environment and people is established. A Zube et al. [17] model shows feedback on what people find interesting and impressive in their interactions with the physical environment. By studying the interactions with each other and the contents that occur within them, implications for a better urban environment can be found. The landscape is a form of physical space, and humans see and perceive the landscape through sight and subjectivity. However, since humans observe landscapes based on personal, social, cultural, and environmental characteristics, even spaces with the same physical conditions can be perceived differently depending on the characteristics of humans or groups. Lynch [18] would be a representative researcher who, through mapping, has found out how people perceive images of the cities they live in. He conducted an analysis of the city's image through "cognition", which stems from people's experiences or memories of a particular environment and is the process of creating likes and dislikes. Cullen [19] is a representative researcher regarding the urban environment and people's visual perspective. He perceived the urban landscape from a continuous perspective and said that the urban landscape should be designed from a visual perspective.

Craik [20] set the framework for a research methodology that measures and analyzes people's responses to the environment. A methodology was prepared to measure how people think about the environment through four factors: "Environmental Displays", "Media of Presentation", "Observers", and "Response Formats". The perception-based method targeting the general public emphasizes the aspect of the observer, the human, on quality of the landscape, and is an evaluation of the landscape based on visual perception [21–23]. However, this methodology has its limitations because there is no consensus on what the aesthetic quality of the landscape is. Accordingly, Vining and Stevens [24] presented a model that requires dual feedback from the expert and the public on the landscape. Landscapes that visually evoke positive feelings are evaluated as of high quality, and landscapes that evoke negative feelings are evaluated as low quality. It is necessary to objectively measure the visual quality of subjective values, which leads to the methodology of eye-tracking. However, the concentration of the gaze is not necessarily a positive signal. Therefore, a subjective survey must be conducted together to supplement this limitation. Eye-tracking is mainly used in fields such as interfaces and advertisements, but it has also been introduced in landscape-related fields and research is ongoing. Existing researches related to streetscape mainly rely on surveys from people's perceptions. This method has limitations because the data is measured based on the overall feeling, not knowing where people look specifically to feel that way.

Various studies analyzed the landscape and the perspective of people. As a result of analyzing the landscape bordering the river, the study in Cottet et al. [25] found that nature has a longer time of fixed gaze in urban and natural scenes. In addition, Holmes and Zanker [26] demonstrated the correlation between aesthetic preference and average gaze fixation time. Looking at the contents of these two studies, it is likely that those with high aesthetics like nature will have a high gaze-inducing effect. However, being natural does not necessarily mean that the gaze fixation effect is high. People's gazes are the focused points in the landscape is a point factor. Among the landscape elements, the elements that focus people's attention are the ones that are emphasized. A transition phenomenon occurs where the natural environment becomes a visual attention factor in artificial facilities and artificial facilities become a visual attention factor in natural environments [27,28].

The study by Li et al. [29] shows that the attention is focused on the letters at the sign or entrance in the streetscape, and the more understandable the letters are, the higher the eye fixation is. Elements such as letters on a signboard have a higher amount of information than a picture or a simple wall, and in order to understand this, the human eye causes fixation of the gaze. Since store information transmission is an important factor in selling products, gaze distribution studies on signboards, displays, and directions during shopping were also conducted [30,31].

Landscape analysis has been carried out by various methodologies so far, and it has reached the stage of analyzing by tracking a person's gaze. As a result of reviewing previous studies, fixation of gaze in the landscape is an element that becomes a point, and in the case of a streetscape, signboards, and letters can become the point. A high gaze fixation effect means that visual communication is active, which can be an element that can induce interest in people. Therefore, it is believed that the analysis can provide more precise implications for landscape design by using a questionnaire survey, which is subjective data, and distribution of gaze, which is objective data, and this study proceeds with the following methodology.

3. Methods

3.1. Design

In this study, the following methodology was carried out to determine whether signboards influence the formation of active street images. First, photographs of streetscapes are taken for various commercial streets, and images suitable for eye-tracking experiments are selected. Second, the Image J program is used to measure the area of the signboard to classify the area of the signboard in the streetscape. This program can measure the area of a picture in pixels. Third, an eye-tracking experiment is conducted by recruiting experimenters and conducting a survey after the experiment. Finally, a statistical analysis was conducted to see if people feel a difference in the active image of the streetscape depending on the sign.

This study selects Jonggak, Insa-dong, Myeong-dong, Garosu-gil, and Gangnam as the most representative commercial areas of Seoul (Table 1). These five sites are located in the city center and Gangnam and represent commercial districts that attract both Koreans and international tourists. Jonggak, Insa-dong, and Myeong-dong are roads for mixed use, with a D:H scale of less than 2 and more than 2. Garosu-gil and Gangnam are basically separate roads for pedestrians, but there are roads for mixed pedestrians on the back road. In the case of D:H scale, Garosu-gil is a human-scale street and Gangnam is a massive scale street. The sites are suitable for extracting streetscape samples from the perspective of the street structure because they are separated and mixed with road and have various D:H scales. Eye-tracking experimental photographs were randomly taken throughout the entire section of the street through field trips in sites.

Table 1. Sites.

Jonggak		Myeong-dong
		
Insa-dong	**Garosoo-gil**	**Gangnam**
		

3.2. Photograph Experiment

Pedestrians in the pictures were deleted for the streetscape research. Therefore, this excludes locations where photo correction could not be performed in the future due to the narrow width and large floating population. The shooting was done on a clear day with a Canon D100 camera and an 18 mm lens at a height of 1.5 m at the center of the street or at the center of the walkway. When a person walked on the street, the streetscape structure changed frequently, depending on where the person was or according to the movement of the head. However, due to the nature of walking forward, the eyes were mostly fixed towards the front. Therefore, in this study, the photo was taken from the center of the street (sidewalk) pointing to the front, assuming that the pedestrian stared at the center of the street or the center of the pedestrian path. For one month in September 2019, the researchers visited the site in person, and a total of 133 photos were taken. Thereafter, a total of 23 photos were selected for the eye-tracking experiment through a screening process, and in the analysis of this study, 17 photos were finally selected except for photos without signs (Table 2). Based on the pixel area, images with more than 10% signboard area compared to the total area were grouped as high sign groups (HSG), and images with less than 10% are selected to be low sign groups (LSG).

Table 2. Photos and pixel of signboards. High Signs Group (HSG): 1, 2, 7, 8, 9, 13 and Low Signs Group (LSG): 3, 4, 5, 6, 10, 11, 12, 14, 15, 16, 17.

Image 1	**Image 2**	**Image 3**	**Image 4**
2,234,268 (28%)	2,202,198 (28%)	520,424 (7%)	333,805 (4%)
			
Image 5	**Image 6**	**Image 7**	**Image 8**
742,967 (9%)	309,540 (4%)	845,278 (11%)	844,590 (11%)

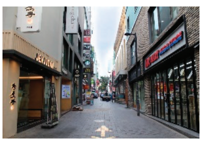
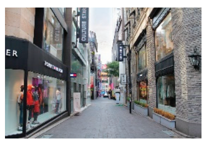
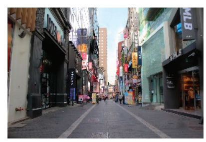

		

Image 9	**Image 10**	**Image 11**	**Image 12**
824,735 (10%)	609,046 (8%)	184,354 (2%)	339,709 (4%)

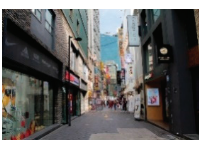
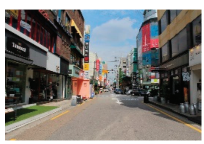
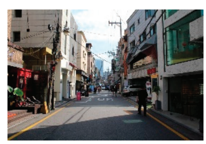
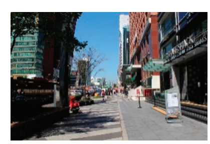
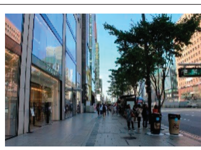

		

Image 13	**Image 14**	**Image 15**	**Image 16**
1,030,933 (13%)	578,453 (7%)	201,077 (3%)	416,808 (5%)
			
Image 17			
83,275 (1%)			
			

3.3. Participants and Apparatus

This study was approved by the Institutional Review Board (IRB) of the University's Institutional Bioethics Committee for the purpose of the eye-tracking experiment and survey. Participants were then recruited for the experiment. Participants had to have no vision problems, but those who wore glasses could participate. Due to the characteristics of the five sites mainly used by young people, participants in their 20s and 30s conducted experiments in March and April 2020. At the time the experiment was conducted, it was difficult to recruit external participants due to COVID-19. So, the recruitment of test subjects was mainly conducted within urban engineering students and experts who work in the same field, and the rest from the general public. Finally, a total of 41 people, including 26 majors, 15 of which were non-Communists, participated in the eye-tracking experiment and survey.

The eye-tracker device used was the GP3 HD Eye Tracker, from Gagepoint. The device is a fixed eye-tracker capable of measuring eyeball movement at 150 Hz per second. After the eye-tracker was installed on a 24-inch monitor, the distance between the participant and the monitor was set at 40–60 cm. Before the experiment, a calibration task was performed to properly fix the eyes of the participants to the camera of the eye tracker (Figure 1). Calibration is to adjust the distance and height between the eye and the eye-tracker so that the eye-tracker recognizes the eye of the participant. Figure 1 shows that the eye-tracker recognizes the participant's pupils and appears in green. The next step in viewpoint adjustment is to test whether the eye tracker properly recognizes the participant's pupil. The test is a method of checking whether the green cursor moves exactly to the participant's viewing position by looking at the screen with 11 circles drawn on the monitor and moving their gaze (Figure 2). If the cursor moves differently from the participant's gaze, the viewpoint is adjusted again and tested.

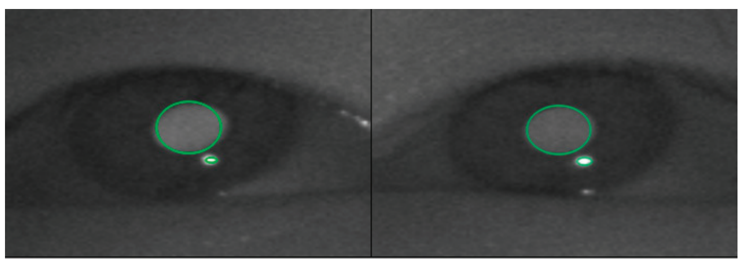


Figure 1. Calibration Processing.

Figure 2. Eye movement testing.

Before showing the picture, a situation is assumed where the experimenter visits the commercial street in the picture and walks the streets and looks around freely. Participants looked at the experimental photos for 10 s per photo and conducted eye-tracking tests. After the eye-tracking experiment was over, they filled out a questionnaire for the photos. The total required time for this survey including the eye-tracking and questionnaire took 30–40 min.

3.4. Data Processing

The data obtained from the experiment was exported in a CSV file format and checked whether it is properly measured. Since the device used in the experiment measures 150 hz per second, about 1500 gaze data were secured for 10 s per photo. However, as a result of the review, there were participants whose data were collected less than 1500. As a result of checking the recorded eye-tracking gaze video, there was a case where the participant's posture was excessively disturbed and changed from the initial viewpoint adjustment and the eye-tracker missed the participant's pupil due to the nature of the fixed eye-tracker. In addition, when wearing thick plastic glasses or earrings, the eye tracker recognized the part as a pupil due to the reflection and was measured incorrectly. 33 of the 41 participants' data of the experiment were finally used in the analysis, except for those samples whose eyes were incorrectly measured or did not respond to further surveys.

Eye-tracking collects data on eye movements. For each image, the "number of fixations," "fixation time," and "Saccade (eye movement distance)" were collected. In addition, by setting the signboard in the image as an area of interest (AOI), gaze data for each AOI was collected so that gaze data for the signboard were secured (Figure 3). The gaze movement and fixation time can be visually displayed as a heat map in Table 3, and red indicates a longer fixation time while blue indicates a short fixation time. The survey is a question of the streetscape, with each photo being measured from high to low (five-point scale) by aesthetic qualities of streetscape from interesting to dull and dynamic to still, with signboard satisfaction and complexity from high to low. Also, there were questions where when looking at the streetscape, the most important streetscape elements (signboards, green spaces, facades, street structure shapes, sky, ground floors, and other facilities) were checked. Information regarding participants' gender, age, major status, and offline consumption activities was collected. Questionnaire data were collected using a total of 561 samples by surveying 17 images from 33 people.

Note: -1 values indicate an AOI that was never viewed

AOI Summary

Media ID	Media Name	AOI ID	AOI Name	Viewers (#)	Total Viewers (#)	Ave Time to 1st View (sec)	Ave Time Viewed (sec)	Ave Time Viewed (%)	Ave Fixations (#)	Revisitors (#)	Average Revisits (#)
46	1-2.jpg	87	AOI 87	25	35	2.313	0.772	7.715	4.56	14	1.786
46	1-2.jpg	88	AOI 88	16	35	5.297	0.617	6.17	3	5	1
46	1-2.jpg	89	AOI 89	12	35	5.504	0.252	2.521	1.5	3	1.667
46	1-2.jpg	90	AOI 90	34	35	1.25	1.869	18.691	10.471	34	5.147
46	1-2.jpg	91	AOI 91	35	35	2.209	0.989	9.894	5.657	31	3.645
46	1-2.jpg	92	AOI 92	25	35	3.889	0.469	4.693	3.16	15	2.4
46	1-2.jpg	93	AOI 93	19	35	5.518	0.335	3.355	2.579	11	2.727
46	1-2.jpg	94	AOI 94	21	35	4.011	0.437	4.366	2.714	8	1.625
46	1-2.jpg	95	AOI 95	26	35	4.557	0.475	4.747	3.385	15	2.533
46	1-2.jpg	96	AOI 96	8	35	5.687	0.328	3.281	2.5	4	1.5
46	1-2.jpg	97	AOI 97	17	35	4.314	0.267	2.668	1.941	8	1.375
47	1-7.jpg	98	AOI 98	30	35	3.509	0.669	6.692	4.1	14	2.286
47	1-7.jpg	99	AOI 99	34	35	1.356	1.565	15.653	9.971	32	3.375
47	1-7.jpg	100	AOI 100	34	35	2.716	0.66	6.598	4.176	25	2.4
47	1-7.jpg	101	AOI 101	9	35	5	0.163	1.628	1.444	2	1
47	1-7.jpg	102	AOI 102	25	35	4.264	0.61	6.099	3.96	9	1.444
47	1-7.jpg	103	AOI 103	23	35	2.497	0.486	4.861	3.696	17	3.353
47	1-7.jpg	104	AOI 104	30	35	3.459	0.532	5.321	3.733	19	2.211
47	1-7.jpg	105	AOI 105	24	35	3.55	0.504	5.039	3.125	13	3
47	1-7.jpg	106	AOI 106	9	35	5.114	0.557	5.566	2.444	5	1.2
47	1-7.jpg	107	AOI 107	22	35	4.607	0.409	4.091	2.818	14	1.714
47	1-7.jpg	108	AOI 108	5	35	5.091	0.07	0.703	1.2	2	1
48	1-16.jpg	463	AOI 463	12	35	3.689	0.33	3.3	2.417	8	2
48	1-16.jpg	464	AOI 464	30	35	1.948	0.467	4.674	3.033	18	2.333
48	1-16.jpg	465	AOI 465	25	35	3.951	0.293	2.931	2.2	14	2.357
48	1-16.jpg	466	AOI 466	24	35	4.083	0.218	2.177	1.958	12	1.833
48	1-16.jpg	467	AOI 467	26	35	3.159	0.525	5.25	3.462	21	2.81
48	1-16.jpg	468	AOI 468	11	35	3.899	0.279	2.789	2.545	8	1.75

Figure 3. AOI Data.

Table 3. Heat map.

Image 1	Image 2	Image 3	Image 4

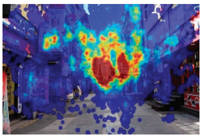
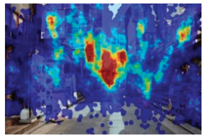
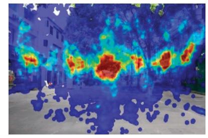
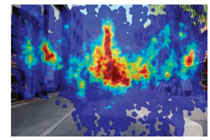
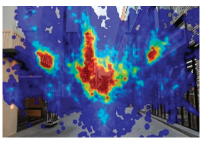
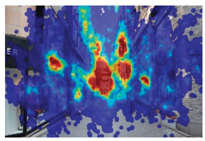
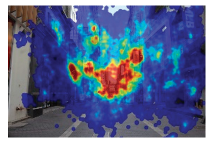
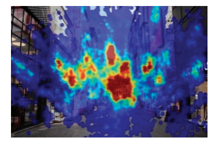

			

Image 5	**Image 6**	**Image 7**	**Image 8**
			
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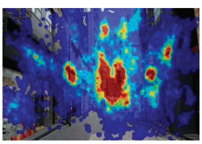	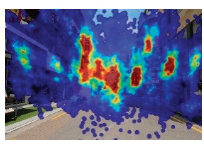	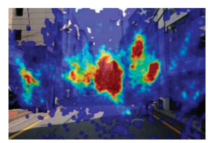	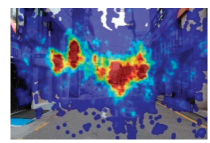
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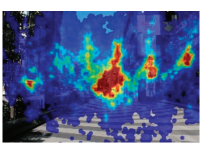
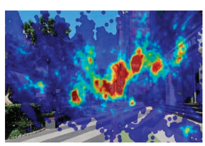
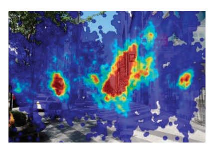
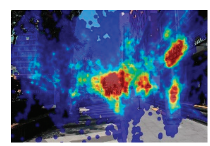
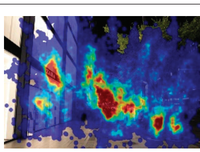
			

Image 17			
			

4. Analysis and Results

The gender of the participants was 21 males and 12 females, 17 in their 20s and 16 in their 30s. Among them, 20 people were studying related majors or working in the field, and 13 were non-majors. Table 4 shows the average number of gazes was 43.5 when looking at the picture, with an average of 178.346 for the Saccade, which indicates the distance of the eyeball, and 0.213 s for each gaze. According to the eye-tracking characteristics of the signboard extracted through the AOI setting, the number of gazes was 17.24 s, the fixed time of gaze was 2.542 s, and the number of revisits was 8.392 times. The participants' street satisfaction averaged 3.23, the signboard satisfaction was 2.97, the aesthetic quality of the streetscape was 3.29, the dynamic image was 3.42, the interesting image was 3.32, and the complexity of the streetscape was 2.95.

The fixation time for each streetscape element was the highest at 5.86 s for buildings, 2.54 s for signboards, and 0.91 s for green areas and the shortest was 0.24 s at floors (Table 5). However, the building's gaze time includes signboards and show windows, so the participants are considered to have the highest gaze time for the building and the signboard.

Table 4. Mean and standard deviation.

	N	Min	Max	Ave.	S.D.
Number of fixations	561	12.000	74.000	43.54011	8.353715
Fixation time	561	0.077	0.819	0.21340	0.051916
Saccade	561	125.751	224.228	178.34608	15.482827
Number of fixations to signs	561	0.00	50.00	17.2424	9.96485
Fixation time to signs	561	0.00	9.00	2.5420	1.74246
Revisit of fixation to signs	561	0.00	30.00	8.3922	5.64544
Street satisfaction	561	1.00	5.00	3.2371	0.99235
Signboard satisfaction	561	1.00	5.00	2.9733	1.14064
Aesthetic qualities of streetscape	561	1.00	5.00	3.2959	1.05803
Dynamic	561	1.00	5.00	3.4296	1.07692
Interesting	561	1.00	5.00	3.3280	1.01211
Complexity	561	1.00	5.00	2.9590	1.08237

In addition, 24 people selected signboards which were the highest in the question about the most important landscape elements when looking at the streetscape. Next was green space (14 people), street structure shape (12 people), and floor (11 people). In streetscapes, signboards appear to attract people's attention and be an important factor in recognizing the streetscape.

After classifying the signboard into two groups (HSG, LSG) according to the high and low area of the signboard in the streetscape, we checked whether the gaze characteristics of people changed using the *t*-test. Table 6 shows those results. As a result of the analysis of the number of fixations, fixation time, and saccade, which are basic gaze movements between the two groups, only saccade ($p < 0.05$) was significant. The gaze movement distance appeared longer in LSG than in HSG. The gaze movement distance appeared shorter because the number of signboards and the amount of data that came into the eyes was higher when the area of signboards was wider.

Table 5. Fixation time to streetscapes elements.

	N	Min	Max	Ave.	S.D.
Building	561	0.18	9.32	5.8646	1.66897
Signs	561	0.00	9.00	2.5420	1.74246
Sky	561	0.00	5.29	0.6979	0.85512
Ground	561	0.00	4.79	0.2486	0.64850
Show window	561	0.00	4.63	0.6859	0.81096
Green	561	0.00	7.61	0.9196	1.19706

When looking at the AOI result value for the signboard, basically, in the gaze movements the number of fixations to signs ($p < 0.01$), fixation time to signs ($p < 0.01$), and revisit of fixation to signs ($p < 0.01$) are all significant, confirming that there is a difference between the two groups.

Table 6. Gaze pattern analysis using *t*-test.

	Signs	N	Ave.	S.D.	S.E.	*t*
Number of fixations	HSG	198	43.79798	8.372641	0.595018	0.540
	LSG	363	43.39945	8.351577	0.438344	
Fixation time	HSG	198	0.21351	0.047440	0.003371	0.037
	LSG	363	0.21334	0.054265	0.002848	
Saccade **	HSG	198	176.49070	14.346795	1.019582	−2.103
	LSG	363	179.35811	15.997241	0.839637	
Number of fixations to signboards ***	HSG	198	3.6753	1.64632	0.11700	12.518
	LSG	363	1.9239	1.46163	0.07672	
Fixation time to signboards ***	HSG	198	24.6061	9.25808	0.65794	14.676
	LSG	363	13.2259	7.81864	0.41037	
Revisit of fixation to signboards ***	HSG	198	11.0303	5.74139	0.40802	8.703
	LSG	363	6.9532	5.04789	0.26495	
Time of fixation to signboard per area of signboards ***	HSG	198	6.013	0.26148	0.01858	11.325
	LSG	363	0.3438	0.25509	0.01339	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The results of confirming the difference in images between the two groups are shown in Table 7. First, LSG was high in terms of street satisfaction, signboard satisfaction, and aesthetic qualities of the streetscape. This is a negative effect of the signboard on the street environment and has been confirmed in prior studies. However, HSG is higher than LSG in dynamic and interesting images of the streetscape. The presence of signboards seems to have the effect of giving interest, fun, and dynamic images to the streetscape. In addition, people perceived more complex streetscapes when signboards were located high in the verification of complexity differences. While the appropriate level of complexity in streetscape can be attractive, excessive complexity can have a negative effect.

Table 7. Street images and satisfaction analysis using *t*-test.

	Signs	N	Ave.	S.D.	S.E.	*t*
Street satisfaction ***	HSG	198	2.8939	0.99942	0.07103	−6.251
	LSG	363	3.4242	0.93824	0.04924	
Signboard satisfaction ***	HSG	198	2.4545	1.06416	0.07563	−8.439
	LSG	363	3.2562	1.08120	0.05675	
Aesthetic qualities of streetscape ***	HSG	198	2.7828	1.01176	0.07190	−9.079
	LSG	363	3.5758	0.97577	0.05121	
Dynamic ***	HSG	198	3.8939	0.91455	0.06499	8.336
	LSG	363	3.1763	1.07549	0.05645	
Interesting *	HSG	198	3.4242	1.01852	0.07238	1.666
	LSG	363	3.2755	1.00613	0.05281	
Complexity ***	HSG	198	3.5051	1.09335	0.07770	9.130
	LSG	363	2.6612	0.95380	0.05006	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5. Discussion

The results of the analysis objectively show people's gaze movements on signboards and images of streetscapes through eye movement and surveys. As the subject area is a commercial street, people focus their gaze on buildings and stores to get information on the stores. In terms of the theory of the Gestalt, the sign in the background of the building becomes a foreground element containing information. Recognition of foreground elements can influence the overall image of the landscape. The result of the research supports this theory. As a result of t-testing by dividing into HSG and LSG based on signboards, significant differences between the two groups were confirmed in all matters such as street satisfaction, signboard satisfaction, aesthetic qualities of streetscape, dynamic, interesting, and complexity (Table 7). This tells us that signboards are the most common streetscape element people see in streetscapes and that streetscape satisfaction, signboard satisfaction, and streetscapes' aesthetic qualities were low in streetscapes with a wide signboard area.

In this analysis, it should be noted that the values of the two variables Dynamic ($p < 0.01$) and Interesting ($p < 0.1$) were high in HSG and were significantly different from the opposite group. Dynamic and Interesting can be seen as essential images to make the commercial street attractive. In particular, these results contrast with the overall low-profile street satisfaction ($p < 0.01$), signboard satisfaction ($p < 0.01$), and the low-level aesthetic quantities of streetscape ($p < 0.01$) all showing positive possibilities for the effect of signboards. In addition, Table 6 objectively shows that HSG is higher than LSG in the number of Fixation to signboards ($p < 0.01$), Fixation time to signboards ($p < 0.01$), and Revisit of Fixation to signboards ($p < 0.01$) all of which are visual attention factors. It may be thought that the group with a large area of the signboard simply showed a high gaze because the ratio of the area occupied by the signboard in the images was high. However, checking the fixation time compared to the area of the signboard confirmed that the HSG was 0.6 sec and the LSG was 0.34 sec ($p < 0.01$), showing a significant difference to indicate that the fixation time was high not just because the signboard was wide.

Signboards can make visual attention in two ways: First, is the morphological feature. Korean signboards stand out as protruding from the building. This is in the same context as previous studies related to eye-tracking [27,28] that the prominent part of the landscape attracts attention. Second, the signboards have letters, which are the medium of information transmission. People constantly try to attain information through eyesight. In addition, since a form such as a letter requires more visual concentration to understand information, attention to the signboard occurs. This result means that depending on the use of signboards, it is possible to design more attractive commercial streets. For the street to be attractive, it must be able to draw the interest and activity of pedestrians.

On the street, the activity eventually begins with a visual stimulus to pedestrians, which comes from the function of delivering store information to the buyer. Among the scape elements, signboards are important because they are the most intuitive and can deliver a lot of information from sellers to consumers. The external environment of a commercial street that delivers information is important, and to attract and retain shoppers, the importance of a high-quality streetscape must not be overlooked in the contact between the streets and visitors of the commercial district. As mentioned in previous studies [3–6], unorganized signboards are a negative factor in the streetscape and lead to various issues. However, the results of this study indicate that signboards fundamentally increase people's visual participation and are clearly the best physical environmental factor for information delivery. The government is also conducting signboard maintenance projects to improve the streetscape and enhance the uniformity of the shape and scale of signboards. For systematic streetscape management in the future, detailed guidelines (e.g., scale, color, shape) for signboards will be needed when establishing guidelines such as district unit plans. In addition, signboard design should be based on the function and location of the street and its resulting design.

When evaluating a particular landscape, it is important how it is presented to whom. Over the past half-century, landscape evaluation can be seen as a competition between an approach by design experts and a public-based approach [17,32,33]. This means that the landscape evaluation that comes from the differences in experiences and perspectives of the two groups may lead to different evaluations. In this study, the reflection of group characteristics in streetscape evaluation was minimized by conducting an experiment by mixing urban design majors and the general public. In Table 6, the results of the study also show that, since all variables showed significant differences between HSG and LSG, streetscape evaluation was performed without significant differences between experts and ordinary people.

However, this study has some limitations. First, this is an experimental study based on photographs. There may be a difference between the three-dimensional image seen outside the study and the images in the study viewed as photographs. Second, the angle of the shooting was taken in the middle of the street. When people walk, they move their heads and look at the streetscape from various angles. However, this study used images taken from the center of the street as a photographic experiment. If research is conducted to supplement these limitations using VR utilization or wearable eye-tracker in the future, more accurate and detailed implications may be presented in streetscape design.

6. Conclusions

Until now, research regarding signboards in the commercial streetscape has been conducted based on a questionnaire on people's perceptions. However, surveys have the limit of not knowing which ones the participants looked at and evaluated. This study is meaningful in that it focuses on the foreground elements of the landscape and analyzes people's viewing patterns in terms of the theory of the Gestalt to solve this problem. The result confirms that the focus of attention on signboards arouses people's interest, which makes them perceive a dynamic streetscape image. This represents the effect of a signboard as a foreground element, and also confirms the importance of the foreground element when people perceive streetscape.

This study can suggest the following implications. When designing guidelines for outdoor signboards in streetscapes, consideration of Signboards area and design should proceed. Signboards are an important element in the commercial street landscape. The District unit plan guideline [34] states the signboards should follow "outdoor advertisement guidelines" once the necessary changes have been made to prevent excessive exposure to the outside or a sense of disparity with the building or surrounding buildings. The results of this study show that signboards can induce people's gaze and let people feel the image of the active commercial street landscape, but disorganized signboards have a negative aesthetic effect. Therefore, when establishing guidelines for outdoor signboards, considering a plan to harmonize the shape and size of signboards to maintain unity, will benefit the commerciality of signboards which transfers information to people. The research results suggest the importance of signboards in future commercial streetscapes and show that improved visual communication between pedestrians and streetscapes can create attractive streetscapes.

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sustainability

Article

Creative Street Regeneration in the Context of Socio-Spatial Sustainability: A Case Study of a Traditional City Centre in Podgorica, Montenegro

Svetlana K. Perović * and Jelena Bajić Šestović

Faculty of Architecture, University of Montenegro, Džordža Vašingtona bb, 81 000 Podgorica, Montenegro; jelena.bajic@ucg.ac.me
* Correspondence: svetlana.perovic@ucg.ac.me; Tel.: +382-69-385-190

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Abstract: The physical structure of Podgorica was predominantly developed with a traditional planning concept, whereby public open spaces of the city are as important as the city's architectural objects. The focus of this paper is the perception of a traditional street in the context of sustainable urban regeneration. The aim of this study is to submit a proposal, through the Urban Design course at the Faculty of Architecture in Podgorica, for the physical regeneration of twelve traditional streets (eight street directions) that define the central core of Podgorica, known as Mirkova Varoš. These streets are the sites of social processes, interpreters of cultural and identity values of the society, and primary keepers of collective memory. It was detected that the attractiveness of the case study streets is weakening due to inadequate social and professional engagement in the processes of preservation and regeneration over time and also due to new users' needs. Global requirements reflect the weakened role of public open spaces as places of social interaction, in favour of primarily closed shopping centres that are the new urban artefacts of the 21st century city. The first phase of this study is related to the theoretical interpretation of regeneration and the role of public space in the context of socio-spatial sustainability. The second phase of the study is directed toward estimating the perception of the current state of the street area in Mirova Varoš, as seen by the case study area users and architecture students, using (1) visual, (2) tactile, and (3) auditory criteria. The obtained results serve as a platform for concrete urban design proposals for sustainable street regeneration that will reflect a stronger socio-spatial interaction between (1) user–place, (2) the place–city system, and (3) local processes–global flows.

Keywords: creative street regeneration; socio-spatial sustainability; perception; traditional city centre; Podgorica

1. Introduction

1.1. Sustainable Urban Regeneration of Open Public Spaces

Urban regeneration is a dynamic process that involves strategies, activities, and collective efforts to develop sustainable solutions. These solutions are adapted, transformed, and modified over time to adequately respond to economic, sociological, environmental, political, and other challenges, in line with Sustainable Development Goals [1–4]. The successful regeneration of urban spaces requires the commitment of local communities, developers, financiers, funds, and the public sector [5]. Social activation, economic strength, and a strategic vision of urban space management are all necessary. The process of physical urban regeneration requires much more input than traditional patterns of urban element reconstruction.

In contemporary urban practice, the process of regenerating public spaces, or planning and forming new ones, is expected to promote social life, collective interest, and generate values of spaces that are appropriate for all users, as well as to contribute to creating a sense of place [6,7]. Physical structures cannot be viewed separately from urban life, so the urban regeneration of public spaces, based on sociological research, forms the foundation of the city planning process [8]. Socio-physical regeneration occurs as a logical method of reactivating public spaces, establishing a dialogue between the inherited development fund, new architectural language, and sociological specificities without jeopardizing cultural identity, and with a balance between local needs and global requirements. Urban regeneration involves the promotion of traditional values [9] in the inherited types of public spaces and at the same time adapting those spaces to the needs of modern-day users, in the context of the sustainable development of society. Regenerated public spaces should offer a higher form of communication that corresponds to the relation between local processes and global requirements—that is, to the relation between real, material, and virtual needs.

1.2. Creative Urban Design

Globalization, as an economic, political and cultural process, enables networking into the global system, the rapid exchange of information, and implies spatial and temporal compression [10]. Cultural globalization contributes to the expansion of universal world culture patterns while weakening the influence of traditional local values [11]. In the duel between global recognition and local authenticity, culture and "genius loci" are becoming important factors in the creative regeneration of public spaces. The urban theory of a creative city encourages the development of techniques and principles of creative regeneration, which are based on culture, creativity, and social inclusion [12]. Research indicates the need to form new modes of communication in the creative city, with the aim of creating a multidisciplinary and interdisciplinary system [12].

Creatively oriented regeneration is the cornerstone of the "renewal" of traditional centres [13]. Various authors promote the concept of a creative city, city diversity, and competitiveness based on specific features of regeneration [12–14]. In contrast to the general treatment, policies, and emphasized theoretical discourse, this study uses urban design to analyse and identify the phenomena of a creative city and creative place in the context of the global hierarchy of cities and the economic competitiveness. The starting point is the concept of unconventional and concrete physical intervention on a small scale in the regeneration of the microenvironment into creative places with a range of contents that interpret new forms of connections, encounters, and events.

Starting from the very definition of public space in urban design [15], creative urban design has been identified in this study as a mechanism for sustainable placemaking. This process includes the active involvement of concepts based on art and culture and new forms of correspondence: "Creative placemaking animates public and private spaces, rejuvenates structures and streetscapes, improves local business viability and public safety, and brings diverse people together to celebrate, inspire, and be inspired" [16]. Placemaking in a modern, regenerative sense implies integration of the real needs of the local user, which have become globalized due to the dominance and impact of the information age.

1.3. Traditional Urban Spaces in the Context of Socio-Spatial Sustainability

From the perspective of socio-spatial sustainability, it is important to reflect on traditional frameworks in the theoretical interpretation and generation of urban areas. Various authors have studied and interpreted the interdependence of society and spatial forms [17–26]. An urban area occurs as an expression of the relationships in social production and represents a material and symbolic reflection of a society [17,19,20,27]. Mumford identifies the city as a social institution and states that the objective of city planning is the proper dramatization of communal life [28]. He considers social factors as primary, and the physical organization of the city, as well as its industry and trade and communication and traffic, subordinate to social needs. Castells also emphasizes the city's role within social structures and human life [29]. In addition, the authors give advantage to places rich in information and activities and those that have visual transparency [30–32]. Giddens [19] refers to social interaction as being mutually affective between users of a space or collectiveness in spatial and temporal continuity, through all stages of the city's development. All spatial forms and relationships are produced by human actions and represent the fulfilment of the interests of the dominant class in accordance with a given mode of production and a specific mode of development [29]. The issue of the relationship between physical structure and the movement of users is treated as a measure of a good space [30]. The connection between the history of social practices and spatial cultures (structures) is a fundamental dialogue [33]. In a historical context, sociological sequences have a direct impact on urban space. Bogdanovic emphasizes the city as a historical product, not just in terms of its physical materiality but also in the cultural sense—a city that creates a sense of historicity and feeling of continuity [34]. Bogdanovic recognizes the personalities of cities (i.e., persona cities) that have a strong cultural identity, as well as the cities that are lacking the qualities he considers necessary to be called cities [34]. Bogdanovic points out that every city carries a certain energy (i.e., a "quantum of energy potential") and a certain psyche or awareness of existence [34]. Cultural patterns of forming urban structures and ways of life are what determine a city's cultural identity and at the same time, these are what makes them substantially different from each other.

1.3.1. Open Public Spaces

Public open spaces, primarily streets and squares, are the basic elements that define the structure of urban spaces. According to Woolley, the power of open public spaces can be channelled through the social, economic, and environmental benefits of the city [22]. The role of public space in the initial development of cities is clearly defined: From a social perspective, they represent primary sites of social processes; public spaces are also informative sites of the city and areas of communication and information exchange. From an economic viewpoint, public spaces are defined by their main trade flows, so their blocks are formed at the cross sections of important routes [35]. From an aesthetic point of view, public spaces imply an attractive setting, a highly aestheticized space, even a work of art, which, on a daily and continual basis, has a guiding influence on large masses of the population [36]. Public spaces, with their morphologies, define the "framework" of public life and form the scenery for the performance of everyday dialogue between the users of space [28,34,37]; often authors put these spaces in the context of mental, cognitive shows [25,27,38,39]. In addition to representing the city in a physical, morphological sense, public spaces are essential, cultural and identity interpreters of the social community. The physical framework of a city's public space and the social activities that take place within it function in a cause-effect relationship.

Some authors suggest that public spaces have always been subject to numerous changes that have taken place in society under human influence. Globalization and transition processes have accelerated their transformation [40]. Capitalistic production has uniformed spaces, breaking down the barriers between society and spaces, thereby intensifying the processes of homogenization of spaces. Creating an abstract space that strives for immobile monotony has led to the unification of public spaces, and this process has weakened the identities of cities. Capital has taken control over spaces [41], and even over the creators of urban image, since, under the influence of capital, stakeholders create spaces to meet their needs. Public space has become the setting for a spectacle that is its own goal, equating itself to what it "has" i.e., pride in its appearance (spectacle spaces) [42] and spaces of "urban glamor." The postmodern aesthetics of public spaces that nourish and magnify the transience, spectacle, and commodification of cultural forms [10] require the transformation of cultural activities into cultural industries, merchandise, forms of consumption, and cultural pleasures. The space "is not only produced by the forces and relations of production and property, it is also a political product, a product of administrative and repressive control, a product of the relations of domination and strategies of state leadership" [41].

In cities accompanied by a long period of transition and stagnation, such as in the case of Podgorica, the public spaces in the physical structures of cities have become sensitive to changes in society. Cultural patterns created in one temporal, political, economic, or social system need to be transformed and adapted to meet new demands. However, the transformations of public spaces over time have been much less frequent and slower than those of all other urban elements. This is largely reflected in their sustainability. In the contemporary circumstances of a global and information-based society, public open spaces, traditionally recognizable places of identity and cultural meaning and social interaction, in the 21st century will need to take on a new communicative role in the relationship between "local processes" and "global flows." However, in the current process of regeneration, traditional public spaces, instead of becoming generators and interpreters of global interaction [43], are frequently losing their identity values, thereby becoming inactive; they have become a field of social conflict or transformed into new forms, such as pseudo-public spaces [5,44–47].

1.3.2. Streets as the Social Space of the City

In addition to being the basic functional element of an urban space, and defining the planning foundations of a city according to their position and layout direction, streets also represent a spatial phenomenon that is inseparable from the categories of users of the space. The street, as a form of public space, should represent a democratic space in the city, a space of communication and user interaction, through all stages of the city's development. The energy in social interaction and the physical framework of public spaces determines the specificity of a place and contributes to positioning its local identity on the map of its global values. By considering the street as a field of social interaction and by applying this phenomenon, it is possible to improve urban life and the state of social relations in user-place and place-city systems, as well as local process-global flows. In this respect, sustainable street regeneration plays an important role in the competitiveness of cities in the 21st century.

1.4. Aims and Significance of the Study

The first aim of this study was to identify, through a theoretical background, the role of traditional public open spaces in the context of the socio-spatial sustainability of a city. Another aim was to point out the inadequate treatment of historically recognizable public open spaces through time with a specific case study in Podgorica. The final aim of this study was to propose the specific physical regeneration of streets, with a creative urban design, in order to preserve the authentic values of sites, improve the content-based and visual usability of spaces and, at the same time, strengthen the role of public open spaces as primary interpreters of global processes.

The basic relevance of this study relates to the identification of the socio-spatial and identity roles of public open spaces in Podgorica, followed by detecting the inadequate treatment of these areas during the transition period; finally, this study offers a proposal for the physical street regeneration of twelve streets in the city centre in order to improve the global competitiveness of the modern city.

1.5. Research Directions

The study is based on three main research directions:

Level I: The interactions between users and places, including the identification of local and global communication, engagement of visual, auditory and tactile perceptions, and sustainability of local aspirations in the era of consumerism;

Level II: The interaction between a place and the city system, including the socio-physical integration of places into the urban system;

Level III: The interaction between local process and global flows, including the level of spatial flexibility, thereby balancing the communication and establishment of an equilibrium between real and material values and the needs of the information age.

The initial research relates to the theoretical background and issues of preserving traditional spatial values, as well as the needs of users in the age of information, and contemporary environmental and technological capabilities. Three identified levels of interaction in the development of new spatial and social values in a particular street's micro space were articulated through creative urban regeneration of the case study streets via the method of creative urban design. Existing fragmented, dominantly inactive material contents can be regenerated into new, physical, dynamic, perceptually attractive programs that promote a high level of spatial–social connections. Road traffic, as the dominant catalyst for such processes, should lose its primacy in favour of more sensitive forms of networking and interaction, which promote functional, aesthetic, ecological, creative, and interactive comfort both within the street, and in interaction with the wider material and immaterial context. These changes include flexible small-scale architectural and urban interventions, creative checkpoints, new art programs, parterre and green areas and zones, attractive street fronts, and new spatial impulses, which are supplemented to a certain extent with digital information algorithms that promote global spatial-social networking.

2. Materials and Methods

2.1. The Case Study Area

The case study relates to the traditional historical centre of Podgorica, Mirkova Varoš (Figure 1) and its twelve characteristic street spaces (Figure 2).

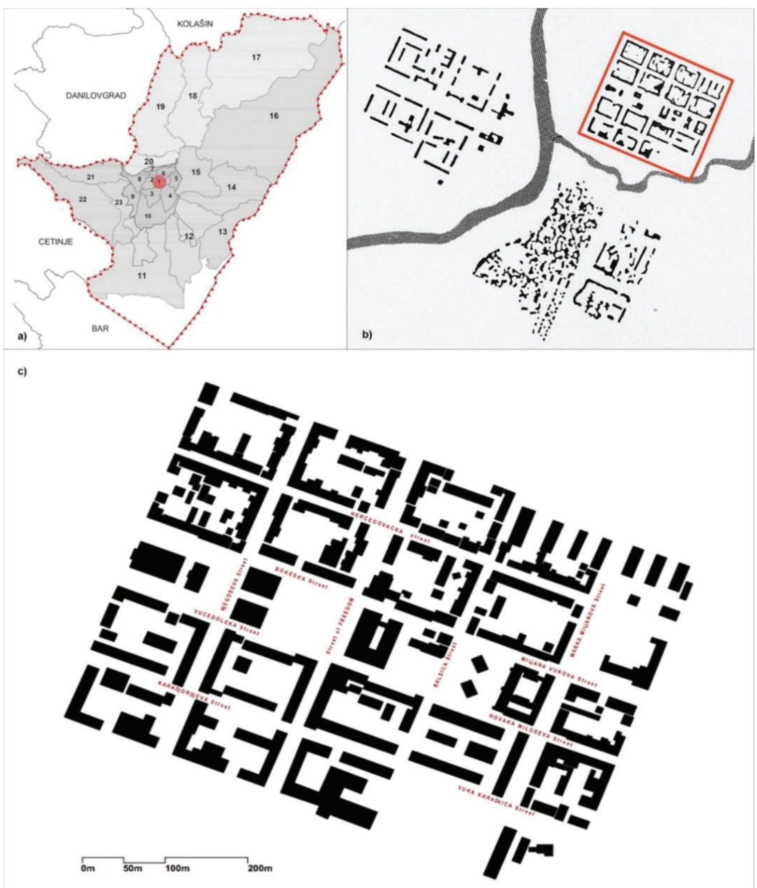


Figure 1. (**a**) The municipality of Podgorica [48]; (**b**) the position of Mirkova Varoš [49]; and (**c**) identification of 12 streets in Mirkova Varoš.

Streets in Mirkova Varoš:

1) Hercegovačka; **2)** Bokeška; **3)** Miljana Vukova; **4)** Vučedolska; **5)** Novaka Miloševa; **6)** Karadjordjeva; **7)** Vuka Karadzića; **8)** Njegoševa; **9)** Slobode (segment I); **10)** Slobode (segment II); **11)** Balšićeva; **12)** Marka Miljanova

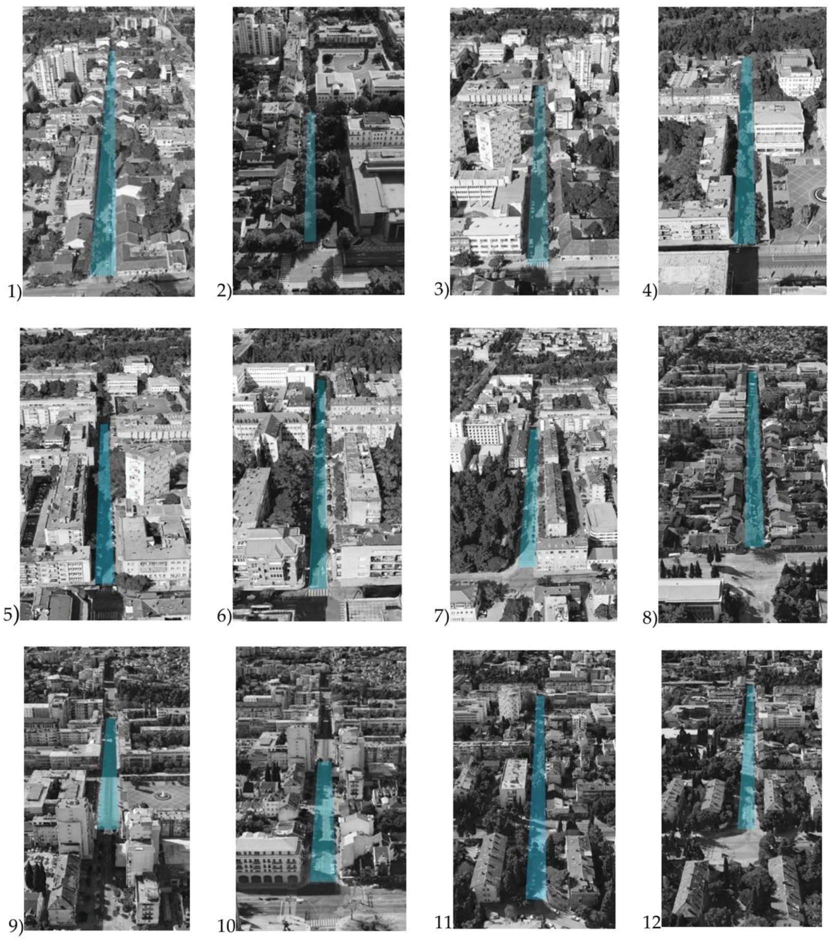


Figure 2. Spatial disposition of the case study streets of Mirkova Varoš.

2.1.1. The Urban Genesis of Podgorica. The Structure and Development of the Traditional Centre, Mirkova Varoš

Podgorica is the capital of Montenegro and, according to the latest census in 2011, it has around 186,000 inhabitants [50]. We traced the urban genesis of Podgorica through several periods: (a) the Roman period (Doclea and Birziminium); (b) the period of medieval Slavic states (Ribnica); (c) the Turkish period (Podgorica); (d) Podgorica 1879–1945; and e) the period after the Second World War (Titograd 1946–1992; Podgorica 1992–present) (Figure 3).

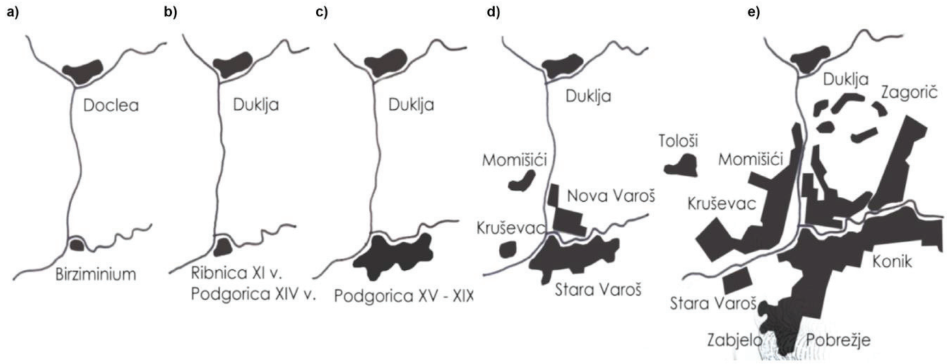


Figure 3. The urban genesis of Podgorica/Titograd; (**a**) The Roman period; (**b**) the period of medieval Slavic states; (**c**) the Turkish period; (**d**) Podgorica 1879–1945; and (**e**) Titograd 1946–1971 [49].

The initial beginnings of the development of present-day Podgorica are linked to the first settlement at the mouth of the river Zeta into the river Morača, founded by the Illyrians (the tribe of Doclea) at the end of the 3rd century BC. Accordingly, the later formed state was named Duklja. Under Roman rule, from the 1st century AD, Duklja became part of the province of Dalmatia. Romans formed the Roman settlement Birziminium on the river Ribnica [51–53]. Due to its strategic location, Duklja was repeatedly destroyed and rebuilt, most recently in the 6th century. Stagnation of the city followed this period.

During the Turkish period, in the late 15th century, the Turks began to build a large fort, made of stone from Duklja. A town developed within the fortress with towers and ramparts. Structures also developed outside the walls, along the left bank of the river, and a trade and craft centre was formed. At the beginning of the 17th century, Podgorica had about 900 houses and around 6540 inhabitants [54,55].

The period after the Berlin Congress is significant because of the city's strong transformation, as well as the influx of new population and higher levels of social development, with strong implications for the city's overall spatial development. With the annexation of Podgorica to the Principality of Montenegro, the planned development of the city began on the undeveloped areas of the right bank of the river Ribnica. The construction period under the first regulation plan of the Russian engineer Vorman, lasted from 1879 to 1945 [54–58]. This plan was developed on an orthogonal grid of streets, with a rectangular square resting on the main connection of the new part of the city, Nova Varoš (better known as Mirkova Varoš) and Stara Varoš, and the city had functionally good connections with inherited urban tissue.

The urban structure of Mirkova Varoš, with a recognizable orthogonal matrix, was generated with seven inner and four circumferential traffic routes, and a total of 20 (five in one direction and four the other way) urban blocks of 90 × 120 m, of which the central block contains the main city square of Podgorica—Independence Square.

The urban conception of Mirkova Varoš was based on the true measure of urban formation and the possibility of expansion via a similar principle. Subdivision within the blocks was carried out according to the principle of uniformly wide, narrow, and long parcels, varying between 10, 12 and 14 m, with equal storeys in the buildings that form a recognizable street sequence, while private gardens form the inner areas of the blocks (Figure 4).

a) b)

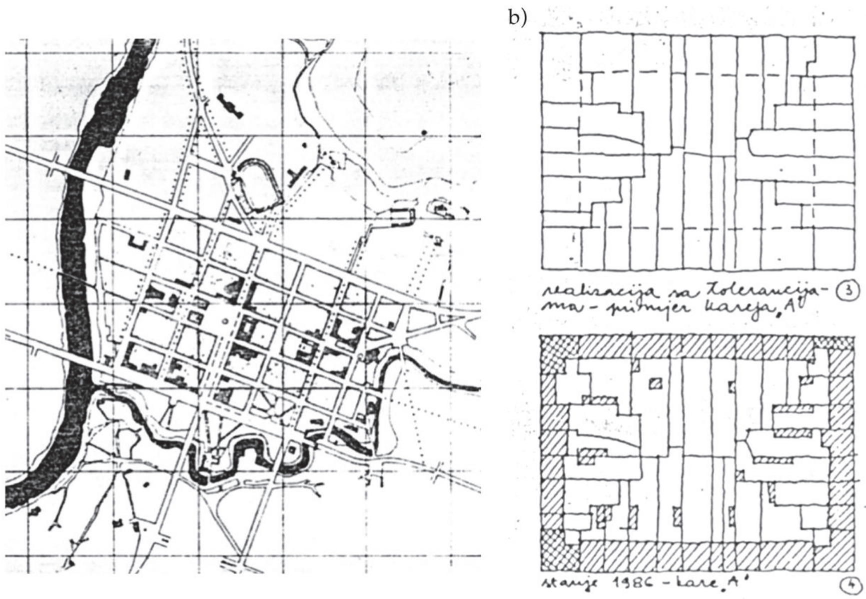


Figure 4. (**a**) Vorman's plan [52]; and (**b**) parcelling of the characteristic block of Mirkova Varoš [49].

During the Second World War, Podgorica was bombed several times, with over 60% of its construction stock destroyed and 96% of its buildings damaged. After the war, there was a period of reconstruction (Figure 5) and more intensive development of the city, predominantly over the Morača River—the development of the New City, with the formation of a new centre and significant consolidation of the urban block size [48,54,55]. The main axis, the "via principalis", was set up as the urban backbone of the city, which linked all three city structures: the Old Town, Mirkova Varoš, and the New City across the Morača River. The period after the Second World War is also significant for the rapid development of industry in Podgorica, largely located in the part of the city across the Morača. In macro terms, this industry becomes a leading economic branch, in accordance with the Socialist Federal Republic of Yugoslavia development strategy.

The urban structure of Mirkova Varoš was formed by planning, in a specific historical and socio-political context, according to the urban conception of engineer Vorman, and this established the foundations of the urban and cultural identity of present-day Podgorica. However, transitional and globalization processes have contributed to the rapid transformation of the city's society, which is more oriented towards consumerism and different types of entertainment in interior public spaces. This is reflected in the traditional public spaces of Podgorica, reducing the attractiveness of the traditional city centre and street spaces. With the construction of the Delta City shopping mall in 2008, in the part of the city across the Morača, the shopping streets of Mirkova Varoš began to noticeably lose their former importance (commercial, business, and touristic). The urban life of the historic centre is vanishing, and with the development of a consumer society, there has been an "urban spillover" of users who replace the open public spaces of the traditional city centre with closed public spaces (i.e., shopping centres with impoverished social power).

Figure 5. Reconstruction of the city after World War II. Photo from the 1960s.

2.1.2. Current Condition of Mirkova Varoš

The transition period, beginning in the 1990s, was fatal for the industrial giants that built Podgorica's economy and the identity of the city (Radoje Dakić and Marko Radović factories, Tobacco Plant, Titex). The lack of financial resources to modernize production techniques and maintain facilities, the lack of adjustment to global trends, and the lack of market competitiveness have all led to the weakening and closure of factories, suggesting a social crisis. The city began to expand, and abandoned industrial sites became breakpoints of continuity in the city's development. The increased influence of private investors in city planning processes has led to the dominant planning of new residential blocks and shopping malls in the city area across the Morača at former industrial sites. The apparent "comfort" of indoor public spaces (inside shopping malls) has caused a large number of users to leave the traditional city centre. The reduced number of users and the lack of attractiveness of public spaces and content within the commercially oriented streets of Mirkova Varoš have led to a state of physical and urban degradation in the traditional centre of Podgorica. The regulated demolition of objects within the defined urban matrix and the insertion of inadequate architecture have contributed to the loss of the authentic Mirkova Varoš' identity.

Detailed urban plans for Mirkova Varoš, made in the 1990s for each of the blocks, allowed for upgrades in its street structures. This plan led to the expansion of construction in that part of the city, with a significant increase in housing density. The increased number of occupants also meant an increase in the number of cars, which resulted in an infrastructural congestion and reduced comfort of life in the historic city centre. The construction of a large number of new apartments and commercial buildings was not supported by an adequate solution for parking places, and increased car traffic in the centre disrupted pedestrian traffic.

The Spatial Plan of Podgorica [48] recorded demographic changes, which indicate a constant population increase in the capital, with a change index of 1.11 during the period 2003–2011, while in Mirkova Varoš, the traditional city centre, there has been a population decline, with a change index of 0.93, during the period 2001–2011.

Numerous authors are looking at the reduced concentration of users as the cause behind people "abandoning" the centre. This type of reduction is often caused by insufficient commercial and business activities, and the reduced options for employment, as well as in housing conditions [58,59]. This further reduces the intensity of use of public urban spaces [59] and has precipitated a decline in cultural and creative capacities [59], as well as a lower productivity of the centre [60].

2.2. Methodology

This research was carried out at the Faculty of Architecture, University of Montenegro, within the semester course Urban Design Project 2016/17. Under the supervision of a professor and associates, 15 postgraduate students were included in the study.

The study was articulated with the goal of regenerating the central core of Podgorica through a creative urban planning design in the context of socio-spatial sustainability. Primarily on the basis of the subjective perceptions of users and students of architecture, for the 12 streets of Mirkova Varoš, we obtained objective criteria for the physical regeneration of the case study area.

Lynch points out the importance of perception as a two-way process between the observer and the environment-built structure—i.e., the interaction between a person and the city, stimulus, perception and cognition of a space [38,61]. In the cognition of a space, the observer goes through four stages: cognitive (thought sorting and archiving of data), affective (involving feelings affecting perception), interpretive (linking and comparing with one's own "database" of previous experiences), and evaluative (forming "opinions" or values of a space) [62]. The richness of the multidimensional aspects of experiencing a space is one of the main goals in the urban design process [61]. A series of mental images and "experiences" (feelings) are formed by the observer based on stimuli that receptors of the observer take in from the environment to form a sensory image-experience [38,63,64].

This study offers 12 specific urban street solutions developed by architecture students, with the goal of promoting the sustainable regeneration of streets through physical creative intervention. The ultimate goal of this study is to promote the concrete impact of physical transformations in a space—the influence of "small" urban design interventions that, in accordance with the needs of users (social beings), can shape a space that activates human senses and interacts with local processes and global requirements.

2.2.1. Methods

This study applied a combined research method. The first phase of the research was related to the theoretical basis for the general role of public spaces in the context of global socio-spatial sustainability. The theoretical platform that began this research had a strong significance in this study, as the chosen method was creative street design in the regeneration process for the case study streets. Some theoretical determinants were especially important in understanding the general perception of the regeneration of traditional open public spaces and the changed role of public space in the information age. Emphasis has been placed on the socio-spatial sustainability of contemporary public open spaces, through creation of the new spatial values, and their new role as an interpreter for the interaction between local processes and global demands.

The second research phase was based on a survey of the subjective perceptions of area users and architecture students, through three perception factors (visual, tactile, and auditory), with a specific case study of 12 streets of Mirkova Varoš in Podgorica. Perception criteria were defined based on a complex analysis of urban elements of the central zone, including general elements (socio-economic, environmental, cultural, and geographical effects), and taking into account the fieldwork examinations of specific physical, functional, and program characteristics of these street spaces. The results obtained were used as input data for the third phase of the study, which entailed the physical regeneration of the case study area, interpreted by the application of a creative urban design concept.

Figure 6 shows the research process and the applied methods.

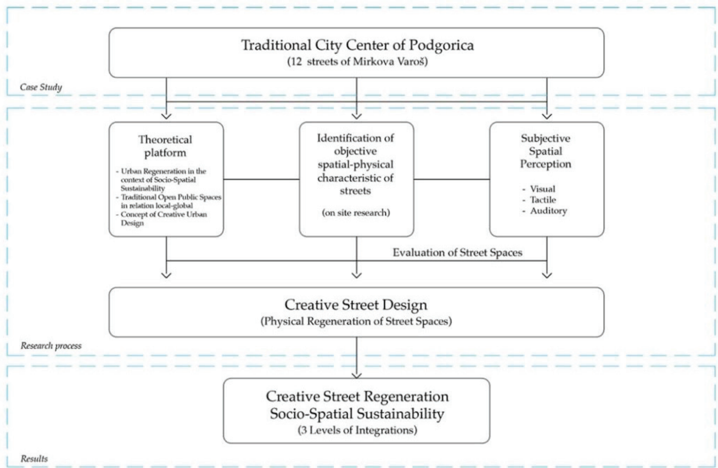


Figure 6. The research process and applied methods.

2.2.2. Instruments

The theoretical portion of this study was primarily implemented through the selection and systematization of literature relating to regeneration and the role of traditional public space in the context of socio-spatial sustainability, as well as the application of the concept of creative urban design and the case study analysis.

The conducted survey used a Semantic Differential questionnaire, which contained a list on a seven-point scale (−3, −2, −1, 0, +1, +2, +3) between bipolar contrasting pairs and a neutral zero point [65,66]. The visual factor used 8 contrasting pairs, and there were 6 pairs each for tactile and auditory factors. A total of 20 contrasting pairs and 36 semantic scales were used in the study. Table 1 shows the factors used for the street evaluation, including the bipolar contrasting pairs.

Table 1. Factors and bipolar adjectives for street evaluation in Mirkova Varoš, Podgorica.

Factors	Visual	Tactile	Auditory
Contrasting Pairs	static/monotonic–dynamic	rough–smooth	loudly–quietly
	disharmonized–harmonized	hard–soft	intense–calm
	colourless–colourful	cold–warm	irritating–pleasing
	narrowly–widely	unpleasant–pleasant	disturbing–comforting
	gloomy–sunny	artificial–natural	road traffic noise high level–low level
	poor greenery–rich greenery	simple–complex	unenjoyable–enjoyable
	disarranged–arranged		
	unattractive–attractive		

For each of the 12 streets in the study, we surveyed 15 architecture students and 15 area users. Recognizing the benefits of the "walking interview" methodology [67–69], the questionnaire was conducted directly in the specific street space that was subjected to the study, in order to gain precise and holistic results from the survey, including the observer's peripheral perceptions (such as experience). The data processing method was the arithmetic mean, and the results obtained with the semantic differential scales served to define the objective criteria as the input data for the realization of the creative urban design process.

3. Results

3.1. Theoretical Research

The theoretical aspect of the paper is articulated towards a better understanding of the role of traditional open public space as the dominant generator of a city's physical structure and the need to re-identify traditional street spaces according to the global needs of society. Further theoretical research treats the morphogenesis of the subject area in the context of different temporal sequences and identifies the concept of creative street design as the method for sustainable regeneration in the case study. By applying the concept of creative urban design, it is possible to articulate the socio-spatial sustainability of public spaces, which operate on the intersecting line between the preservation of the local values of a place and the global uniformity that tends to shape contemporary urban spaces.

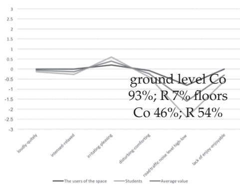
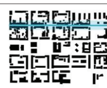
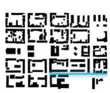
The public open spaces of cities can become new generators and interpreters of cultural values and technological opportunities. The wealth of information in a global context can be transposed through the creative regeneration of physical and material spaces, which will promote the sustainability, and more strongly encourage various forms of connections, from the local to global level.

3.2. Analysis of the Current State of Mirkova Varoš Street

Field surveys carried out during the exploration phase of the analysis of the current spatial and physical condition of Mirkova Varoš streets included the detection of the following parameters: the length, position, building types, number of floors, traffic rating, greenery, and urban furniture (Table 2). The analysis of the existing physical conditions of the case study streets reflects the direct objective data obtained from the characteristics of the determinants in the space, including the traffic rating, which refers to the primarily objective urbanistic criteria for the assessment of the buildings in terms of construction preservation and general fit within their existing context (object location, size, shape, structure of the dimensions of the building, and architectural heritage).

Field research has also identified the following issues in the case study streets: functional issues (insufficient number of parking spaces, inadequate parking of cars on the street and on the sidewalks, and lack of urban furniture on the streets), economic issues (unprofitable hospitality and trade facilities due to the small number of users in the centre), ecological issues (pollution from traffic congestion at the centre, a lack of greenery, impaired bioclimatic comfort, and noise), visual issues (inadequate facades of buildings, illegal upgrades, disappearance of genius loci), and psychological problems (unpleasant atmosphere (a consequence of an "empty" space) and the experience of a monotonous and unattractive ambience)) [70,71].

Table 2. Physical characteristics of Mirkova Varoš streets. Current state analysis.

Street Name	Length	Position	Building Types	Number of Floors	Traffic	Buildings Rating	Greenery	Urban Furniture
(1) Hercegovačka	656 m		ground level Co 93%; R 7% floors Co 46%; R 54%	P - P + 3	west segment pedestrian; east segment road-pedestrian	C high; A poor	+ -	+
(2) Bokeška	275 m		ground level Co 100%; floors Co 35%; R 65%	P - P + 4	one-way street; frequent traffic; linear street parking	C mediocre; A high	+	-
(3) Miljana Vukova	381 m		ground level Co 92%; R 8% floors A 40%; Cu 20%; R40%	P - P + 10	one-way street; traffic jam; inadequate parking	C mediocre; A poor	+ -	-
(4) Vučedolska	275 m		ground level Co 100%; floors Co 35%; R 65%	P - P + 3 + Pk	one-way street; frequent traffic	C mediocre; A mediocre	+	-
(5) Novaka Miloševa	381 m		ground level Co 100%; floorsCo 38%; R 62%	P - P + 10	one-way street; frequent traffic	C mediocre; A poor	+ -	-
(6) Karađorđeva	275 m		ground level Co 77%; R 23% floors Co 12%; R 88%	P + 3 - P + 4	two-way street; access to the public garage; linear street parking	C mediocre; A mediocre	+ -	+ -
(7) Vuka Karadžića	381 m		ground level Co 81%; R 11%; A 8% floors A 26%; R 74%;	P - P + 4 + Pk	two-way street; frequent traffic	C poor A poor	+ -	-
(8) Njegoševa	506 m		ground level Co 84%; R 8%; A 8% floors A 26%; R 74%	P - P + 3 + Pk	south segment pedestrian; north two-way street with a pedestrian component	C mediocre; A high	+	+ -
(9) Slobode (segment I)	291 m		ground level Co 100%; floors Co 24%; R 76%	P + 1 - P + 5	two-way street; closed for cars in the period 17–05 h; pedestrian oriented	C mediocre; A high	+ -	+ -
(10) Slobode (segment II)	215 m		ground level Co 100%; floors Co 6%; R 94%	P - P + 12	two-way street; closed for cars in the period 17–05 h; pedestrian oriented	C mediocre; A poor	-	-
(11) Balšićeva	506 m		ground level Co 92%; R 8%; floors R 100%	P - P + 10	north segment is one-way street south segment is a two-way street with inadequate parking	C mediocre; A high	+ -	-
(12) Marka Miljanova	506 m		ground level Co 85%; R 7%; A 8% floors A 24%; Co16%; R60%	P - P + 4 + Pk	two-way street; frequent traffic; inadequate street parking	C mediocre; A poor	-	-

Building types: Co—commercial; R—residential; C—culture; A—administration; Floors: P—ground level; P + n—ground level and number of floors; Pk—attic. Building conditions: C—construction rating; A—ambient rating; poor, mediocre, high; Greenery: + over 75% street length covered with greenery; + - between 25% and 75%; - less than 25%. Urban furniture: + street with high quality urban furniture; + - street with insufficient or inadequate urban furniture; - street with no urban furniture.

3.3. Perception of the Streets of Mirkova Varoš

3.3.1. Visual, Tactile, Auditory Perception

Urban perception as a result of the human-environment interaction in this study has served as the basis for the evaluation and proposal for physical regeneration of the streets in Mirkova Varoš in Podgorica.

The importance of the visual representation of a public space and its impact on the observer has been recognized by various researchers and repeatedly confirmed [23,37,38,62,63,72]. Visual perception is predominant in the interaction between man and space, whereby the complexity and nature of visual elements create the feeling of satisfaction in a particular area or a particularly negative experience.

Tactile stimuli play a significant role in the formation of the overall perceptual image of an urban space and can contribute to different experiences and influence quality of life [61,73,74]. This is especially pronounced for people with visual disabilities [75]. However, despite the importance of tactile senses and their "universality and diversity," this form of perception is not sufficiently present in the evaluation of public spaces [61].

Auditory interaction in a physical space is very complex and contributes to different experiences. The important role of auditory perception in the context of the sustainable development of urban open public spaces has been indicated by numerous measurements of sound perception, acoustic comfort evaluation in urban public spaces, analyses of factors that influence perception, experimental studies [76–80], analyses of aspects in creating "sound space" [81], and the understanding of urban spaces and design through auditory perception [82].

The Semantic Differential Scales for the perceptions of users and architecture students (with arithmetic means) for the case study of the Mirkova Varoš streets are shown in Table 3.

The results obtained by surveying the area users and architecture students indicate different approaches in the evaluation of space, and in visual, tactile and auditory terms, within various categories of the respondents. There are differences in the perception of space by architects (in this case, students) and non-architects (area users) i.e., differences in their reactions to the impulses from public spaces, as has been indicated by various authors [83–86]. Architecture students had high criteria in their evaluation of the aesthetic components of the area (applied materials and colours), while other users of the public space were more critical toward the functional and infrastructural deficiencies in the public space, as well as acoustic comfort. On a semantic differential scale, the majority of respondents reacted positively to historically valuable objects and cultural content, while negative reactions were provoked by issues of traffic frequency, noise, pollution, and inappropriate parking. The survey found that streets with fewer users received lower ratings on the semantic scale of visual criteria. This is especially pronounced in the category of non-architect respondents. Area users generally used a rating of 0 for criteria without stimuli, either positive or negative.

Finally, it is possible to conclude that critical judgment and reasoning was more pronounced among students of architecture compared to area users. The respondent group, comprising randomly selected area users, has less ability to independently evaluate interpretive visual factors in relation to auditory "impressions" and the subjective experience of images in relation to the auditory display is also inseparable.

Figure 7 shows the qualitative results of the street evaluation in Mirkova Varoš, Podgorica.

Table 3. Semantic Differential Scales of perception of the Mirkova Varoš streets in Podgorica.

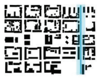
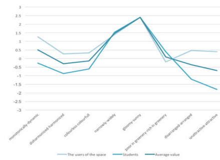
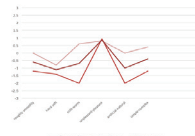
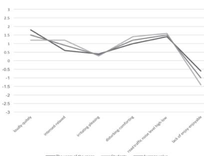
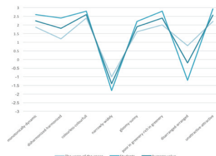
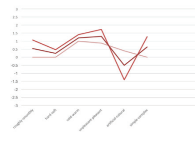
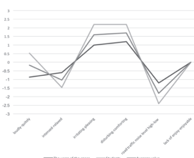
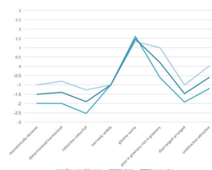
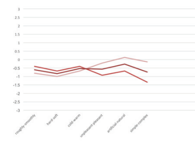
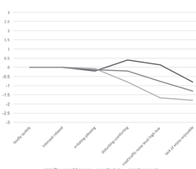
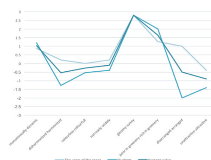
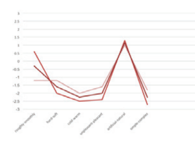
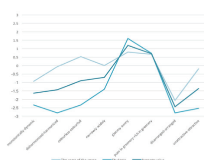
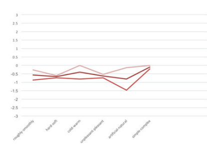
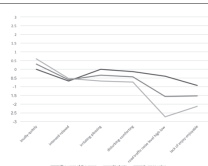
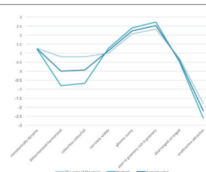
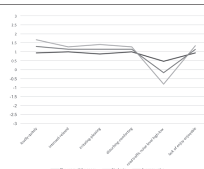
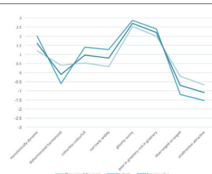
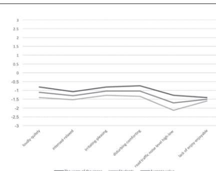
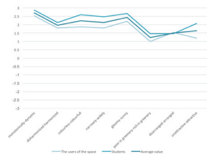
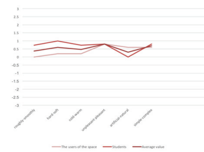
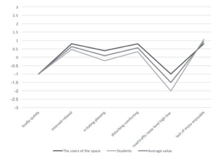
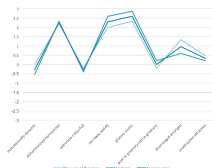
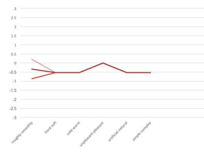
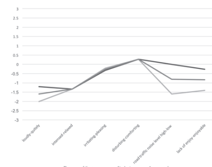
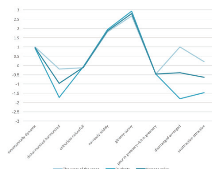
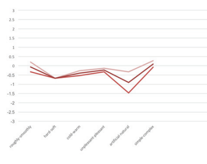
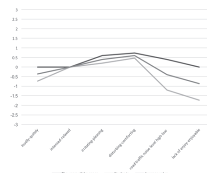
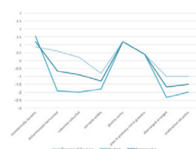
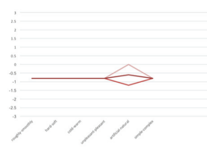
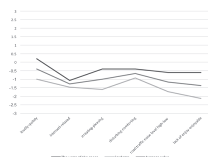
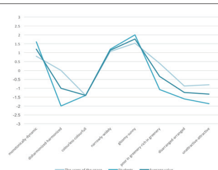
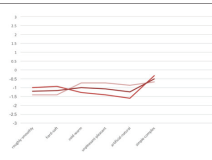
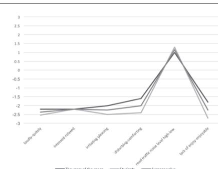
Street		Perceptual Factors		
		Visual	Tactile	Auditory
(1)				
(2)				
(3)				
(4)				
(5)				
(6)				
(7)				

Table 3. *Cont.*

Street		Perceptual Factors		
		Visual	Tactile	Auditory
(8)				
(9)				
(10)				
(11)				
(12)				

Street		Perceptual factors					
		Visual		Tactile		Auditory	
		positive features	negative features	positive features	negative features	positive features	negative features
1)	**Hercegovačka**	- street morphology - sun conditions - dynamic street front	-unattractive and colourless facades - spatial fragmentation	- pleasant	- inadequate materials applied (cold, hard and roughly) - lack of digital information	- low level of road traffic noise - comforting, pleasing and relaxed ambience	-unenjoyable ambience
2)	**Bokeška**	- dynamic and attractive street front - harmonized structure - plenty of greenery - sun conditions	-disarranged facades - morphology (narrowly street) - disintegration in the city street system	- materials applied (smoothly, soft,warm, complex and pleasant)	- mixed artificial surfaces	- pleasing, comforting and enjoyable ambience	-road traffic noise high level - intensed ambience
3)	**Miljana Vukova**	- sun conditions	-lack of greenery - static, disharmonized, disarranged and unattractive street front - spatial disintegration	/	- inadequate materials applied (cold, hard, roughly, simple and unpleasant) - lack of digital information	/	-unenjoyable and disturbing ambience -road traffic noise high level
4)	**Vučedolska**	- morphology - sun conditions - dynamic street front	- disarranged disharmonized and unattractive street front - spatial fragmentation	- natural surfaces	- inadequate materials applied (cold, hard, roughly and unpleasant) - lack of digital information	/	-unenjoyable and disturbing ambience -road traffic noise high level
5)	**Novaka Miloševa**	- sun conditions	-lack of greenery - static, disharmonized, disarranged and unattractive street front	/	/	- quitely ambience	-unenjoyable, irritating and disturbing ambience -road traffic noise high level
6)	**Karadjordjeva**	- plenty of greenery - sun conditions - street morphology	-unattractive ambience - disintegration in the city street system	/	/	- pleasing, comforting and enjoyable ambience	-road traffic noise high level
7)	**Vuka Karadzića**	- sun conditions - greenery - dynamic street front - street morphology	- disarranged and disharmonized street front	- natural surfaces	- simple surfaces applied - lack of digital information	/	-unenjoyable, irritating and disturbing ambience -road traffic noise high level
8)	**Njegoševa**	- sun conditions - greenery - dynamic and harmonized street front - street morphology - arranged structures	/	/	/	- relaxed, comforting and enjoyable ambience	-unenjoyable ambience -road traffic noise mediocre level
9)	**Slobode (segment I)**	- sun conditions - street morphology - greenery - dynamic, harmonized and arranged street front	-static/ monotonic and colourless facades - spatial fragmentation	/	/	- comfort and safety	-unenjoyable irritating and loudly ambience -road traffic noise high level
10)	**Slobode (segment II)**	- sun conditions - street morphology - dynamic and harmonized street front	-unattractive ambience - disharmonized structure - spatial fragmentation	/	- inadequate materials applied (hard, cold)	- comfort and safety	-unenjoyable, irritating and loudly ambience -road traffic noise high level
11)	**Balšićeva**	- dynamic and harmonized street front - sun conditions	-unattractive ambience - disarranged structure - disintegration in the city street system	/	/	/	-unenjoyable -road traffic noise produce loudly and intense ambience
12)	**Marka Miljanova**	- street morphology - dynamic street front - sun conditions - disintegration in the city street system	- disharmonized and disarranged structure - unattractive and colourless ambience	/	- inadequate materials applied (roughly, hard, cold and unpleasant) - lack of digital information	-road traffic noise neutral level	-unenjoyable, loudly, intensed and irritating ambience

Figure 7. Qualitative results of the street evaluation in Mirkova Varoš, Podgorica.

3.3.2. Physical Street Regeneration Directions

The results achieved by the survey measuring the subjective perception of architecture students and other users of the space formed a qualitative basis (input data) for the physical street regeneration of Mirkova Varoš. By analyzing the results (the average values) achieved at the scales of the semantic differential, the characteristic positive and negative aspects of the 12 analyzed streets can be seen.

All streets were evaluated most positively for their morphological characteristics (street width) and natural sun conditions (100%). In addition to these criteria for the visual perception of streets, positive results were obtained for a large number of streets for their dynamic street fronts and the presence of greenery (75%). The highest percentage of negatively assessed streets in visual terms relates to the contrasting pairs disharmonized–harmonized (75% negative, 25% positive), colourless–colourful (83% negative, 17% positive), and disarranged–arranged (83% negative mean).

In terms of tactile perception criteria, the obtained mean values (close to neutral zero point) are fairly uniform in most streets (over 80%). In Hercegovačka, Bokeška, Vučedolska and Vuka Karadžića streets, there are greater fluctuations in the evaluation of criteria, in terms of the contrasting pairs artificial–natural, unpleasant–pleasant, and simple–complex.

Regarding auditory perceptual factors, a mostly negative mean was obtained for road traffic noise low–high level criteria (83%), unenjoyable–enjoyable (75%), as a result of the irritating–pleasing criteria (50%). This shows that, despite the negative effect of traffic noise, which is predominantly represented in Mirkova Varoš, and other types of noise, users do not record dissatisfaction (age structure defines the tolerance threshold for sound perception).

The structure of the obtained results indicates the dissatisfaction of the users of the space and students, with regard to the level of organization of the public space, as well as the lack of content and activities that could increase the number of users in the "abandoned" traditional city centre. In most cases, street comfort depends on the frequency of traffic through the street, except in streets where these deficiencies are offset by the aesthetic and ambient values of the street itself, but also by a satisfactory level of public facilities (cultural and creative capacities).

Based on the street space perception results obtained by surveying users and architecture students, several general directions for the physical regeneration of the case study streets were articulated.

- Reducing road traffic and establishing the dominance of pedestrians (auditory and visual aspects);
- Enhancing the creative environment through sustai'nable principles of regeneration (visual, tactile, and auditory aspects);
- Establishing different levels of integration in order to enhance user–place interactions, interactions between a place and the city system, and interactions between local processes and global flows (socio-spatial interactions).

3.4. Creative Street Regeneration in Mirkova Varoš

Solutions for the physical regeneration of the 12 case study streets, made by architecture students, are presented in Table 4.

Creative regeneration, through the prism of the urban paradigms of the 21st century, has the task of preserving and improving the traditional values of a space (authenticity, recognisability) [8], to create a field of active creative interaction and enable economic prosperity with benefits to all stakeholders. Emphasis is placed on encouraging the creativity of all who are involved in the process, not just the creative class [12].

Street regeneration interventions in the context of socio-spatial sustainability in the case study streets have been specifically implemented in three key directions:

1. *Functional*: infrastructural (program dynamism and multifunctionality (hospitality, culture, trade, entertainment, and recreation), reducing road traffic and encouraging the dominance of pedestrians (underground car parking, new routes, integration with a narrower and wider context, and a network of micro public spaces), information points, digital street installations, etc.;

2. *Ambient*: *Aesthetic comfort*: reconstructing facades on street fronts, using walls as art canvases, incorporating vertical and horizontal greenery (on the facades of buildings and parterre), lighting effects, new facilities for entertainment and relaxation, urban tapestry, solar and smart systems, water elements, natural ecological material, new green areas, colours, etc.;
3. *Creative interaction*: creating dynamic areas of social entertainment, activation of cultural and educational content within existing structures, creating collective culture platforms in open spaces, continuous art lines and creative points, culture and art stations (pavilions, jazz, music performances, exhibitions, and outdoor libraries), creating common spaces on the flat roofs of buildings, new spaces for socialization, panoramic lifts, digital interactive platforms, etc.

In a wider context, the creative urban street regeneration of Mirkova Varos used in this study is intended to highlight the important role of a combined, unconventional method of physical space regeneration, with a strong intention to promote a rational and realistic physical redefinition of the current image of traditional public open spaces and reactivate their role in 21st Century cities. In a narrower sense, this study suggests that it is possible to regenerate concrete traditional streets by respecting tradition and at the same time developing new spatial scenarios. These scenarios are intended to promote a dynamic relationship between man and space—a humane, cultural, creative, ecological, informational dimension—and interact with the local capabilities and needs of global society. Generating new forms of creative activities (by regenerating existing content and introducing new content, new forms of integration) reactivates the socio–spatial interaction in (1) the user–place system, (2) the place–city system, and (3) local processes–global flows.

Table 4. Proposals for the physical regeneration of the 12 streets in Mirkova Varoš in Podgorica.

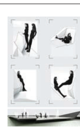
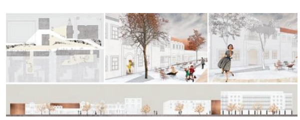
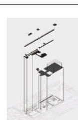
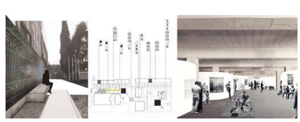
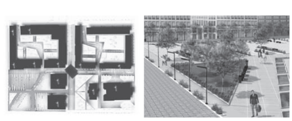
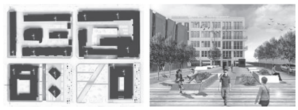
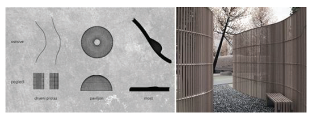
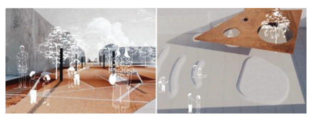
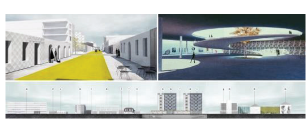
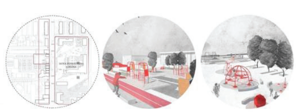
Street	Project			
	Name	**Concept Visualization**	**Urban Design Visualization**	**Summary of Street Intervention**
(1)	Walkable street			The preservation of architectural heritage; reactivation through the introduction of new content; implementation of a continuous "blue water line" and green parterre (introduction of natural forms into an artificial space; transformation of monotonous spaces into dynamic environments for social entertainment).
(2)	Culture Promenade			Interpolation of new structures; implementation of ephemeral installations into the space of the street; an installation that can "partition" and "integrate" space at the same time; a space for "sitting" (inaction); integrating urban furniture and green spaces into a system that "naturally" arises from the street level.
(3)	Culture Manifesto			Eliminating road traffic; creating a multifunctional, flexible space that gives the user an opportunity to choose and create space; a reactive urban place; a series of micro squares, accentuating surfaces according to purpose (dividing the square into "fields" of different textures and contents); new green spaces.
(4)	Green street			Reactivation of the central fragment of the city and its integration with open spaces in Mirkova Varoš; engaging the function of pedestrian movement through the introduction of a "diagonal" element; in response to the high frequency of road traffic and insufficient green space; incorporating new stopping points.

Table 4. *Cont.*

Street	Project			
	Name	**Concept Visualization**	**Urban Design Visualization**	**Summary of Street Intervention**
(5)	Human scale			Creating a multi-functional environment according to the human scale; implementation of interactive content; reactivating the street through the dominance of pedestrian traffic; constructing a parterre geometry that follows the lines of pedestrian movement; creating a new urban parterre.
(6)	Enjoyable street			Displacing road traffic from the surface to the underground level and freeing up the area for pedestrians; flat roofs of buildings become new public spaces in the city; panoramic lifts are formed adjacent to existing facilities; introduction of new green spaces and revitalizing existing green spaces and urban furniture.
(7)	Nature in			Eliminating traffic and creation of a pedestrian zone; introduction of new cultural objects; generating space for socializing, resting, recreation; "green invasion"; the existing park expands and the street becomes green, with the introduction of a water body and accompanying urban furniture.
(8)	Open space museums			Interweaving art throughout the street, incorporating new content into the existing, clearly defined envelope (predominantly art, culture and education); introduction of a continuous line of art with different contents; regeneration of the street into a place of comfort, creativity, interaction, and identity.
(9)	Micro space integration			Eliminating traffic from the street level; separation of pedestrian and vehicular traffic; visual integration of public spaces; introduction of new cultural content and programs; generation of creative placemaking and urban coworking, characterized by social, environmental and urban comfort.
(10)	Eco-friendly street			Layering of the road, pedestrian, and bicycle traffic; generation of ecological comfort (green facades, smart and self-sustaining systems, energy efficiency); implementation of new content, regeneration into a new, environmentally friendly ambience of social interaction, recycled public space, smart street.
(11)	Jazz street			Eliminating road traffic and parking spaces; returning the street to pedestrians; generation of interactive urban environment through new zones of housing, trade, hospitality, culture; new interactive squares connected to the main city square; revitalization of urban "pockets"; visual sequences, "discovery" of the city.
(12)	Street for all			"Reanimation of the centre" of the city; new experiences through the creation of a park area that includes a cultural zone (summer scene and exhibition spaces) and a recreation area; introduction of new programs with an interactive character; eliminating road traffic and activating underground traffic; implementing horizontal and vertical greenery.

The following students have participated in the proposals for the physical regeneration of streets: Danica Čvorović, Milan Rahović, Bojana Raspopović, Branka Vujović, Aida Kujović, Ana Nenezić, Vlado Jegdić, Stefan Mušikić, Ivana Kapetanović, Marija Petričević, Andjela Marković, Nikola Popović, Nina Simović, Jovana Jušković, and Anja Lješković.

4. Discussion and Conclusions

This urban regeneration depends on two different sets of processes: dynamic (the flow of people, interactions, and kinaesthetic energy) and static (the urban structure, shape, and defined public space) [7], which are interdependent. Traditional reconstructions of public spaces put an emphasis on their static components (the physicality of the space), while modern theories with an interdisciplinary approach give primacy to a dynamic set of processes. In this sense, successful public places, according to the "Project for Public Spaces" [87], are:

1. Available (good connections to the main movement routes);
2. Active (give the user an opportunity to "do something" and participate in various activities and cultural events);
3. Visually and ambiently friendly and safe (providing high safety and cleanliness);
4. Enable social interaction (with a clearly defined social character of a public place, with a pronounced integration between users, community, and place, and with the participation of different structures: age, cultural, and social).

The physical aspect of urban regeneration is primarily generated through the urban design process. Understanding the relationship between people and the physical environment is an essential component of urban design [31,88]. In this context, the perception of street spaces in the urban design process is treated as primary by our study. Some of the most recent studies precisely indicate the importance of the relationship between the environment and user's behaviours in the street (i.e., a user's behaviour toward the street environment) [89].

The streets of Mirkova Varoš have traditionally had a distinct identity and social importance among the public spaces of Podgorica. The distinctive setting of the orthogonal matrix, an innovative expression in the planning of cities of the time, articulated the directions for the development of the modern city. This urban concept was bold and advanced in its socio-political context and the time in which it was created. However, after a long period of inferior relations to its heritage and neglecting the identity of its historical core, we are confronted with the fact that the streets of Mirkova Varoš are more active in the collective memory of Podgorica residents than in its actual physical and material interpretation. The diminished attractiveness of the public space has influenced its rapid abandonment [7]. Montgomery points out that, if not active, a city loses its urban features. However, Montgomery also notes that it remains possible to create an active urban environment through urban design [90].

Urban creative regeneration provides a logical model for the reactivation of streets in Mirkova Varoš through the creation of a dialogue between the development legacy fund, architectural language, and the social specificity of places, without jeopardizing the city's cultural identity and while establishing a balance between local aspirations and global challenges.

In a contemporary context, in order for a model of urban regeneration to be complete, it is necessary to achieve interactions at a higher level, as the contemporary user has more pronounced needs. A public space, whether a square or a street, and whether it is positioned in a recent or historical part of the city, should offer the possibility for a higher form of communication, which responds to the relationship between local processes and global demands.

Through the application of the concept of the creative regeneration of a traditional city centre, we proposed a series of concrete guidelines for the urban regeneration of 12 streets in Mirkova Varoš through 12 different solutions. Respecting the traditional values of the street's environment, contrasted with the mutated artificial environments and uniform shopping malls on offer, existing streets in Mirkova Varoš were regenerated in accordance with the needs of modern people. These interventions include the creation of approachable spaces, and the introduction of attractive new contents, new visual determinants, and new forms of interaction. The aim was to generate a new perceptual experience through the reactivation of existing streets and to develop diverse, dynamic, and active street spaces.

The solutions suggested by architecture students show a high level of understanding of socio-spatial contexts, as well as cultural needs.

This study highlights the importance of the concept of creative urban design in sustainable urban regeneration, which can contribute to a new method of using open urban public spaces. Urban street spaces should promote new values and new places for the generators and interpreters of interactions in modern global urban contexts.

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A Hybrid Tool for Visual Pollution Assessment in Urban Environments

Khydija Wakil [1,*], Malik Asghar Naeem [1], Ghulam Abbas Anjum [2], Abdul Waheed [1], Muhammad Jamaluddin Thaheem [3], Muhammad Qadeer ul Hussnain [1] and Raheel Nawaz [4]

1 Department of Urban & Regional Planning, National University of Science & Technology (NUST), Islamabad H-12, Pakistan; asghar.naeem@nit.nust.edu.pk (M.A.N.); drwaheed@nit.nust.edu.pk (A.W.); plannerqadeer.urp@nit.nust.edu.pk (M.Q.H.)
2 Department of City & Regional Planning, University of Engineering & Technology (UET), Lahore 54000, Pakistan; gaanjum13@hotmail.com
3 Department of Construction Engineering, National University of Science & Technology (NUST), Islamabad H-12, Pakistan; jamal.thaheem@nit.nust.edu.pk
4 Department of Operations, Technology, Events and Hospitality Management, Manchester Metropolitan University, Manchester M13 9PL, UK; r.nawaz@mmu.ac.uk
* Correspondence: khydijawakeel.urp@nit.nust.edu.pk; Tel.: +92-333-626-0791

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Abstract: With increasing focus on more nuanced aspects of quality of life, the phenomenon of urban visual pollution has been progressively gaining attention from researchers and policy makers, especially in the developed world. However, the subjectivity and complexity of assessing visual pollution in urban settings remain a challenge, especially given the lack of robust and reliable methods for quantification of visual pollution. This paper presents a novel systematic approach for the development of a robust Visual Pollution Assessment (VPA) tool. A key feature of our methodology is explicit and systematic incorporation of expert and public opinion for listing and ranking Visual Pollution Objects (VPOs). Moreover, our methodology deploys established empirical complex decision-making techniques to address the challenge of subjectivity in weighting the impact of individual VPOs. The resultant VPA tool uses close-ended options to capture the presence and characteristics of various VPOs on a given node. Based on these inputs, it calculates a point based visual pollution scorecard for the observation point. The performance of the VPA tool has been extensively tested and verified at various locations in Pakistan. To the best of our knowledge, this is the first such tool, both in terms of quantitative robustness and broad coverage of VPOs. Our VPA tool will help regulators in assessing and charting visual pollution in a consistent and objective manner. It will also help policy makers by providing an empirical basis for gathering evidence; hence facilitating evidence-based and evidence-driven policy strategies, which are likely to have significant impact, especially in the developing countries.

Keywords: Visual Pollution Assessment (VPA); Visual Pollution Objects (VPOs); Analytical Hierarchy Process (AHP); urban visual pollution; urban areas; evidence based policy; urban planning

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1. Introduction to Visual Pollution

Recent decades have witnessed an exponential growth in urbanization demands, especially for improved governance in response to an ever-increasing urban complexity in a global and multi-level context [1]. In the developing countries, economic development, urban growth and dynamic economic transformation are accompanied by many other phenomena [2]. Usually, amenities are provided to the citizens without a well-managed plan of service provision; this results in the visual deterioration of the urban fabric. For example, marketing agencies install various kinds of outdoor advertisements particularly hoardings and billboards, which in the absence of strict enforcement policies, often emerge as eye-sores and visual blights [3]. Similarly, provision of other services without strong management result in solid waste dumps, cluttered hanging communication wires, encroachments, slums, bad road infrastructures, dilapidation of historical buildings, etc. Resultantly, urban life has come across as a disaster of aesthetic deterioration, transportation issues, air pollution, fumes, smog, and land and water pollution. However, in contrast to other types of pollutions, visual pollution has remained the most neglected aspect of urban life, both in policy and enforcement.

From the definitional evolution aspect, the term 'visual pollution' has been primarily recognized and researched in the mid of 20th century. Although earlier references to air and water pollution can still be found in the literature [4]. During the 19th century, recognition of types of pollution started from the laws on air and water pollution due to their harmful influences on the human environment. The era of the 1970s yielded a number of laws and treaties on 'noise pollution' that denotes the beginning of accepting other types of pollution. During the same period, the visual and light pollution was acknowledged in general, particularly in legal documents, and their management was mandated to local authorities, state agencies, and municipalities [4].

Parallel to that, since the 1960s, visual pollution has been discussed in the developed part of the world resulting in the emergence of different acts, rules and policies for the protection, preservation and enhancement of the urban visual environment [5]. A school of thought defined visual pollution as the type of pollution which offends human vision, spatial orientation, physical, mental health, or has psychological and economic effects on a community [6–8]. All those elements which a community finds unattractive, ugly, intrusive, disturbing come under visual pollution [9]. While, Nami et al and Jana describe visual pollution as "unbridled and uncoordinated diversity" of form, color, light, materials and accumulation of heterogeneous visual elements which make the manmade environment and urban landscape ugly and unattractive [3,7]. Chmielewski et al quote the term as compound and the resultant effect of "clutter, disorder and excess of various objects and graphics in urban landscape" [10]. Jūratė et al define visual pollution as "negative visual impact of Visual Pollution Object (VPO) on landscape" [11]. Additionally, the Supreme Court of the USA declared that "pollution is not limited to the air we breathe and the water we drink, it can equally offend the eye and ear" [12,13]. The scholars engaged in the visual impact assessments of natural landscapes have used the term visual pollution objects (VPOs) to refer to the physical components that have the ability to decrease the landscape's visual quality, may contribute to diminish visual significance, or may obstruct the view of valuable natural complexes [11]. A similar analogy is valid for urban visual pollution. In an urban context, we define the term 'VPOs' to refer to all the manmade features along with their physical characteristics (placement, appearance, size, color, view and functional hindrance etc.) that affect the visual quality of urban surroundings from a human's eye view.

Urban visual pollution is the negative physical condition of a number of objects which have a direct as well as an indirect relation with the quality of the built environment which ultimately has implications for humans living in that place [14–18]. It has been reported that visual pollution objects (together or individually) impact human health [19,20], distract drivers particularly along main highways [3,14,21,22], reduce property values, deface public places, spread annoyance, encourage needless consumption, or affect the identity of places [5,13,23]. It has been argued that better visual quality of a space has a relation to the safe and good behavior of residents and so as with better communities at a larger scale [24,25].

Furthermore, it is important to mention that the term visual pollution must not be confused with the concept of neighborhood disorder. As discussed earlier, visual pollution is the compound effect of disorder, excess of a number of physical elements while neighborhood disorder can be defined as "observed or perceived physical and social features of neighborhoods that may signal the breakdown of order and social control, and that can undermine the quality of life" [26]. The examples of neighborhood disorder may be adult loitering, drug dealing, crime, fighting in the streets and prostitution, and physical characteristics such as abandoned cars, dilapidated buildings, or litter in the streets [26,27].

Visual pollution is very much linked with the visual quality of public and community spaces [25] which includes regularity, order, beauty, symmetry, and simplicity, etc.

In previous studies, the subject of visual pollution has been explored from the dimensions of concept development, the listing of visual pollution objects and mitigation strategies [28]. However, the quantification and measurement have not been explored sufficiently. We have synthesized the previous work on the measurement of visual pollution and have provided a systematic approach to the development of a visual pollution assessment tool.

2. Approaches to Assessing Visual Pollution

Although visual pollution is recognized as a type of pollution, most of the city governments find it hard to regulate it since they do not have any systematic way of quantifying its presence and measuring its level of intensity vis-a-vis its local impacts [10]. Various scholars have used different techniques to measure visual pollution in their respective contexts, and at various scales ranging from a single street to a city. Table 1 presents a list of the relevant studies and highlights their respective scale, VPO coverage and methods.

Table 1. List of studies containing components similar to visual pollution assessment.

Sr.	Study	Scale	VPOs Coverage	Methods Employed
1	Visual Preferences in Urban Signscapes [29]	City	Single VPO; Signs	Color Photograph
2	Evaluating Commercial Signs in Historic Streetscapes: the Effects of the Control of Advertising and Signage on User's Sense of Environmental Quality [28]	Street	Single VPO; Commercial signs, (outdoor advertisements)	Opinion survey
3	Evaluation of visual pollution in urban squares, using SWOT, AHP, and QSPM techniques [30]	Neighborhood	Multiple VPOs; Outdoor advertisements, Garbage, Congestion, Graffiti, Absence of green spaces, Building heights	AHP, QSPM, and SWOT (Strengths, Weaknesses, Opportunities, Threats)
4	Measuring visual pollution by outdoor advertisements in an urban street using inter-visibility analysis and public surveys [10]	Street	Single VPO; Outdoor advertisements	Inter-visibility analysis Public survey
5	Introduction to a quantitative method for assessment of visual impacts of Tehran Towers [31]	City	Single VPO; Cell Towers	Quantitative, Visibility Analysis using GIS
6	Visual pollution can have a deep degrading effect on urban and suburban community: a study in a few places of Bengal, India, with special reference to unorganized billboards [3]	District	Single VPO; Billboards	Visual comparisons
7	Citizen science and WebGIS for outdoor advertisement visual pollution assessment [32]	City	Single VPO; Outdoor advertisements	Opinion survey Visual pollution score Spatial mapping
8	Urban Environmental Graphics: Impact, Problems and Visual Pollution of Signs and Billboards in Nigerian Cities [33]	City	Single VPO; Billboards	Color photos
9	Examining Impact of Visual Pollution on City Environment: Case Study of Pune, India [34]	City	Multiple VPOs; Hoardings, Billboards, Dustbins, Utility Wires, Light Poles, Parking	Public Opinion Survey
10	Free Standing Billboards in a Road Landscape: Their Visual Impact and Its Regulation Possibilities (Lithuanian Case) [35]	State road	Single VPO; Free Standing Boards (FSB)	Orthophoto Maps, Field Survey
11	Visual pollution and statistical determination in some of Karrada district main streets, Baghdad [36]	Street	Multiple VPOs; Garbage, electric wires, military weapons, demolished buildings, excavation works and rubbles, billboards, etc.	Public Opinion, Statistical Analysis
12	Regulating outdoor advertisement boards; employing spatial decision support system to control urban visual pollution [37]	Primary road	Single VPO; outdoor advertisement	GIS

The Challenges of Measuring Visual Pollution

It is evident from the literature review that the quantification of visual pollution at any point has always been challenging because of its subjective nature [28] and there doesn't seem to exist any standard set of guidelines for systematic assessment of visual pollution [7]. This further highlights the need for the development of a unified quantitative assessment tool. Although, researchers all around the globe have contributed to the assessment of visual pollution, they have had a certain set of limitations which are discussed below:

Micro vs. Macro-level research: Previous studies on visual pollution can be broadly categorized into two extremes of micro and macro scale. Some of the previous studies have on a small case study area like a commercial street, public buildings in a residential area, or a neighborhood with maybe one or two VPOs (billboards, commercial signs). In contrast, other groups of researches adopted a bigger working scale like a city, with multiple VPOs. Consequently, two (somewhat opposite) strategies with narrow and broad classes of indicators are found in the literature to assess the visual pollution of any area.

Lack of quantification: Since visual pollution is intrinsically sensitive, subjective and a complex type of pollution, no specific tool or instrument is available to measure the scale of visual pollution at any node [29].

Dependency on subjective variables: Most of the available research has used a mix of subjective and objective indicators where the proportion of subjective indicators has been considerably high. Hence, the results can be potentially influenced either by the respondent or the researchers' interpretation, expertise, interest and prevailing literature concepts. So, they may not be agreed upon or adopted in a different context.

Narrow coverage of VPOs: Visual pollution has a broad area of knowledge of built and aesthetic environments comprising multiple objects. However, most previous work has focused on the measurement of visual pollution by means of single VPOs, which has resulted in single-object assessment approaches.

The absence of structured tools: Unlike other types of pollution, structured instruments and tools are not available for the measurement of visual pollution. Moreover, in some cases a combination of different kinds of methodologies like public surveys [2,7], inter-visibility analysis, triangulation method, focus group discussions, photo comparisons [28,38], visual comparisons and experimentation, etc. [3] has been explored to assess a few (or often a single) VPO, which again indicates the need of a composite VPA tool. In most cases, statistical validity or reliability of the methods has not been assessed and discussed thoroughly.

From the above discussion, it is evident that there is a strong need to develop a comprehensive visual pollution assessment tool that can cover a wider variety of VPOs and can be used at various scales to calculate the visual pollution level at a certain point.

When it comes to subjective ranking and weighting, expert evaluation is preferred as they use their knowledge and experience for comparing objects or phenomena under study [39–41]. The relevant literature contains several weighing methods and techniques (e.g. Delphie method, ordering method [42–44]) that have experts evaluation at their core but possess respective pros and cons. In contrast, an Analytical Hierarchy Process (AHP) is considered comprehensive as it is a multi-criteria decision-making approach to deal with subjective and multiple conflicting criteria. The most prominent feature of the AHP method is the ability to compare both the quantitative and qualitative variables (verbal, graphics or numerical) on the same preference scale [45]. From the psychological point of view, it is also efficient and consistent to compare two alternatives at a time rather than comparing them all at once. It is based on a ratio scale instead of an interval scale unlike other methods [27,45–47]. The other advantages of using AHP include its ability to handle multi-fold subjects, higher consistency among choices and the ability to evaluate the composite and compound scores of alternatives [48].

3. Materials and Methods

A pragmatic research design was adopted with several sequential and inter-linked steps to design the VPA tool, as summarized in Figure 1. It employs a combination of visuals, public opinion and observations to enlist visual pollution objects. These methods have been used in several studies to investigate public preferences [3,25,29,35,49–52]. A carefully selected panel of experts was engaged to group, rank and weight VPOs using AHP, which is a widely tested approach to handle subjectivity [30,48,53]. Furthermore, AHP findings have been arranged in the form of a VPA scorecard. To measure the reliability of the tool, it has been applied to locations with diverse land-uses, and inter-rater reliability of the tool has been calculated. Figure 1 explains the employed methods, adopted processes and obtained outputs that led to developing the final visual pollution assessment tool. Details of each stage are given below.

First, a list of VPOs has been prepared based on various sources including a literature review, personal observations, a public survey and a university-based photo competition. In literature, only a few VPOs have been frequently listed primarily including outdoor advertisements and billboards. However, through a public survey (available at https://goo.gl/forms/LjKobwAK9m1wUBZc2), 107 participants were asked as to what do they find visually annoying in their neighborhood or urban fabric around them. Similarly, a photo competition was arranged among the students of urban planning to identify and capture VPOs in their surroundings.

The second step included the determination of size for the panel of experts and their identification. Literature indicates that the size of an expert panel for AHP studies may vary from just a few people to large groups depending upon the nature of the problem and availability of experts. Generally, AHP does not need more interviews as results get stable after a few responses [54]. Furthermore, when the availability of experts is limited, many studies have presented their results with smaller panel sizes; n = 5 [55,56], n = 7 [57], n = 18 [58], and n = 25 [59]. In our case, a group of 20 professionals (with 10 or more years of experience) was selected to help on the grouping, ranking and weighting of various VPOs. By means of variability sampling, it was ensured that due representation was achieved from various stakeholders. Consequently, five members were selected from urban planning related academia, three from city district government, three from development authorities, two from cantonments of armed forces, five from private consultants on urban planning, and two civil society members having a history of expressing concern on urban planning matters. In addition to ensuring the thematic diversity of experts, they were selected from various cities of Pakistan representing a variety of cultural and urban contexts. This diversity was particularly helpful since they have been engaged to record their opinion based on their mental images in urban areas.

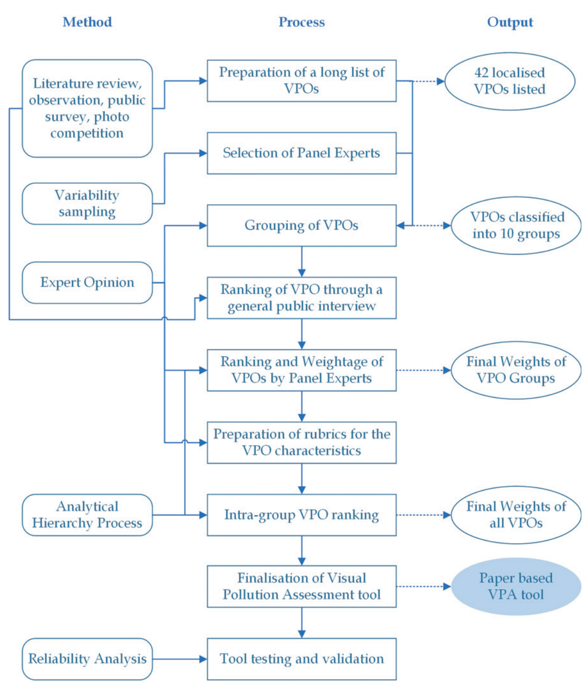

Figure 1. Visual Pollution Assessment (VPA) Tool Development Process.

In the third step, the experts classified the listed VPOs into 10 groups considering the similarity of objects. For example, billboards, signboards, advertisement banners, poster and streamers have been clubbed into the group 'outdoor advertisements'. Similarly, out-of-proportion building structures, irregular building facades and an uneven skyline have been grouped into 'architecturally poor structures'. The key reason behind this classification was to reduce the number of VPO groups which can be compared to assigning ranks and weights based on their contribution to visual pollution on a site. It was not possible to handle the larger number of VPOs in AHP without this categorization. AHP was employed for the ranking and weighting of VPOs groups to remove subjectivity associated with the measurement of VPOs. AHP allows the decision maker to consider objective and subjective factors in assessing the relative importance of each VPO through a pairwise comparison.

Since there were 10 VPO groups, a 10 × 10 matrix was formed. The AHP template by Goepel [60] had been adopted for the compilation of results. Since the matrix size and number of panel experts was reasonably large, we used a commercial spreadsheet application (Microsoft Excel) for the compilation of results. To capture their opinion, each member was asked to provide (1) ranking for the VPOs and (2) pairwise comparison of all VPOs groups among themselves based on the level of a VPO's contribution to visual pollution.

Similarly, each of the criteria (VPOs group) were compared with every other criterion by means of a pair-wise comparison over a 9-point Saaty scale. Every member was thoroughly trained on the process and the definitions of scale values. To do so, a series of the dedicated session was conducted with experts where along with the scale and ranking criteria, practical examples were also discussed in detail. For example, in a typical comparison, the expert decides which among outdoor advertisement (A) and wall chalking (B) is the bigger contributor to visual pollution. Suppose the expert selects A, then the next question is that on a scale of 1-9 how much more A contributes to visual pollution than B (while 1 means equally severe, 3 means moderately more severe than the other, 5 means more strongly severe than the other, 7 means very strongly severe and 9 means extremely severe compared to the other while the values 2, 4, 6 and 8 represent the micro-scale between them). Figure 2 presents the screenshot of the excel sheet where pairwise comparisons are recorded and how they are used to generate the automated matrix.

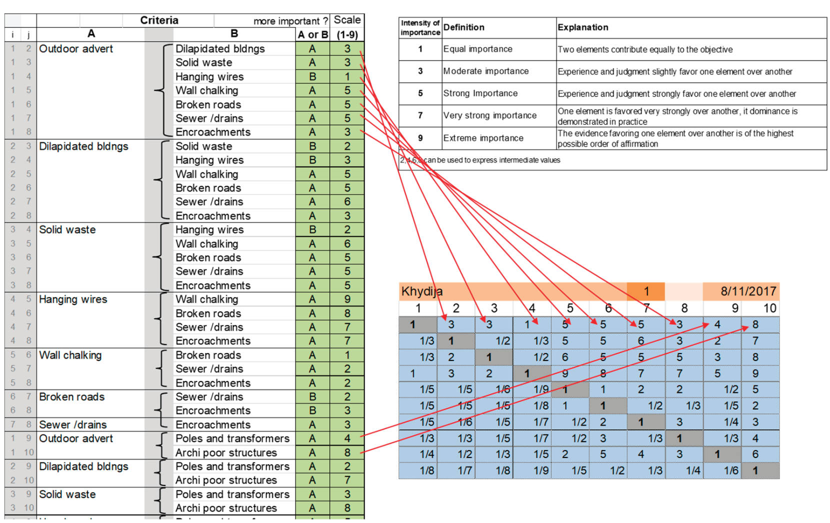

Figure 2. Screenshot of AHP sheet reflecting the capturing of pair-wise comparison and formation of a comparison matrix by one expert. A Similar process has been adopted to capture inputs of all panel members.

Parallel to the ranking and weighting of VPOs, characteristics of each type of VPO were listed and rubrics for these characteristics were prepared. At this stage, panel members identified those characteristics for each VPOs that have a direct relationship with the visual impact generated by that VPO. Furthermore, rubric values have been defined against each characteristic. At the next step, intra-group VPOs were weighted and finally, the objects were arranged in the form of a scorecard to be used in the field (see Figures 7 and 8). Finally, the validation and reliability of the VPA tool were assessed. The inter-observer/ inter-rater reliability (IRR) analysis (also called the inter-observer agreement) by a pilot study was applied. Reliability analysis facilitated in finding the extent to which results in scale is consistent even when observed by different observers. For IRR, the tool was also experimented with at 20 distinct locations of different land-uses in Lahore (the second largest city of Pakistan) by a group of five trained observers (Figure 3). The reason behind selecting 20 locations was to ensure that they cover different combinations of land-uses (residential, commercial, open spaces and public buildings, etc.) and land-use activity intensity. Each location was a three-or-more-legged road junction. The observer was positioned at the centre of a junction or a similarly appropriate location with a 360° view of the location to record VPOs on the tool. The observers were final year students of urban and regional studies undergraduate programme, who were thoroughly trained on the VPO identification and assessment of their characteristics. Each observer completed the VPA exercise for all 20 locations. Resultantly, 5 assessments (filled VPA scorecards) were available for each location – it is important to highlight that the VPA tool requires capturing 205 values to represent characteristics of different VPOs. Subsequently, responses were analyzed in ten observer pairs and several agreements between each were calculated to get percentage agreement-based IRR.

Figure 3. Map showing the distribution of sites for piloting of VPA tool and IRR analysis (each blue numbered dot represents one site).

4. Results

The first stage of VPO identification and listing resulted in a long list of 42 VPOs containing more localized and non-conventional visual pollution objects including hanging wires, electricity transformers, broken poles, dilapidated buildings, etc. Such VPOs have not been considered in earlier studies with such emphasis. The listed VPOs have been classified by the panel experts on the basis of the similarity of objects which resulted in 10 wider groups as presented in Table 2. A few glimpses presenting some key VPOs from the streets of Lahore, Pakistan are presented in Figure 4. More graphical evidence of these VPOs can be accessed at https://urbanvisualpollution.wordpress.com.

Table 2. Classification of VPOs in Major VPO Groups.

VPO Group	VPOs
1. Outdoor Advertisements	1. Over bright digital signboards 2. Billboards 3. Political advertisement 4. Unethical advertisements 5. Banners 6. Hanging Steamers 7. Irregular signboards 8. Posters
2. Graffiti/wall chalking	1. Wall Chalking 2. Graffiti
3. Open dumps of solid waste	1. Solid waste dumps 2. Medical waste 3. Overflowing trash bins 4. Construction material dumps
4. Overflown sewerage/drainage	1. Uncovered manholes 2. Blocked manholes 3. Standing water in streets 4. Open sewers 5. Wide open drains
5. Architecturally poor structures	1. Bad building structures, out of proportion 2. Irregular building faces 3. Uneven and irregular building skyline 4. Blue water tanks on rooftops 5. Dish receivers and broken antennas
6. Dilapidated buildings	1. Dilapidated buildings 2. Squatter settlements 3. Poorly maintained structures 4. Unpainted buildings
7. Encroachments (temp and permanent)	1. Roof projections in front houses 2. Uneven ramps 3. Encroachments (permanent and temporary)
8. Various poles and transformers	1. Improper placement of Electricity poles 2. Communication towers 3. Improper placement and broken/leaning Tel poles 4. Improper placement and broken TV cable poles 5. Improper placement and broken street lights
9. Hanging and cluttered wires	1. Cluttered Electric, communication and other wires
10. Broken roads/ditches	1. Broken roads 2. Ditches

Figure 4. Pictures from the streets of Lahore, Pakistan capturing some key VPOs including outdoor advertisements, poles, hanging and cluttered wires, architecturally poor structures, dilapidated building and encroachments.

The identified groups were ranked by the experts and their weights were calculated. The consolidated weights and ranks generated by experts through AHP reveal that open dumping of solid waste is marked as the largest contributor to visual pollution (23.8%), followed by outdoor advertisements and signage (20.1%). Dilapidated buildings have been ranked as the third major contributing VPO (13.8%) followed by hanging and cluttered wires (11.1%). The list continues with overflown sewers and drains at fifth place (10.4%), graffiti/wall chalking at sixth place (6.9%), various poles and transformers at seventh place (4.5%), encroachments at eighth place (3.8%), and broken roads/ditches at ninth place (3.5%). The VPO group of architecturally poor structures is ranked at the tenth place with a score of 2.1%. Figure 5 presents the consolidated matrix generated from the individual responses of panel experts while Figure 6 represents the final weights and ranks for VPO groups.

Matrix		Outdoor advert 1	Dilapidated bldngs 2	Solid waste 3	Hanging wires 4	Wall chalking 5	Broken roads 6	Sewer /drains 7	Encroachments 8	Poles and transformers 9	Archi poor structures 10	normalized principal Eigenvector
Outdoor advert	1	-	2	1	2 1/9	3 7/9	5 1/6	1 2/3	4 2/9	4 3/5	6	20.06%
Dilapidated bldngs	2	1/2	-	3/7	1	3	4 2/5	1 2/3	4 1/6	3 1/4	5 3/4	13.79%
Solid waste	3	1	2 1/3	-	2 1/2	5	6	2 2/3	6 1/2	4 2/5	6 8/9	23.81%
Hanging wires	4	1/2	1	2/5	-	1 5/8	3 2/9	5/6	3 1/5	3 4/5	5 2/5	11.15%
Wall chalking	5	1/4	1/3	1/5	3/5	-	2 2/5	2/3	2 1/2	1 2/3	4 2/3	6.86%
Broken roads	6	1/5	2/9	1/6	1/3	2/5	-	2/7	4/5	1	2 2/3	3.53%
Sewer /drains	7	3/5	3/5	3/8	1 1/5	1 1/2	3 2/3	-	3 7/8	1 1/2	4 2/5	10.41%
Encroachments	8	1/4	1/4	1/6	1/3	2/5	1 1/4	1/4	-	1	3	3.81%
Poles and transformers	9	2/9	1/3	2/9	1/4	3/5	1	2/3	1	-	2 8/9	4.51%
Archi poor structures	10	1/6	1/6	1/7	1/5	2/9	3/8	2/9	1/3	1/3	-	2.07%

Figure 5. Consolidated AHP matrix generated from individual responses of panel experts.

VPO Group	Weights	Rank
Outdoor advertisements and signage	20.1%	2
Dilapidated buildings	13.8%	3
Open dumps of Solid waste	23.8%	1
Hanging and cluttered wires	11.1%	4
Graffiti/wall chalking	6.9%	6
Broken roads/ditches	3.5%	9
Overflown sewerage/drainage	10.4%	5
Encrochments (temp and permanent)	3.8%	8
Various poles and transformers	4.5%	7
Architectural poor structures	2.1%	10

Figure 6. Final weights and ranks for VPO groups.

In order to understand the pattern of ranking by each expert, an AHP consensus indicator was calculated using Shannon alpha and beta entropy [60]. The consensus indicator ranges from 0% (no consensus) to 100% (full consensus). The calculated consensus turned out to be 80.1%, which reflects a high overall level of consensus among the experts. Figure 7 represents the mapping of VPO weights given by each panel member. Each line represents one expert while the bold red line shows the average value. The dispersion in the opinion of experts on certain VPOs reflects the diversity which comes in opinion because of their experience, knowledge or professional background.

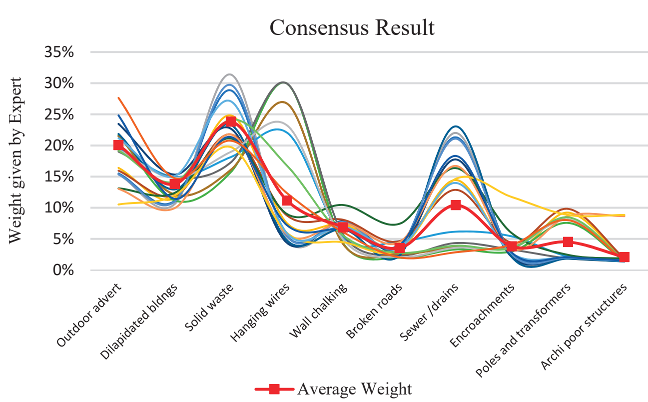

Figure 7. Mapping of weights assigned to VPO groups by each panel expert.

After ranking, rubrics were prepared to systematically measure the characteristics of VPOs. Table 3 shows some of the characteristics and rubric values listed for billboards. Similar tables were prepared for each VPO under study and vetted by the panel of experts.

Table 3. Listing of VPOs Characteristics and Preparation of Rubrics for "Billboards".

Characteristics	Rubrics	Assigned Values
1. Physical appearance	Structure Broken	5
	Leaning	4
	Torn off	3
	Normal	2
	Very well shaped	1
2. Adjacent land-use	Cultural Heritage	5
	Education	5
	Open space	4
	Health	4
	Religious	3
	Residential	2
	Commercial	1
3. Functional hindrance	1 means no hindrance while 5 means max hindrance	Scale of 1-5
4. Placement	Standalone	2
	On wall	3
	On rooftop	5
5. Display Surfaces	Single facing	1
	Double facing (back to back)	3
	V facing Triangle	5
6. Size	Small	1
	10X20	2
	20X30	3
	30X40	4
	Larger	5
7. Color scheme	Pleasant	1
	Normal	2
	Irritating	3
	Disturbing	4
	Highly disturbing	5
8. View hindrance	1 means no hindrance while 5 means max hindrance	Scale of 1-5

After the AHP based ranking, the weighting of VPO and preparation of rubrics, VPOs and their characteristics were arranged in the form of a scorecard. This VPA scorecard is a condensed resource (available at https://urbanvisualpollution.files.wordpress.com/2019/02/visual-pollution-assessment-tool-scorecard.png) that can be used to record the prevalence of various VPOs and their characteristics on a site under observation. In addition to VPO related information, the tool records the elements related to place character (number of road legs, dominant land-use, nature of activity, average height of buildings, average road width, average distance between facing building lines, area type (planned/unplanned), and socio-economic status of the place along with the geospatial coordinates. Place character is particularly useful to generate correlations at the analysis stage. The data collected through the scorecard is processed through a visual pollution score calculator sheet (available at https://urbanvisualpollution.files.wordpress.com/2019/02/visual-pollution-assessment-tool-score-calculator-sheet.png) that presents the sequential stages of assigning inter-group weights, rubric values for VPOs and then the contribution of the total of those assigned numbers in the VPO score calculator.

The final form of the VPA tool has been made available under GNU General Public License v3.0 at GitHub with open public access at https://github.com/khydijawakeel/UrbanVisualPollution. Furthermore, the tool has been placed at https://urbanvisualpollution.wordpress.com as well where other researchers can access and use for similar studies.

As discussed previously, the tool has been tested at 20 locations to assess its validity and reliability through IRR analysis. Figure 8 shows the level of calculated visual pollution on those 20 assessed sites. Table 4 presents the number of inter-observer agreements for each location/site. Furthermore, agreement ratio has been calculated for each observer pair and then the mean of each row has been calculated to see the overall agreement ratio at each site, as presented in Figure 9.

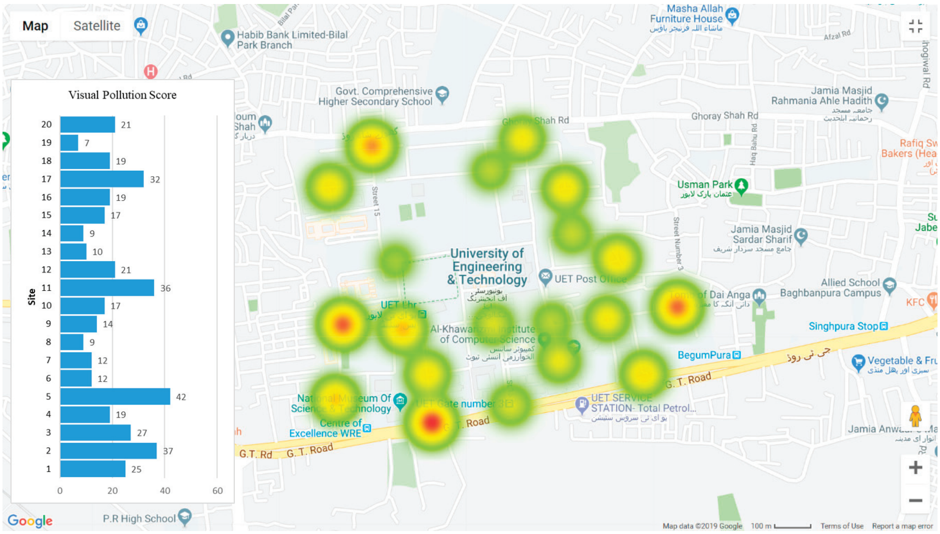

Figure 8. Map showing the spatial spread of visual pollution on the 20 assessed sites (heat map color scale from red to green represents highest to lowest visual pollution).

Table 4. Number of inter-observer agreements.

Site No.	Total Observations	Combinations of Observer Pairs (O=Observer)									
		O1/O2	O1/O3	O1/O4	O1/O5	O2/O3	O2/O4	O2/O5	O3/O4	O3/O5	O4/O5
1	205	178	158	151	190	190	166	169	186	172	167
2	205	189	176	174	173	160	189	159	167	151	169
3	205	164	187	180	186	171	153	181	157	179	179
4	205	182	150	188	190	168	156	153	155	170	165
5	205	188	175	184	175	155	158	151	190	157	153
6	205	152	152	187	171	160	168	166	181	164	184
7	205	158	173	188	187	168	156	163	159	158	184
8	205	169	169	172	184	171	166	160	152	164	184
9	205	183	165	179	152	172	179	151	150	154	171
10	205	174	162	189	154	190	156	177	180	152	186
11	205	186	183	183	186	171	179	181	157	176	186
12	205	172	165	177	168	182	167	166	158	170	152
13	205	182	182	177	165	158	159	164	157	151	184
14	205	181	190	175	184	169	185	187	181	157	161
15	205	184	190	169	160	173	157	152	190	178	165
16	205	165	176	151	152	174	158	155	182	168	186
17	205	182	163	163	190	163	166	154	151	158	186
18	205	181	188	167	175	177	188	171	165	160	173
19	205	173	151	158	153	180	167	160	183	184	160
20	205	187	179	189	186	172	182	161	155	159	180

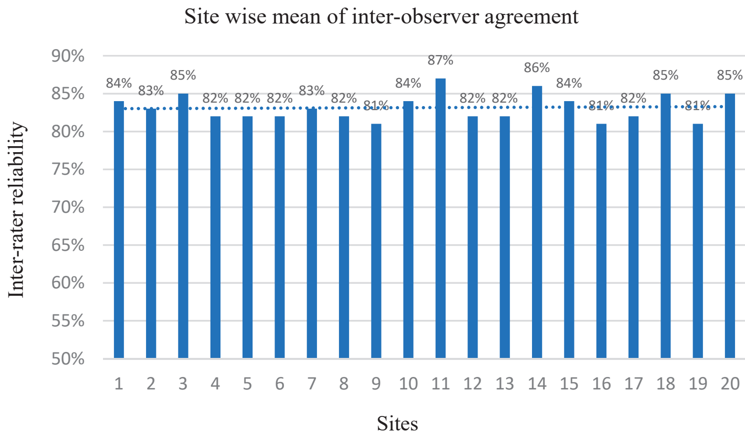

Figure 9. Site wise mean agreement ratio based on inter-observer agreements.

The results of inter-rated reliability analysis reflect a very good level of agreement at 83% which indicates the potential soundness of the methodology and the resulting VPA tool. It is important to highlight that out of 100 observer pairs, the minimum agreement ratio is 73% while the highest agreement ratio is 93%. The key reason behind the higher agreement ratio is that the tool collects data on 205 variables out of which 134 can get discrete answers with almost no potential of variance in observations (if observers are well trained).

From the initial testing, it is clear that the developed VPA tool tends to mitigate the previously identified limitations related to the assessment and quantification of visual pollution. The tool can deal with the subjective problem of visual pollution in a more objective way. It offers a wider coverage of 40 VPOs in local urban settings. Furthermore, it can record detailed characteristics against each VPO and quantify them by assigning weights and calculating visual pollution score. The tool can be used at both the micro and macro level scale for the measurement of visual pollution, i.e., nodes, street, neighborhood, or a city. The effective utilization of the tool requires the collection of geolocation and pictorial evidences as complementary information. In addition to the VPA scorecard, the collection of such attributes requires handling of additional gadgets (GPS device, camera or a hybrid device). From initial testing, it has been learnt that careful attention must be given to the systematic storage and labeling of these additional pieces of information so that they can be synchronized with the score card data.

5. Conclusions and Future Work

In this paper, we have presented a novel methodology for the systematic development of a robust and consistent VPA tool, which provides a structured mechanism for quantification of visual pollution at any given location by measuring the presence and characteristics of various VPOs. Since the VPO characteristics have been explicitly quantified, the tool provides the resultant quantitative score representing the level of visual pollution on a scale of 1-100. The incorporation of (diverse) expert opinion makes the methodology robust and suitable for almost all urban areas of Pakistan. Moreover, given the broad coverage of the tool, it is applicable in other parts of the world, especially the developing countries. This VPA tool can help urban planners and government stakeholders to better understand the prevalence of visual pollution, assess its spatial spread, identify primary contributing VPOs per location, take any corrective actions, and (most importantly) inform policy decisions in a robust, quantifiable and evidence-driven manner.

Further to the national and global application of this tool, an interesting future research dimension will be the determination of visual pollution threshold defined by means of public opinion and statistical method. Although the tool has been primarily designed, tested and being implemented in different geographical contexts and it has wide coverage of the VPOs (local, national, international), there is a possibility to upgrade/adapt it, especially for the more developed part of the world where the frame of visual pollution is different from developing countries. In addition to this, the transformation of a paper-based VPA tool into a mobile-based VPA tool is another important area of future work, which will (in itself) lead to further research avenues.

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Article

How to Create Walking Friendly Cities. A Multi-Criteria Analysis of the Central Open Market Area of Rijeka

Tiziana Campisi [1,*], Socrates Basbas [2], Giovanni Tesoriere [1], Mirto Trouva [2], Thomas Papas [2] and Iva Mrak [3,*]

[1] Faculty of Engineering and Architecture, University of Enna KORE, Cittadella Universitaria, 94100 Enna, Italy; Giovanni.tesoriere@unikore.it

[2] Department of Transportation & Hydraulic Engineering, School of Rural & Surveying Engineering, Aristotle University of Thessaloniki, 541 24 Thessaloniki, Greece; smpasmpa@topo.auth.gr (S.B.); mnikkitrouva@gmail.com (M.T.); thomaspapas1@gmail.com (T.P.)

[3] Faculty of Civil Engineering, University of Rijeka Radmile Matejčić 3, 51000 Rijeka, Croatia

* Correspondence: tiziana.campisi@unikore.it (T.C.); iva.mrak@uniri.hr (I.M.)

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Abstract: Current mobility strategies tend to pursue sustainable solutions with low environmental and economic impact, such as the disincentive to the use of private vehicles. Mobility on foot is among the most advantageous forms for short distances, especially if different technological and infrastructural solutions are inserted in the urban context such as underpasses that limit the likely conflicts with motor vehicles. These solutions, however, are not easily perceived as positive because people often do not like to change their usual routes or because they feel psychological discomfort when they pass through closed places. This research work focuses on the evaluation of the benefits of including a small underpass in the city of Rijeka, Croatia and through an Analytical Hierarchy Process (AHP), a multi-criteria analysis, it was possible to prioritize a number of decision-making alternatives, related to qualitative and quantitative evaluations, otherwise not directly comparable, and combining multidimensional measurement scales into a single priority scale. This analysis allows to provide cues for local and non-local urban planning, encouraging through the participatory form an active comparison between the population and local authorities and at the same time allows to assess which multidisciplinary processes (psychological/engineering) are possible to put in place to encourage the research on pedestrian behavior.

Keywords: pedestrian mobility; AHP method; itineraries selection; sustainable mobility; pedestrian behavior

1. Introduction

The increase of pedestrian mobility and studies related to urban spaces to facilitate accessibility and walkability is defined as a sustainable strategy for the smart and inclusive growth of cities in perfect harmony with what is enshrined in [1].

The definition of strategies to be adopted at the local level must place particular importance on the bottom-up approach both through participatory planning and through the implementation of the Urban Agenda [2,3].

Walking has recently been one of the most popular forms of mobility proposed in many urban plans and in the new concept of sustainable mobility. It is the most economic form of transport especially for short-haul distances (<1 km). Services and infrastructures often facilitate and simplify the mobility of people with disabilities or the elderly. Empirical data are often acquired through video cameras or sensors and processed in well-known flow allocation models to study the behavior of pedestrians and identify their preferences [4–6].

In literature there are several works related to the choice of itineraries. According to [7], the influence of the variables [8] that describe the visual aspect of the urban landscape can influence the choices of the route and outline the positive role of the urban atmosphere linked to the commercial function of the roads.

Several variables in this context can be analyzed and are in general related to the user's behavioral [9] and perceptual aspects [10] both in terms of safety and usability of the places, i.e., ease in being able to walk around them, especially in shared spaces [11,12]. From the point of view of infrastructure, it is necessary to be able to recognize areas or lanes dedicated to pedestrians and the presence of traffic mixing (pedestrians with cyclists or cars). It is also essential to define specific index or variables in order to avoid phenomena that can produce reduced safety and low comfort. In particular, pedestrian's safety is analyzed through interviews by the distribution of questionnaires but also through micro-simulation tools that allow to evaluate the Level of Service of the confined or extensive infrastructure such as Pedestrian Level of Service (PLOS) [13]. The assessment of safety and the reduction of the possibility of collisions with vehicular flows is analyzed by defining surrogate parameters on pedestrian trajectories in accordance with [14,15]. The tracking of the pedestrians and therefore the definition of the trajectory and the choice of the routes can be facilitated using technology. This can make the modal choices of the user more understandable. Different technologies and applications on smartphones and tablets allow the analysis of the trajectories through GPS systems and permit the furnishing of information to the user regarding the best route available, varying the places and reasons for moving [16]. The geographic information system platforms (GIS) could be very effective for understanding the spatial aspects of walkable spaces such as distances, densities, points of interests, and so on by themselves or integrated with other tools [17–20]. Generally, improving parameters such us speed and safety is fundamental to structure a city friendly for walking.

This can be pursued by introducing both motor vehicle travel restrictions and space reallocation, but road pricing must also be combined with the effort that many countries and cities attempt to achieve through the restriction of motor vehicle travel in urban areas. On the other hand, there is a risk that this restrictive approach can actually have a detrimental impact, especially for elderly people, persons with disabilities, and persons with chronic illnesses or otherwise vulnerable users such as parents with strollers [21–23].

It is also necessary to support strategies to reduce speed and volume. The traffic speed and volume are major determinants of whether people choose to walk or cycle, how safe they feel, and how possible it is to let their children walk [24,25]. Speed limits of 20 miles per hour are now visible in many cities, along with the closure of school streets and the expansion of low-traffic neighborhoods, which use modal filters to limit the travel speed in residential neighborhoods, and reduce volume and speed while promoting walking and cycling [26].The definition of safe and comfortable environments for walking is another element to analyze [22]. It is not enough to limit the use of the car and reduce the dominance in cities, but it is also essential to invest in improving the pedestrians' environment.

Cities must increase people's desire to walk by creating attractive, safe, and direct pedestrian networks that are viable alternatives to the use of private vehicles [27–29]. Therefore, pedestrian networks play a fundamental role in connecting urban, residential, commercial, educational, and recreational centers. Accessibility and walkability within different urban areas enables strategies to be pursued that encourage resilient mobility, i.e., the ability to adapt to sudden events, useful for mitigating the impacts of catastrophic and pandemic events [30–32].

The implementation of some actions, strategies, and policies that can be considered as tactical urbanism and the planning of green infrastructures within the urban context allow to improve the usability of spaces for pedestrians [33].

These actions can be of different types; for example, they can start from the bottom up and not be regulated or they can refer to top-down actions decided by the municipal administration and by technicians or middle streets that see the support of local policy and the involvement of citizens and the territory.

In this way, tactical urbanism makes it possible to carry out projects for the modification of public spaces that are temporary and of an experimental nature with a high communicative value [34,35].

Today's pedestrian mobility is encouraged by local and community policies in order to reduce the use of vehicles. Considering also that the European population is characterized by 20% of people being over the age of 65, many administrations are trying to make the routes more comfortable and safer by using underpasses or overpasses and thus reduce the potential of conflicts with the vehicular flow. Mobility is also facilitated by the inclusion of mechanized systems such as stairs, elevators, or treadmills in order to improve accessibility in these areas. On the other hand, the use of underpasses is not often positively perceived by people as they do not like changing their habitual routes or they experience psychological distress when they pass through closed places.

The speed of pedestrians, the perception of users, and the geometric-functional evaluation are useful parameters for the planning of pedestrians' structure. During the last few years, it has been quite difficult for designers to understand the relationship between the characteristic pedestrian flow and the pedestrian movement using only their experience and their senses. Interactions between pedestrians are difficult to understand and often the presence of closed or small spaces alters their behavior.

The planning and the design of spaces in which pedestrians can be moving as they do in streets and squares must be considered as certain parameters in order to increase the perception of safety in users and therefore to make them more usable. Among these parameters, streets are the spontaneous surveillance that increases the offender's apprehension given by the risk of being seen by people [36].

This is achieved by maximizing visibility and developing positive social interactions between legitimate users of private and public space. In this way, potential offenders experience increased control and limitations on their potential escape routes.

Another variable to be attenuated is the natural access control that limits the opportunities for criminal behavior by clearly differentiating public and private spaces. This is achieved by intervening on lighting, inserting selective entrances and exits, fencing, and creating large spaces that restrict access or generate a controlled flow.

Finally, the natural territorial reinforcement promotes social control by increasing the definition of spaces and the perception of private property. This can be achieved by using buildings, fences, flooring, signs, lighting, and landscape to express property and define public, semi-public, and private spaces. More specifically, this research tries to analyze the key components that influence the behavior of pedestrians, in particular their attitude, perceptions, motivations, behavior, and habits by implementing a comparison through an Analytical Hierarchy Process (AHP) approach. Therefore, the present work starts from a literature review related to the estimation of the propensities of weak road users to the use of roads with underpasses or high walkability. Generally, the possibility to walk in an urban context depends on the interactions between pedestrians, infrastructure, and context, as represented in Figure 1.

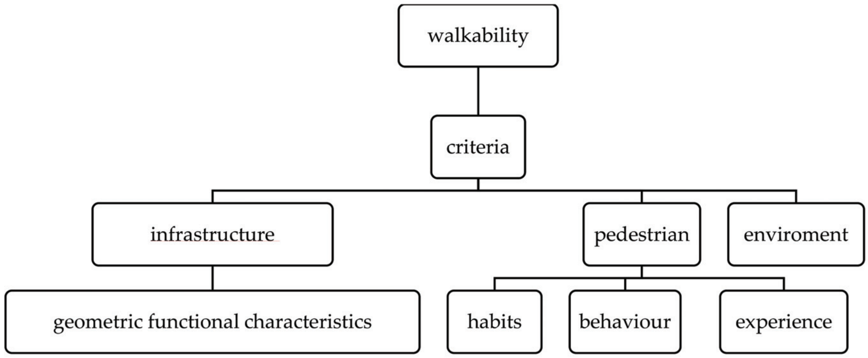

Figure 1. Description of variables related to walkability concept.

Several examples of pedestrian or mixed infrastructure are presented in the literature: think for example of sidewalks or pedestrian lanes within the same road superstructure but often refers to the use of shared space within urban areas in order to accustom pedestrians but also cyclists to mutual respect and sharing space [37].

The research is therefore aimed at analyzing and comparing different pedestrian routes in order to understand which of them can define a unitary, fluid, safe, and quality road space, where all road users can live together in appropriate and attractive conditions. The objectives of the comparison carried out by this study has allowed to

- improve the functionality and attractiveness of the road space, separating in some cases the different pedestrian/vehicular currents
- improve the safety (objective and subjective) of all road users: pedestrians, cyclists, motorists;
- improve the fluidity of pedestrian flows and other types of vehicles—reduce atmospheric emissions and noise.

The evaluation of different qualitative and quantitative parameters related to the perception of the itineraries and to the measurement of their level of service but also to their frequency of use must be analyzed by choosing appropriate methods. The present work focuses on the multicriteria analysis via AHP method.

The creation of open spaces where people can spend time and visit attractions makes it easier to walk in different cities. In addition to good walking routes and discouraging other modes of travel, people also need a reason to walk to or through an area or to stay in a place [22,38,39]. The possible conflicts between pedestrians and other traffic components must be minimized by considering the creation and management of underpasses. The search for walking routes is also essential to promote walking in the city. To ensure that, pedestrians' networks are easy to navigate and comfortable for everyone [40].

It is essential to create sustainable public transport networks in cities as an alternative way of travelling for high distances that cannot be covered on foot or bicycle in order to reduce motorized travelling by private vehicles [41]. In addition, transport bus stations and hubs must be strategically located and support and improve mixed land use to encourage greater walking [42]. Several strategies have been implemented such as the creation of dedicated lanes [43] or the advent of the rapid transit bus (acronym: BRT) [44] or demand responsive transport (acronym: DRT services) for weak demand areas [45]. Providing public transport that improves accessibility (not only for the wealthy) is very beneficial for all the areas of a city. It is also essential that the pedestrians can easily reach the bus platform using safe and comfortable crossing points and infrastructures that are accessible on foot and by bicycle. While public transport must be treated as an investment for the city and not just as a mobility investment, it must benefit the city in total.

The implementation of shared mobility services such as cars, bicycles, micromobility, and the study of specific transport demand (by age, gender, work) can reduce the use of private vehicles and thus traffic congestion in urban areas [46,47]. In terms of urban planning, the integration of pedestrian networks and routes into urban planning is essential for cities which try to encourage people to walk [48]. It has been shown that creating cities that embrace mixed-use planning principles, bringing together residential, commercial, recreational, and educational elements in areas of around 400 m2 of neighborhood/town center, has increased the rate of pedestrians and cyclists among residents and visitors [49]. While the more an area of a city has a mixed use of land, the more there are reasons to visit and walk on it. The active participation of the inhabitants [30,50] can also help in the urban planning phase, exploring the critical and positive aspects of every part of the city such as a neighborhood or an infrastructure [51]. Green infrastructure is also a key element of a city and has multiple benefits for both people and the built environment. It has been shown that cities and places that have a high level of greenery both in the streets, including trees and plants in buildings, and in regular open green spaces and parks, present an increase in the level of people's desire to walk [52–56].

In addition, greenery on the streets improves pedestrian safety because of the reduction of the vehicles' speed in the road. In order to be able to consider the six previous points, considering the need to implement sustainable policies and to make the best use of the routes in the area under investigation, this research analyzes the user's perception, which is connected to the transition in an area with a strong pedestrian vocation, laying the foundations for more in-depth research. The goal of this research is the exploration of users' perception as the short itineraries change, considering the same origin/destination in order to evaluate the ease of walking in the analyzed area.

2. Materials and Methods

The research is carried out by introducing a phase of data acquisition according to face-to-face interviews using a survey format and then processing the data through an AHP methodology. The interviews were conducted through the PAPI method (pen and paper interview-paper questionnaire interview) [57]. In fact, the paper questionnaire interview is the most classic of the survey techniques. The interviews were completed by recording the respondent's answers on a paper questionnaire. Then, the data are entered into a database and analyzed. The database is created in an excel sheet in which the quantitative data have previously been collected in order to be quantified and normalized via equations. The interview approach allows the direct exploration of the perceived sensations through a bottom-up approach. This strategy is also useful to spread a democratic urban planning that can motivate different population groups to cooperate with the local administration [58,59]. The interviews were conducted before the pandemic phase when there were no restrictions on the flow of people moving outdoors. Each interview lasted less than 7 min in order not to cause stress in the interviewed user. The interview involved the acquisition of socio-demographic data and perception of the paths through the evaluation of the LOS (Level of Service) and the definition of the feelings felt in terms of safety, comfort, and confusion. More specifically, the questionnaire that was used consists of three parts and eight questions in total. The first part includes 3 questions concerning the profile of the respondent. Two more questions, which are included in the second part, ask the respondent to show the frequency of use of the road network and his preferences about the four itineraries. The last two questions of the second part request from the respondent to rate the level of service (LOS) of the infrastructure and the possibility to go on walk in the road network. The third part of the questionnaire collects the data that are necessary for the AHP analysis. In this part, the respondent had to compare the four itineraries in pairs using a nine-point scale. This process was accomplished three times in order to collect data concerning the safety, the comfort, and the confusion that the pedestrians feel during the use of the infrastructure. The research steps dealt with in this work are schematically shown in Figure 2.

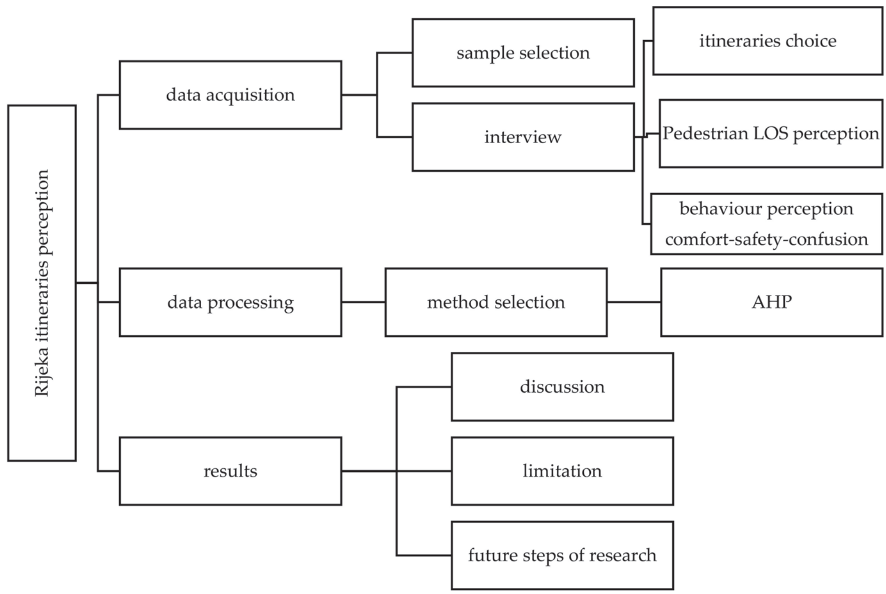

Figure 2. Flow-chart related to the research steps related to the study of the choice of itinerary in the urban area of Rijeka.

A specific questionnaire was defined and administered to citizens and tourists allowing a comparison of the results and providing useful judgments to the Local Administrators for the improvement of the connection routes to the examined areas. The choice of the itinerary is often evaluated through mathematical modeling that correlates different input parameters selected by the user through direct or indirect surveys on one's walking habits. This work aims to describe the selection of the itineraries through the AHP method relating to an area of the city of Rijeka with a high pedestrian flow rate and shows how users can choose one of the proposed itineraries, considering as positive aspects those related to safety and comfort and as negative aspects those related to chaos.

A number of factors can induce and facilitate the creation of a city that can encourage walking. Although each city has its own culture, climate built environment, and social built environment, the fact that the local context and priorities are integrated is also essential; this creates the best walking environment for a city and its people.

2.1. *Analytical Hierarchy Process (AHP)*

The method that was used for the data analysis of the research is the Analytical Hierarchy Process (AHP). AHP is a Multi-Criteria Analysis (MCA) method, developed by [60]. MCA is a method that is commonly used in the Decision-Making Theory and takes into account all available parameters. It is a complex process that aims to resolve each problem that the surveyor might have. The goal of MCA is the approach of multiple solutions that present the best possible option in the majority of available criteria of the problem [61]. The transparency and mathematical structure of this technique is what establishes it as the most suitable in accomplishing the concept of sustainability by many researchers. Furthermore, its practical value in combination with a user-friendly software increases its attractiveness to practitioners [62]. Through the Analytical Hierarchy Process (AHP), a multicriteria evaluation, it is possible to assign priorities to a series of decision-making alternatives, relating qualitative and quantitative assessments, otherwise not directly comparable, and combining multidimensional scales of measurements in a single priority scale, as in Figure 3.

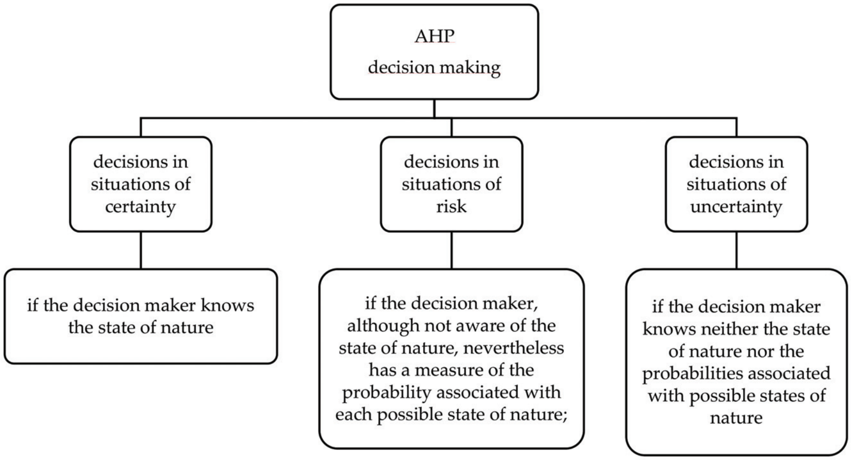

Figure 3. The approach to decision making and different situations [63,64].

AHP has the advantage of quantifying quality data that are collected. At first, it defines some criteria with which it creates pairs of comparisons. The goal of the method is to attribute a weight in each criterion that will define its importance. The higher the weight of a criterion, the more important it is [65]. The attribution of the weight is performed by comparing the criteria in pairs using a scale. There are several scales that can be used that stem from psychological theories [66]. One of the most used scales in AHP is the Saaty scale. It is a nine-point scale where 1 is the minimum value and 9 is the maximum. In between these values, numbers 3, 5, and 7 are used. Number 1 is considered the weight multiplied by the criteria that shows the absolute balance in a comparison pair. It is a scale based mainly on empirical studies [60]. The attribution of a weight to each criterion leads into the final ranking of the criteria. For an AHP to be considered complete, all possible pairings of comparisons must be created so that all criteria can be compared.

Cases with a high number of criteria and therefore a high number of comparative pairs may make the research difficult, thus, some comparative pairs may be excluded. In such cases, it is preferred (suggested) to create the minimum number of comparison pairs required in order to acquire the rest of the comparison pairs from them. The number of comparison pairs results from the formula $n\ (n-1)/2$ where n equals to the number of criteria [60]. Finally, the AHP method is able to calculate the possible inconsistency between the survey responses using a specific index called Consistency Index (CI). This index has its lowest value as zero (0). The closer to zero the CI is, the smaller the inconsistency. In particular, if $CI/RI < 0.1$, where RI stands for Random Index (Consistency Index for Random Entries), the inconsistencies are considered acceptable [60].

2.2. AHP Online System-AHP-OS

An AHP online software was used in order to implement the Multi-Criteria Analysis (MCA) with the method of the Analytical Hierarchy Process (AHP), which is called AHP Online System (AHP-OS), and can be found in the Business Performance Management Singapore (BPMSG) website [67]. This software provides a special excel sheet, in which all collected data are entered. It is a very simple and practical way of applying and completing an AHP which allows the user to directly configure the basic parameters of the process (number and name of criteria, size of input data, etc.). From a mathematical point of view, this method is based on the solution of an Eigen value problem.

The data must be quantified in order to import them into the software. More specifically, the quantification of the interviewees' answers is carried out according to the nine-point scale of Saaty. The software uses these quantitative data (numbers from 1 to 9) of all the comparisons between the criteria and automatically calculates the weight of every criterion. During the data processing, a matrix is created in order to calculate the weight of every criterion and the consistency ratio. The result of every pair-wise comparison is placed into this matrix. The weighting of the criteria, which is the ratio scale, is given from the first dominant right Eigen vector of the matrix. It is essential to mention that a normalization of the quantified data is previously required in order to not import negative values. In this way, the final classification (ranking) of the criteria is made according to the weight of each criterion. Finally, the software can calculate the Consistency Ratio (CR). The CR is defined by the Eigen value of the matrix and it can lead to useful conclusions regarding the inconsistencies between the respondents' answers as well as the reliability of the AHP's final results [67].

2.3. Case Study Description

Rijeka, Croatia, is a capital of the Coastal Mountain Region county in north-western Croatia, which partly corresponds to the territory of Liburnia and Kvarner. Road safety, especially for pedestrians, requires a lot of attention because out of 404 traffic deaths in Croatia in 2017, 60 were pedestrians (14.9%) and 27 in non-motorized vehicles (6.7%). Injuries were 10.5% for pedestrians and 7.3% for non-motorized vehicles (out of a total of 14,608). Regarding the road deaths, 16.9% were caused by pedestrians and 6.9% by cyclists. According to [68], almost 90% of pedestrian deaths in traffic are in the over 40 age group, showing a high importance of the age factor. Among the main causes of accidents are not only the conditions and the maintenance of infrastructure, but also the limited visibility and the behavior of pedestrians and drivers [12,13]. These data highlight the need to improve the infrastructure and spread a greater culture of road safety among the population. The document considers the comparison of different routes with identical points of origin and destination, allowing walking as the only form of short distance travel.

The city was selected as a case study because it was named as the European Capital of Culture in 2020 and a good flow of tourists was observed in recent years, until the beginning of the pandemic. The center of the city is used by 160,000 pedestrians daily. Most of the pedestrians arrive to the center by vehicles, and 20% of them arrive by foot [68,69].

As the pedestrian mobility is becoming increasingly important, the City of Rijeka is planning several important enhancements: new pedestrian traffic spaces in the portual area, additional underpasses and overpasses related to railway structures, pedestrian access to healthcare services, and the creation of urban microcenters based on pedestrian mobility as residential centers which have a tertiary function (the pedestrian zones, such as squares and roads, are indicated for development). In some parts of the city, the sidewalks are planned with 2 m tree line division for the vehicles. In the center, pedestrian roads are planned with a 12 m section or roads with 6 m pedestrian corridors alongside. Moreover, the elements of mechanical vertical and horizontal mobility are planned in several parts of the city [69,70].

The selected area is the most crowded area of the city by pedestrians due to the tourist attractions and the commercial and tertiary activities present. The analysis was conducted in the city of Rijeka where about 130,000 inhabitants live. Over 19.7% of the resident population is made up of people over the age of 65 years [70] who have a habit of moving on foot or using the public transport. The city is recently characterized by a strong attendance of tourists. The area, which is located closest to the historic center and the port, is fairly flat and allows pedestrians and cyclists to move easily. The city faces the sea and is characterized by large areas that can be easily traveled on foot and characterized by numerous tourist and commercial attractions, as in Figure 4.

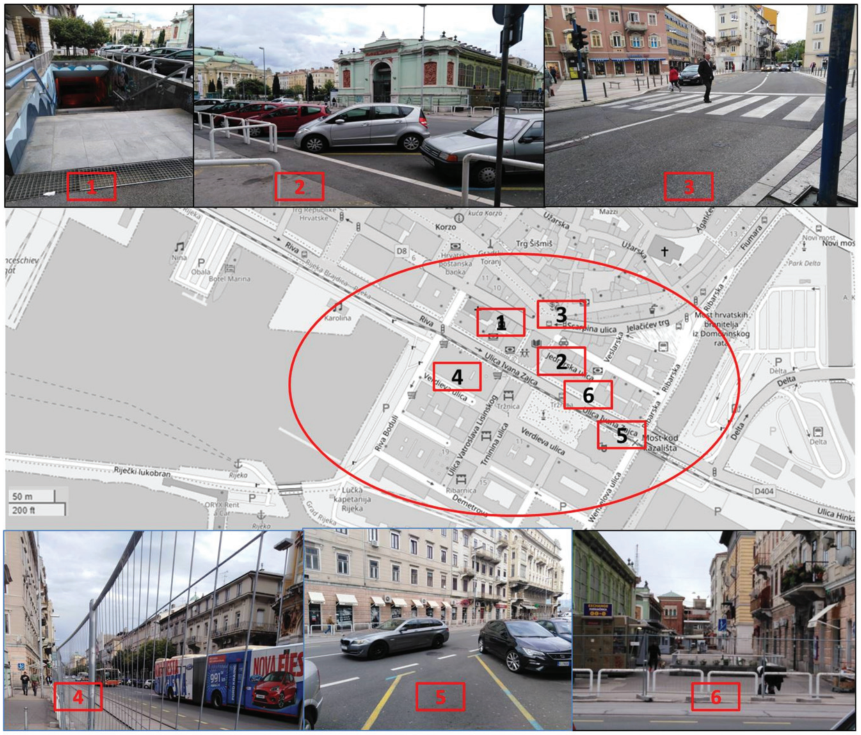

Figure 4. Geolocation of the study area and photos of the outdoor market area in Rijeka (map source: https://www.openstreetmap.org/).

Other parts of the city are on sloped terrain. Traffic lights exist in every intersection in the center of the city. These intersections provide very long pedestrian crossings. The traffic light cycle, however, does not provide times of more than 25 s and therefore people, especially the elderly and other vulnerable users, find themselves in difficulty during the crossing and are forced to stop in the middle of their route, waiting for the next green [22]. Almost all of the crossings do not have pedestrian areas that can protect them.

This study involves in an area between the pedestrian center and the outdoor market. These two areas are connected by different itineraries that can be travelled on foot or by car. The work focuses on four pedestrian itineraries characterized by different infrastructural elements.

The area is delimited by two main roads for vehicular flows called Adimićeva (near the open market define by photos n°2 and 6 on Figure 4) and Ivana Zajca (near the Korzo, the main pedestrian only street defined by photo n°3,4 and 5 on Figure 4). They are covered in one way, and today they represent the main transit corridors to and from the city.

The presence of numerous sidewalks allows users to move easily anywhere. The presence of an underpass that connects the two areas analyzed (origin and destination of the movements) reduces this type of potential collision. Specifically, it was considered appropriate to define the main pedestrian area called Korzo as the origin of the four itineraries (yellow area) and the open market (blue area) was instead selected as the final destination, as shown in Figure 5.

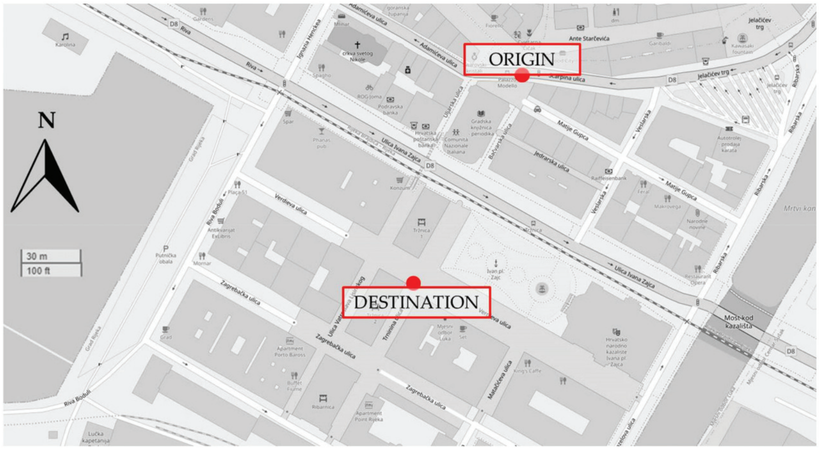

Figure 5. Evaluated area of Rijeka (Croatia) [22] (map source: https://www.openstreetmap.org/).

The two areas, of the Korzo and the open air market, constitute the two centroids of the exemplified traffic network covered in this study. They are characterized by a high flow of pedestrians during the various hours of the day for both business and pleasure reasons. In addition, the origin node is also characterized by the presence of numerous offices while the destination node is characterized by the presence of the historic covered market and the municipal theater, as well as by numerous restaurants and pubs that attract many tourists. The monitored area was recently embellished with numerous artistic installations and Rijeka finally defined as the European capital of culture 2020.

The questionnaire was given to the citizens of Rijeka who have a good knowledge of the city. The PAPI method was applied in order to acquire the sensations perceived by pedestrians as they travel through the various selected itineraries.

The survey was administered considering the same environmental conditions for all users, i.e., the same period of the day with similar sunlight and similar traffic conditions near the area which is under investigation. Therefore, the sample was limited precisely because of the finding of the same external conditions during the administration of the questionnaire. Among the different sensations experienced by the users during the walk, particular attention was paid to the feeling of safety [71], comfort, and confusion [72,73].

In particular, the area is described in Figure 6. It has been analyzed, proposing the comparison of four itineraries represented in Figure 6 and thus defined:

- itinerary 1 (IT1) it consists of a path on the sidewalk and traffic-lighted pedestrian crossings
- itinerary 2 (IT2) also formed by a path on the sidewalk and traffic-lighted pedestrian crossings
- itinerary 3 (IT3) formed by a direct path on the sidewalk and secondary road
- itinerary 4 (IT4) formed by a direct route on the underpass

The analysis also considered the presence of a railway track dedicated to a train for the transport of goods to and from the logistics port area which interrupts the pedestrian crossings of the various routes. The Euclidean measure, which is the one taken between origin and destination, is 135 m, and is similar to the length of itinerary IT4. Itineraries 1 and 2 are characterized by lengths of 340 and 300 m while IT3 is 168 m. Since the itineraries are less than 500 m (defined as short-haul journeys), they can be easily walked on.

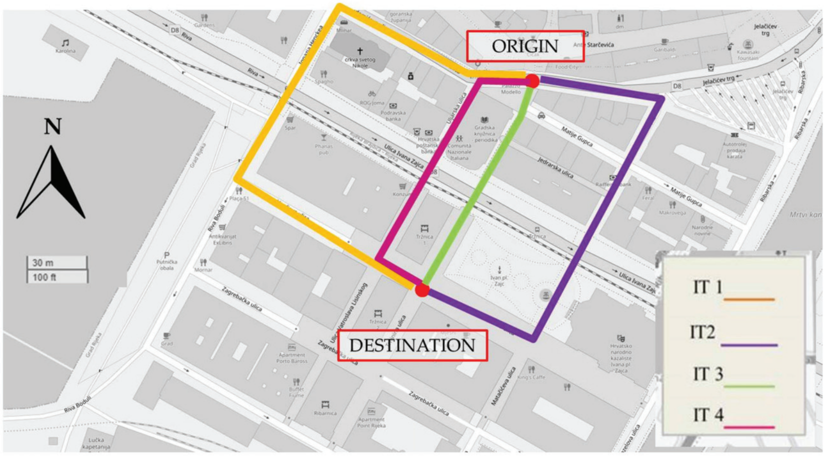

Figure 6. Different itineraries selected for Analytical Hierarchy Process (AHP) analysis [22] (map source: https://www.openstreetmap.org/).

2.4. Data acquisition. Sample and Survey definition

The sample was randomly selected by carrying out PAPI method at the end of 2019. The survey templates were organized in such a way to ensure unambiguous interpretation of questions and answers. The variables investigated are summarized in Table 1. In particular, they have been included in (socio-demographic data with closed answers), Section 2 (travel habits and road network judgment with closed answers and answers on a scale Likert 1–5), and Section 3 (travel perception with AHP comparison method on a scale of judgment 0–4).

Table 1. Summary of the widespread questionnaire.

Section 1	Variable	Attribute	Variable	Attribute		Variable		Attribute
	Gender	Male Female	Age	18–24 25–39 40–54	55–64 ≥ 65	Job		Student Retiree Worker Other
Section 2	Variable	Possible reply	Question	Possible reply	Question	Possible reply	Question	Possible reply (Likert scale)
	road use frequency	Every day 4 times per week 2–3 times per week Once per week More rarely	itinerary selection	Itinerary 1 Itinerary 2 Itinerary 3 Itinerary 4	Level of Service (LOS) of road network	A B C D E F	ease of access	1 2 3 4 5
Section 3		comparison of routes in pairs (AHP)			User perception comfort safe confusion		Scale Saaty scale (0–4)	

3. Results

3.1. Data Analysis through the Use of Descriptive Statistics

Human factors related to walking are the subject of numerous studies in the literature and are increased comparing with other studies on other road users [74,75]. In general, the functional geometrical characteristics of an infrastructure can be related only to a small part of the pedestrians' behavior in urban areas. Understanding pedestrians' behavior in urban areas can lead to significant improvements in the design and planning of pedestrian road and traffic environment, and consequently in the comfort and safety of pedestrians [76,77]. The questionnaire was designed aiming to acquire socio-demographic data, walking aptitude data, and data related with the perception of the risk from the point of view of safety, comfort, and confusion (chaos). Each question allowed only one answer expressed through Likert scales [78,79] or bivariate choice or multivariate choice. In particular, the Likert scale made possible to express a judgment instead of the bivariate and multivariate choice of selecting between two or more options. Section 1 of the survey focused on the evaluation of socio-demographic data i.e., gender, age, and work. The investigated sample shows a higher percentage of men than women as shown in Table 2.

Table 2. Distribution of respondents based on gender.

Gender	Frequency	Relative Frequency	Cumulative Relative Frequency
Male	38	54.3%	54.3%
Female	32	45.7%	100.0%
Total	70	100.0%	

The age that most characterized the sample is between 18 and 24 years of age and followed by the age group 25–39 as shown in Table 3.

Table 3. Distribution of respondents based on age group.

Age	Frequency	Relative Frequency	Cumulative Relative Frequency
18–24	43	61.4%	61.4%
25–39	20	28.6%	90.0%
40–54	5	7.1%	97.1%
55–64	1	1.4%	98.6%
> 65	1	1.4%	100.0%
Total	70	100.0%	

The age groups have a close connection with the work activity, in fact the highest percentage of users interviewed were students as shown in Table 4.

Table 4. Distribution of respondents based on profession group.

Profession	Frequency	Relative Frequency	Cumulative Relative Frequency
Student	34	48.6%	48.6%
Worker	34	48.6%	97.1%
Retiree	1	1.4%	98.6%
Other	1	1.4%	100.0%
Total	70	100.0%	

Section 2 of the questionnaire focuses on the frequency of walking on the monitored routes and the selection. In fact, Table 5 shows how often the respondents use the road network.

Table 5. Distribution of respondents according to the frequency of use of the road network.

Use Frequency	Frequency	Relative Frequency	Cumulative Relative Frequency
Every day	9	12.9%	12.9%
4 times per week	18	25.7%	38.6%
2–3 times per week	15	21.4%	60.0%
Once per week	10	14.3%	74.3%
More rarely	18	25.7%	100.0%
Total	70	100.0%	

Table 6 indicates the respondents' preference regarding the four itineraries, showing a slight predominance in the use of the IT4 itinerary.

Table 6. Distribution of respondents according to the frequency of use of each route.

Route Travelled Most Frequently	Frequency	Relative Frequency	Cumulative Relative Frequency
Itinerary 1	19	27.1%	27.1%
Itinerary 2	15	21.4%	48.6%
Itinerary 3	14	20.0%	68.6%
Itinerary 4	22	31.4%	100.0%
Total	70	100.0%	

A synthetic judgment pertaining to the global road network was examined through the definition of perceived type of level of service. This parameter incorporates a general vision of the movement both from the point of view of safety and of the hypothesis of congestion that can increase the travel time. The perceived Level of Service (LOS) of the users stands at an average value equal to LOS C as shown in Table 7. Only 8.6% of respondents rated the LOS with A or B i.e., optimal service levels. This result proves the uncertainty of users regarding the overall quality of the infrastructure.

Table 7. Distribution of respondents according to the level of service of the infrastructure.

LOS	Frequency	Relative Frequency	Cumulative Relative Frequency
A	1	1.4%	1.4%
B	5	7.1%	8.6%
C	44	62.9%	71.4%
D	15	21.4%	92.9%
E	5	7.1%	100.0%
F	0	0.0%	100.0%
Total	70	100.0	

Finally, through a judgment on a Likert scale, it was expressed on the possibility of being able to move on foot along the monitored road network. The predominant judgment in this case was encouraging and included between positive and very positive, as shown in Table 8.

Table 8. Distribution of respondents based on the possibility to walk in the road network.

Possibility to Go on Walk	Frequency	Relative Frequency	Cumulative Relative Frequency
Absolutely negative	0	0.0%	0.0
Very negative	1	1.4%	1.4%
Negative	3	4.3%	5.7%
Positive	32	45.7%	51.4%
Very positive	28	40.0%	91.4%
Absolutely positive	6	8.6%	100.0%
Total	70	100.0%	

3.2. Multi-Criteria Analysis through the Use of AHP Method

Therefore, the assessment of the perception of safety within the itineraries was connected to the combination of pedestrian and vehicular flow with reference to both pedestrian crossings and the traffic light cycle. The feeling of comfort was associated with the presence of sidewalks and handrails, in addition to good lighting.

The perception of chaos, on the other hand, has been correlated to a hypothetical congestion of pedestrian and vehicular traffic and to the increase in travel time useful for arriving from origin to destination. All these objectives are often connected to a subjective component of the evaluation of the parameters, that is, judgments and opinions with the objective data or the measurement. The AHP was applied three times using different input data for each column. Table 9 presents the final rankings of each itinerary based on the comfort, the safety, and the confusion (annoyance) of the user. The three parameters (comfort, safety, and confusion) constituted the basic criteria that the respondents took into consideration in order to compare the four itineraries. The ranking of the itineraries in each AHP derives from attributing a weight in each one based on their importance. Additionally, the Consistency Ratio (CR) of each AHP was generated. The CR of an AHP represents the inconsistencies between the responses of the users in a single questionnaire. As mentioned before, if the CR is lower than 10%, the inconsistencies are considered acceptable.

Table 9. Results of the Multi-Criteria Analysis through the use of AHP method.

AHP RESULTS								
Comfort			Safety			Confusion		
Routes	**Weights**	**Ranking**	**Routes**	**Weights**	**Ranking**	**Routes**	**Weights**	**Ranking**
Itinerary 1	22.0%	3	Itinerary 1	22.8%	3	Itinerary 1	29.6%	1
Itinerary 2	25.8%	2	Itinerary 2	23.6%	2	Itinerary 2	23.1%	3
Itinerary 3	21.8%	4	Itinerary 3	17.6%	4	Itinerary 3	28.8%	2
Itinerary 4	30.4%	1	Itinerary 4	36.0%	1	Itinerary 4	18.5%	4
Consistency Ratio (CR) = 1.1%			CR = 0.7%			CR = 0.2%		

As shown in Table 9, the first two AHP analyses give similar results as they represent two positive features (comfort and safety) for the users of the infrastructure. Actually, these two analyses produce the same ranking of itineraries with small differences on their percentages. Itinerary 4 seems to be preferred by the users based on these two characteristics. Itinerary 3 can be characterized as the least preferable itinerary with Itinerary 2 and Itinerary 1 coming second and third respectively. On the other hand, the third AHP analysis, which represents the confusion, confirms the results of the other two analyses placing Itinerary 1 at the first place and Itinerary 4 at fourth place concerning the confusion that the respondents feel during the use of the road network. Itinerary 3 is considered to be second in the ranking of confusion with a very small percentage difference comparing with the percentage of Itinerary 1 followed by Itinerary 2, which seems to create less confusion to the users of the infrastructure.

The design of an urban context refers to multiple interests, often conflicting, that converge on the road space: those of mobility in its various forms, those of residents, traders, passers-by, without forgetting the needs related to environmental protection (air and noise) and architectural and urban quality. The concept of the road space must guarantee and, if necessary, restore a balance between these interests and needs.

According to the questionnaires that were collected during the survey in the city of Rijeka, 54% of the sample were males; therefore the distribution of the sample between males and females is almost even. The vast majority (90%) were students and employees under 40 years of age. Almost 40% of the sample uses the infrastructure at least 4 times per week, while 25% avoids the use of the infrastructure and uses it seldom; less than 1 time per week. The respondents differed widely on which route they use the most. "Itinerary 4" (IT4) is used slightly more than the rest (31.4%) and the percentages of the four itineraries are very close. Additionally, the highest percentage of the respondents (84.3%) evaluates the level of service of the infrastructures with C and D (in a scale of A to F). Furthermore, 94.3% assesses the possibility of using the infrastructure to go for a walk from positive to absolutely positive. The slight preference of pedestrians towards "Itinerary 4" is confirmed by the Multi-Criteria Analysis, which was produced using the AHP method. The routes were compared in all possible pairs by the users. The results of the comparisons were used as data for the AHP in regard to the safety and comfort of the users. Based on the results, "Itinerary 4" was placed first, scoring 30.4% in comfort and 36% in safety, followed by itineraries 2, 1, and 3. It is worth mentioning that both IT4 and IT3 are shorter that the rest. In the last AHP, the results of the comparisons that were used as data for the AHP concerned annoyance. IT1 acquired the most weight (29.6%), followed by IT3, IT2, and IT4.

This work is a first step of investigation which will be subsequently expanded with a second step of investigation and comparison of data in statistical terms. The infrastructure examined is heavily used on an everyday basis by some participants, but by others it is seldom used. The route with the underpass is slightly more used than the other, but as it is shorter than other two routes (IT 1 and IT 2), and safer than the third route (IT 3), it is actually surprising that the preference is not higher. Even more so, as it ranked as the best by AHP in the category of "annoyance." This shows that the use of this route is impacted by other factors, which should be further analyzed.

4. Discussion

Through slow mobility, it is possible to guarantee social distances and avoid traffic congestions without increasing the number of cars. From this point of view, it is necessary to study all possible zero-impact solutions starting from the analysis of itineraries and comparing the judgments before and after the pandemic. Mobility on foot within urban centers is being increasingly used by students and workers who want to move from home to their destination at distances of less than a kilometer. The results obtained in this research are in line with the results obtained in another recent research.

The distribution in the choice of itineraries was quite uniform with a slight prevalence in the selection of Itinerary 4 characterized by the presence of a well-lit and clean subway.

In accordance with [80], there was a decrease in the use of the subway with age. The perception of the pedestrian safety level was not entirely negative due to the fact that the infrastructure is constantly maintained, and local policies tend to promote strategies in favor of walking.

The AHP analysis has revealed the perceptions of pedestrians concerning the 4 routes in the same environmental conditions. However, this assessment is carried out on a small sample, which highlights the need to know not only the geometrical-functional characteristics of an infrastructure, but also the judgement of the people who habitually use the roads. This fact is of fundamental importance if a participatory planning of the city is to be implemented [81,82].

The overall satisfaction regarding the infrastructure was average, a fact that indicates that this aspect could be analyzed further. The greatly positive assessment of walkability of the infrastructure by the participants indicates that the lower satisfaction regarding the level of service has some complex motives.

5. Conclusions

The estimation of the ease with which it is possible to move around the city on foot depends on several factors, some of which are related to the surrounding environment and psychological and perceptual aspects. The conducted analysis has shown with the results obtained that urban planning is much improved when a democratic approach that allows the population to participate in the choices to be made is included [49,83]. This also shows that there is room for a scientific and professional approach based on analysis and evaluation to arrive at the factors that shape our understanding and perception of space and thus influence our well-being. For example, a more in-depth study of the perception of enclosed spaces, such as flyovers or underpasses, could help to create a series of mitigation actions aimed at maximizing people's propensity to use them (light diversification, presence of a controller, more escalators) [84,85] The analysis based on the AHP method has allowed to compare different design solutions implemented in a high pedestrian flow area and therefore it is assumed that this approach can be supported by a micro simulation approach in order to better understand the behavior of pedestrians.

The scientific approach could significantly improve the attention and the understanding of the needs of vulnerable users who are underrepresented not only in the usual policy making process, but also in traditional processes of public participation. In addition, as a professional and scientific tool, the implementation of tactical planning could improve the usability of open spaces (location of street furniture, signage, etc.), allowing for better communication and greater involvement of citizens. This is particularly important because of the growing importance of pedestrian traffic in many fields such as transport, climate, walking, economy, and health, and even more so in cities where pedestrian traffic allows social distancing, pollution, and congestion abatement.

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Understanding Green Street Design: Evidence from Three Cases in the U.S.

Alvaro Rodriguez-Valencia [1,2,*] and Hernan A. Ortiz-Ramirez [2]

[1] Department of Civil and Environmental Engineering, Universidad de los Andes, Carrera 1E N° 19A-40, 111711 Bogotá, Colombia
[2] Sostenibilidad Urbana y Regional (SUR) Research Group, Department of Civil and Environmental Engineering, Universidad de los Andes, Carrera 1E N° 19A-40, 111711 Bogotá, Colombia; ha.ortiz10@uniandes.edu.co
* Correspondence: alvrodri@uniandes.edu.co; Tel.: +57-1-3394949 (ext. 1877)

Abstract: World cities need more green areas to promote social, economic, and environmental well-being; the problem, however, is that the space available for green infrastructure (GI) within the built environment is limited. Finding empty, free, or underutilized spaces within the built environment to be repurposed for GI has been a challenge. Streets are public, numerous, and evenly distributed, being a desirable place to fulfill this requirement. However, they are also heavily regulated public spaces, where design is standardized, and ruled by codes and manuals. Some cities in the US have implemented an increasing number of green streets (green infrastructures within the rights-of-way with environmental purposes), because of green stormwater management federal policies. This paper aims to understand the green street design procedure, based on empirical evidence. Three cities were studied (Portland, Seattle, and Philadelphia) by means of documentary information, visual inspections, and interviews. It is of special interest to unveil how traditional street design has been modified to adopt these new green elements within rights-of-way (ROW). Results show a longer and more complex street design process for green streets, where many more disciplines intervene. These results are discussed in the light of recent movements and trends in street design.

Keywords: green streets; green infrastructure; street design; stormwater management; right-of-way

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1. Introduction

Our streets are currently undergoing a transformation that might lead to a substantial change in the way valuable urban space is allocated, and, consequently, in the way it is designed. Back in time, streets were public spaces essential to our social needs (i.e., provision of recreational space and places to enhance social links [1]), cultural needs (i.e., cultural heritage preservation and provision of sense of place [2]), and economic needs (provision and sustainment of economic interchange places [3]), transportation notwithstanding [4,5]. In time, a change for streets involved the introduction of automobiles to the urban scene. The speed of motor vehicles and the demand for additional road capacity were the two main factors that affected the allocation of street space. Nowadays, streets have been rethought to make that space serve more functions than mere transportation. Green streets, or streets that devote some space for green infrastructure (GI) with an environmental purpose, are an example of this.

More green areas are required in cities for social, economic, and environmental purposes; however, there is limited space within the built environment to allocate GI. Cities and towns have been growing in such a way that some basic environmental services have been seriously affected and their delivery compromised [1]. The provision of GI within the built environment contributes to alleviating, mitigating, or resolving environmental problems that include heat island effect [6], non-regulated runoff speed [7], or urban noise [8] at local and global scale and to enhance the quality of life.

GI requires land and cities might not have enough free, empty, or underutilized space to house enough GI to cope with the demand. This limitation has shifted the attention to the rights-of-way (streets) to provide these services, because they are numerous, accessible, and evenly distributed public lands. The rights-of-way (ROW), however, are heavily regulated public spaces, where design is standardized, ruled by codes and manuals. But some cities have found mechanisms to make green streets a common practice within ROW.

The original purpose of this paper is to better understand green street design, analyze how it differs from the traditional standardized and rigid transportation-landscape design approach, and unveil general design commonalities based on case studies. This paper qualitatively revises the processes in three US cities to understand how green infrastructure was considered and included in the traditional standardized and rigid transportation-landscape design procedure. Since all cases are related to stormwater management, this paper also contributes to understanding the assessment of the environmental service that justifies the process. A qualitative case study methodology was grounded in in-depth multi-agent interviews, documentary information, and on-site visits.

2. Literature Review

In recent decades, urban development has restricted green space in cities whether by removal of vegetation or increase of impervious surfaces in cities' streets [9–11]. This phenomenon implies that ecosystem or environmental services provided by greenery tend to decrease as the space is urbanized, and challenges arise from the perspective of the difficulties in finding green space or free space to use as GI.

Different methods have been identified to find potential empty, free, or underutilized spaces within the built environment, in private or public areas, to be repurposed as GI. The most common methods and tools found in the literature to find potential spaces include multi-scale Geographic Information Systems (GIS) analyses [12,13], with a multi-criteria approach [14], or methodologies of space assessment with the involvement of stakeholders and public participation [2]. Other methods include mixed GIS with satellite image analysis [8,9], and geographic object-based image analysis [6]. To find potential spaces, other methods include the green building framework, where facades and roofs are considered to fulfill green space requirements [15,16] also inventories of vacant lots [17], roadside allocation [18], and accessibility analysis [19] have been developed to assess this issue.

The need to find potential space for GI implementation is not trivial. The methods mentioned above were developed to identify spaces where the benefits of GI could emerge. Such environmental benefits, in general, are related to biodiversity services such as the support of avian biodiversity [18], temperature regulation [18,20], and water purification [21]. GI implementation also bring health benefits (e.g., noise and pollution reduction) [22], mental restoration, stress reduction, and emotional wellbeing [22–25], and behavioral changes related to more active lifestyles [19,24].

Extensive services have been found to be provided by GI. The revision developed by Wang and Banzhaf [26] summarizes these services and show that the most commonly studied functions of GI include regulation of water runoffs, temperature control, amenity provision, and recreational services. Specific examples of such services can be found in the literature. For instance, Karteris et al. [6] estimated the potential of carbon sequestration provided by GI. The authors also studied the potential of rainwater retention and drainage improvement associated with the implementation of GI. The perspective focusing on water and runoff management has also been studied by Grunwald et al. [27], Jiménez et al. [13], and Meerow and Newell [14]. Another service associated with GI provision is the control of urban temperature. For example, Anguluri and Narayanan [8] and Grunwald et al. [27] focused their studies on thermal climate and comfort, whereas Meerow and Newell [14] and Norton et al. [9] studied the potential reduction of the heat island effect in the presence of GI. Water and air quality improvement is another example of services provided by

GI [13], as is the preservation of urban biodiversity related to the availability of green space and landscape connectivity [14,27].

Additional services provided by the GI include social benefits such as inclusion and civic engagement, recreation and psychological services [18,28,29], and aesthetic enjoyment and education [1]. Besides, economic benefits mainly comprise property value enhancement [30–32], goods and food production [18,33,34], and they attract a skilled workforce [22]. The reduction of social vulnerability and increased access to green space [14] are other examples of these services. Given these general benefits, it could be assumed that GI reconciles the city with its ecosystem and addresses sustainability and resilience goals [35,36].

Urban GI provides important services that result in benefits for everyone. People demand better air quality, sufficient water, safe places to live, and beautiful landscapes. The concern in cities might be to provide livable, safe, and healthy places, and to enhance walking and biking. State and federal agencies, on the other hand, are concerned with water quality, flood control, urban heat island effect (climate and radiation regulation), health, equity, and general welfare. Finding space for GI and its installation is simultaneously a measure to adapt urban areas to climate change [20], to reduce ecological footprints, to close inequity gaps, and to improve people's quality of life. Table 1 summarizes the many benefits derived from constructing green infrastructure in the built environment, grouped by environmental service.

Table 1. Benefits of constructing green infrastructure (GI), grouped by environmental service.

Environmental Service	Benefits	Source
Visual availability	Higher property values	L. M. Anderson and Cordell [37], Tajima [10], Tyrväinen and Miettinen [38], Lu and Noyce [30], McCord et al. [31], Yang et al. [32], Mell et al. [39]
	Better health (mental and physical)	Mitchell and Popham [40], de Vries et al. [41], Grahn and Stigsdotter [42], Akpinar et al. [23], Douglas et al. [24], van den Bosch and Nieuwenhuijsen [22], van Vliet and Hammond [25], Caparrós Martínez et al. [34]
	Aesthetics and positive valuation	Nowak et al. [43], Jim and Chen [44], Price [45], Zhou and Parves Rana [1] Zwierzchowska et al. [29]
Perviousness	Filtration non-point pollutants	Arnold and Gibbons [46], Characklis and Wiesner [47], Transportation Research Board [48]
	Wastewater cost reduction or rainfall interception	Niemczynowicz [49], Hogland and Niemczynowicz [50], Grunwald et al. [27], Jiménez et al. [13], Meerow and Newell [14]
	Ground water recharge	Hogland and Niemczynowicz [50], Caparrós Martínez et al. [34]
Processing capacity	Carbon sequestration	Beckett et al. [51], Brack [52], Akbari [53], Nowak et al. [43], Karteris et al. [6], Sebastiani et al. [54], Caparrós Martínez et al. [34], Voordeckers et al. [55]
	Reduce energy consumption	Pillsbury et al. [56], Akbari [53], Konopacki and Akbari [57]
	Mitigate heat island effect	Akbari [53], Konopacki and Akbari [57], Jansson et al. [58], Anguluri and Narayanan [8], Grunwald et al. [27], Meerow and Newell [14], Norton et al. [9], Caparrós Martínez et al. [34]

3. Materials and Methods

Based on qualitative research, three case studies were selected. Case studies have the distinctive characteristics of dealing with many more variables of interest than simple data points (cases) and of relying on multiple sources of evidence [59]. For this study, three kinds of information sources were used: documentary information, visual inspections, and interviews. The interview questionnaire started by requesting interviewees to tell the story of how green streets emerged in their cities. Following up on responses, clarification questions were added to complete the understanding of the design process. Follow up questions covered federal and state stormwater regulations, implementation within ROW, design standards and manuals, factors affected by the process, and coordination of participating agencies. In addition, interviewees were asked to provide relevant literature and official documentation. Figures 1–3 present some of the on-site visits for visual inspection.

Figure 1. Green strip in Seattle (WA). The curb is lowered to allow runoff to infiltrate through a green trench.

Figure 2. Curb extension in Portland (OR) to catch runoff from the roadway and the sidewalk.

Figure 3. Rain garden in a former parking area in a residential neighborhood in Philadelphia (PA).

Case studies were selected based on the "similar to another and both least similar to a third case" approach suggested by George and Bennett [60]. This approach allows us to learn from controlled similarities and differences. The cases were selected from the same country, with similar total annual average rainfalls, comparable areas, the same types of sewer systems, and with ongoing green street programs. Seattle, Portland and Philadelphia were selected from a list of 20 potential cities. Portland and Seattle, the similar cases, are both green streets pioneers in the US, and both are located on the Pacific coast. Philadelphia, in contrast, is a late implementer and is located on the eastern coast. In the end, over 100 documents and websites were reviewed and nine phone or in-person interviews were conducted in the three cities. This research is presented as parsimoniously and succinctly as possible here. The stakeholders interviewed were officials of environmental, transportation, utility, and planning departments, a delegate of the office of the mayor in Philadelphia, advocacy group members, academics, and practitioners (consultants). Interviews were recorded to be later transcribed.

4. Results

Early on in this research, when exploring potential case studies, it was evident that the common ground of early green street implementers in the US was stormwater management. All three cases (and many other cases explored in the case selection process mentioned in the methods section) were related with stormwater regulation. The story started in 1983, when the US Environmental Protection Agency (EPA) released a report proving that stormwater was not harmless [61]. The EPA was especially concerned with the discharges of combined waters (stormwater and wastewater). These combined sewer overflows (CSOs) occurred during heavy storm events in cities, generating vast discharges of combined waters into the bodies of water. If combined sewer discharges were central in the debate, separate sewer discharges also were found as not harmless. In 1987, when Congress amended the Clean Water Act, local governments became responsible for finding ways to control stormwater to protect surrounding waters.

Different cities adopted different strategies. Besides the traditional alternatives (e.g., separating the sewer systems), the purpose of green alternatives is to provide permeable areas in order to mimic previous urban conditions in which the soil perviousness facilitated water retention and delayed runoff [7,62]. Green streets and green roofs are examples of green stormwater infrastructures (GSI) to retain or detain runoff, and thus reduce pollution discharges into US waters. By GSI, we mean rain gardens, bioswales, bio strips, infiltration planters, street trees, and all permeable areas that provide one or more environmental services.

Each case study has the same structure. First, there is a general introduction of the case with the story of how green streets came into existence locally. Next, the description focuses on the street planning and design process and how GSI was introduced within the ROW. Finally, for each case, the variables that each city took into account to develop their approach are presented, as well as the proposed process to achieve green streets. Here, for the sake of simplicity, the term "green street" refers to a street that contains green infrastructure even though it is sometimes used differently, for example in Seattle.

4.1. Seattle: The Pioneer

Seattle is an innovator in green streets in the US. The city is located in a populated region surrounded by a fragile and delicate estuary. The Puget Sound estuary, a rich ecosystem, faced continuous degradation that reduced the salmon population and diminished recreational appeal. Even before the EPA identified the problem, scientists in Seattle found that stormwater from urbanized areas highly contributed to that degradation [63]. Yet, back in 1995, the effects of watershed urbanization on streams around the US were well documented [64]. But at the time (in 1995), nothing concrete for green street implementation was available besides timid sentences in plans suggesting the idea of front-end solutions able to mimic pre-development conditions instead of end-of-pipe solutions.

Although there were earlier experiments with GSI in Davis, California, and Prince George's County, Maryland, Seattle has the merit of initiating the first green street pilot project in the US. Called the Street Edge Alternative (SEA street) project, it involved the complete reconstruction of the street and its drainage system. The roadway was narrowed from 7.62 m to 4.27 m to create a meandering road surrounded by permeable green zones, including 100 new evergreens and 1100 shrubs, in the remaining 18.28 m of the ROW [65]. The emblematic curb-free design allows water to drain into swales along the street edges. The project, completed in the spring of 2001, was designed to decrease the quantity of stormwater discharged into Pipers Creek [66]. Besides meeting the Clean Water Act's water quality requirements, decreasing stormwater quantities discharged into creeks was one of the main goals for the Seattle area, in order to prevent channel erosion and to enhance reduced salmon reproduction rates.

Pilot projects like SEA streets provided real performance data, which served for the planning and design of future green streets. Results were overwhelmingly good in hydrological, acceptance, and even financial terms. The hydrological performance estimation of SEA street was too conservative by far when designed. The SEA street could fully attenuate up to 19 mm of precipitation and has prevented the discharge of all dry season flow (10% of the yearly rainfall) and 99% of the wet season and overall runoff. The SEA street drainage performance increased in time, withholding more water from discharge as time went by [67,68].

The ROW allocation principles in Seattle are very progressive for the US and likely in other latitudes, as they explicitly consider the fulfillment of many functions in the street. The Right-of-Way Improvement Manual is Seattle's reference for street design and states that "they [the ROW] must safely accommodate multiple modes of travel, offer universal access around and through the city, provide access to private property, enhance a place's character, protect environmental resources, and allow for the delivery of utility services" [69]. This manual contains the necessary information to design streets with GSI measures (hereafter referred to as green street, even though in Seattle the meaning of the term green street is different). This manual proposes two modalities of green streets: GI can be used as part of partial street improvements or as complete ROW retrofit. Partial street improvements usually include improvements to sidewalk and planting strip areas (Figure 1). Full ROW improvements involve sidewalks, planting strips and full roadway width reconstruction [70].

The procedure used to select the street to be intervened was not particularly strict. Seattle Public Utilities, the entity responsible for green streets implementation, wants projects in places that serve their stormwater objectives. The location of the projects within the city is determined with the drainage system and the sewer basins (combined, partially separated, or separated) in mind [71]. Maps with the drainage basins show the zones of combined sewers, which are the preferred places for infiltrating stormwater. Once the zones had been selected for the pilot projects, with the protection of a specific creek as the objective, a neighborhood was selected; low traffic streets are the preferred location for such projects. However, since few projects have actually been completed in Seattle, it is not clear how a specific street is selected. The green streets coordinator at Seattle Public Utilities suggests some criteria for selecting the location of the block: first, that the type of soil on the block can infiltrate the water; second, that there is space available (opportunity to narrow the roadway or replace parking); and finally, that the community accepts the implementation [72]. The Right-of-Way Improvement Manual enumerates the following factors to be considered when designing each GSI: native soil permeability, longitudinal and cross slopes, presence or absence of curbs, and space availability [70].

Once the zone and street are selected, engineers then provide the street designer with actual sizes of the GSI to be provided. According to the water practice director at a specialized consulting firm in Seattle, the GSI is sized for minimum goals; for example, to retain 90% of the runoff or a fixed amount (at least the first 19.05 mm) [73]. It includes the determination of the catchment area of each of these GSIs and, depending on the expected probable runoff for a given return period, the GSI facility designed. In practice, the manual also provides design standards for different types of GSI: conveyance swale, curb extension, tree planting within bioretention swale, and bioretention biofiltration cell with or without underdrain. Following this, the manual directs the designer to other codes and other technical documents for the sizing and design of hydraulic elements.

To complement the street design story in the city, Seattle has a Complete Street policy (ordinance No. 122386). The way in which both complete and green streets have been harmonized is through a street design checklist that gives extra points for GSI according to the Seattle green streets coordinator [72]. But not every Complete Street project will necessarily have GI. Both the lack of space on busy streets and the Seattle Department of Transportation (DOT) budgetary priorities have brought green streets to be an exceptional outcome, not the norm. In main and arterial streets, where pavement and safety priorities are concentrated, space is scarce. An official at Seattle Department of Planning and Development, explains that attempting to force the inclusion of GSI within Complete Streets redesigns could result in subnormal designs, for example, “narrower than standard bike lanes, sidewalks” [74]. In addition, the usage of permeable pavements and other alternative stormwater infrastructure is expensive. Seattle’s green streets coordinator states that the DOT has not had the money for stormwater management facilities within the ROW (bioretention and permeable pavements) or for their maintenance [72].

4.2. Portland: Pioneer and Fruitful Implementer

Portland is a progressive city that has been at the forefront of many topics, and street design is one of them. Recurrently, plans and manuals reaffirm the importance of having streets beyond cars. The famous tram system and extensive bike network prove this strong tendency towards multimodal mobility. This multimodal approach existed in Portland prior to any Complete Streets policy or other influence. Already in 2002, the metropolitan regional government for the Portland area (METRO) published Creating Livable Streets, a guideline that explicitly acknowledged the incompleteness of the conventional mobility-accessibility street classification system of the American Association of State Highway and Transportation Officials (AASHTO) [75]. It recalled the importance of considering all modes, 15 years before the city adopted its Complete Street policy in 2012. In Portland, balancing the multiple interests that use the ROW is important [76], and those interests can go beyond transportation.

Portland's development of green streets began early in the 2000s and has more than 1200 operating GSI within its streets. Like any other city with combined sewer systems, in 1987 Portland faced federal requirements to manage stormwater. However, in this case, the city defined its stormwater strategy after a litigation process with an environmentalist advocacy group that pushed for definite solutions. As a result, in 1991, the city of Portland entered into an agreement with the Oregon Department of Environmental Quality (EPA's designated authority) to control 99% of the combined sewer overflows in 20 years. At that time, traditional solutions were evaluated and the problem was approached by means of the construction of three big underground pipes to collect the mixed water during wet seasons to be stored and later conveyed to the wastewater treatment plants. However, due to technical and budgetary reasons, the biggest pipe was downsized, requiring alternative solutions. After the success of rainwater infiltration in the roof disconnection program and experimentation with green roofs and other GI, the city started a green street pilot from 2003 to 2007 that included several street interventions. Green streets emerged as this alternative to fulfill the requirements of the agreement. A Cross-Bureau Task Force, a program launched in 2005, led to the enactment of the green street policy in 2007 (passed by resolution) [77]. The program was a temporal effort aimed at creating a programmatic approach, which would make GSI possible in street projects wherever feasible [76].

Portland issued many different plans and manuals to support the development of green initiatives: Green Spaces Master Plan [78], the Best Management Practices Manual [79], Creating Livable Streets [75], Green Streets Handbook [80], and the Stormwater Management Manual (SWMM) (first in 1999 and updated in 2003, 2008, 2014, and 2016). Out of this set of documents, two deserve special mention. The 2002 Creating Livable Streets manual was a visionary document published by METRO that provides general and descriptive design guidelines of GSI in the ROW. However, this idea was never developed or updated with qualitative and technical information. In contrast, in the 2003 version of the SWMM, a set of green street design minimums was defined. The SWMM is fundamental because it contains the stepwise procedure used to design green streets first introduced in the 2008 version. In 2006, the Drainage Manual was updated (to replace the 1991 Sewer Design Manual) and it currently considers green infrastructures as a legal element for treating stormwater. The SWMM, issued by the Bureau of Environmental Services BES (not by the DOT), became the primary reference manual for managing stormwater from public and private areas, and designing water quality facilities and storage structures for managing stormwater flows [77].

The green streets design comprises nine steps summarized in Table 2. The process has evolved and the manual currently explains, in a clear but technical fashion, a complex and comprehensive design process. It begins by evaluating the condition of the project site, which is derived from a regional or citywide analysis. Step 3 considers an analysis of the GSI project in the current stormwater urban system, which implies revising at all scales (from the city scale to the street scale). Steps 4 and 5 are dedicated to details of the local street design. Several steps (e.g., 2, 7, or 8) represent procedural or legal requirements. Many steps direct us to other documents, for example, to the Sewer and Drainage Facilities Design Manual, to appendixes with technical information, and to calculators (worksheets).

Like Seattle, the Portland case has no clearly defined procedure for selecting locations of projects within the city. Nevertheless, there are some criteria. The first is the soil's infiltration capacity at the desired location. For example in Portland, most projects are on the eastern side of the Willamette River where soils are very forgiving, compared with the eastern part. A Green Street Program official at the Bureau of Environmental Services (BES) in Portland, was interviewed for this study. She stated that another criterion for selecting a street for GSI is sewer network capacity. Congested sewers produce backflows in basements during heavy rain events. By modeling the sewer, points where the sewer is congested can be identified, and GSI installations upstream from congested segments within the sewer basin prevent runoff from entering the sewer (Figure 2). An example of this is the "Tabor to the river program."

Table 2. Steps in the design and permit process for green stormwater infrastructures (GSI). Source: Bureau of Environmental Services [81].

Steps for GSI Implementation
1. valuate the site
2. Confirm current requirements
3. Characterize site drainage area, runoff, and hierarchy
4. Develop a conceptual design
5. Develop a Landscape Plan
6. Complete Stormwater Management Plan
7. Prepare Operation and Maintenance Plan
8. Submit final plans and obtain permits
9. Construct and inspect

Once the zone of the city has been selected, the choice of a specific street depends on the availability of space, or in other words, the amount of the right-of-way that is not devoted or assigned for a specific use. A former official and a hydraulic engineer at BES agreed that green streets in Portland tend to be low traffic volume streets [82]. The engineer pointed out that more projects should be located within arterial roads because most pollutants settle there. The former BES official is convinced that GSI can be added to busy streets if they are carefully designed. He points out the advantages that there would be if more stimuli and funds ever become available for retrofitting these roads.

As a current Green Street implementer with a high number of constructed works, the Portland experience serves as an example. Two major elements have been identified as key factors in the fruitful implementation of green streets. The first is the simplification in the exception process for alternative designs, i.e., making it less tedious and risky for officials in terms of professional liability. The second key point is the development of a clear, simple, and standardized procedure for designing (sizing), testing, and constructing green streets. The pilot project process in Portland strongly contributed to developing a straightforward design method. The key was the monitoring and testing of constructed projects, which provided real and accurate information with regards performance. Table 3 shows the performance figures of five green street pilot projects. As a remarkable result, the "sizing factor" arose as the ratio of the facility area over the drainage area. In this way, an estimate of the size of the planter or garden can be easily calculated (e.g., 6% of the drainage area), providing orders of magnitude. Dimensions, materials, types of plants, locations, etc. of different projects were compared to achieve state-of-the-practice in design. Pilot projects were also educational for professionals for different agencies and they helped to explain the possible barriers and difficulties for a large-scale green street program.

Table 3. Characteristics and performance of some green street pilot projects in Portland. Source: Kurtz [83].

	Facility Area (ft^2)	Drainage Area (ft^2)	Peak Flow Reduction	Flow Vol. Reduction	Sizing Factor
Glencoe Rain Garden	2000	35,000	80%	89%	0.057
NE Siskiyou and 35th	300	6000	81–85%	61%	0.050
SW 12th and Montgomery	272	7500	n.a.	50–74%	0.036
NE Fremont and 131st	300	4500	95%	96%	0.067
SE 21st and Tibbetts	300	4500	n.a.	70%	0.067

The strategy used to overcome the transportation dominance of the ROW was multi-disciplinary work according to the former BES official in Portland [84]. In Portland this was possible after years of inter-agency work by, for example, the Sustainable Infrastructure Committee and the Cross-Bureau Task Force. A frank debate among distinct disciplines brought interesting ideas, where green stormwater solutions could have initially emerged. Portland's former official considers that it was fairly easy to break the mono-functional thinking of transportation professionals by using the following logical thinking: 1. Portland has stormwater problems; 2. there are regulations and the city has to comply with them; 3. we are all in the same city and we were appointed to solve these problems; 4. we need to do this in streets because the city does not own lands. At the end, he stated: "They are engineers . . . they are trained to find solutions to problems" [84].

4.3. Philadelphia: A Systemic Approach

The process in Philadelphia was different. Rather than a formal green street program, green streets are just one of the city's eight strategies to transform the city into a "green machine." The program, known as Green Cities Clean Waters was launched at the very end of the first decade of the 2000s, almost 10 years after the first green street was implemented on the west coast. Its objective is to manage stormwater to solve the CSO situation in the US by means of GSI. The approved Green City Clean Waters plan requires the city to manage the runoff of nearly 40 square kilometers (10,000 acres) of impervious surfaces, at least one-third of the impervious area served by Philadelphia's combined sewer system [85,86]

In 2008, after a decade of approaching CSO problems with palliative actions, the city was required to adopt a strategy to substantially reduce CSOs. After a series of studies, the city decided to manage stormwater through a massive greening program of schools, public facilities, parking lots, parks, industry, business, streets, alleys, and homes. An example of GI implementation in a former parking area is shown in Figure 3. The green stormwater plan is a 25-year program in which the Philadelphia Water Department (PWD) will invest approximately $2.4 billion ($1.2 billion in 2009 dollars) [85].

During the first decade of this century, PWD was leading an inter-agency, multi-disciplinary process to address water quality problems together with municipalities and counties that share one or more watersheds with the city. Since 1999, Philadelphia has established partnerships with six neighbors (counties and cities) to develop an Integrated Watershed Management Plan, which operates under a three-phase structure: (a) preliminary reconnaissance survey, (b) watershed assessment and planning, and (c) watershed plan implementation [87]. Simultaneously, the city of Philadelphia evaluated five different alternatives including green and gray infrastructure in light of the experiences of other cities, including those using GSI, facing the same problem. According to a former Director at PWD, a systemic decentralized green stormwater alternative with limited additional gray infrastructure to reduce CSO ranked first among the five alternatives [88]. It was determined that the green alternative provides maximum returns of environmental, economic, and social benefits within the most efficient timeframe, making it the best approach for Philadelphia.

The Philadelphia case is especially important in the green streets design process described in this study because its comprehensive analysis of the situation brought the importance of greening cities beyond pure stormwater management. The specific results of the Stratus Consulting report showed that green solutions provide such a vast and varied set of benefits (social, economic, and environmental) that the green scenario is unbeatable by any other option [89]. For example, the study showed that in a scenario of 50% runoff served by GSI with a large underground storage tunnel handling the remaining 50%, the benefits from GSI surpassed $2.84 billion from 2009 to 2049 (in 2009 US dollars), while the benefits from the tunnel only reached $120 million [89]. Surprisingly, the benefits in water quality improvement rank third on the list. Heat stress mortality reduction (accounting for 37%) is in first place followed by improved aesthetics and property value (20%). In third place, accounting for only 12% of the benefits, are increased recreational opportunities and water quality and aquatic habitat enhancement [89]. These results bring the discussion to a tipping point, since the main benefit of green streets in Philadelphia is not stormwater management.

Green streets are a major component of the Green City Clean Waters plan since the city's street network is its most abundant asset for reaching its goal. In Philadelphia, the target (based on models and simulations) is to provide at least some green elements on 50% of the 4465 km (2775 miles) of roads by 2028 [86]. The goal is to manage 25.4 mm (one inch) of runoff onsite, relying on green infrastructure for billions of gallons of required sewage overflow reductions.

What is the local design procedure? The Department of Streets (in the Office of the Deputy Mayor for Transportation and Utilities) and the Water Department worked hard to compile the design standards manual to accommodate green street elements, for street typologies that represent typical conditions in Philadelphia. As background, the Department of Streets issued the Complete Streets Handbook beforehand in 2009. The Complete Streets Handbook is a supplement to existing design codes, and considers the existing design codes and the Bike and Pedestrian Plan. Although the Complete Streets Handbook mentions the stormwater plan and the green streets movement, it does not even consider in its design procedures any functional green infrastructure. It barely mentions that wider ROW, like the planted strips along some of the city's 418 km (260 miles) of state and federal highways, offer opportunities to naturally drain stormwater runoff and incorporate bike lanes [86].

The Green Streets Design Manual defines a complete procedure for the design of green streets with "the primary goal of implementing GSI is stormwater volume reduction." It starts first by presenting a menu of GSI options available to be implemented (types of GSI): street trees, trenches, pump-outs, planters, permeable pavements, green gutter, and drainage wells (all for stormwater infiltration). The so-called sustainability matrix considers the seven types of GSI and the 11 types of street. For each cell of the matrix, the manual suggests whether a certain GSI type is suitable, possible, or not recommended for a given street type. For the most frequent type of streets, with low traffic, local, and residential, all seven types of GSI are suitable.

The manual defines a four-step procedure for designing a green street:

(1) Identify potential streets where GSI can be implemented based on existing conditions. Here, streets are screened by gradient or conflict with existing utilities.
(2) Identify the street's typology according to the Complete Streets Handbook.
(3) Consider potential GSI type for each selected street according to the "Sustainability Matrix."
(4) Choose the most appropriate GSI.

5. Green Street Design and Implementation

Unlike the traditional street design process, green streets require complex, multi-scale, multi-agency, interdisciplinary, stepwise processes. Thus, when speaking of implementing green streets, the word "design" should go hand-in-hand with the word "planning," as long as each GI installed is part of an overall strategy to reach a goal.

Out of the three cases, three main steps were identified for green stormwater infrastructure in rights-of-way: first, a large-scale environmental system analysis; second, a meso-scale assessment to analyze the needs and suitability in different areas within cities; and third, a local-scale street design process (Figure 4). Despite the fact that the three cities have undergone their own independent processes (see Table 4), the same scales proposed by Norton et al. [9] have been evidenced in the case studies presented. In terms of green street planning and design, Portland, Seattle and Philadelphia started with a large-scale (city/basin) systemic analysis. In Seattle, this work was carried out by ecologists and environmentalists who studied the declining environmental condition of the Puget Sound Estuary beginning in the 1980s. In Portland, they used this regional approach to understand both problems and potentials. In Philadelphia, after developing an understanding and diagnosis of the problem at regional level, citywide modeling and simulations were carried out to evaluate the most suitable solutions. The results obtained in the first step are an input for the following steps (meso and local scales) and are required only once.

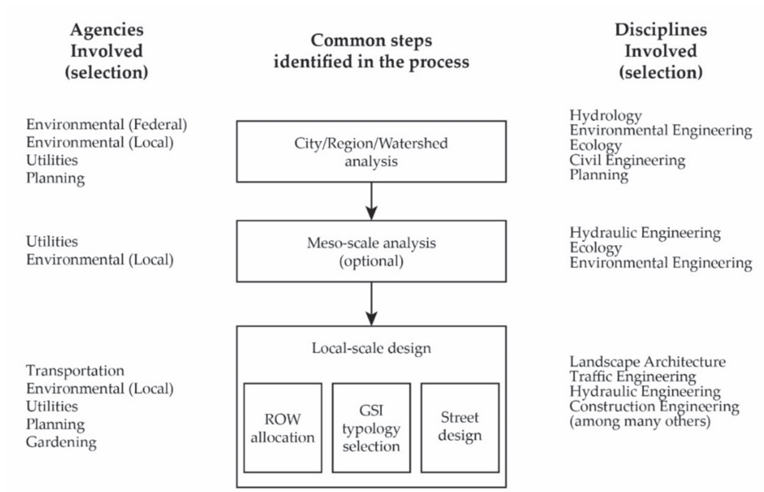

Figure 4. General process for green street planning and design.

Table 4. Cross-comparison of many process characteristics.

	Seattle	Portland	Philadelphia
Rooted in Stormwater Management?	Yes	Yes	Yes
Previous larger scale planning, prior on-site design?	Yes	Yes	Yes
Born as part of a citywide greening strategy?	No	No	Yes
Other benefits of green streets assessed and acknowledged?	No	No	Yes
Multidisciplinary process?	Yes	Yes	Yes
Defined stepwise procedure or routine?	Yes [a]	Yes [a]	Yes [a]
Inter-agency collaboration during the process?	Yes	Yes	Yes
Competing with transportation interests within the ROW?	Yes	Yes	Yes

[a] Each city has undergone its own process. Differences and similarities are described in the text.

The second meso-scale stage, probably the least well-developed of the three, deals with site selection including both the zone within the city and the specific streets upon which to locate the GSIs. Sewer deficiencies, combined sewer system zones, areas with good soil permeability, and sewer basin backflows due to congested sewer lines were some of the reasons used to explain decisions in these cases.

The third stage includes three separate activities: finding space within the ROW, selecting the GSI typology, and the traditional transportation-landscaping design. Depending on space availability, different GSI typologies can be installed. The decision is a matter of performance, costs, and available space. According to Gallo et al. [90], a simplified design method makes it easy for designers with poor experience in hydraulics to incorporate GSI into streets. Portland is a good example as they created the sizing factor, which has contributed to easy approximation of size by professionals in other disciplines (but not replacing the technical hydraulic design for each facility itself). The construction phase take place following the local scale design.

These previous processes imply complex institutional interactions, a systemic view of the problem, and multidisciplinary work. We found that the planning and design of green streets implicate various federal, regional, and local public entities, besides the DOTs, including the EPA and the local environmental, water, and utility departments. However, the local DOTs still play a paramount role in this complex process.

6. Discussion

The engineering design process by Nigel Cross [91], points to the importance of fully understanding the "problem definition" and to develop a "conceptual solution". Following this, clear functions of the object to be designed have to be defined. For almost a decade, Seattle and Portland worked hard on these two tasks; the keystone of green street design. The SEA street project in Seattle served as the initial credible evidence of the effectiveness of green streets for stormwater management. Experimentation determined the features of different GI technologies (ponds, bio swales, trenches, etc.), and performance rates. Philadelphia had a much shorter problem definition period and conceptual process, given that the technologies had already been defined before.

The large-scale analysis serves to determine the overall demand of GI (e.g., in the watershed) and some relevant citywide characteristics for the design, such as precipitation, imperviousness rates, infiltration rates, or sewer performance in different city zones. Conversely, demands for traditional street designs (e.g., traffic demand), are not accountable for the entire city, but rather estimated more locally (e.g., corridor). Recall that traditional design practices usually consider traffic volumes and infrastructure capacity (for different transportation modes), road safety, aesthetics, or other variables, which can be resolved at local/corridor scale.

The meso-scale stage is the least developed of the three stages. Worthy of note are the contrasting points of view of interviewees regarding the most suitable type of road (locations) for constructing green streets. Should green streets be located on low-traffic roads, busy streets, or both? Streets with low volumes of traffic seem to be the right location for GSI, since there is more space available for reallocation. In general, such streets account for the vast majority of city road networks. This type of street in the US is characterized by generous rights of way [92], by oversupply of parking [93], and by a desire for traffic calming to enhance livable areas. In addition, the literature suggests that green infrastructure should be located close to people, as benefits can be attained by mere proximity to green infrastructures [31]. On the other hand, interviews with the Deputy Water Commissioner of the Philadelphia Water Department and the director of environmental services (DES) on Gresham, Oregon [94] provided reasons to locate green infrastructure in busy corridors. The DES director pointed out that locating the GSI on busy roads would do more to reduce the discharge of pollution into rivers than locating it on quiet streets since most pollutants come from vehicle operation. In addition, people tend to walk along busy roads, highlighting them as places where people would benefit most from green streets [94].

A concern in the lower-scale analysis deals with developing a standardized manner for finding spaces within existing consolidated streets for GI. Different strategies become feasible depending on the hierarchy of roads selected in Stage II. These include the narrowing of vehicle lanes, reclaiming underutilized pavement, conversion of borders, furnishing zones, and traditional landscape areas, and eventually substituting parking boxes to function as GI. Overall, the interviewees agreed that it is important to maintain (or affect at the minimum) the street performance and services provided by the street before the addition of GI. Tackett [95] reinforces this idea when she suggests that an implicit design rule should be to ensure a similar service for motorists as in original designs while accommodating infiltration swales. One of the most sensitive topics is parking. Any change in the amount of space devoted to parking could generate opposition to green streets. The principle this implies is that GI should be built "at the edges of the right-of-way."

Street design has been experiencing ground transformations in recent years. One of these changes is due to the evolution of street functions; a process that began in the transportation field with a broader understanding of the street, beyond movement for cars. Under a new mobility paradigm presented by Banister [96], he supports the idea that a much broader notion of the street is needed, where streets are no longer considered mere roads but also as spaces for people, active modes, and public transport. In the environmental field, little has been reported in the context of street design with regards environmental functions. This paper provides empirical evidence of the effect in street design of the environmental function of the street introduced in the past by Hui et al. [97] and other authors [98].

It is important to remark that neither multi-modal street designs nor green streets come from the self-evolution of traditional street design. Both movements, multi-modal streets and green streets, succeeded quite independently in breaking the rigid code-based, transportation-focused street design. Both movements proved that a well-defined, understandable, and sharply focused workhorse is a strength that increases power and that allows goals to be reached more easily. This workhorse is safety for complete streets and, in this case, stormwater management for green streets. Transportation officials and policymakers, who are more concerned with the right-of-way, are more likely to be motivated to change if the problem is framed as one that the city or society cares about: safety and water quality.

GI provision in several US cities has been rooted in stormwater management, especially in those with combined sewer overflows. For this initial group of green street implementations in US cities, the workhorse was stormwater management. Since new GI in cities can produce other benefits, the workhorse can potentially involve many other aspects, such as public health (improved air quality), property damage prevention (flood control), or the reduction of heat wave mortality (for urban cooling). In terms of design, the citywide analysis and meso-scale step are required to define the overall amount of GI required and to efficiently allocate that infrastructure within the city.

Paradoxically, the insertion of green infrastructure within the ROW, instead of harming or diminishing the movement function, might strongly benefit pedestrians and cyclists. These modes, also known as active modes, are important within the urban transportation strategy for sustainability. Evidence suggests that there is a causal effect between tree planting and cyclist satisfaction [99,100]. Another transportation-related benefit provided form bio-swales installed next to intersections, is that the crosswalk distances for pedestrians can be shortened, reducing risk exposure, while slowing traffic down.

GI in streets provides many other benefits beyond stormwater management, making green street programs an attractive option in working towards sustainability. In practice, cities in the US might still have a partial or incomplete grasp of the concept, beyond stormwater management. In other countries, the lack of incentives and dissemination to policymakers can be reasons for the limited implementation of green streets in many other countries. The case of Philadelphia shows that a mono-target green streets program (for stormwater management) is not actually accurate when evaluating a massive green streets program, as long as many other important benefits of GI are not considered. This paper contributes in the practical scope by summarizing these benefits (addressing other environmental functions of green streets) and expanding on the practical design process.

7. Conclusions

Literature and the empirical evidence have demonstrated the convenience of providing GI in cities. GI requires physical spaces and the actual implementation of GI in cities has been proved to be difficult and challenging, especially in finding areas to be devoted to that end. Streets have been found as a convenient location for GI in urban areas. Based on three cities in the US that advanced in the planning, design and implementation of green streets, this paper explored the green streets processes and reported the evolution of the traditional street design routine.

The main outcome of this research is the identification of common elements in the design process among the case studies. The green street design process includes various steps and addresses different issues at different scales; it is a complex, multi-scale, multi-agency, interdisciplinary, stepwise process, that requires a longer time frame and the development of a specific legal framework. We have found that the word "planning" appears necessarily attached in the green street design process. A framework for a green street planning and design procedure was presented and discussed in the paper.

This paper contributes to enriching the discussion and reporting cases with actual green streets. The street design process reported, guided by the stormwater management approach, is a confirmation of the existence of the environmental function of the street and confirms the ROW allocation conflict. At the same time, this study provides a glimpse or a sense that there is a substantial amount of underutilized space within ROW, which can be optimized through careful multifunctional design. The cases show that there are possible ways to allocate spaces within the ROW, without reducing the capacity or diminishing the level of service for other traditional street uses.

As final recommendations, cities can explore the transformation of current ROW into green streets as a smart way to deal with many current problems or situations (e.g., the deficit of green areas or adaptation to climate change). Since qualitative research is interpretive and contextual, it is suitable to describe phenomena rather than provide conclusive results. The presented planning and design process associated to green streets, rather than providing an applicable method, should be seen as inspiration to guide similar processes in other cities, learning from the good and the bad experiences of the three cases presented.

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Green Streets to Serve Urban Sustainability: Benefits and Typology

Joowon Im

Program of Landscape Architecture, College of Architecture, Planning and Public Affairs, University of Texas at Arlington, Arlington, TX 76010, USA; joowon.im@uta.edu

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Abstract: Urbanization and climate change have impacted the ecosystems of the US cities. Impervious surfaces in the urbanized areas are a critical issue for both challenges and green infrastructure can be an alternative solution to achieve urban sustainability. Green infrastructure protects urban ecosystems by reducing imperviousness as treating stormwater runoff and providing other multifaceted benefits. However, even with the great potential, its adoption is still discouraged due to limited understanding and guidance especially for the cities with a growth-driven policy. This paper proposes that green infrastructure, particularly green streets in relation to impervious surfaces, can deliver urban sustainability by providing a better understanding to promote the acceptance and successful adoption of green streets through literature review and case studies in the US. Green streets are primarily implemented within the right-of-way and facilitate stormwater treatment along with diverse street designs providing multiple benefits such as flood management, wildlife habitat and natural pathway creation, neighborhood beautification, cost-effective solution, and more. The defined green street typology in this paper is an important tool for communicating among planners and the public by providing form-based standardized classification. Green streets can be utilized as a sustainable development approach, fulfilling a variety of environmental, social, and economic objectives.

Keywords: green street; green infrastructure; urban sustainability

1. Introduction

Urban sustainability in the US is at risk as the ecosystems of cities have been impacted by increasing population density in urban areas [1], further challenged by climate change such as extreme weather conditions (e.g., urban flooding, droughts) [2]. Rapid development in cities with high population density results in the increase of impervious surfaces (e.g., paved surfaces, building footprints) that affect urban ecosystem with excessive stormwater, accumulation of pollution in streams [3,4], and temperature increase (e.g., urban heat island) [5]. Extreme weather conditions such as urban flooding causes massive destruction on infrastructure, economics, and human lives in affected regions [6] while heat waves make people ill and die as exposed to extreme temperature for a longer period of time [7]. While impacts of extreme weather are aggravated by the excessive imperviousness leading to extreme flooding events [8] and heat waves [7], the consequences of urbanization and climate change ultimately threaten human well-being and our environment.

In regard to the mitigation of such conditions in urban cities, green infrastructure can provide an alternative solution by treating and reducing impervious surfaces to amend and improve already challenged urban ecosystems by using natural materials such as soils and plants. Adopting green infrastructure can promote sustainable urban ecosystems by increasing vegetation with greater biodiversity, improving well-being by promoting more green space [9], and climate resiliency by treating stormwater [10] and urban heat island effects [11].

However, despite its affordable and multifunctional benefits that can prove to be very effective solutions [12], its application is sometimes discouraged due to lack of comprehensive guidance [13] and "lack of understanding and knowledge of what green infrastructure is and the benefits it provides" [14] (p. 2). Thus, this paper focuses on green streets (also called green alleys), one of the eleven elements of green infrastructure as recognized by the US Environmental Protection Agency (EPA) (apart from downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bioswales, permeable pavements, green parking, green roofs, urban tree canopy, and land conservation). In addition to the potential benefits that municipalities and institutions intend to provide in the US, this paper focuses on examples in the US to fill the gap in the scholarly literature lacking topics primarily dedicated to green streets in the US. Given the fact that the sum of the US public roads and streets is about 4,146,410 miles long [15], almost half of urban areas are dedicated to streets, highways, and parking areas [16], and roads are primary reasons related to issues of impervious surfaces [17], studying and promoting green streets can be an effective solution for issues related to impervious surfaces among other elements of green infrastructure. Street greening projects without stormwater management consideration were not treated in this paper. The goal of this paper is to provide a better understanding about green streets of comparatively recent development approaches for those concerned with urban ecosystems with interests in implementing such projects and also for members of the public who have little knowledge about what green streets are and how they can benefit communities [18]. The long-term goal is to help promote the acceptance and successful adoption of the green streets by probing its potential as a sustainable strategy in achieving livable and healthy communities in urban cities. This study investigates various definitions, objectives, and types of stormwater treatment facility designs as outlined mainly in selected manuals. The author then discusses future green street studies by taking into account case study projects and their applications from other countries while examining the roles of green streets in the context of sustainable development paradigms.

1.1. Definition of a Green Street

Green streets in the US are known as on-site solutions installed primarily in the public right of way (public street/passage) to treat polluted stormwater runoff generated from impervious surfaces and conveyed to local waterways without filtration [16]. The implementation of green streets on the public right of way is often times easier than the implementation on private streets due to ownership issues. It mainly reduces impervious surfaces by adding more vegetation to increase permeable areas for treating stormwater runoff, which is one of the key design components of green streets not featured in conventional street designs. As a stormwater treatment measures, the construction of green street impacts appearances of streets and technical applications in different ways, depending on the types of pollutants, available space, land uses, and community needs that are involved.

Green street manuals and websites of various cities and agencies implementing this approach are used to arrive at a common understanding of how green streets are defined (Table 1). Aspects of green streets were generally agreed on: (1) They are implemented within the right of way, (2) they are a means of treating stormwater runoff, and (3) the adopted stormwater treatment process includes vegetation and soil beds. In sum, the great majority of the definitions depict a green street as a sustainable stormwater treatment practice that is mainly implemented in the right-of-way and includes the utilization of natural materials for this purpose. As an example, Portland, OR is one of pioneering cities that adopted green streets, with the first green street project being implemented as early as 2003 [19]. The city approved the green street approach in public and private development in 2007. The working definitions of this approach used by Portland Environmental Services and Metro (Portland Metropolitan Area) primarily emphasize stormwater treatment and watershed health. Most other cities in Table 1 which are now adopting projects of this nature also appear to view them as a means of stormwater management and to be working from a definition of green streets that is similar to Portland's. While the definitions primarily emphasize stormwater management functions, there is some variability in the objectives of green street projects across the country, depending on the goals of the individual cities to be discussed in a later section.

Table 1. Definition of green streets.

Source	Definition of Green Streets
Portland Environmental Services (2019) [20]	A street that uses vegetated facilities to manage stormwater runoff at its source is referred to as a green street. A green street is a sustainable stormwater strategy that meets regulatory compliance and resource protection goals by using a natural systems approach to manage stormwater, reduce flows, improve water quality, and enhance watershed health.
City of Arlington (2019) [21]	A Green street is a street with a vegetated area in the public right-of-way that reduces the volume of stormwater and stormwater pollutants that enter our local streams, the Potomac River, and Chesapeake Bay.
Environmental Protection Agency (2019) [22]	Green streets and alleys are created by integrating green infrastructure elements into their design to store, infiltrate, and evapotranspire stormwater. Permeable pavement, bioswales, planter boxes, and trees are among the elements that can be woven into street or alley design.
City of Philadelphia (2014) [23] (p. 16)	Green streets present opportunities to manage stormwater while maintaining the primary function of the street for vehicles and pedestrians. A green street acts as a local stormwater management system, capturing stormwater runoff, allowing it to soak into soil, filtering it and, at the same time, reducing the amount of stormwater that would otherwise make its way into Philadelphia's sewer collection system.
Environmental Protection Agency (2009), [24] (p. 1)	A Green street is a street that uses natural processes to manage stormwater runoff at its source.
Water Environment Research Foundation (2009) [25]	Green streets are an example of how individual stormwater BMPs are used as elements of a broader program aimed at mitigating a significant source of stormwater pollution.
Lukes, Kloss, & Low Impact Development Center (2008), [26] (p.2)	Urban transportation right-of- ways integrated with green techniques are often called "green streets". Green streets can incorporate a wide variety of design elements including street trees, permeable pavements, bioretention, and swales. Although the design and appearance of green streets will vary, the functional goals are the same: Provide source control of stormwater, limit its transport and pollutant conveyance to the collection system, restore redevelopment hydrology to the extent possible, and provide environmentally enhanced roads. Successful application of green techniques will encourage soil and vegetation contact and infiltration and retention of stormwater. Alternative Street Designs (Street Widths) A green street design begins before any BMPs are considered. When building a new street or streets, the layout and street network must be planned to respect the existing hydrologic functions of the land (preserve wetlands, buffers, high-permeability soils, etc.) and to minimize the impervious area. If retrofitting or redeveloping a street, opportunities to eliminate unnecessary impervious area should be explored.
Metro (Portland Metropolitan Area) (2002), p. 2 [27] (p.2)	A "green" street: Is one component of a larger watershed approach to improving the region's water quality; is designed to incorporate a system of stormwater treatment within its right of way; minimizes the quantity of water that is piped directly to streams and rivers; incorporates the stormwater system into the aesthetics of the community at points where it crosses a stream or other sensitive area; a "green" street is located and designed to ensure the least impact on its surroundings requires a more broad-based alliance for its planning, funding, maintenance, and monitoring.

1.2. Green Street versus Street

The definition of a street according to Cambridge Dictionaries Online is "a road in a city or town, usually with buildings along one or both sides." Conventional streets are seldom integrated with stormwater treatment systems or connected to open spaces; they are automobile-oriented thoroughfares with a high proportion of impervious surfaces and decreased pedestrian safety [28], and they utilize prescribed street standards that limit the type of multifunctional adaptation considering the pedestrians' use of the street.

In contrast, green streets can be distinguished from typical streets in a number of respects (Table 2). As noted by the EPA, green streets incorporate integral stormwater treatment systems that are designed to improve the water quality and reduce the quantity of runoff [22]. In most cases, they are also connected with open spaces [29] and intended to be pedestrian-oriented for the purpose of supporting a safer and healthier community [20,23]. Green streets are implemented with less impervious surfaces than conventional streets because they feature narrower roads and wider planting beds (which create more available permeable surfaces); green streets also provide a safer walking environment for local residents [24]. In addition, green streets potentially allow flexibility for planners and designers to come up with designs that meet local needs. For instance, integrated stormwater treatment facilities can be of different sizes, and the plants used can be varied to suit local climate conditions, as suggested in numerous green street manuals.

Table 2. Street versus green street.

Typical Streets (Non-Green Streets)	Green Streets
 Typical street example 1: Road + Typical Planted Areas (Portland, OR)	 Green street example 1: Safe Crossing + Stormwater Planter on a curb extension (Fremont Streets, Portland, OR)
 Typical street example 2: Road + Gravel Parking + Planted Areas (Seattle, WA)	 Green street example 2: Underground Cistern + Cascade Stormwater Planter (Maynard Street, Seattle, WA)
 ©2019 Google Typical street example 3: Road + Street Parking + Lack of Planted Areas (Bainbridge Island, WA)	 ©2019 Google Green street example 3: Safe Wide Crossing + Stormwater Planter + Seating (Winslow Way Green Street, Bainbridge Island, Seattle, WA)
No application of stormwater management No connection to open space Auto oriented (wider roads) Large impervious surfaces	Integrated with stormwater treatment facilities Integrated with public open space Pedestrian oriented Large permeable surfaces (narrower roads and large planted area)

Green streets, however, also need to retain their traditional function as streets because, although they may have design applications for a better community, they are implemented in the right of way. Streets are one of the key elements that physically comprise a city and can be exciting places "where people walk, shop, meet, and generally engage in the diverse array of social and recreational activities that, for many, are what makes urban living enjoyable" [30] (p. 283). Streets are also important elements that connect one point to another, substantially forming and shaping a city. Streets run between private and public spaces, conveying both pedestrians and vehicles from one place to another. Thus, the benefits of integrated elements of streets are distributed throughout the adjacent communities and to the people who use and live on the streets. Therefore, streets can help form the character of a city influencing its culture and history. They, along with building footprints, comprise one of the largest areas of impervious surfaces in an urban area, and impervious surfaces are a useful measure for other features such as the water quality in local streams in relation to stormwater runoff generated from them [31]. Moreover, the flow of water is affected by the patterns of streets [26]. Thus, important roles of streets need to be considered with the adoption of green streets including proper facilities (stormwater management, street furniture, vegetation strips, and other recommended facilities and design features) implemented within the context of the larger street network: Applying the effective and creative approach of green streets should be an useful strategy for resolving urban runoff problems generated from impervious surfaces in a more sustainable way as providing multiple benefits.

2. Materials and Methods

This paper primarily adopts a descriptive case study with a multiple-case design that will require investigating the phenomenon in various cases [32] such as green street manuals and constructed projects for the analysis. The primary data source for this study consists of manuals dedicated solely to green street applications; only manuals with a specific focus on such projects have been selected so that the contexts to which they refer are rigorously related to green street implementation regarding objectives and design applications. The selected manuals were primarily created by the federal, municipal agencies, or related research foundation/organizations including the corresponding codes and ordinances. Manuals were searched by such key words as green street manual and green alley manual via search engines (e.g., Google and Bing). The search engines were more efficient than using any academic databases since they were not scholarly literature but uploaded to websites or databases created by government or non-profit agencies. The primary manuals used here can be found in Table 3. In addition to the data from these manuals, data from site visits to constructed/in-progress green street projects were included, along with webpages and reports of green street cases from different cities and agencies, to ensure the breadth of the data used.

Table 3. List of manuals.

Author	Type/Agency	Place
Pioneer Valley Planning Commission, 2015 [33]	Manual/ Nonprofit	Springfield, MA
City of Philadelphia, 2014 [23]	Design Manual/ Municipality	Philadelphia, PA
District Department of Transportation, 2014 [34]	Manual/ Municipality	Washington, DC
Carlson, Caughey, & Ward, 2014 [35]	Design Manual/ Municipality	Holyoke, MA
City of Cleveland, 2013 [36]	Manual/ Municipality	Cleveland, OH
City of Seattle, 2012 [29]	Manual/ Municipality	Seattle, WA

Table 3. *Cont.*

Author	Type/Agency	Place
Chicago Department of Transportation, 2010 [37]	Handbook/ Municipality	Chicago, IL
US Environmental Protection Agency, 2009 [24]	Design Manual/ Federal	Washington, DC
Water Environment Research Foundation, 2009 [25]	Design Manual/ Nonprofit	Alexandria, VA
Lukes, Kloss & the Low Impact Development Center, 2008 [26]	Handbook/ Federal	Washington, DC
Metro Portland, 2002 [27]	Manual/ Municipality	Portland, OR

There were two sets of analyses: (1) A descriptive study of goals and objectives to investigate the breadth of benefits that can be generated by adopting green streets and (2) a descriptive study of green street design typologies focusing on stormwater facilities, which is one of prominent characteristics, to understand physical application of green streets within the right-of-way. An analysis based on phenomenological method suggested by Ratner [38] is conducted to identify accurate themes through multiple iteration by forming staged structures that require a rigorous analysis of the content of the data. All the contents related to objectives and benefits in the manuals were collected and "meaning units" [38], which contain specific meaning of a certain idea, were identified. Then, each identified meaning unit was summarized and grouped based on relative agendas (subcategory). The identified lists have been grouped and categorized again to get higher level criteria (top category) that can represent the lists that belong to the lower stage.

The definitions of a green street and general differences between green streets and typical streets were evaluated to understand the specific characteristics of green streets in the previous chapter. With the analysis, a closer look at the list of objectives in the green street manuals provided the basis for discussion about primary characteristics and the breadth of potential benefits for the surrounding communities. Typologies of green street designs applied to green street projects, especially those involving stormwater treatment facilities, were categorized according to different design applications and locations where they were placed. Once the typologies were defined, a member check process was conducted with experts who worked on green street projects from governmental or non-profit agencies. The typologies were presented to the experts, whose feedback helped to modify and improve them to increase the validity of the created typologies. Overall, this paper aims to provide a comprehensive understanding of what green streets are and to work toward promoting green streets with consistent design approaches that can provide successful implementation with more benefits.

3. Results

3.1. Potential Benefits of Green Street

Thirty-six items in an exhaustive list of benefits (subcategory) were identified from the first-round analysis derived from the objectives and definitions in the manuals. Five themes (top category) were identified as higher level criteria upon summarizing and grouping subcategories (Figure 1): Stormwater management (at its source), environmental preservation and improvement, social improvement, transportation enhancement, and economic efficiency. Among the identified benefits grouped under the five themes, significant benefits were found based on the frequency mentioned in the manuals, in particular, stormwater quality improvement (1), stormwater volume reduction (2), stormwater infiltration (3), stormwater capture and store (4), basement alleviation and flood management (5), utilization of soils and vegetation (7), connection to landscape areas and natural areas (9), wildlife habitat and natural pathway creation (10), urban heat reduction (11), neighborhood beautification (21), pedestrian experience and safety enhancement (27), urban street design and function improvement (30), and cost effective solution for stormwater management (34). As stated, benefits related to stormwater management were the most frequently mentioned elements in the manuals. The overall elements are not limited solely to stormwater treatment but also include a range of environmental, social, and economic aspects, indicating that green streets are clearly expected to provide a number of benefits in addition to stormwater treatment.

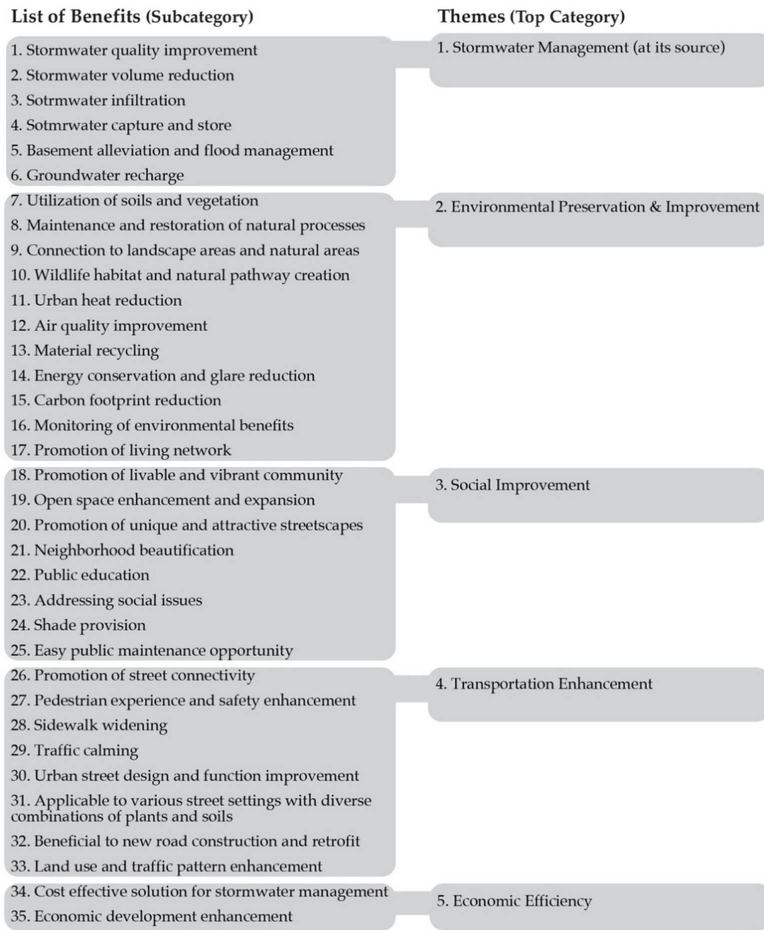


Figure 1. List of potential benefits derived from the selected manuals.

3.2. Green Street Typology: Form-Based Approach

Many municipalities that are adopting green streets describe their design, specifications, and applications in a set of manuals, standards, municipal plans, and online databases: Philadelphia, PA has the Green Streets Design Manual and the green street information provided on the Philadelphia Water Department website; New York published green street information in its NYC Green Infrastructure Plan, along with design standards from the city's Parks Department and Environmental Protection Agency; Portland, OR's green street information is provided under their Sustainable Stormwater Management initiative; and Seattle, WA, defines green streets in its Right-of-Way Improvement Manual, which also covers its Green Stormwater Infrastructure approach.

Those design standards published by various municipal agencies provide technical designs for the green street stormwater treatment systems that generally include items such as the sizes of the different types of stormwater treatment facilities involved, inlet designs, plant selection, soil combinations, and other related technical and design specifications. In order to deliver the potential benefits that are frequently discussed in the manuals, these items need to be integrated with contexts of streets where any given green street projects are applied.

It is important to note that each of the manuals and design standards selected for the research has adopted various types of green street practices that they refer to under slightly different terms (Table 4). Thus, the author first categorized stormwater treatment measures applied to green street projects depending on where they are located within the right of way and their structural shapes based on the manuals. This approach to categorization was possible because each manual actually shares quite similar types of green street facilities, despite the various ways they were referred to. Then, a list of green street practice types and typologies were created to help develop a better understanding of current practices and techniques and thus facilitate communication efficiently among designers and planners based on the different facility types in the design manuals and case study projects (Table A1). The form-based categorization for deriving typologies was taken into account for defining different types of green street practices integrated into street network systems (Figure 2). Here, the types are divided first according to whether the practice is applied at an intersection, midblock, or both (a combination), then subdivided based on whether the facility was located within the sidewalk or extended outward from the curb towards the roadway. After the different shapes of facilities have been listed, permeable paving, runnels (open/closed), cisterns (above/underground), fountains, street furniture, and structures are then categorized as special applications of green street practices based on constructed green street projects studied.

Table 4. Green street typology and terms from selected manuals.

Manuals	Green Street Typology and Terms
City of Philadelphia (2014), [23] (pp. 24–37)	• Stormwater planter • Stormwater bump-out • Stormwater tree • Stormwater tree trench • Permeable pavement • Green gutter • Stormwater drainage well
District Department of Transportation (2014), [34] (p. 10)	• Permeable pavement: Permeable unit pavers, pervious concrete, porous asphalt, porous rubber • Bioretention: Bioretention planter adjacent to roadway, curb extension, bioretention in open area, bioswale. • Tree Space: Small, medium, large trees
City of New York, Department of Environmental Protection, & Bureau of Engineering Design and Construction (2017), [39] (pp. 1–2)	• Right of way bioswale (with variable sizes) • Right of way Greenstrip (with variable sizes) • Right of way infiltration basin with concrete top (with variable sizes) • Right of way infiltration basin with grass top (with variable sizes)
Portland Environmental Services (2016), [40] (pp. 2–175)	• Swale • Planters • Curb extensions • Tree well
Lukes, Kloss, & Low Impact Development Center (2008), [26] (pp. 3–7)	• Swale • Bioretention curb extension and sidewalk planter • Permeable pavement • Sidewalk trees and tree boxes

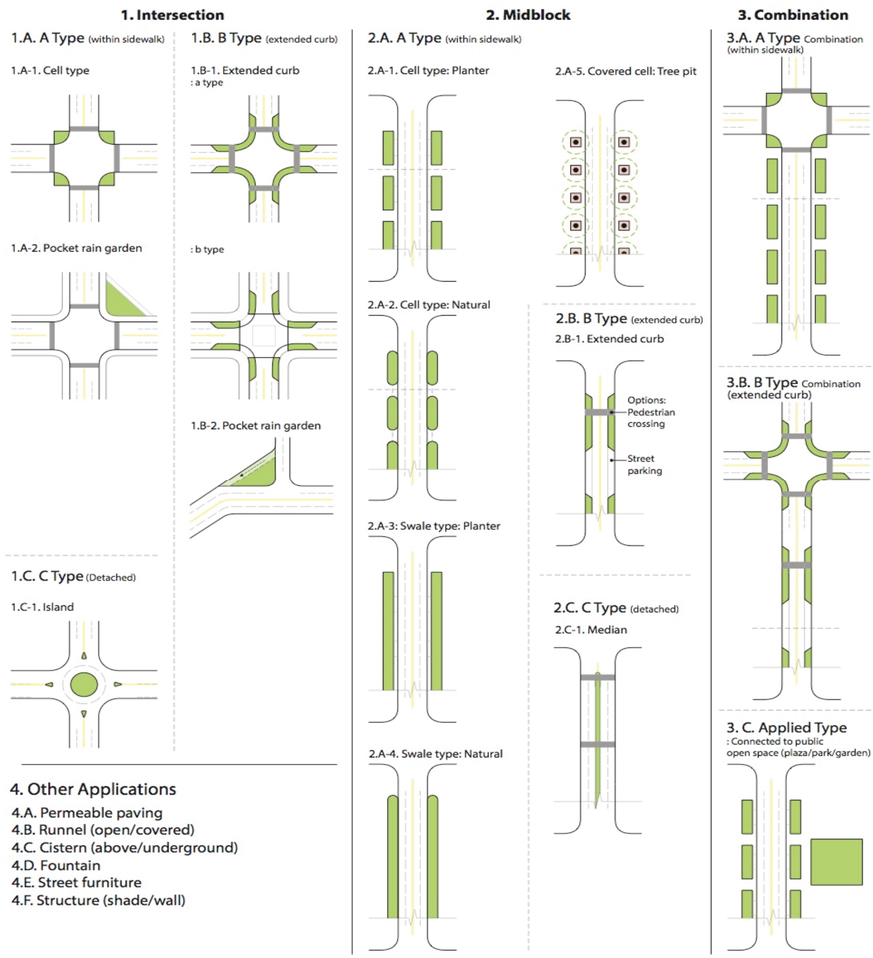


Figure 2. Form-based green street typology.

The green areas in Figure 2 indicate where green street stormwater facilities are located. In these areas, stormwater runoff is treated with plants and soils. An overflow and underdrain system with perforated pipes should be considered as well. At a street intersection, stormwater treatment facilities can be implemented on all four corners. They can be located within the curb (1.A-1. *cell type*) or extended from the curb (1.B-1, 2. *extended curb*: a type, b type). One of the benefits of *extended curb type* is that it can provide safer pedestrian crossing by reducing the crossing distance and introducing a traffic calming effect. If the stormwater treatment structure is a *cell type* (normally a singular facility) but has a more organic shape than the usual rectangular shape, it is categorized as a *pocket rain garden* (1.A-2, 1.B-2). These are typically found in isolated areas such as gore points (normally a triangular shape) and areas close to intersections rather than the midblock of streets. The *pocket rain garden* can be conveniently implemented in a smaller area but may be less effective in treating stormwater runoff compared to the *cell type* or the *swale type* in the midblock. It can also serve as a small community park with additional design features such as benches and shade structures. The *island type* (I.C-1) can be a focal point in the area to promote a better image of a city with beautification while accepting and treating stormwater runoff from the surrounding roads.

In the midblock area of a street, if a facility is small and repeated in one or more blocks, it is referred to as a *cell type* (2.A-1, 2), which can be divided into two forms: A *planter* form or a *natural* form. The walls of the *planter* form are made of durable materials such as concrete and are often rectangular in shape. The walls of the *natural* form are constructed with more raw materials such as soils and stones and have more natural/organic shapes than the *planter* form. The *cell type* can be accepted better by the users since its form is similar to the conventional street planters. Each cell can be connected with an overflow system for optimized stormwater runoff treatment. It can then provide continuous planting bed for providing greenness and community beautification. The *cell type* can also provide better access utilizing spaces in between planters, such as pedestrian movement from the sidewalk to street parking. If the stormwater treatment facility is linear and long, it is labelled a *swale type* facility (2.A-3, 4). These can again be subdivided into a *planter* form and a *natural* form depending on the materials used and the type of construction as mentioned above. The *swale type* can be more efficient in treating stormwater runoff since it has more contact area with stormwater than the *cell type*, however, it may obstruct pedestrian movement on the street because it lacks breaks along the linear facility. Similar to the *cell type* in the midblock, the *covered cell type* (2.A-5) appears in the conventional form of a planter. *Extended curb* (2.B-1) and *median types* (2.C-1) are also implemented in the midblock and can provide safer pedestrian crossing as making the crossing distance shorter.

The *combination types* (3.A, 3.B, 3.C) are composed of types in the intersection and types in the midblock. The *applied type* (3.C) suggests an integration of any available public open spaces with green street stormwater facilities. The integration can enhance the experience in a community by improving walkability, providing gathering spaces, effective stormwater treatment with connected system, and more. *Other applications* (4.A, 4.B, 4.C, 4.D, 4.E, 4.F) are additional design features that can be integrated within green streets for providing multifaceted benefits for users.

These typologies can be understood as a form-based implementation tool that can be systematically referred by designers and planners during the green street design processes. The implementation tool emphasizes on the importance of addressing multiple benefits while treating stormwater efficiently. Table 5 is provided to help better understanding of green street typology developed in this paper with more descriptions and constructed green street project samples for each typology.

When planning and designing green streets, it is important to note that street elements (e.g., roads, sidewalks, structures, furniture, buildings, and users) also need to be considered along with the application of stormwater treatment facilities (e.g., planter type, swale type) because street's contexts differ from one another while current manuals tend to focus primarily on the stormwater facilities instead. It is not easy to standardize design applications that can deliver certain benefits since every site has its own unique conditions, and an approach that may be suitable for one location could potentially inhibit some of the multiple potential green street benefits in another location. Thus, typologies in this study are an important tool for communicating among planners and the public: They consider standardized designs but also offer flexibility concerning adaptive design application and the considerations of the different conditions and needs of each site.

Table 5. Green street typology with descriptions.

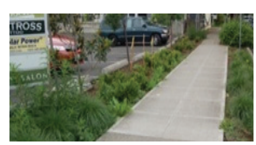
Term	Description of the Stormwater Facility	Example Project
	1. Intersection	
	1.A. A Type (located within sidewalk)	
1.A-1 Cell type	Smaller planting area with constructed walls (e.g., concrete boxes)	 Pringle Creek Community, Salem, OR. Image Capture: April 2012 ©2016 Google
1.A-2. Pocket rain garden	Smaller planting area with some natural edges (e.g., stones, grassy side slopes) and irregular shape	
	1.B. B Type (extended curb)	
1.B-1. Extended curb: a type, b type	Smaller planting area with constructed walls (e.g., concrete boxes)	 SE Clay St Green Street, Portland, OR. Image Capture: Mar 2016 ©2016 Google
1.B-2. Pocket rain garden	Smaller planting area with some natural edges (e.g., stones, grassy side slopes) and irregular shape (e.g., traffic island)	
	1.C. C Type (detached from sidewalk)	
1.C-1. Island	Located in the middle of the road	Roundabout, col-de-sac
	2. Midblock	
	2.A. A Type (within sidewalk)	
2.A-1. Cell type: Planter	Smaller planting area with constructed (raised) walls (e.g., concrete boxes)	 College Ave Promenade, Blacksburg, VA
2.A-2. Cell type: Natural	Smaller planting area with some natural edges (e.g., stones, grassed side slopes) and irregular shape	
2.A-3. Swale type: Planter	Linear planting area with constructed walls (e.g., concrete boxes)	 Seven Corners New Seasons Market stormwater planter, Portland, OR
2.A-4. Swale type: Natural	Linear planting area with some natural edges (e.g., stones, grassy side slopes) and irregular shape	
2.A-5. Covered cell: Tree pit	Tree pit with constructed soils covered with tree grate	 Tree Trench at W Palmer St. ©2016 Google

Table 5. *Cont.*

Term	Description of the Stormwater Facility	Example Project
	2.B. B Type (extended curb)	
2.B-1. Extended curb	Smaller planting area with constructed walls (e.g., concrete boxes)	 NE Siskiyou Street, Portland, OR
	2.C. C Type (detached from sidewalk)	
2.C-1. Median: Constructed/natural edges	Median planting area with constructed walls (e.g., concrete boxes) or natural edges (e.g., stones, grassed side slopes)	 Patrick Henry Drive Green Street, Arlington, VA
	3. Combination (Intersection + Midblock)	
3.A. A Type Combination (within sidewalk)	Combined type located within sidewalk	Large scale application
3.B. B Type Combination (extended curb)	Combined type extended from curb	Large scale application
3.C. Applied Type	Planting area connected to open space, plaza, park, garden, etc.	Integrated system
	4. Others	
4.A. Permeable paving	Permeable paving for pedestrian or vehicular roads	Permeable asphalt, permeable concrete, permeable pavers
4.B. Runnel (open/covered)	Rainwater conveyance	Runnel in planter or sidewalk
4.C. Cistern (above/underground)	Rainwater harvesting for reuse (e.g., irrigation)	Cistern connected to the stormwater facility
4.D. Fountain	Located on slopes or designed for ornamental purposes	Cascades, fountain
4.E. Street furniture	Furniture to support site users	Benches, light fixtures, information kiosk
4.F. Structure (shade/wall)	Spatial composition or safety consideration	Shade structures, walls, seat walls

4. Discussion

As demonstrated by the thirty-five identified benefits from the manuals, green streets need to be understood as a multifaceted and comprehensive street improvement/sustainable development approach. The following figures (Figure 3) present suggested application of green streets reflecting the typologies identified from the previous chapter with the most common typologies found in the constructed green streets such as cell type stormwater planter (2.A-1), cell type natural (2.A-2), median (2.C-1), extended planter (2.B-1), which were found to be popular in the forty-five green street cases when types of green street application to cities' right-of-way was investigated (Table A1).

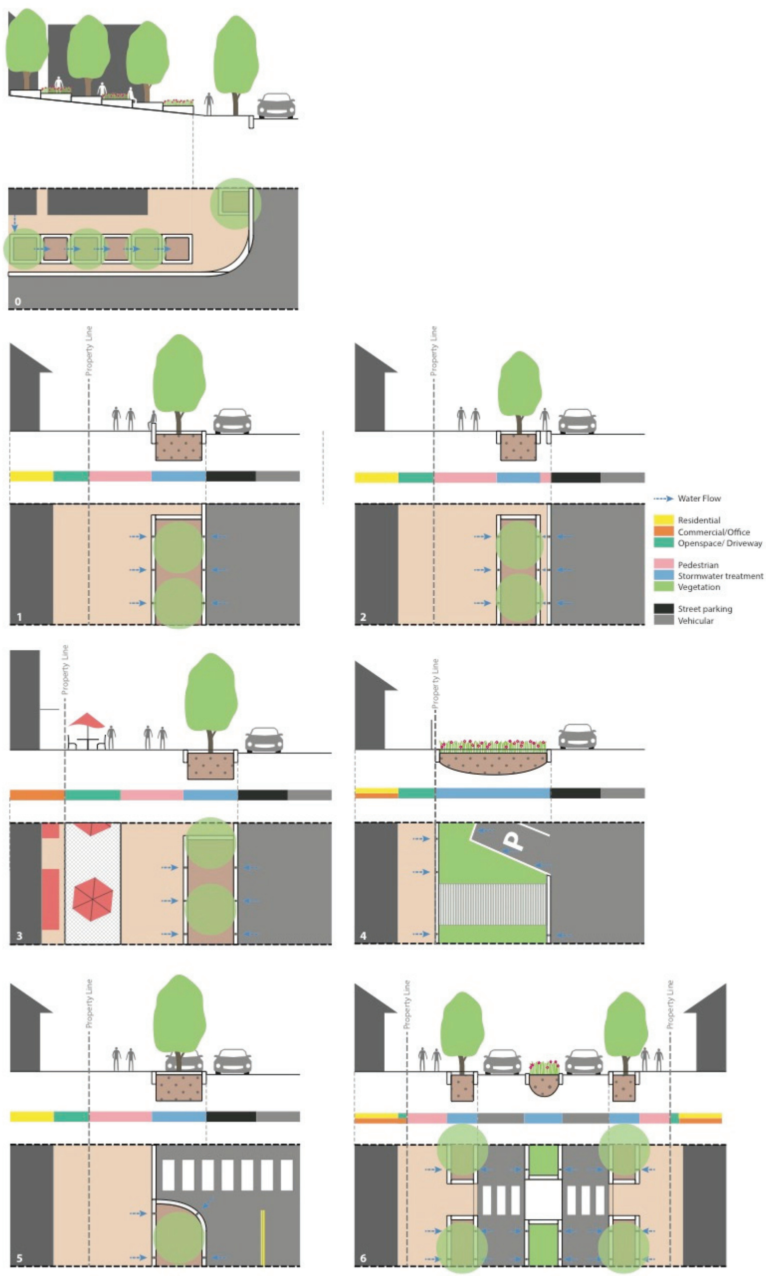


Figure 3. Examples of green street practice [41] (Modified from pp. 601–601): **0**. Green street on slope with planter type cascades; **1**. Green street with wider sidewalk and seat wall; **2**. Green street with wider sidewalk and landing space for street parking; **3**. Green street with outdoor activity area in conjunction with sidewalk; **4**. Green street with wider and leveled stormwater planter, access to the building, and diagonal parking space; **5**. Green street with extended stormwater planter for traffic calming; **6**. Green street with stormwater planter in median for safe crossing.

These examples show ways to apply different types of green streets into various street settings to create a more walkable and safer environment for users by utilizing available spaces within the right-of-way. The examples are not to represent a certain scale but to demonstrate different compositions of various green street elements visually and specific dimensions are to be determined by available spaces, amount of stormwater runoff from catchment areas, users' needs, and more. It should be discussed that design standards in the majority of the manuals seldom include site context objects such as buildings, street furniture, or dimensions of the sidewalk/roadway, along with other factors that support users' activities. In order to have stormwater planters/swales on streets, a certain amount of space including a pedestrian path is required. Moreover, stormwater treatment facilities need to perform infiltration, provide planting beds, and incorporate underdrain pipes if necessary, and most of all, it should allow the stormwater to be collected in the facility with an opening toward catchment areas. Consequently, for green street practices in particular, underground conditions need to be investigated through on-site inspections because they can differ from what is recorded in existing documentation. If space is insufficient for the subgrade portion of a green street project, it cannot be implemented in the first place. Thus, not only the surface areas of a site, but also its underground conditions (i.e., whether it has a shallow groundwater level and bedrock layers or underground utilities) must be taken into account to ensure the success of a green street project.

This paper mostly deals with green street projects in the US and further study can include case study projects from different countries of various cultures and policies to implement green streets, thus expanding the scope of investigation. Moreover, it must be noted that 'green street' is not a universally adopted term around the world to describe sustainable street improvement with stormwater management consideration, hence the term needs to be redefined to be more inclusive for the further research. The findings from this paper will contribute to the knowledge database for green street implementation and the developed typology can be utilized as a system to analyze the diverse sample projects with more multifaceted green street approaches (unique aspects) as well as similar approaches (common aspects) of case study projects around the world. Table 6 shows various features of the case studies in the US, Germany, and South Korea as an example for further research. All projects are implemented on residential streets with green street applications that can be categorized with the typology developed in this paper. However, integrated features can be different as shown in the table: The green street in the US has a flush curb to allow the stormwater runoff to flow into the system as well as parking spaces to accommodate the neighbors' needs [42]. The green street project in Germany is simple but practical with reflection poles for vehicular safety and a series of planters implemented along the street for traffic calming effects [43]. The green street project in Korea has a planter type stormwater facility collecting roof stormwater runoff. The stormwater is stored in a tank and pumped automatically to an adjacent planter with a drought detection sensor. This unique automated watering system is operated by solar power. The wall trellises are used for greening the wall for the narrow street [44]. These examples suggest that further research can present diverse features integrated with green street applications, which will help designers and planners to come up with more effective and creative strategies that can be applied to complex and place-sensitive sites. Its focus will be on multifaceted benefits that green streets can provide rather than solely engineering solutions for stormwater runoff from the street.

Table 6. An example of further research: Green street projects in the US, Germany, and Korea.

Green Street Projects	Descriptions
SEA (Street Edge Alternative) Street Project, Seattle, WA (2nd Ave. NW)  ©2019 Google	Land Use: Residential Typology: 2.A-2. Cell type: Natural Catchment Area: Road Integrated Features: Vegetation, flushed curb for water flow into the cell, angled parking, curvilinear street
Birkenstein Innodrain, Birkenstein, Germany 	Land Use: Residential Typology: 2.B-1. Extended curb Catchment Area: Road Integrated Features: Vegetation, raised curb, reflection pole for vehicle safety, traffic calming
Smart Planter, Seoul, Korea 	Land Use: Residential Typology: 2.A.-1. Cell type: Planter Catchment Area: Roof Integrated Features: Vegetation, wall trellis, smart self-watering system powered by solar panel

How green streets can be then discussed in the theoretical paradigm of sustainability? Green streets have been implemented primarily to manage stormwater runoff as one of the strategies of green (stormwater) infrastructure in the built environment in the US. The term green street has been "adopted by many cities to refer to streets that emphasize environmental quality in numerous ways, including reducing pavement widths, increasing tree planting, and incorporating stormwater treatment" [45] (p. 83). However, this stormwater management function is only one component of green streets. For instance, the City of Seattle's definition of green streets in its 'Right-of-way Improvement Manual' [29] includes considerations such as promoting pedestrian-oriented streets, enhancing open spaces, managing traffic speed, and adapting to individual localities. Stormwater treatment is mentioned in the manual, but only as one of the possible applications of a green street system, along with solar access, the preservation of historic buildings or street features, and better utilization of the topographical conditions of the site. The other manuals and reports on green streets and green infrastructure that were discussed earlier also describe multifunctional applications of green streets in a community, primarily including their ability to deal with stormwater. Considering this fact, studies of definitions and multiple potential benefits indicate that green streets need to be understood as satisfying a number of diverse strategic characteristics, which can be categorized by three incremental scales in terms of their developmental paradigm: A strategy for stormwater treatment (targeted narrower development strategy), a strategy for green infrastructure (integrated development strategy), and a strategy for sustainable development (inclusive optimal development strategy). Along with the characteristics presented by green streets, it is critical that green street functions as a street need to be understood in the context of street systems. The following subsections include discussions on these two views.

First, as observed in the previous sections, stormwater treatment function is one of the critical elements that green streets provide. As a component of stormwater treatment systems, green streets are usually integrated with stormwater best management practices (BMPs), such as storm tree planters, bioswales, and permeable paving. BMPs are effective treatments for the improvement of stormwater quantity and quality that utilize "natural drainage mechanisms" with "the infiltration and storage properties of semi-natural features" [46] (p. 17). The Virginia Runoff Reduction Method lists the following possible BMPs [47]:

- Reducing treatment volume and pollutants: Vegetated roof, rooftop disconnection, permeable pavement, grass channel, dry swale, bioretention, infiltration, extended detention pond, sheet flow to filter/open space;
- Reducing pollutants: Wet swale, filtering practices, constructed wetland, wet ponds, manufactured BMP.

In the US cities, extensive tracts of natural lands have been converted into impervious surfaces due to urban development, and these prevent stormwater runoff from infiltrating into the ground [48]. Without some consideration of where and how runoff flows, problems such as polluted water, erosion, and flooding will eventually arise [49]. Thus, green streets can provide effective networks for stormwater runoff conveyance and release, especially when implemented in environmentally sensitive areas with those issues.

Second, green streets pursue the objectives of the green infrastructure approach—which recognizes the larger scope of environmental issues in addition to BMPs when treating stormwater runoff. Boyle et al. described green infrastructure as "natural and engineered ecological systems which integrate with the built environment to provide the widest possible range of ecological, community and infrastructure services" [50] (p. 5). Similarly, Benedict and McMahon stated that green infrastructure is "an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife. . . . [It] is the ecological framework for environmental, social, and economic health" [51] (p. 1). Others have suggested that when green streets are considered for treating stormwater, a watershed approach needs to be adopted, without regard for political boundaries. On-site treatment to enable effective protection of the water quality and protect downstream sites is important, and the plans should consider human health and property as well as ecological preservation [52,53].

The American Society of Landscape Architects has described green infrastructure as "a conceptual framework for understanding the 'valuable services nature provides the human environment'" [54]. The ASLA also characterizes green infrastructure on three scales: (1) At the national or regional level, with a consideration of networks of parks and wildlife corridors; (2) at the urban level, with a consideration of parks and urban forestry as ecologically central hubs; and (3) at the level of buildings, with a consideration of smaller applications such as green roofs and green walls. The ASLA also cites multiple benefits of green infrastructure, such as reducing energy use, improving water and air quality, decreasing solar heat within a city, providing a wildlife habitat, controlling floods, reducing the cost of stormwater treatment facilities and preventing erosion [54]. As one constituent component of green infrastructure recommended by the US EPA, green streets are considered to provide those multiple benefits rather than focusing on only stormwater treatment. Green streets should be applied as a network, reflecting local needs. They play an important role in the larger landscape as a way of improving and protecting the built and natural environments to which the larger ecological conception is applied.

Lastly, green streets can be discussed in the context of sustainable development. Sustainable development follows a holistic approach that promotes balance between human settlements and natural environments in planning processes. The United Nations defined sustainable development in their report, Our Common Future, as a development that "meet[s] the needs of the present without compromising the ability of future generations to meet their own needs" [55] (p. 37). Similarly, the Department for Environment, Transport and the Regions (DETR) in the UK defined it as follows: "sustainability is about ensuring a better quality of life for everyone—now and for generations to come" [56]. These definitions do not mention a specific scope for the concept of sustainable development, although it can be inferred that sustainable development is extensively interconnected with phenomena on the earth that are caused by humans and nature. Other descriptions of sustainable development note that it is "elusive ... [but] important and does deserve attention. ... the core of the idea of sustainability is the concept that current decisions should not damage prospects for maintaining or improving living standards in the future" [57,58] (p. 716). Ritchie and Thomas have described sustainability in urban design as planning a city with more consideration for people. In this sense, "creating pedestrian, cyclists and public transport is a key aspect of sustainable development" [59] (p. 3), a clear contrast to existing built environments that are overwhelmingly automobile oriented. Ritchie and Thomas have described two more aspects of urban sustainability: making a city greener for biodiversity as well as for the well-being of humans and creating a more delightful environment to keep people "secure and happy" [59] (p.3). The specific scope of sustainable elements can be described as follows: "1) To protect natural resources, 2) to use resources efficiently, 3) to strengthen the sense of community, and 4) to consider the regional context" [51]. Moreover, sustainable development is frequently recognized as development that is "ecologically sustainable or environmentally sound" [60,61] (p. 608). Consequently, successful achievement and balance among three aspects of sustainability—economy, environment, and society [55]—in the larger scope of the environment can be promoted by adopting a sustainable development approach, which green streets potentially and optimally aim for.

In conclusion, sustainable urban development does not always include a green infrastructure approach, and a green infrastructure approach does not always include stormwater management considerations (Figure 4). However, the planning and implementation of stormwater management and a green infrastructure do need to be discussed in the context of sustainability, where sustainability means more holistic and renewable strategies for improving and protecting a built and natural environment. As Odum has stated, humans have forgotten that ultimately, they depend for everything on nature, and they are likely to continue to forget this "as long as life support services [from nature] are considered free" [62] (p. 3). Therefore, pursuing sustainable development does not just involve taking into account the well-being of humans or the reclamation of one part of a river corridor but is more about realizing how the elements of an environment are integrated on a larger scale. When we are planning and developing new projects, we need to realize what kind of impact we ourselves, as parts of the environment, will have on the whole environmental system. In this sense, sustainability does not always mean green, but green tries to achieve sustainability.

Figure 4. Green street in three development paradigms.

As an element of green infrastructure, an ideal green street project seems to be one that is designed using a complex strategy for pursuing sustainability. It can "act as a synthesis of a number of other areas of planning (greenways, green spaces, high-density planning) to promote a coherent discipline for future development" [55] (p. 24). Therefore, green streets should be designed differently from a conventional stormwater treatment system, which is solely designed to target a very specific goal such as reducing stormwater runoff or preventing local flooding. The multiple objectives of sustainable development are the ultimate goal for green streets in relation to a given site. This means that green streets need to emphasize a network system approach that can successfully integrate multifunctional disciplines to promote their influence throughout the site.

5. Conclusions

While various definitions of the concept were identified in the previous chapter, green streets are most commonly described as an effective and affordable tool that treats stormwater with plants and soils pursuing multiple benefits for the better quality of life. Green streets embrace stormwater runoff as a resource to do more rather than treating it as harmful waste. Thus, green streets differ from conventional streets because they include stormwater treatment facilities and emphasize multiple benefits such as promotion of pedestrian safety and aesthetic qualities of the environment by incorporating larger (permeable) landscape areas and narrower roads. Types of stormwater treatment facilities vary according to the needs of specific locations and the available space in the right-of-way. Thus, green streets can be considered as a sustainable development approach, fulfilling a variety of environmental, social, and economic objectives so that cities may be more apt to implement green streets with a reduced concern for overconsuming resources. They also maintain all functions of conventional streets by forming the image of a city, connecting destinations, and improving the flow of water. This naturally leads to the study of urban livability at the street level. Green streets should be understood as an approach with multiple visions which include stormwater treatment, green infrastructure, and sustainable development strategies. Openness to the larger sense of what green street projects entail will enable planners and citizens to realize the potential benefits to surrounding communities and help in the planning and promotion of successful green street applications.

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Appendix A

Table A1. A list of green street projects collected for developing the form-based green street typology.

Status	Green Street Projects	Implemented Typology
Constructed Projects	21st Street, Paso Robles, CA	1.B-1. Extended planter: b type, 2.C-1. Median
	Avalon Green Alley Network Project, Los Angeles, CA	4.A. Permeable paving
	Elmer Avenue Neighborhood Project, Los Angeles, CA	2.A-4. Swale type: Natural
	El Cerrito Green Streets Project (First Site) Madison Site, El Cerrito, CA	2.A-1. Cell type: Planter
	El Cerrito Green Streets Project (Second Site) Eureka Site, El Cerrito, CA	2.A-1. Cell type: Planter
	Elmer Paseo Stormwater Improvements, Los Angeles, CA	2.A-4. Swale type: Retention, 4.A. Permeable paving
	Glen Oaks Bioswales and Drywells Project, Los Angeles, CA	2.A-1. Cell type: Planter
	Hacienda Avenue Green Street Improvement Project, Campbell, CA	2.A-1. Cell type: Planter, 2.B-1. Extended planter
	Malibu Hills Stormwater Enhancement and Green Street Project, Calabasas, CA	2.C-1. Median

Table A1. *Cont.*

Status	Green Street Projects	Implemented Typology
	Ocean Park Boulevard, Santa Monica, CA	2.A-3. Swale type: Planter
	Oros Green Street, Los Angeles, CA	2.A-1. Cell type: Planter
	Riverdale Avenue Green Street Demonstration Project, Los Angeles, CA	2.A-1. Cell type: Planter
	The Park Avenue Green Streets, Sam Jose, CA	2.A-1. Cell type: Planter, 1.C-1. Island
	Woodman Avenue River Project, Panorama City, CA	2.C-1. Median
	Buchanan Green Street Project, Mount Rainier, MD	1.B-1. Extended planter: a type, 2.A-4. Swale type: Natural
	Dennis Avenue Green Street, Montgomery County, MD	2.A-5. Covered cell: Tree pit, 2.A-2. Cell type: Natural, 4.A. Permeable paving
	Person Street Innovative Stormwater Greenscape Project, Fayetteville, NC	2.B-1. Extended planter, 4.A. Permeable paving
	Maywood Avenue Stormwater Volume Reduction Project, Toledo, OH	2.A-1. Cell type: Planter
	2110 Strong Rd Se, Salem, OR (Pringle Creek Green Street Project)	1.B-1. Extended planter: a type, 1.B-1. Extended planter: b type
	Holman Pocket Park and Green Street Bike Boulevard Project, Portland, OR	1.B-2. Pocket Rain Garden
	NE Fremont Street Green Street Project, Portland, OR	2.B-1. Extended curb
	Ne Siskiyou Green Street Project, Portland, OR	2.B-1. Extended curb
	Se Ankeny Green Street Project, Portland, OR	2.B-1. Extended curb
	Se Spokane Green Street Bicycle Boulevard Project, Portland, OR	1.B-1. Extended planter: b type
	SW 12th Avenue Between SW Montgomery And SW Mill, Portland, OR	2.A-1. Cell type: Planter
	SW 19th Residential Street And Stormwater Project (between SW Taylors Ferry Road and SW Marigold Street), Portland, OR	1.B-2. Pocket Rain Garden
	Sw Huber Green Street, Portland, OR	2.B-1. Extended planter
	Southwest Stephenson Street Roadside Swales, Portland, OR	2.B-1. Extended curb
	Allen Street Rain Gardens, State College, PA	2.B-1. Extended curb
	Stormwater Planters at Columbus Square, Philadelphia, PA	2.A-1. Cell type: Planter
	Queen Lane Water Treatment Plant, Philadelphia, PA	2.B-1. Extended curb
	Waterview Recreation Center, Philadelphia, PA	2.A-1. Cell type: Planter, 2.A-5: Covered cell: Tree pit, 4.A. Permeable paving
	Deaderick Street, Nashville, TN	2.A-1. Cell type: Planter, 1.B-1. Extended planter: a type, 2.C-1. Median, 4.A. Permeable paving
	Congo Street Initiative, Dallas, Tx	4.A. Permeable paving
	John Marshall Drive Green Street, Arlington, VA (between Yorktown Boulevard and Williamsburg Boulevard)	2.C-1. Median
	Williamsburg Boulevard Between 33rd Rd North and 35th Street North, Arlington, VA	2.C-1. Median
	Winslow Way, Bainbridge Island, WA (at Ericksen Ave NE)	2.A-1. Cell type: Planter
	2nd Avenue NW, Seattle, WA (from NW 117th St. to 120th St.)	2.A-4. Swale type: Natural
	Broadview Green Grid, Seattle, WA	2.A-2. Cell type: Natural
In-Progress Projects	103rd Street Green Improvement Project, LA Co, CA	2.A-3. Swale type: Planter
	Rumrill Boulevard, San Pablo, CA	2.C-1. Median, 2.A-3. Swale type: Planter in progress
	Walnut Street Reconstruction and Streetscape Project, Agawam, MA	2.A-1. Cell type: Planter, 2.A-4. Swale type: Natural in progress
	Flower Avenue Green Street Project, Takoma Park, MD	In progress 2.A-1. Cell type: Planter
	Pringle Creek Green Street, Salem, OR (may be same as 2110 Strong Rd Se, Salem, Oregon)	4.A. Permeable paving
	Lid Retrofit for The Ashland Municipal Parking, Ashland, VA	2.A-4. Swale type: Natural (parking lot), bioretention, permeable paving

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Shared Space and Pedestrian Safety: Empirical Evidence from Pedestrian Priority Street Projects in Seoul, Korea

Haeryung Lee and Seung-Nam Kim *

Department of Urban Design and Studies, Chung-Ang University, Seoul 06974, Korea
* Correspondence: snkim@cau.ac.kr; Tel.: +82-282-05-377

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Abstract: To provide safe and comfortable walking environments on narrow streets without sidewalks, the Seoul city government has implemented the Pedestrian Priority Street (PPS) projects. Based on Monderman's "shared space" concept, the PPS involves applying diverse paving design techniques, particularly stamped asphalt pavement of various colors and patterns. This study investigated the effectiveness of the PPS for pedestrian safety. Data sources were (1) video recordings of the nine concurrent PPS in 2014 before and after the projects were completed and (2) a cross-sectional survey at the nine streets. Two groups of multiple regression models analyzed the objective safety, by using the variables, mean vehicle speed and change in mean speed, which were then compared with subjective safety through a questionnaire analysis. The results found that the design strategies reduced the vehicle speed and increased perceptions of pedestrian safety. These suggest that the PPS principles are practical and feasible ways to tackle the safety problems of narrow streets without sidewalks. Further, vehicle speeds increased on streets where the pedestrian zone was clearly distinguishable from the vehicular zone by applying PPS techniques only at the roadside. Thus, clearly separating pedestrians from vehicular zones, which is neither the original principle nor the intent of the PPS, should be avoided.

Keywords: Pedestrian Priority Street; shared space; paving design; pedestrian safety; walking environment

1. Introduction

Streets and their designs are essential elements of urban living in terms of walking [1–3]. Urban transportation planning has paid little attention to walking since motor vehicles became ubiquitous, but walking remains the main travel mode for the first and last miles of a trip. Beyond its transit functions, it enhances individuals' physical and mental health and the environmental, social, and economic sustainability of cities [4–7]. By considering walking, city streets might be revitalized, declining economies might be revived, and the quality of life might be improved [8–10]. Giving streets back to pedestrians is a common goal of most urban design theories [11–13].

However, cars have long been central to urban transportation planning; therefore, in many cities, streets are hostile to pedestrians. The narrow asphalt streets without sidewalks that typically develop in urban areas are the representative legacy of "automobilism" [14]; they are obvious in the dense megacities of developing countries where infrastructure cannot keep pace with population growth and in the older districts of advanced countries where organic patterns remain, such as Beijing, Ho Chi Minh City, Kyoto, and Taipei. These streets tend to be alleys, back roads, or access streets to commercial buildings in urban residential areas. They are frequently used by pedestrians, who are forced to share them with cars under dangerous conditions.

Korea is no exception to the problem. Its typical urban neighborhoods include many narrow streets without sidewalks, named *i-myeon-do-ro* (back roads) (Figure 1). These streets (less than 12 m wide) comprise about 77.1% of Seoul's total street length [15]. Because they are not wide enough and, therefore, do not have sidewalks, pedestrians share them with cars, enduring unsafe conditions. About 73.7% of Korea's pedestrian traffic accidents between 2013 and 2015 occurred on streets less than 13 m wide [16]; as of 2016, pedestrian fatalities as a share of all street fatalities constituted 40%, the highest among the 34 OECD countries [17]. Even though this might indicate a relatively high share of walking for transportation [18], these figures demonstrate the quality of the usual walking environment in Korea.

Figure 1. Typical *i-myeon-do-ro* in Seoul, Korea (before the project: Sanggye-ro 5-gil in Nowon-gu); *source:* © Daum Roadview (https://map.kakao.com/).

To address this problem, the Seoul city government implemented Pedestrian Priority Street (PPS) projects, based on Hans Monderman's shared space approach [19,20]. The PPS uses stamped asphalt pavements of various colors and patterns, to alert drivers of theirs, and pedestrians' rights of way, and ensure safe and comfortable walking environments for pedestrians. The PPS are considered one of the government's most practical and feasible options in addressing the problems associated with narrow streets. The PPS projects are distinct in that they mainly target *organically* shared streets resulting from narrow widths. This is different from other shared space examples, such as Exhibition Road in London, which has a separate sidewalk and wide width [21]. Because the street space is limited, the PPS projects solely rely on the visual impacts of unique paving designs. However, little is known about the effects of the PPS and its design principles in Seoul.

In this context, this study investigated the effectiveness of the PPS's design strategies. We examined the influences of the various paving designs on changes in vehicle speed (objective safety), and on pedestrians' fears of possible car accidents (subjective safety). The eight PPS sites comprising nine streets in Seoul, that implemented the PPS designs in 2014 were analyzed. Video data were collected before and after implementation, and a cross-sectional questionnaire survey was conducted. We used the results to consider the potential of the PPS and policy directions, in order to enhance pedestrian safety and rights.

2. Literature Review

2.1. The Shared Space Concept and PPS Project

The shared space concept aims to ensure self-regulating streets, where various users, particularly pedestrians and vehicles, interact without physical segregation, traffic regulations, or control devices [19,22]. First proposed in the 1970s, by Hans Monderman, a traffic engineer from the Netherlands, the idea has spread throughout the world in response to the negative effects of motorization [20]. Other terms have been coined to define this concept, such as "simplified streets," "naked streets", and "shared streets"; although different, they all share certain schematic aspects [23]. The fundamental purpose of shared space is to improve pedestrian safety and mobility by reducing the traffic control features that tend to encourage drivers to assume their dominance on the street [23,24]. A core feature is to create some uncertainty in terms of priority for motorists by breaking away from segregating pedestrians from vehicles using barriers.

According to Engwicht, *mental speed bumps* encourage drivers to be more attentive to their surroundings and to slow down [25]. This is similar to John Adams' risk compensation theory, which is applicable to a shared street environment [26–28]. According to this theory, street users can be encouraged to be careful on the street, by preventing them from relying on safety devices and regulations. Presumably, responsibility and conscientiousness occur only in states of uncertainty [26]. Hamilton-Baillie likened the shared space to an ice rink, where users negotiate their activities with "an intricate and unspoken set of protocols" [19] (p. 169). Ultimately, the shared space becomes a self-regulating street, creating a safe and efficient traffic environment that enhances public life [22].

To achieve the shared space goals, the Seoul PPS introduced various paving designs. The Seoul city government aimed to minimize the negative effects of excessive vehicle speed, inappropriate parking, and other reckless behaviors by preventing street users from perceiving the space as typical streets for vehicles. Accordingly, the government-run Architecture and Urban Research Institute (AURI) applied the following design principles when they drew up the PPS design alternatives. First, they used the pedestrian-friendly paving approach, which usually has been limited to sidewalks, for the entire street to encourage pedestrians and drivers to think about the entire street as a pedestrian-priority space. In addition to eliminating barriers such as curbs, fences, and street signs, integrated paving designs also helped to blur the boundary between the pedestrian and vehicular zones. However, the average 2014 budget for the projects in this study was about USD $90,000 including planning and construction costs [29]. The Seoul city government encouraged lower level governments to used stamped asphalt, rather than block-type pavements, because it quickly accepts the desired diverse colors and complicated patterns at relatively low cost. Second, the PPS actively used lined patterns, which occasionally cross the streets at right or diagonal angles and, sometimes, section it to break up the driving space continuity. The lines on the colorful surfaces were intended to create visual impacts that cause deceleration. Although most of the PPS generally observed these principles, the final designs differed from each other. Thus, it is reasonable to expect that the effects of the PPS would vary by design type.

2.2. Optical Illusions to Induce Deceleration

Drivers are highly influenced by the various stimuli they see while driving. According to Cohen [30,31], drivers obtain about 90% of information visually. Because the PPS expected behavioral changes by using indirect approaches, it is important to understand the relationship between the visual elements on surfaces, driving behaviors, and travel speeds. In most shared spaces, pedestrian-friendly pavement materials such as square granite setts, bricks, and concrete blocks were used instead of conventional materials, such as asphalt. The differences in surface texture and color were used to encourage street users to visually distinguish the street from streets in general [32–34]. In addition, shared spaces extensively embrace flush surfaces and street furniture (e.g., benches), and minimize traffic control devices (e.g., signals, lane markings) to create seamless and abundant walking experiences.

These elements, including visual impacts, create a combined effect of deceleration, leading to enhanced walking environments [24,32–44].

Previous studies have also examined the influence of visual disturbances caused just by street surfaces. First, a concrete block pavement, the most widely used method to calm traffic [45], might lead to cautious driving and fewer traffic accidents by making drivers perceive specificity of the streetscape [46,47]. Second, regardless of the type of street markings available (e.g., center lines, peripheral transverse lines, or chevron patterns), previous studies revealed that a series of horizontal lines increased peripheral visual stimulation and caused drivers to instinctively slow down [48–53]. Street markings have been extensively used to slow down vehicles by distorting drivers' perceptions of their speed on a highway, particularly one that is curved [52,54]. Thaler and Sustein described this phenomenon as a representative example of the "nudge effect" in their book, *Nudge* [55].

However, the results might happen not only via an immediate intuition; they might be an alerting mechanism [52]. Zaidel et al. [56] and Chrysler and Schrock [57] suggested the drivers interpret painted stripes on street surfaces as warning signs and, therefore, make conscious decisions to drive slower and sharpen their attention. In other words, they might decide to ignore the stripes after the initial novelty of the lines has faded. On the basis of their research on the PPS, Kim and Shim determined that the visual elements were not sufficient to cause drivers to make decisive behavioral changes, although they contributed to creating a feeling of unfamiliarity [58]. Thus, although they might induce some extent of deceleration, the indirect and visual aspects of the PPS might not be effective in the long term - unless they consolidate their symbolic meanings at an early stage.

In short, previous studies have found that visual differentiation on the street surfaces influences instinctive driving behaviors. However, most of the previous studies about the block pavement and the transverse line markings were conducted on spaces exclusively designated for driving, such as highways, which are different from the narrow *i-myeon-do-ro* where the PPS is implemented. Therefore, we examined the visual impacts of these street surfaces on pedestrian safety. Unlike the previous studies, focusing on single sites, this study comprised all the sites transformed by the PPS in 2014 to strengthen interpretive generalization.

3. Materials and Methods

3.1. Study Area

This study investigated the entire 2014 PPS sites, which were concurrently completed: (1) Bukchon-ro 5ga-gil in Jongno-gu, (2) Dongho-ro 11-gil in Jung-gu, (3) Sanggye-ro 3-gil and Sanggye-ro 5-gil in Nowon-gu, (4) Yeonseo-ro 21-gil in Eunpyeong-gu, (5) Gyeongin-ro 15-gil in Guro-gu, (6) Geumha-ro 23-gil in Geumcheon-gu, (7) Bangbaecheon-ro 2-gil in Seocho-gu, and (8) Godeok-ro 38-gil in Gangdong-gu. Figure 2 shows them relatively evenly distributed in Seoul. Although Sanggye-ro 3-gil and Sanggye-ro 5-gil are one site, they are deemed different streets because of their distinct differences, and therefore nine streets actually were examined. The 2014 PPS design proposals initially were intended to extensively use stamped asphalt pavement with various colors and patterns, but some of them were altered by the *gu* (administrative districts) that wanted to reflect their residents' opinions. As a result, the design principles were more or less well expressed among the study sites.

Table 1 provides basic information on the study sites at both times of data collection. The streets were 8.6 m wide on average, which is relatively narrow. The average street length was 333.8 m, which is shorter than the standard walking distance (400 m). The mean traffic (vehicle) and pedestrian volumes of before implementation were 183 vehicles and 509 people per hour, respectively, indicating that more pedestrians than vehicles used the study sites.

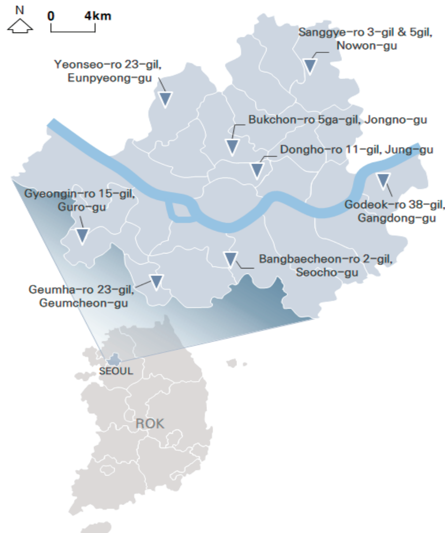


Figure 2. The eight study sites (2014 Pedestrian Priority Street (PPS)).

Table 1. Description of the study sites.

Site Code	Street Name	Street Width (m)	Total Length (m)	Traffic Volume Per Hour [1]		Pedestrian Volume Per Hour [1]		Mean Speed (km/h)	
				Before	After	Before	After	Before	After
1	Bukchon-ro 5ga-gil, Jongno-gu	6.5	240	24	17	628	560	14.86	15.25
2	Dongho-ro 11-gil, Jung-gu	7.5	500	111	61	420	564	18.10	16.97
3	Sanggye-ro 3-gil, Nowon-gu	8.0	150	40	40	1700	1432	13.86	13.11
4	Sanggye-ro 5-gil, Nowon-gu	8.0	220	67	61	269	243	16.47	18.58
5	Yeonseo-ro 23-gil, Eunpyeong-gu	10.0	214	220	245	217	245	22.32	21.35
6	Gyeongin-ro 15-gil, Guro-gu	8.0	400	44	77	195	215	19.22	18.61
7	Geumha-ro 23-gil, Geumcheon-gu	10.0	420	227	223	233	273	23.69	22.84
8	Bangbaecheon-ro 2-gil, Seocho-gu	9.5	430	735	728	592	535	15.16	20.33
9	Godeok-ro 38-gil, Gangdong-gu	10.0	430	183	205	325	293	19.16	26.00
	Mean	8.6	333.8	183	184	509	484	18.09	19.23

[1] Traffic and pedestrian volumes are converted into 'per hour' unit based on the sums of the amounts measured during 15-min data collection periods from 8:30 to 8:45, 16:30 to 16:45, and 19:30 to 19:45; 45 min total time.

3.2. Data Collection

To test the effects of two design types in terms of their objective (observed) and subjective (stated) pedestrian safety, we analyzed video recordings made before and after implementation and conducted a cross-sectional questionnaire survey. The research data were collected by AURI (specifically, this paper's corresponding author collected the data as head of the Pedestrian Environment Research Center, AURI). The videos were recorded at every node and straight-link (between nodes) where the cameras could be installed in September 2014 (before) and June 2015 (after). We finally chose the nine spots on each of the nine streets, which have the straight segment and representative paving designs. The recordings occurred on weekdays when the weather and temperature were similar across days. Camera installation was pre-approved by the district office. The cameras were installed above eye-level to accurately capture all of the street users' activities and record the patterns in the pavement. The sites were continuously recorded from 06:00 to 21:00, and the recorded data, during the three 15-min peak periods, were extracted for analysis: morning (08:30 to 08:45), afternoon (16:30 to 16:45), and evening (19:30 to 19:45). Using this data, vehicle speed was measured as a proxy of objective pedestrian safety. The speed of each vehicle was manually calculated by dividing the distance of the pre-designated section in each street by the time it takes for the vehicle to pass in the videos.

The questionnaire survey was administered once, approximately a year after the 2014 PPS projects were completed (30th September 2015—07th October 2015). Only the residents (70%) or business owners/employees (30%) who had lived or worked near the sites for at least two years were eligible to participate in the survey. The number of respondents per site was between 100 and 106, and the total sample size was 819 people. Because the questionnaire items were about the entire streets, rather than specific locations on the streets, Sanggye-ro 3-gil and 5-gil in Nowon-gu were treated as one location for the survey (but not for the video data). The questionnaire items mainly focused on changes in peoples' perceptions of traffic safety. Although the survey data on subjective pedestrian safety merely provided descriptive data, its function was important to the interpretation of the regression results on vehicle speed.

3.3. Methods of Analysis

Multiple regression analysis was used to assess the effectiveness of the PPS design types, considering the influences of other factors. Vehicle speed is the strongest influence on traffic safety [59], and accordingly, speed variables were used to assess pedestrian safety. We followed convention and assumed that the faster a vehicle moves, the greater the risk of traffic accidents and other threats to pedestrians. There were two groups of regression models, depending on the dependent variable.

3.3.1. Dependent Variables

The first group of the regression models used "mean vehicle speed" at a recording site as the dependent variable. Mean speed was the arithmetic average of the travel speeds of the individual vehicles in the recordings of the three extracted periods at each recording spot. Because there were just nine recording spots in total, the number of observations seemed too few to carry out stable multiple regression results. Therefore, we used the morning, afternoon, and evening recordings before (September 2014) and those after (June 2015) the PPS as separate samples. Thus, the first analysis had 54 observations ($9 \times 2 \times 3$). Gujarati argued that 40 observations would never be too small if a model specification is correctly done [60] (p. 484).

The second group of the regression models used "difference in the mean speed before and after the PPS" as the dependent variable. There were 27 observations (9×3), which did not meet the minimum sample size of 30 observations for regression analysis. However, the regression results were appropriate for verifying the causal relationships found in the first regression analysis.

3.3.2. Independent Variables

The key independent variable was the "type of paving design," where vehicle speed was measured (recording spots). Two criteria for classifying the paving-design types were created, using the data at the recording spots. The first measure was the extent of "visual separation (VS)" between vehicles and pedestrians, which was created by the paving patterns. Three categories of visual separation were developed on the basis of the extent of stamped asphalt and the visual designs, which influence the extent of a sense of a barrier between vehicular and pedestrian zones. The three categories were as follows.

- VS-A: Stamped asphalt pavement covered the entire width of the street and there were no suggestions at the roadside of an exclusively pedestrian zone. This concept was interpreted to intend a genuine coexistence of pedestrians and vehicles.
- VS-B: Stamped asphalt pavement covered the entire width of the street, and there was some suggestion at the roadside of a pedestrian zone. This was interpreted as intending to protect a minimum area for pedestrians, while pursuing user coexistence.

- VS-C: Stamped asphalt pavement covered just a part of the street, which implied that pedestrians should walk within the paved area. This was interpreted as not pursuing coexistence.

We expected that VS-A and VS-B would improve pedestrian safety more effectively than VS-C, because VS-C restricted the pedestrian area and reinforced the idea that street use was exclusively for driving. However, assessing the differences between VS-A and VS-B was complex. Although VS-A more closely adhered than VS-B to the integrative design principle of shared space, VS-B might be more effective under certain conditions. Kaparias et al. suggested that introducing a "safe zone" at the roadside, just for pedestrians, might play an important part in the successful operation of a shared space by increasing pedestrians' mobility and walking freedom [24] (p. 20).

The second measure of the type of paving design was the extent of visually interrupting "driving continuity (DC)," which was based on variation in the transverse and diagonal line designs. The nine study sites were categorized into three groups based on the expected effects of the transverse lines or surface designs as visual interference on consistent driving speed: Specifically, to cause drivers to decelerate. The three DC types are described below.

- DC-A: The lines and surface designs visually impacted drivers by giving the appearance that the street was segmented. We expected that the transverse design would trigger deceleration.
- DC-B: There were some transverse design elements, but they were relatively few; a weaker effect than that of DC-A was expected.
- DC-C: There was no transverse design at the study site; therefore, no segmenting effect was expected.

We expected that DC-A and DC-B would induce more speed deceleration than DC-C. However, similarly to VS, DC had problems in the comparisons between DC-A and DC-B. Kim and Shim argued that drivers cognize the entire change created by a PPS, and the surface design details do not significantly influence their behaviors [58]. Considering that argument, there might be little difference in the effects of DC-A and DC-B on speed.

The method used to categorize the VS and the DC design types was a focus group interview with three experts on 11 January 2019, to eliminate researcher bias. The three interviewees were highly qualified professionals with PhD degrees in the field, who teach urban design as a full-time faculty. We outlined the project and the PPS designs' goals to them, and we showed them pictures of the paving status at each site.

3.3.3. Statistical Analysis

Because of the relatively small sample size, the three dummy variables, which depended on each criterion for classification, were used in both groups of the regression models. Altogether, four regression analyses were estimated. First, a dummy indicator of "before implementation" was used as a reference variable. In the change analysis, the VS-C or DC-C was regarded as a reference variable.

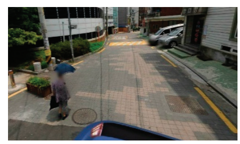
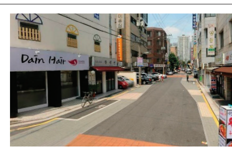
We controlled for the effects of factors expected to influence vehicle speed on shared streets (i.e., street width, traffic volume, and pedestrian volume), with the assumption that the narrower the street and the larger the volume of street users, the slower the vehicle speed. In addition, we controlled for traffic calming devices that might directly influence vehicle speed. The only traffic-calming device at the study sites was a speed bump, which we used as a control variable. To account for factors related to the filming location (intersection or mid-block), a variable, indicating the distance from the recording spot to the nearest intersection entrance, was included ("distance to closest intersection"). Last, dummy variables, indicating "morning" or "afternoon," were included ("evening" was the reference group) to control for the effects of the recording periods. The second regression analysis was about change and it used difference (change) values instead of absolute values for the time-variant variables (i.e., "Δ traffic volume," "Δ pedestrian volume," and "Δ number of speed bumps").

4. Results

4.1. Design Type Classification

Table 2 shows the results of categorizing the nine study sites in the two three-category design type variables. Most, but not all, the VS and DC types were clearly defined. Geumha-ro 23-gil, Bangbaecheon-ro 2-gil, and Godeok-ro 38-gil were obviously VS-C because the stamped asphalt was paved only at the roadside, which created a clear distinction between pedestrian and vehicular zones. Sanggye-ro 5-gil and Gyeongin-ro 15-gil were ambiguous in relation to the pedestrian zone. Sanggye-ro 5-gil had a zigzag design with triangular shapes drawn in a row at the roadside. Gyeongin-ro 15-gil did not have an obvious design, but there was a strip of bright color in the middle in sharp contrast to the color used on the rest of the street. The three experts considered Sanggye-ro 5-gil as VS-B and Gyeongin-ro 15-gil as VS-A.

Table 2. Paving design classifications.

Paving Design	VS Type	DC Type	Paving Design	VS Type	DC Type
	A	C		A	B
Bukchon-ro 5ga-gil, Jongno-gu			Gyeongin-ro 15-gil, Guro-gu		
	B	A		C	C
Dongho-ro 11-gil, Jung-gu			Geumha-ro 23-gil, Geumcheon-gu		
	A	B		C	C
Sanggye-ro 3-gil, Nowon-gu			Bangbaecheon-ro 2-gil, Seocho-gu		
	B	B		C	C
Sanggye-ro 5-gil, Nowon-gu			Godeok-ro 38-gil, Gangdong-gu		
	A	B			
Yeonseo-ro 23-gil, Eunpyeong-gu					

Source: © Daum Roadview (https://map.kakao.com).

Regarding the DC types, Sanggye-ro 5-gil and Dongho-ro 11-gil had transverse lines; however, only Dongho-ro 11-gil was classified as DC-B. The experts determined that the triangular features of Sanggye-ro 5-gil stood out more than the transverse lines, which weakened the lines' impacts. In addition, Sanggye-ro 3-gil and Yeonseo-ro 21-gil were identified as DC-B. Although Sanggye-ro 3-gil had an "X" mark across the street, the experts believed that drivers were unlikely to sense the segmented-street effect because the lines were too close to each other. The effects of the transverse lines at Yeonseo-ro 21-gil were also believed to be marginal because the lines were at the speed bumps.

Because the questionnaire survey covered the entire area of each site, the classification results were changed for Sanggye-ro 3-gil and Sanggye-ro 5-gil, which originally were one site; so, the VS type was merged with VS-B.

4.2. Before and After Comparisons of Speed by Paving Design Type

Table 3 presents the *t*-test results, which compare the mean speeds before to those after the PPS. Regarding VS-C and DC-C, the fastest speeds were observed after the PPS. This is an unintended effect of PPS, which could occur when there is an exclusive driving zone or a lack of transverse designs. This result is still valid when we consider the mean speed of the control group, although it has not been statistically tested due to the limited data.

Table 3. Comparison of speed before to that after the PPS was implemented by design type.

Criteria	Type	Target Group						Control Group [1]		
		Number of Cases		Mean Speed (km/h)				Mean Speed (km/h)		
		Before	After	Before	After	Change Rate (%)	*t*-Value	Before	After	Change Rate (%)
VS	A	246	285	20.33	19.64	−3.39	1.16	17.90	16.58	−7.33
	B	133	92	17.49	17.46	1.54	−0.33	15.92	18.25	14.66
	C	858	867	17.49	21.82	24.76	−11.37 ***	18.86	21.67	14.87
DC	A	83	46	18.10	16.97	−6.24	0.90	18.57	23.23	25.13
	B	278	318	19.99	19.67	−1.60	0.58	17.08	15.07	−11.76
	C	876	880	17.43	21.72	24.61	−11.38 ***	18.28	21.08	15.32

[1] The control groups were selected for each target site where the mean speed can be extracted through Seoul TOPIS (Transport Operation and Information Service) among the streets most similar and nearest to the target sites. Since it is not possible to obtain individual vehicle speed of control group, only average values are presented. (http://topis.seoul.go.kr). * = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.

4.3. Multiple Regression Results on Paving Design Types

Tables 4 and 5 show the multiple regression results. The adjusted R^2 values of mean vehicle speed models were 0.71 and 0.70, which is relatively high; those of the change in speed models were 0.34 and 0.29. All of the variance inflation factors were less than 10 (data not shown). The results are explained in two table sections depending on the two classification methods (VS and DC).

Table 4. Multiple regression analysis by design type (dependent variable: mean vehicle speed at recording sites); $n = 54$.

Variable	By VS Type			By DC Type		
	B	***t*-Value**	***p*-Value**	**B**	***t*-Value**	***p*-Value**
VS Types: "before implementation" is reference variable.						
VS-A	−0.752	−0.770	0.446			
VS-B	−0.359	−0.276	0.784			
VS-C	3.189	2.758	0.009 ***			
DC Types: "before implementation" is reference variable.						
DC-A				1.202	0.653	0.517
DC-B				−1.103	−1.122	0.268
DC-C				2.171	2.260	0.029 **
Time Slot: "evening" is reference variable.						
Morning	3.886	3.983	0.000 ***	4.037	4.103	0.000 ***
Afternoon	−0.158	−0.172	0.864	0.068	−0.073	0.942
Street width (m)	1.470	3.708	0.001 ***	1.887	4.853	0.000 ***
Distance to the closest intersection (m)	0.023	0.420	0.676	−0.001	−0.022	0.983
Traffic volume (vehicles/15 min)	−0.020	−2.292	0.027 **	−0.021	−2.315	0.025 **
Pedestrian volume (people/15 min)	−0.017	−5.052	0.000 ***	−0.016	−4.677	0.000 ***
Existence of speed bumps	0.580	0.670	0.506	1.019	1.213	0.232
(Constant)	6.405	1.781	0.082	2.943	0.862	0.394
Adjusted R^2		0.71			0.70	
D-W		1.93			1.96	
F		13.70			13.42	

* = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.

Table 5. Multiple regression analysis by design type (dependent variable: differences in the mean speeds before and after the PPS); $n = 27$.

Variable	By VS Type			By DC Type		
	B	***t*-Value**	***p*-Value**	**B**	***t*-Value**	***p*-Value**
VS Types: "VS-C" is reference variable.						
VS-A	−7.200	−3.041	0.007 ***			
VS-B	−5.772	−1.893	0.076 *			
DC Types: "DC-C" is reference variable.						
DC-A				3.139	0.584	0.567
DC-B				−3.694	−2.162	0.045 **
Time Slot: "evening" is reference variable.						
Morning	0.155	0.096	0.925	0.403	0.238	0.815
Afternoon	0.936	0611	0.550	0.901	0.566	0.579
Street width (m)	0.074	0.092	0.928	1.404	2.030	0.058 *
Distance to the closest intersection (m)	−0.177	−1.634	0.121	−0.294	−2.251	0.038 **
Δ Traffic volume (vehicles/15 min)	0.050	0.391	0.701	0.032	0.249	0.807
Δ Pedestrian volume (people/15 min)	−0.032	−1.975	0.065 *	−0.039	−2.181	0.044 **
Δ Number of speed bumps	−3.087	−1.756	0.097 *	−0.641	−0.258	0.800
(Constant)	7.953	0.990	0.336	−4.758	−0.766	0.454
adjusted R^2		0.34			0.29	
D-W		1.59			1.47	
F		2.50			2.19	

* = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.

4.3.1. Results by VS Type

As expected, only VS-C was positively and significantly associated with mean speed ($p < 0.10$) after controlling for the effects of other factors. The finding indicates that vehicle speed was faster on average as the distinctions between the vehicular and pedestrian zones became more obvious. Moreover, VS-A and VS-B were negatively associated with the change in traffic speed, compared to VS-C (Table 5), meaning that VS-C had the smallest influence among the three levels of distinction in improving pedestrian safety. It also supports the contention that the application of the PPS design principles was effective.

The survey results further support this interpretation (Table 6). The percentage of respondents who answered that they experienced a decrease in vehicle speeds, collision risks, and the number of vehicles overtaking pedestrians were the lowest in the VS-C group, whereas the percentage of negative responses to these items was the highest. However, the number of positive responses on pedestrian safety was higher at VS-B sites, which ambiguously indicate pedestrian zones, than at VS-A sites, which more closely reflects the PPS principle of coexistence. There are some possible reasons for this finding. First, residents' subjective perceptions are from the pedestrian's perspective, but the change in speed reflects changes in driving behavior. In other words, even if the PPS induced deceleration, pedestrians might not perceive an improvement in safety. Moody and Melia found similar results [42,43]: Despite a significant reduction in average traffic speed and the number of traffic accidents after the shared space concept was implemented at Elwick Square in Ashford, UK, most of the pedestrians perceived that the situation was safer before the change, or they were still concerned about being hit by cars. Moreover, regardless of speed change, the respondents seemed to prefer a somewhat segregated walking space. Kaparias et al. proposed a "safe zone" in shared spaces to encourage walking freedom by increasing pedestrians' comfort [24] (p. 20). In other words, the perception of safety supposedly offered by a designated pedestrian zone might influence people's perceptions of safety.

Table 6. Survey result: Perceptions of pedestrian safety by Visual Separation (VS) types.

Category	Strongly Agree/Agree	Neutral	Strongly Disagree/Disagree	*n*
1. As a Pedestrian, I Feel the Vehicle Speed has Decreased.				
VS-A	31%	33%	36%	309
VS-B	38%	20%	41%	206
VS-C	27%	12%	61%	304
2. As a Pedestrian, I Feel the Risk of Collision with the Vehicle has been Reduced.				
VS-A	31%	36%	33%	309
VS-B	46%	32%	22%	206
VS-C	28%	31%	41%	304
3. As a Pedestrian, I Feel the Number of Vehicles Overtaking Pedestrians has Decreased.				
VS-A	31%	36%	33%	309
VS-B	48%	31%	21%	206
VS-C	28%	27%	45%	304

4.3.2. Results by DC Type

Table 4 shows that DC-C, which had no transverse designs, was statistically significant and positively related to speed change ($p < 0.10$), and Table 5 shows that DC-B was negatively associated with the differences in the mean speeds, compared to DC-C (reference group). These results suggest that transverse markings were important in achieving the PPS goals. However, only Dongho-ro 11-gil was in the DC-A category, which may have influenced the statistical non-significance. Even so, the presence of the transverse lines seems to contribute to improving the walking environment more than their absence. A comparison of the average speed changes at the study sites after the PPS to before it was implemented, considering only the presence or absence of these lines, shows a significant speed reduction where the transverse lines were applied.

The survey data revealed a high percentage of positive opinions about safety at DC-A sites, which clearly emphasized the transverse designs (Table 7). In relation to DC-B, where the transverse designs had a smaller visual impact than DC-A, the responses were less positive about safety than they were for DC-C, which has no transverse line designs. Most of the study sites in the DC-C category were also in the VS-C category, which presents an exclusively pedestrian zone. Thus, people's preference for clearly marked pedestrian areas might have influenced these results.

The effects of the control variables generally were as expected. Study sites with narrow street widths and large traffic and pedestrian volumes experienced slower average driving speeds after the PPS were implemented. In addition, the farther the distance to the intersection and the more speed bumps, the stronger the impact of speed change in the negative direction.

Table 7. Survey result: Perceptions of pedestrian safety by driving continuity (DC) type.

Category	Strongly Agree/Agree	Neutral	Strongly Disagree/Disagree	*n*
1. As a Pedestrian, I Feel the Vehicle Speed has Decreased.				
DC-A	43%	9%	48%	100
DC-B	28%	32%	40%	313
DC-C	31%	18%	51%	406
2. As a Pedestrian, I Feel the Risk of Collision with the Vehicle has been Reduced.				
DC-A	53%	33%	14%	100
DC-B	26%	36%	38%	313
DC-C	34%	31%	35%	406
3. As a Pedestrian, I Feel the Number of Vehicles Overtaking Pedestrians has Decreased.				
DC-A	57%	26%	17%	100
DC-B	26%	39%	36%	313
DC-C	35%	27%	38%	406

5. Conclusions and Policy Recommendations

This study examined the influences of the PPS paving design types on safety and the perception of safety (the main goals of PPS), using video analysis and survey research. The results suggested several things. First, even when there was a difference by type of paving design, traffic speeds were slower at the study sites where the PPS paving strategies were faithfully applied. Where the pedestrian and vehicular zones were clearly distinguished using PPS techniques, however, vehicle speeds were faster after than before the PPS were implemented. Vehicles traveling at high speeds are more dangerous to pedestrians when the level surfaces are used for pedestrian zones. In sum, the PPS design principles should be followed to avoid adverse outcomes.

These findings are useful for informing government officials and residents about the value of PPS paving designs. When the PPS projects were implemented in 2014, it was difficult to persuade residents of the value of the designs because they did not understand the projects and there were no empirical data to prove its effectiveness [29]. Most of the survey respondents wanted a completely independent pedestrian zone in the final design plan, which changed the original plans for several sites [29]. The municipal governments, which prioritized the local residents' opinions, ultimately used stamped asphalt pavement only for the parts of the street that would create exclusive pedestrian zones. This study's results provide evidence for avoiding that approach, which conflicts with the PPS's original intention, in future projects.

The PPS approach might be useful to other metropolitan cities with narrow asphalt streets without sidewalks. The low cost and rapid construction time are obvious advantages of using stamped asphalt pavement. Moreover, the shared space concept, which causes a paradigm shift toward coexistence among street users, might be a feasible option for solving problems with sidewalk installation. In this sense, the PPS is a reasonable transitional solution to achieve pedestrian-friendly environments, although, on the basis of our findings, its benefits might be realized only when its principles are followed.

Last, related policies are needed to ensure appropriate PPS implementation, as Kim and Shim argued, regarding promotion, speed control, guidance, and the physical improvements [58]. It is most important to legally ensure safe and convenient walking on shared streets. Currently, Korean legislation does not guarantee or protect pedestrians' rights on these streets. The Road Traffic Act (Article 8) states that, "on a road that is not divided into a sidewalk and a roadway, pedestrians shall walk on the fringe of the road in the direction opposite to horses and vehicles or the side of the road" [61]. Until the law protects pedestrians' right to unrestricted walking on *organically* shared streets, people are compelled to walk defensively, even on the PPS streets.

Despite its contributions, this study has several limitations. Although we obtained speed data on every vehicle that passed through the recording spots of the study sites, we had to average them, and other information about individual vehicles, such as driver characteristics, travel purposes, and so on was not available. This limitation might have created an ecological fallacy. Because the number of values decreased by using the mean, it was difficult to simultaneously verify all the types of PPS designs. To overcome these limitations, we analyzed separate regression models. We also could not fully control for the effects of natural changes over time because the design and data did not allow for testing a control group; however, we minimized the effects of these limitations by using the nine PPS sites that were concurrently completed.

More discussion is needed regarding the establishment of distinct pedestrian zones at PPS sites. We tried to inform this discussion by classifying the design types in two ways, but conflicting results were found depending on the perspective. Although safety was objectively determined as better when the PPS principles were followed, there was a gap between the objective results and the residents' subjective perceptions about safety. It would be helpful to harmonize these points through future research, in order to help improve future PPS plans.

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The Paradox of "Eyes on the Street": Pedestrian Density and Fear of Crime in Yaoundé, Cameroon

Paul Emile Tchinda [1] and Seung-Nam Kim [2,*]

1 Department of Urban Development and Policy, Chung-Ang University, Seoul 06974, Korea; tchindapaule@gmail.com
2 Department of Urban Design and Studies, Chung-Ang University, Seoul 06974, Korea
* Correspondence: snkim@cau.ac.kr; Tel.: +82-2-820-5377

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Abstract: Most studies highlighting the link between the urban environment and fear of crime (FoC) have focused on less populated spaces in urban areas, and concluded that the presence of activities and people in a space makes its users more confident. This study analyses the paradoxical phenomenon of FoC in occupied public spaces in the setting of Yaoundé, Cameroon. To this end, this study analyses the relationship between intersection level, pedestrian density and perceived FoC. The results of the multi-level binary logistic regression demonstrate that women, vulnerable age groups, people with a weak sense of community and high-income people tend to express a higher level of FoC. Among the major FoC theories, these results confirm the theories of physical vulnerability and social networks and invalidate the theory of social vulnerability in the local context. The results also reveal that the relationship between "pedestrian density" and FoC seems to be a convex curve with the minimum value, implying that the concept of 'eyes on the street' is not valid in places where pedestrian density exceeds a specific threshold. This suggests that policy makers and planners should consider pedestrian density when designing public spaces, not only to secure wellbeing, but also due to the impact it can have on perceived FoC among those who use such spaces.

Keywords: street life; pedestrian density; fear of crime; quality of life; density threshold theory

1. Introduction

The observation that 'insecurity is everywhere in the city of Yaoundé' was made two decades ago as part of the *Diagnostic Study of Urban Crime in Yaoundé, Cameroon* and remains relevant today [1]. According to the 2017 report of the National Institute of Statistics (INS in French), the safety situation has deteriorated throughout the country over time. From 2013 to 2016, the number of crimes recorded by the police and related to property offences ('thefts and stolen goods', 'robberies with firearms and assaults in taxis' and 'home and business robberies', etc.) rose from 29,632 to 53,142, representing an increase of approximately 80%. In the same period, crimes relating to physical injury (homicide, assault, etc.) rose from 6084 to 11944, representing an increase of approximately 96% [2] (p. 173), a figure that continues to increase in the various urban centres. This security crisis reflects the urban context in Cameroonian cities, which are marked by the proliferation of slums, increased youth unemployment, aggravation of urban disorder, the spread of informal activities, deterioration of existing urban infrastructure, etc. [3], all of which contribute to residents' fear of crime (FoC) and low quality of life. To address this scourge, State interventions have focused on increasing security equipment, including the police reform resulting from Decree No. 2002/003 of 4 January 2002 on strengthening police intervention in the fight against urban crime, creating new gendarmerie units in Yaoundé by Presidential Decree of 2 October 2001, as well as the establishment of Special Rapid Intervention Units. Most of these interventions started in 1998 when Cameroon was preparing to apply for the hosting of the African Union summit and the security issue was a major factor in the choice of the country to host the summit. More recent actions have also been taken to install CCTV and improve public lighting at certain points considered criminogenic in urban centres. In August 2019, the political and security authorities inaugurated the CCTV command centre of the national police in Yaoundé. Despite these efforts, the situation on the ground remains extremely worrying, raising the question of the relevance of the diagnosis and the proposed solutions. In fact, apart from the few actions listed above, the strategy adopted at the national level has not considered the role of better land management in reduction of FoC.

Previous studies have demonstrated that certain defensible characteristics of space and territoriality have contributed significantly to reducing the level of perceived FoC [4] (p. 81). One of the first and most widespread studies on the subject was conducted in the 1960s under the doctrine of situational prevention, which took shape in the United States under the leadership of Jane Jacobs. Jacobs considers that safety in public space is guaranteed "when a street has what it takes to open up to the outside world, when, in this street, the public domain is clearly distinguished from the private domain and when activities, such as eyes, are sufficiently numerous ... " [5] (p. 34). According to Jacobs, therefore, the securing of a space does not depend primarily on police presence, but is held together by a complex and almost unconscious network of the population itself. She goes on to argue that a well-frequented city street is likely to be a safe street, whereas a deserted city street tends to be dangerous. Considering the example of well-lit subways, she also notes that light alone is not sufficient to guarantee safety in a space. Effective eyes are also required. For example, in darkened theatres where eyes are present, crime is almost non-existent. Thus, according to Jacobs, the presence of 'eyes on the street' can guarantee safety and thereby reduce FoC. The link between crime and FoC is made based on the findings of numerous studies that have concluded that the higher the level of crime in a community, the more likely it is that community members tend to express a greater FoC compared to communities with comparatively lower levels of crime [6,7]. For example, using British Crime Survey data, Brunton-Smith found that recorded crime has a direct and independent effect on FoC at the individual level [7]. Similar results are obtained by Markowitz et al. [8] and Wyant [9]. However, by referring to the statistical data on crime and FoC in the city of Yaoundé, particularly the Central Post Office area, which is the largest crossroads in the city centre, the results obtained are relatively mixed. Indeed, despite being densely populated with people, activities, and even police stations, this area continues to be perceived as a dangerous space [10]. The populations of the city of Yaoundé who converge daily in the city centre to conduct their activities feel insecure in a space that would a priori be secure due to the considerable number of people, activities, and police stations; hence, the paradox of the 'eyes on the street' concept exists in the context of Yaoundé.

Overall, the study of population density as a factor influencing crime level, and therefore FoC has received considerable attention from researchers [11]. However, previous studies have had mixed results. While Schuessler [12] and McPherson [13] found a positive correlation between population density and crime level, other authors such as Kvalseth [14] found a negative correlation. More recent studies with advanced technology in data collection techniques dissociated the mobile and residential populations for more relevant analyses. Thus, by referring to the mobile population, these studies showed that these population categories had a considerable impact on crime rates [15–17]. Malleson et al. explored the impact of ambient population measures on crime hotspots in London and showed that areas that were less conducive to attracting volumes of people (predominantly residential areas) had a higher proportion of crime attractors to stimulate crime [18]. Meanwhile, at the national level, little research has been conducted on this issue [19] (p. 54) and in most of the planning documents and strategies implemented by the Ministry of Housing and Urban Development, the issue of FoC is overlooked. The purpose of this study is to analyse the paradoxical phenomenon of FoC in spaces that conform to the principles of security planning in the setting of Yaoundé city. More specifically, it aims to investigate the relationship between FoC and pedestrian density of intersection. Referring to the mixed results of previous studies, and taking into account the paradox observed in our study area, we thus postulate that: 'high pedestrian density increases FoC at a congested intersection with higher density than a certain threshold level'.

2. Literature Review

2.1. Fear of Crime and Its Determinants

The definition of 'Fear of Crime' is not unanimously accepted by researchers, perhaps because our understanding of FoC is largely based on how it is measured rather than how it really is [20] (p. 658). Put simply, FoC can be understood as a set of emotional reactions that occur out of fear of being a victim of certain types of crime [21] (p. 126) or symbols associated with the crime [22] (p. 23). Considered as such, FoC would be the result of a coherent process. However, several studies have shown that this is not the case. One of the 'paradoxes' identified by scientific experiments is the great difference between the low victimisation of certain categories of people (such as women and the elderly) and their particularly high FoC [23] (p. 160). In a defining and otherwise widely accepted approach, Shepherdson [24] (p. 1) and Lee [25] (p. 33) argue that FoC is not a 'coherent' entity, but 'an experience or set of experiences that are deeply individual'. In an earlier definition, Skogan noted the existence of a link between FoC and a broader set of modern anxieties, 'a diffuse psychological construct affected by a number of aspects of urban life' [26] (p. 14). Thus, in this study, we define FoC as an individual's emotional and physiological response when confronted with symbols associated with crime.

The concept of FoC was first introduced in the 1960s [27] (p. 33). Originally discussed by criminologists, it has gradually become an area of growing interest for researchers [28] (p. 14). A significant number of studies have demonstrated that certain defensible characteristics of space and territoriality contribute significantly to reducing the level of perceived FoC [4] (p. 81). For example, from the 1970s onwards, Oscar Newman's work brought crime closer to its physical context (the neighbourhood, house, company, and public space). Newman focused mainly on how urban planning and architectural devices can reduce or prevent crime and FoC from occurring and his numerous publications from 1972 to 1996 enabled him to explore in greater depth how space management can lead to FoC control [6]. This work by Newman and criminologist C. Ray Jeffery, based on previous publications by authors such as Elizabeth Wood [7], Jane Jacobs [4], and Schlomo Angel [8], gave birth to the concept of Crime Prevention Through Environmental Design (CPTED) in the early 1970s, which was considered to be a crime prevention approach that can help reduce feelings of FoC through natural, mechanical, and procedural means [3] (p. 81). Furthermore, these studies cumulatively made it possible to deduce five different theories of FoC. Although these theories have been widely accepted by all researchers, the prevailing debate has focused on how to construct a measure of FoC, what indicators should be considered [29] (p. 8), what the causes of FoC may be, and how to mitigate them [27] (p. 18). Factors influencing the level of FoC identified in previous studies have been summarised by Austin et al. [30] (p. 418) into three main areas of interest: (1) demographic effects, (2) victimisation experiences, and (3) neighbourhood and urban condition. In his report for the Auburn City Council, Shepherdson detailed the following factors: gender, age, socio-economic status, prior victimisation, ethnicity, media, neighbourhood factors, lack of neighbourhood cohesion, specific locations, and global insecurity [24]. Overall, however, little research has been conducted to examine how the overcrowding of a space influences the level of perceived FoC. This lack of interest is understandable since many previous studies have concluded that a space is more secure if there are 'eyes on the street'. However, this statement is still the case, which led to the idea of this study, to address the issue of FoC in densely exploited and occupied urban spaces.

2.2. Pedestrian Density and Fear of Crime

Although few studies have analysed the association between FoC and pedestrian density in a given space, several studies have focused more broadly on the relationship between crime and density. In 2010, with the support of the U.S. Department of Justice Office of Community Oriented Policing

Services (the COPS Office), Khadija et al. published a guide on street robberies [31]. According to the authors, the density of pedestrians influences where robberies occur on the street. However, since the densest activity centres are subject to more extensive surveillance, very few robberies are recorded in these areas. In the peripheries, on the other hand, the reduced number of robberies is justified by the reduced number of targets. Thus, the areas most targeted by offenders are located between these two extremes. While it is true that 'extensive surveillance' and 'number of targets' defined by Khadija et al. actually influence the offender who wishes to move to the criminal act, what is not clear is the degree of influence of these parameters, since some parameters are obviously minimised and ultimately give the impression that they no longer really count. For example, Bernasco et al. in their study utilise the discrete choice framework to assess which criteria motivate the location decisions of street robbers [32]. The authors identified several other criteria: (1) the proximity of the crime scene to the offenders' place of residence, (2) the accessibility of the crime scene, and (3) the presence of legal and illegal cash economies [32]. For this reason, we disagree with the approach adopted by Khadija et al., particularly with regard to the link between population density and the level of crime on a given street.

Our position is more or less justified by the results obtained by Chen et al. [33], who, on the basis of statistical data from a Chinese city (not specified by the authors), examined the impact of a floating population on residential burglaries. Using a negative binominal model and a geographically weighted Poisson regression model, the authors found that 'the floating population of other provinces has a significant positive impact on residential burglaries, while the impact of the floating population of the same province on burglaries varies across the city' [33] (p. 13).

Using a similar approach to that presented above, Lee et al. [34] also studied the relationship between crime and population flow in a Korean city. By overlaying the sedentary and floating population hotspots and crime hotspots of the city under study, the authors found that there is a strong correlation between the two types of hotspot (0.5297 with $r = 0.71$) but no correlation between the sedentary population hotspots and crime (0.0948 with $r = -0.13$). The authors thus conclude that, 'Given the population flow pattern of urban residents, high population density in particular time periods and spaces may greatly affect crime occurrence' [34] (p. 7). Another important result of Lee et al.'s work is the location of criminal acts. According to the authors, the areas or activities of people who have changed significantly based on their location are the most vulnerable. These are specifically those areas between residential and commercial areas [34] (p. 10). Although these results were obtained in an analysis related to crime and not to FoC, we believe that they are quite revealing insofar as, crime and FoC variables are positively linked [28,35–40].

However, concerning studies on the FoC itself, there are theoretical studies to understand how urban design, urban planning and management influence the fear of crime. Examples include approaches such as Crime Prevention Through Environmental Design (CPTED) [41] and Crime Prevention through Urban Design and Planning (CP-UDP) [42].

Also, using applications and crowdsourcing to collect more accurate spatial and temporal data, Solymosi et al. explored the fear of crime based on people's experiences in their immediate environment. This approach allows the authors to inform evidence-based policy making and urban planning for safer places [43] (p. 35). Additionally, by applying digital sketch maps and statistical GIS methods, Jakobi et al. found both in coincidences and opposite correlations of crime statistics and perception of unsafe places [44].

2.3. Fear of Crime in the Context of Yaoundé

In recent years, Cameroon has been facing major security crises. The northern regions of the country are under attack from the terrorist group Boko Haram, while the eastern border faces threats from gangs and armed groups scouring neighbouring countries but making incursions into Cameroon [45] (p. 3). In addition to these two major crises, there is also the crisis in the North-West and South-West Regions. According to the International Crisis Group report, in 20 months, the conflict has killed 1850 people, displaced 530,000 internally, and displaced tens of thousands of refugees [46].

These crises have had a significant impact on the FoC situation in the city of Yaoundé. Although there are no up-to-date data to quantify the phenomenon, exchanges with experts and heads of security services demonstrate that the feeling of insecurity is increasing in the city. This opinion must be taken with great care. Indeed, it is generally accepted that security officials often tend to exaggerate the real situation on the field. However, to support their position, they refer to the significant migratory inflows to the capital city of refugees from other regions and neighbouring countries [45].

Even before these crises, however, the security situation was already in bad shape. In 2001, all actors (populations, civil society, and religious leaders) were already calling for the government to take responsibility for security, an issue that was considered to be of great concern [1] (p. 28). The 2014 national survey conducted as part of the Governance, Peace and Security (GPS) programme, which included a representative sample of 4926 randomly selected households, found that 29% of adults had been victims of assault or robbery in the 12 months preceding the survey. This investigation also revealed that most crimes and misdemeanours are not reported and when they are, it is not necessarily to the authorities in charge of security (police and gendarmerie) but to acquaintances who may be friends or relatives. In addition, 7% of the households surveyed consider that the risk of being a victim of crime is high, while 21% think it is rather high. Another important result of this survey is the feeling of mistrust in interpersonal relationships. Indeed, approximately half of the households surveyed (49%) said that they did not trust most of the people around them [47] (p. xi). In a survey organised as part of the diagnostic study of urban crime in Yaoundé, 89% of respondents stated that their neighbourhood is not safe [1] (p. 91). This widespread sense of insecurity may explain the ineffectiveness of Jacobs' principle of presumption of general support for people [5] (p. 55).

3. Data and Methods

3.1. Study Area and Data Collection Method

The study area covers five intersections in Yaoundé, Cameroon: (1) Central Post Office, (2) Carrefour Bata, (3) Carrefour Mokolo, (4) Vog-Ada, and (5) Etam Bafia (Figure 1). These hubs were selected on the basis of criteria such as: compliance with CPTED principles, the presence of a nearby police station, and relatively high density. At each intersection, a spatial delimitation of the area considered in the study was carried out as shown in Figure 1.

For contextual and efficiency reasons, we opted for data collection by the paper-based method, entitled Interview Paper and Pencil (IPC). The on-field interview in the study areas was conducted for three weekdays (8, 9, and 11) on July 2019. To control for potential impacts of brightness level on FoC, the interview was conducted only during the daytime (from 10 a.m. to 6 p.m.). To carry out the data collection in the field, a team of 5 interviewers consisting of 2 male urban planners and 3 female social science students were involved, and they were divided into two teams with one urban planner each.

Because the target population of this study was pedestrians on the five intersections, it was difficult to apply any pre-designed systematic sampling techniques. In addition, due to the severely congested local context, probability sampling method like stratified or random sampling could not be applied either. Accordingly, we had to adopt a non-probability sampling method, the so-called 'street corner sampling'. That is, each interviewer team approached the pedestrians present on the sidewalk (within red lines in Figure 1), asking for their consent before submitting the questionnaire. Although we did not count the exact number of people we approached, a significant number of them did not wish to respond to the questionnaire. Great care was taken to avoid any form of discrimination on the basis of age, ethnicity or any other discriminatory characteristics of the respondents, as the objective of the interviewers was to obtain the opinion of as many people as possible. Finally, a total of 186 pedestrians were surveyed. However, only 185 samples were used in the analysis because one respondent did not want to continue with the survey after completing the first part of the questionnaire. Apart from this, to preserve as many observations as possible, a mean imputation approach was applied when treated minor missing values in two variables: Income Level and Sense of Community (Table 1).

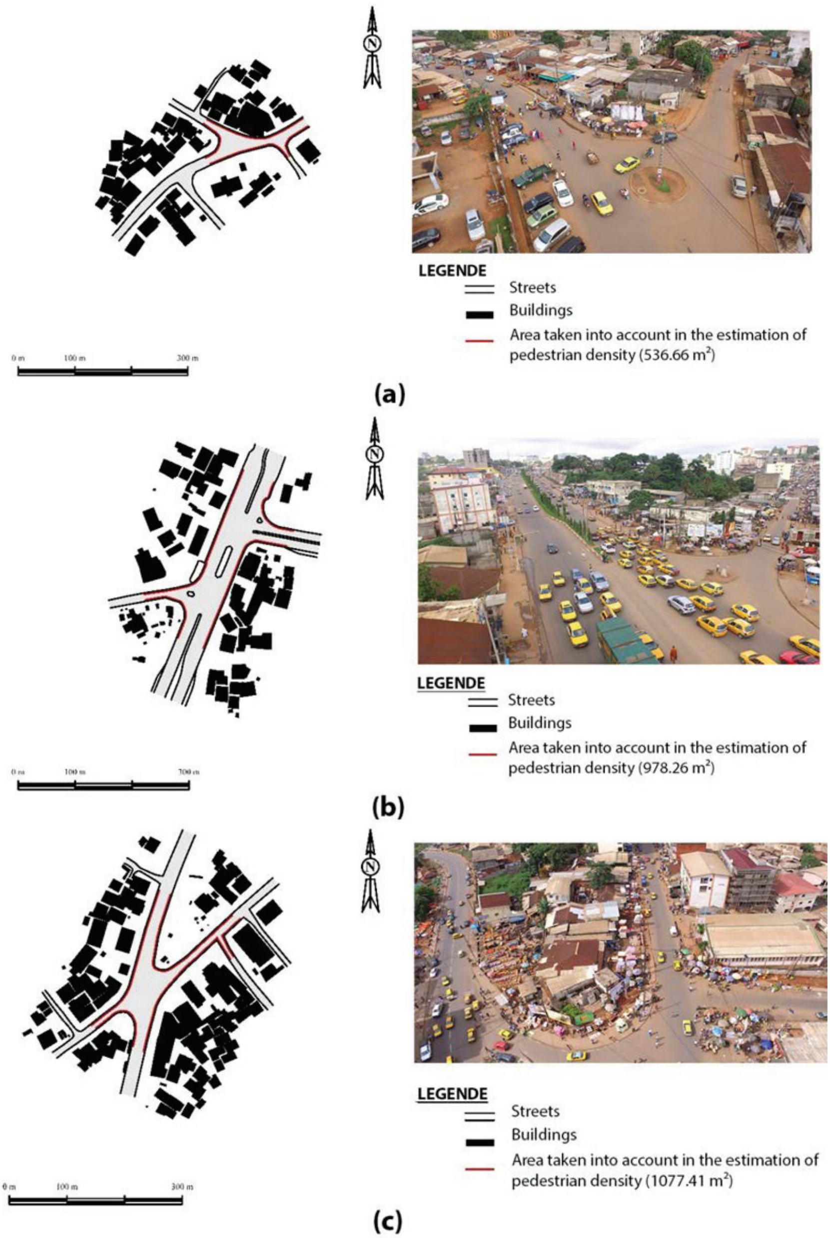
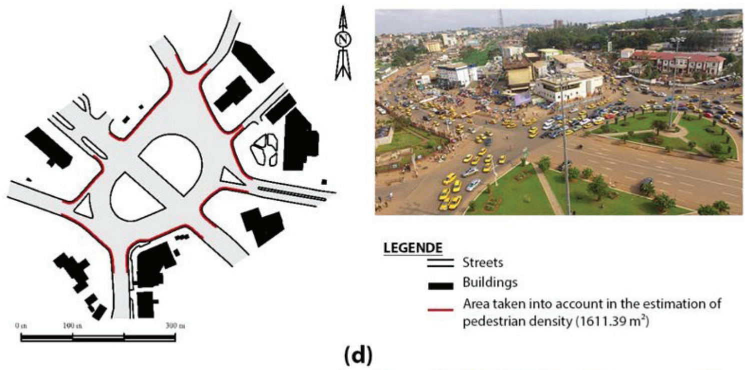


Figure 1. *Cont.*



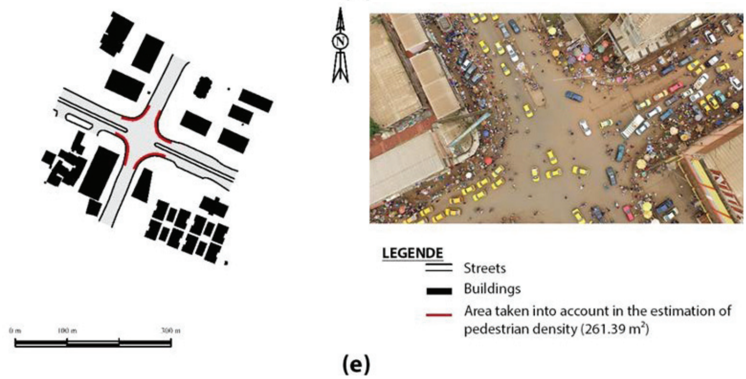


Figure 1. Intersection map: (**a**) Etam-Bafia (**b**) Bata (**c**) Vog-Mbi (**d**) Central Post (**e**) Mokolo. Note: We used several photos for each intersection to count people. The images presented above only aim to show the whole area of each intersection we are interested in.

Table 1. Definitions and descriptive statistics of the variables.

Variable	Description	Mean	S.D.	% of Cases = 1
Dependent Variable				
Fear of crime	Perceived FoC defined using two questions (yes = 1) (See Table 2)			28.1%
Individual-level independent variables				
Female	Reference group is male			25.4%
Vulnerable age group	Minors and the elderly (under 20 or 50 or more)			10.3%
Single	Reference group is married, divorced, and widowed			71.9%
Religion				
Christian	Reference group is other religions			72.4%
Muslim	Reference group is other religions			16.2%
High income HH	Larger HH income than average ($117)			44.9%
Victimisation experience				
Heard of a crime	Reference group is 'no experience'			10.8%
As a witness	Reference group is 'no experience'			35.7%
As a victim	Reference group is 'no experience'			38.4%
Strong sense of community	Reference group is weak sense of community			41.6%
Positive stance on CCTV	Agreed that CCTV could reduce fear of crime (yes = 1)			65.9%
Time of the day	Time of the day at which the survey was conducted (between 10 a.m. to 6 p.m.)	14.362	2.256	
Good weather	Weather condition was good when the survey was conducted (yes = 1)			88.1%
Intersection-level independent variables				
Pedestrian density	Number of people on the sidewalk divided by its area (person/m^2)	0.719	0.437	
Pedestrian density^2	Pedestrian density squared	0.707	0.857	
Bus stop	Presence of bus stops at the intersection (Presence = 1)			39.50%
N = 185				

Table 2. Interviewees' responses on the two questions regarding Fear of Crime (FoC).

		Are You Frightened to Cross the Intersection?		Total (Count)
		No (Count)	Yes (Count)	
Do you feel like making a detour if approaching the intersection?	**No**	133	**14**	147
	Yes	**6**	**32**	38
Total (count)		139	46	185

Note: Bold cases were defined as people who felt FoC.

Each survey had an average duration of 30 min including the time taken to explain the purpose of the survey to the respondent. The questionnaire was structured into two main parts: (1) perceived FoC and (2) general socio-demographics, respectively served as dependent and control variables in the analysis. Details are described in Section 3.2. (Variables and Model Specification).

To measure intersection-level key test variable (i.e., 'pedestrian density'), we used aerial photographs (snapshot) taken by drone on the same day with the interview. Because a single still image cannot capture whole area of each intersection, we took 4 (Bata and Etam-Bafia) to 17 (Central Post) photos for each area and stitched them to count pedestrians on the sidewalk. Every photo had a resolution high enough to distinguish a person. We calculated the surface area of the sidewalk using the city map produced as part of the Yaoundé City Master Plan and available in AutoCAD format.

In our multi-level analysis, the number of clusters were very small, just five. However, Austin's Monte Carlo study suggested that five or less clusters can be considered, "as long as the number of subjects per cluster exceeds approximately 30" [48] (p. 18), and this study met this minimum requirement.

3.2. Variables and Model Specification

As shown above, the data of this study are nested (i.e., pedestrians nested within intersections). While FoC and other socio-demographics are measured in individual level, pedestrian density is measured at the intersection level. Therefore, we applied hierarchical linear modelling (particularly, multi-level binary logistic regression analysis) using the IBM SPSS 25 software.

Level-1 variables include dependent variable and control variables. The dependent variable, 'fear of crime', was defined using two dichotomous choice questions: (1) "are you frightened to cross the intersection?" and (2) "do you feel like making a detour if approaching the intersection?" (see Table 2). Both questions were selected based on the results of previous study [49], in which they concluded that an individual's level of FoC could be observed and understood at different psychological levels such as perception, cognition, and behaviour. Namely, the two questions were designed to capture these three dimensions of individual perception of FoC. By our operational definition, the pedestrians who answered "yes" to any of the two questions were defined as feeling FoC. Because respondents were likely to say "yes" to the above two questions due to the fear of traffic accidents, we asked them to answer the questions, considering only fear of crime before asking.

The other level-1 variables include various control variables deduced from the five theories of FoC summarised in the work of Vilalta [50] and other literatures suggested below.

(1) *Victimisation theory*: this theory is based on the assumption that people who have previously been victimised by crime are likely to suffer from a higher level of FoC than those who have not [35,51]. Regarding this, we applied the 'victimisation experience' variables, which was measured by the following question: "have you ever been a victim of a crime, personally witnessed a crime, or heard of a crime in your surroundings?".

(2) *Physical vulnerability theory*: based on an analysis at the individual level, the theory of physical vulnerability is the feeling that people with physical limitations are likely to exhibit a higher level of FoC. With respect to this theory, previous studies have demonstrated that women and the elderly expressed the highest levels of FoC [35,50]. We also applied 'gender (female)' and 'vulnerable age group' variables. Based on the legal age of adulthood and average retirement age in Cameroon, a vulnerable age group was defined as the minor (under 20) and the elderly (50 or more).
(3) *Social vulnerability theory*: this theory is based on the assumption that socially vulnerable people, including minorities, low-income people [52], and the least educated [53], tend to express a higher level of FoC. The variables considered in most of the research related to this theory are education levels, income, occupation, and unemployment [53–55]. For the purposes of this study, the variable considered is 'income level'. This variable was measured by asking respondents if their monthly income was higher than the average gross monthly income per inhabitant of $117 (67500 F CFA) in Cameroon.
(4) *Social disorder theory*: the theory predicts that a neighbourhood's physical condition; social composition; function; and reputation (vagrancy of adolescents, outdoor drug sales, street fights, graffiti-covered walls, empty and dilapidated housing, dirty sidewalks, etc.) have an impact on the residents' FoC. Regarding this theory, previous researches considered age structure of the local population, criminal activity, proportion of vacant houses, poverty levels, and family structure variables [50]. In view of the local context characterised by a general state of degradation of almost all the intersections, this theory was not taken into account in this study.
(5) *Social network theory*: there are two schools of thought underlying this theory. The first group argues that people in the socially connected communities express a lower level of FoC due to the informal social control by the community [56]. Conversely, the other group suggests that the rapid spread of victimisation news in connected communities makes people perceive a higher level of FoC [35]. In this study, we linked the variable 'sense of community' to this theory. Using a 5-point Likert scale, respondents were asked the following question: "do you feel like a member of this community?" We then defined 'agree (4)' or 'strongly agree (5)' as a strong sense of community.

In addition to them, marital status, religion, stance on CCTV, time of the day, and weather condition were applied as level-1 control variables.

As explained above, level-2 (i.e., intersection level) variables include our key test variable: 'pedestrian density'. This was defined as the number of people on the sidewalk captured by drone photographs divided by its area (person/m^2). To test the potential non-linearity discussed in Section 1, we took quadratic regression forms by applying both density and density squared variables. Table 1 shows the definitions and descriptive statistics of the variables.

4. Results

4.1. Descriptive Statistics

Table 2 shows that only 25% and 20% of respondents were afraid to cross the intersection and felt like making a detour to avoid crossing intersection. Based on this, only 52 respondents (approximately 28%) were defined as people who felt FoC at the intersections. Considering the increasingly degraded security situation throughout the country [45] and UN-Habitat's report that found that 89% of people in Yaoundé considered their neighbourhood to be unsafe [1] (p. 91), the low percentage of people reporting FoC was well below our expectations. However, the relatively small percentage obtained could be explained by the fact that our survey was conducted in a public place. Most of the persons surveyed were at the intersections in question, and felt more or less comfortable using these spaces.

Table 3 describes the frequencies of reporting FoC and the pedestrian density by intersection. The result of Fisher's exact test showed that the proportion of people who felt FoC significantly varied across intersections at 0.01 probability level. However, the relationship between the proportion of people who felt FoC and the pedestrian density of intersection was not significantly associated ($p = 0.104$) although they showed quite high positive correlation (0.800). Thus, we need to test this hypothetical relationship that 'high pedestrian density increases FoC at a congested intersection with higher density than a certain threshold level' after controlling for other factors.

Table 3. Fear of crime and pedestrian density by intersection.

Intersection	Number of Respondents	Fear of Crime (Yes = 1)	Fear of Crime (No = 0)	Area (m^2)	Pedestrian Density (Person/m^2)
Bata	34	5 (14.70%)	29 (85.29%)	978.26	0.46
Etam-Bafia	45	14 (31.11%)	31 (68.89%)	536.66	0.30
Mokolo	33	18 (54.54%)	15 (45.45%)	261.39	1.58
Central Post	38	8 (21.05%)	30 (78.95%)	1611.39	0.79
Vog-Mbi	35	7 (20.00%)	28 (80.00%)	1077.41	0.62
Total	185	52 (28.10%)	133 (71.89%)	4465.11	0.67

Note: The proportion of people who felt FoC significantly varied across intersections at 0.01 probability level (results of Fisher's exact test). The proportion of people who felt FoC and the pedestrian density of intersection was positively associated (Pearson correlation = 0.800), but the significance level was marginal ($p = 0.104$).

4.2. Results of Multi-Level Binary Logistic Regression Analysis

Table 4 presents the results of multi-level binary logistic regression models of FoC. Model 1 is an intercept-only (unconditional) model and Models 2 and 3 are random intercept models with different set of independent variables.

Table 4. Multi-level binary logistic regression models of 'fear of crime'.

	Model 1: Unconditional Model			Model 2: Random Intercept Model with Level-1 Variables			Model 3: Random Intercept Model with Level-1 and -2 Variables		
	B	p	Exp(B)	B	p	Exp(B)	B	p	Exp(B)
Fixed effects									
Intercept (grand mean)	−0.981	0.004 ***	0.375	−2.279	0.223	0.102	0.520	0.854	1.682
Individual-level variables									
Female				1.122	0.009 ***	3.071	1.107	0.011 **	3.025
Vulnerable age group				1.631	0.008 ***	5.108	1.654	0.010 ***	5.228
Single				−0.137	0.756	0.872	−0.128	0.779	0.880
Religion									
Christianity				0.407	0.563	1.503	0.367	0.608	1.443
Muslim				0.135	0.871	1.144	0.047	0.955	1.048
High income HH				0.721	0.088 *	2.057	0.719	0.096 *	2.052
Victimisation experience									
Heard of a crime				0.417	0.600	1.518	0.211	0.798	1.235
As a witness				0.512	0.408	1.669	0.405	0.525	1.499
As a victim				0.251	0.683	1.286	0.154	0.804	1.167
Strong sense of community				−0.997	0.022 **	0.369	−0.977	0.028 **	0.376
Activity in the target area				0.313	0.478	1.367	0.176	0.693	1.192
Positive stance on CCTV				−0.015	0.863	0.985	0.020	0.827	1.020
Time of day				0.248	0.714	1.281	0.455	0.515	1.576
Good weather									
Intersection-level variables									
Pedestrian density							−11.864	0.085 *	0.000
Pedestrian density^2							6.627	0.065 *	755.157
Bus Stop (Presence = 1)							1.439	0.221	4.219
Random effects									
Level-2 variance	0.420	0.290		0.373	0.358		0.061	0.879	
ICC	0.113			0.102			0.018		

Note: Number of observations = 185; number of clusters = 5; *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$; ICC: intraclass correlation; In multi-level logit models, level-1 variance is assumed to be $\pi^2/3$ [57].

In the intercept-only model result, intraclass correlation (ICC) was 0.113. This means that 11.3 percent of the probability of feeling FoC is attributable to differences between intersections. However, the insignificant level-2 variance in the model indicates that the usefulness of ICC values as well as the necessity of multi-level analysis are not valid. Thus, we interpret the rest of the result based on the general standard of binary logistic analysis.

First, the results showed that females were more likely to feel insecure than males. The value of odds ratio indicates that female respondents are three times more likely to express FoC than males. This observation is consistent with the result of previous studies [35,39]. This result also suggests that vulnerable age groups (minors and the elderly) tend to express higher level of FoC than middle-aged adults (20 to 49 years old). The odds ratio indicates that the likelihood of expressing FoC is almost five times higher for minors and the elderly than for adults. This result confirms again the theory of physical vulnerability, which states that people who are more physically vulnerable (minors, the elderly, and female) are likely to exhibit a higher level of FoC.

Second, the models revealed that people with a strong sense of community were more likely to feel insecure than people with a weak sense of community. This can be explained by the fact that there is an informal network of mutual support between strongly tied community members. It follows the same logic as Social Network Theory, which states that communities in which members are better connected are more effective collectively in reducing FoC.

Thirdly, the coefficient of the 'income level' variable showed that the respondents with higher monthly income than the average (about $117 per person) expressed higher level of FoC. This result contrasts with the principle of social vulnerability, which is based on the assumption that socially vulnerable people, particularly minorities and low-income people, express a higher level of FoC [52]. This can be explained by the local context that, as high-income people are in the minority, they must take a greater effort to secure their goods and properties. In fact, in the city, or even in the country as a whole, a high rate of poverty, unemployment, and crime overflows. The findings explained so far are true for both models with and without intersection-level variables.

With respect to the intersection-level variables, two density variables showed significant association with FoC at the 0.1 probability level; however, the signs conflicted with each other. This means that the relationships between pedestrian density of intersection and the expressed FoC seem to be convex curves with the minimum value. Meanwhile, the choice to include the two variables ("density" and "density squared") in our model comes from the fact that the results obtained by introducing each of these variables separately proved not to be significant. Indeed, when we introduce only the variable "density" in Model 3 and remove the variable "density squared", we obtain a coefficient equal to 0.899 and a p-value equal to 0.257 for this variable. On the other hand, when we introduce only the variable "density squared" and remove the variable "density", we obtain a coefficient equal to 0.501 and a p-value equal to 0.196 for this variable. Although the p-values are not statistically significant at a 0.1 probability level, both variables commonly showed positive signs, in contrast to the results in Model 3. This means that when we control for one of them, the other's effects can be more accurately identified. This also reveals that the quadratic regression approach of this study is more effective than the general approach using single density variable to identify the non-linear relationships between the key variables. Thus, we can conclude that Jacob's concept of 'eyes on the street' is not valid in places where pedestrian density exceeds a certain threshold level like Yaoundé city intersections considered in this study. We discuss the implication of this result in the following section.

5. Discussion

There have been widespread ideas that the more people and activities in a space, the more secure it is and therefore the lower the feeling of FoC is. Indeed, in the old influential theorists' works like Wood [58], Jacobs [5], Angel [59], and Newman [60] or even in the recent works of Marzbali et al. [4], this idea remains very present. However, the key finding of this study disputes this preconceived notion. In some selected intersections in the Yaoundé city context, this study revealed that a high pedestrian density at an intersection above a certain threshold contributes to an increased FoC, thereby leading to low quality of life. As explained in Section 2.3., the distinctive contexts in Yaoundé city such as high crime rate, low level of social capital (mutual trust) [1,45,47], and overcrowded public spaces could be seen as main causes of such discrepancies between previous studies and this study. This suggests another theory that can be considered in understanding FoC, which we have called 'density threshold theory', based on the principle that there is a density threshold beyond which an urban environment affects an individual's feeling of FoC. This theory could have applications in many other fields. For example, the minimum standard for public spaces could be established in terms of occupancy density. One important indicator to be considered would therefore be the 'density threshold' above which the space is considered unsuitable. Similar ideas exist in other areas. In architecture, for example, many countries regulate the maximum number of people per room by setting the Minimum House standards (Korea, UK, and France). In urban planning, the standard of 100 people per acre (248 ppha) is generally considered a necessary minimum for effective transportation and service [61] (p. 149).

The next issue we should consider is how to reduce FoC although Cordner [62] (p. 4) listed the main arguments against the adoption of targeted police measures to do it. FoC is a real phenomenon that deeply affects individuals and the community, and as a result, living continuously in a state of fear can significantly affect quality of life. Thus, it is necessary to take appropriate measures to mitigate this impact. According to the findings of this study, securing enough pedestrian-only spaces (e.g., sidewalk) in intersection areas may be one potentially effective measure in reducing FoC. This would reduce the density of pedestrians. Another measure to preserve pedestrian space is to prohibit all forms of illegal sidewalk occupations including informal activities, illegal parking, and temporary occupation of the sidewalk by vehicles and motor taxis when there are traffic jams. However, this measure must be examined with great caution with regards to the particular case of the prohibition of 'informal activities'. In fact, such activities are essential sources of income for many households, and therefore, in the case of displacement, it is important to take measures to provide displaced persons with fair and just compensation. Another measure to reduce pedestrian density would be to move bus stops away from the intersection and to adopt more appropriate zoning in general to move away from the intersection activities that attract a large density of people, such as markets and shopping centres. Overall, all measures that help reduce the number of people gathered and to encourage a more balanced use of the intersection area would be welcome. However, attention should be paid to the consequences of these measures at the same time. These measures should be targeted for greater effectiveness and adapted to the local context. Thus, more studies targeting specific areas are needed, like this study.

6. Conclusions

This research aimed to explore the paradox of the phenomenon of FoC in areas that meet the principles of security planning. We initially hypothesised that 'high pedestrian density positively influences the feeling of FoC at a congested intersection with higher density than a certain threshold level'. To verify this hypothesis, we first identified the widely accepted theories of FoC and then established the link between the theories and the context prevailing in the city of Yaoundé. This approach enabled us to identify local specificities and to contextualise the different variables that explain an individual's FoC. This then led us to adopt multi-level binary logistic regression analysis as an analytical tool in view of the nature of our variables and the objective of this study.

The key finding of the analysis is that pedestrian density may increase people's FoC in congested public spaces. In fact, the result revealed that the relationships between both key variables seem to be convex curves with the minimum value. The hypothesis is thus confirmed. One of the major implications of this result is the need to consider the density of pedestrians in the design of public spaces, not only in terms of comfort, but also in terms of reducing the feeling of FoC among users of these spaces.

Another significance of this study is that our analysis results confirm the theories of physical vulnerability and social networks and invalidate the theory of social vulnerability among the major FoC theories in the local context. Indeed, physically vulnerable people (particularly female, minors, and the elderly) or people with a weak sense of community were likely to express higher level of

FoC. In contrast, people with lower income than the average tended to lower level of FoC unlike theoretical expectation.

The main difficulty encountered in this study, which is also a limitation, was the data collection and potential selection bias of the sampling method. Due to the reluctance of many people to engage in the interview, some variables showed large gaps between the characteristics of population and sample groups. For example, 75% of the respondents were male. Furthermore, in the age category, only 10% of those surveyed were minors or elderly people.

Another major shortcoming was the limited number of study areas (only five intersections). Although this met the minimum requirement of multi-level analysis [48], the results of the analysis may seem to be unstable. There may be a possibility that the main findings might result from one single intersection's unobserved characteristics. Thus, this paper should be regarded as an exploratory study that identifies the type of the relationship between pedestrian density and the expressed FoC. To confirm this finding and increase its generalizability, we believe that the results of this study need to be compared to further research focusing on diverse study areas.

Lastly, due to the lack of automated pedestrian counting system in the city, and more generally the difficulty of accessing modern data collection techniques (mobile applications, GPS, mobile phone data, etc.), we solely depended on the drone images when we measured pedestrian density. To overcome this, we recommend that future studies collaborate more with the city's security services, which have the advantage of having a pre-existing database as well as automated pedestrian counting system such as static/mobile sensors.

An additional valuable direction for further research would be to find exact density threshold. To create safer environments based on the results of this study, it is important to define the threshold above which the density of pedestrians in a space can be considered a factor in creating FoC among those who use that space. However, the research data and method used in this study did not perfectly allow us to define this threshold. In future research, this objective can be achieved by using virtual reality technologies, which make it possible to reproduce the urban environment virtually and thereby to test the different density hypotheses by asking respondents to express their feelings when immersed in the virtual environment. This approach could also be beneficial in recreating different types of physical environments that are fairly representative of urban diversity and thus take into account the various contexts. In addition, to find exact density threshold, it would be also desirable to use large random samples that cover various urban contexts. We hope that this research, combined with other related research in this field, will be used to establish a new concept: 'Improving the Urban Environment through Density Management' (IUETDM).

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sustainability

Article

Effectiveness of Fear and Crime Prevention Strategy for Sustainability of Safe City

Seng Boon Lim [1,*], Chee Kong Yong [2], Jalaluddin Abdul Malek [1,*], Mohd Fuad Mat Jali [1], Abd Hair Awang [1] and Zurinah Tahir [1]

1 Social Environmental and Developmental Sustainability Center (SEEDS), Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia; fuad@ukm.edu.my (M.F.M.J.); hair@ukm.edu.my (A.H.A.); zurinahtahir@ukm.edu.my (Z.T.)

2 Federal Government Administration Center, PLANMalaysia (Federal Department of Town and Country Planning), Corporate Division, Ministry of Housing and Local Government, 2nd Floor, Block F5, Complex F, Precinct 1, Putrajaya 62675, Malaysia; yong@planmalaysia.gov.my

* Correspondence: lims@ukm.edu.my (S.B.L.); jbam@ukm.edu.my (J.A.M.)

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Abstract: Crime is a manifestation of incivility that society attempts to curb, yet faces enormous challenges, as crime is a by-product of urbanization and human advancement. As more agglomeration of the population in cities around the globe, humankind's safety from being threatened by crime needed to be safeguard to sustain everyday living in cities. Humans' co-existence with crime and fear of crime in cities vis-a-vis efforts preventing it from occurring has been widely carried out in developed countries. An increasing trend is showing in emerging and developing countries. Therefore, this article provides empirical evidence regarding a safe city program launched in Malaysia. This study aims to identify the factors contributing to the prevention of crime and fear of crime. This study employed a survey questionnaire to 400 pedestrians' perceptions of Kuala Lumpur city's central business district. The result showed that prevention methods through the actor of "capable guardians" (i.e., authorities) are effective; however, methods through the actor of "suitable victims" (i.e., communities) is ineffective. Further studies should explore perspective of the actor of "likely offenders" (i.e., criminals) to fill in the gap of safe city program's effectiveness and sustainability.

Keywords: broken windows theory; crime prevention through environmental design (CPTED); crime prevention methods through social development (CPSD); criminology; delinquency; routine activities theory; safe cities; safe streets; urban studies

1. Introduction

In tandem with human civilization's advancement and the rapid urbanization trend, urban crimes have always been a threat to urban dwellers [1]. Classic statistics reported an increasing trend in the crime rates of robbery, aggravated assault, forcible rape, and homicide in the United States from 1960 to 1975 [2]. However, more recent data by the United Nations Office on Drugs and Crime [3] showed a decreasing trend in 2003 to 2018 globally, particularly in the category of robbery, serious assault, and cities homicide paradox in sexual violence (Figure 1). Proposed solutions have been implemented to combat society disorders but still seem unable to prevent such from happening in safe city planning [4]. One of the explanations for this phenomenon from a criminology perspective is that crime is a by-product of human civilization, and incivility is a part of the nature of human behavior [5]. Thus, humans must admit and accept living in co-existence with these disorders or evil acts while deliberately finding ways to reduce crime and the fear of crime [6].

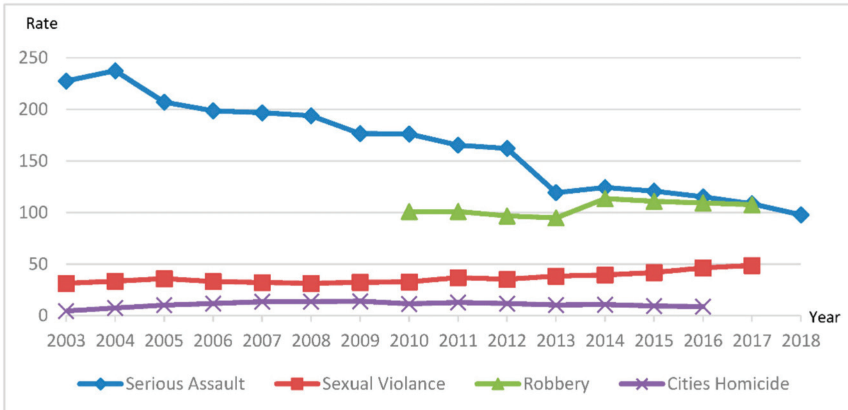

Figure 1. The world crime rate, the selected category (source: plotted from [3]). Note: All data plotted on rates of police-recorded offenses per 100,000 population.

In the United States and most European countries such as the United Kingdom, combating crime has proven to be a long battle for governors, city officers, and police officials [7]. In 1996, the United Nations launched a safe city program due to the increasing crime trends in Africa and throughout the world [8]. Following that, ref [9] has published a guideline on crime prevention for governments. Emerging and developing countries, including Malaysia, have welcomed this idea and launched its Safe City Program in 2004, followed by a revision in 2009 [10,11]. Scholars who have studied the Malaysian case have shown that many local authorities have implemented such programs, but the programs' assessments are still lacking [12,13].

The Safe City Program in Malaysia refers to creating a crime-free environment using strategies under the scope of designing the physical environment, target hardening and management, community involvement, and public awareness [11]. Thus, from this perspective, the crime-free environment is threatened by human-made insecurity, which constitutes mainly property and violent crimes. It excludes the war and terrorism, health and environmental pollution issues, natural disasters, and digital security. This paper does not examine why crimes happen. Instead, it considers crimes as perceived by the respondents in the survey and examines how a safe city program helps people translate crime prevention into routine activities factors. Besides crime, the sense of fear of crime has frequently been highlighted in many studies, and some researchers have even commented that the inner fear of crime has caused more trouble in life than real crimes [14]. Thus, this study aims to identify the factors preventing crime and fear of crime by conducting a case study of the central business district in Kuala Lumpur.

2. Literature Review

2.1. Prevention of Crime and Fear of Crime in Theory

Criminal act is a frequent outcome of interaction between criminally motivated individuals and opportunities for crime [15] (p. xiv). Offenders' motives are considered the root causes of crime, while opportunity refers to the chance afforded to potential offenders to commit crime. Thus, to decrease crime rates, the most effective strategies incorporate the reduction of both motive and opportunity [16]. Broadly, three methods of accomplishing both these tasks have been outlined in the literature. The traditional and earliest strategy involved the threat of arrest and sanction: penal systems in which laws were enforced, and police actions to bring suspects into the courts for judgement and sentencing procedures. The second method focuses on reducing opportunities and possibilities for criminal acts, whereby city authorities prioritize measures involving environmental design.

Thirdly, beyond enforcement and environmental design, alternative motive reduction programs have been introduced covering a range of topics such as education, literacy enhancement, problem-based learning (PBL), conflict resolution, youth mentoring, personal development exercises, job creation, and economic revitalization. Related courses have included parenting and self-confidence skills, emotional intelligence and anger management training, and technical skills acquisition. Under the scope of safe city studies and the responsibility of city authorities, the authors will mainly discuss crime prevention through environmental design (CPTED) and social development (CPSD).

As a place-based crime prevention strategy, crime prevention through environmental design (CPTED) has been promoted since the initial ideas by [17], followed by [18] on defensible space, and consequently formally coined by [19]. This phase is considered as the development of the first generation of CPTED, which draws on environmental and behavioral psychology and consists of seven principles, namely territoriality, natural surveillance, access control, target hardening, legitimate activity support, space management and image, and the influence of geographical juxtaposition [20]. The second generation of CPTED, as promoted by [16,21,22], has added the social aspect of the community, including social cohesion and collective efficacy, in response to criticisms that CPTED was physically deterministic and ignored essential social elements. The importance of social cohesion and collective efficacy has further illustrated in various perspectives and links to crime prevention and fear of crime by scholars such as [23–26].

According to [5], the social aspect in the second generation of CPTED includes an environmental design that suits the human scale and pedestrian-oriented land uses and activities, urban meeting places, resident participation, community culture, neighborhood capacity, community connectivity, inclusion, and identity. Among these elements, the primary concern is on community participation in the self-policing of neighborhoods. These concepts are mainly derived from "eyes on the street" by [27], which recognizes the importance of community "eyes" and their value in promoting the sense of a "caring community." Further, a study by [28] suggested that environmental designs should consider pedestrian density when designing public spaces and impact the perceived fear of crime among those who use such spaces. In recent developments, another attempt has been made to establish the third generation of CPTED through the theory related to human needs (such as [6,29]). However, these are still in early conceptual discussions and require further empirical testing.

Meanwhile, the strategy of crime prevention through social development (CPSD) arguably overlaps with the second and the proposed third generations of CPTED, except that CPSD is motive reduction-oriented [16]. CPSD recognizes the underlying complicated social, economic, and cultural processes that encourage crime and create an atmosphere of fear of crime [29,30]. CPSD attempts to bridge the gap between criminal justice programs and social support for communities, families, and individuals by preventing the causes that allow crime and victimization to happen. In other words, CPSD refers to social programs designed to solve the fundamental causes of crime: poverty, homelessness, inadequate parenting, issues with individual personality and behavior, poor education, harmful peer associations, unemployment, substance abuse, cultural conflict, family dysfunction, social alienation, and unequal distribution of resources [31,32]. In short, most of the CPSD programs are long-term, large scale strategies and criticized by [29] as not suitable for short term policies and implementations.

To clarify this concept, the authors maintain that only one type of CPTED focuses on environmentally related designs for crime prevention, while the second and third generations of CPTED are actually variations of CPSD which mainly refer to social programs or meetings, and which expand upon CPTED (see example cases of Reno in Nevada, New Haven in Connecticut, San Romanoway in Toronto, the suburb of Eagleby in Queensland, Australia, the aboriginal youth project in the Kimberly region of Western Australia, as in [16]). CPTED prioritizes territoriality control, while CPSD focuses on building social cohesion in specific community contexts. Thus, in this study, initiatives beyond those related to environmental design strategies, such as community policing, are regarded as CPSD initiatives.

Literature on crime prevention strategies from around the globe also reveals evidence that the effectiveness of such methods has encountered both support and criticism. Reference [33] reviewed CCTV surveillance used for crime prevention and concluded that CCTV is associated with both significant and modest decreases in crime. Reference [23] investigated seven U.S. cities (Denver, CO; Des Moines, IA; Indianapolis, IN; Louisville, KY; Providence, RI; San Antonio, TX; and Seattle/White Center, WA) and indicated a positive relationship between perceived social cohesion and informal means of social control in urban neighborhoods. Using data from the Seattle Neighborhoods and Crime Survey, ref [26] critiqued its collective efficacy with the intention of expanding its scope into informing community-based practice. In studying 10 island cases of Cape Verde, West Africa, ref [34] suggested the principles of CPTED should consider neighborhood rehabilitation or design from an early stage. After researching the nature of crime in Nigeria, ref [35] confirmed that crime prevention measures assisted in the continued decline of crime rates. However, ref [35] also observed and reported the emergence of an unprecedented range of crimes, such as human trafficking, kidnapping, abduction, drug sales, thuggery, and terrorism, all recent developments whose intensity has multiplied since 2000 when Nigeria became a democracy. Despite their imperfections, these crime prevention methods are improvements on those which simply ignore safety concerns [36].

From a theoretical perspective, these crime prevention methods are derived from environmental criminal/crime opportunity theories, such as routine activities theory, broken windows theory, rational choice theory, crime pattern theory, and awareness theory [15,37]. The key aspect of environmental criminology is assessing the pattern of crimes, especially in urban areas. It measures how emotion-led behavior is influenced by external factors. These comprise several shifting aspects: spatial/geographical, temporal, and legal. Variables also include the offender, the victim, and the guardian [37]. In this study, the authors selected the two most cited and seminal crime opportunity theories for discussion, namely the routine activities theory by [2] and the broken windows theory by [38].

The arguments of routine activities theory are derived from crime observations and socio-economic statistics trends linked to the theory of human ecology by [39]. Following [39], three important temporal components of community structure—rhythm, representing the actors, namely the offender, victim, and guardian; tempo, representing violation events; and timing, representing the right timing that prompts an event to occur—form the everyday routine activities linked by [2]. This understanding of how spatial-temporal trends and fluctuations in social conditions or crime rates can be constructed and further explored locally helps to improve the Safe City Program in Malaysia. For example, in a specific spatial and temporal structure of routine activities, crime events are most likely to happen in specific patterns. Therefore, one can identify the exact location, type, and quantity of illegal events and educate potential victims and potential guardians in a given society or community. Hence, the timing of work, schooling, and leisure may be of central importance in explaining crime rates [2].

Based on an analysis of longitudinal aggregated data for the United States throughout 1947–1974, Cohen and Felson concluded that household activities were a more significant and positive factor in explaining the official change in crime rates involving homicide, rape, and assault, as compared to age structure (i.e., 15–24 years old) and unemployment rate. Household activities refer to marital status attributes, such as has never been married, married, separated/divorced, or widowed. The separated/divorced status variable showed the highest link to being a victim/crime occurrence, while the married status variable showed the least likelihood of being a victim/crime occurrence. However, over the past 40 years, changes may have occurred, and whether someone is single or married may have a different impact in contemporary society. Somehow, in Malaysia, the authors noticed that the Federal Department of Town and Country Planning (FDTCP) has never zoomed into this household activities factor in drafting strategies for the Safe City Program. Perhaps, this gap provides an opportunity for future research in Malaysia to include collecting and analyzing longitudinal data of such household structures or activities and suggests more locational or temporal specific solutions to local contexts.

Among the three actors—offenders, victims, and guardians—[2] explained that the "guardians" concept includes the "third eyes of the public." This "guardians" concept has been adopted in some safe city program strategies, including allowing the conduct of informal activities, such as merchants selling burgers in parks or public spaces or making the sides of pedestrian bridges visible to the public. Indirectly, increasing the public's eyes as guardians can prevent the occurrence of illegal or unlawful activities. Nevertheless, further research is required to answer whether these guardians are "capable" of preventing crime from happening. Among the three elements that assist in understanding crime rates, namely motivated offenders, suitable targets, and the absence of capable guardians, ref [2] argued that criminologists could have underemphasized the targets and guardians while entirely focusing on the offenders. The authors agree with the argument by [2] and suggest that relevant authorities should look at the perspectives of the targets and guardians in order to curb crimes, and doing so requires zooming into the social routine activities factor. This method is identified as CPSD. It requires a longer time and more investment of resources than CPTED or penal control in the forms of law, punishments, and regulations, which are short-term solutions that mainly focus on offenders' behavior [29]. The supporting argument for CPSD is that its results could be multiplicative rather than additive, unlike the CPTED strategies.

In the Malaysian context, the authors notice that among the 23 steps of the Safe City Program, the prime focus is on altering the physical environment to reduce the likelihood of offenders committing crimes. Indirectly, the focus is on protecting potential targets from becoming crime victims. For the guardians, the focus is mostly on the police force's role in setting up police kiosks in neighborhoods, conducting foot-patrol, encouraging community policing activities, and setting up CCTVs as a form of a digital guardian. Other capable guardians, such as the head of the family, are not included as part of the 23 strategies of the Safe City Program. Therefore, while the authors see a gap that the FDTCP guidelines do not consider the role of the "guardians" and changes in social structure, it is noted that these elements could be seen discursively in the initiatives taken by other government agencies.

The second theory adopted in this paper is the broken windows theory. This theory is based on the proposition that small issues should be handled carefully rather than letting them happen and creating significant future problems. Reference [38] has posited that disorder and crime are usually inextricably linked at the community level. Thus, everything, including the environment, should be kept to help reduce crime and the fear of crime. Disorder, e.g., the unattended property, is a fair game for people who are out for fun or to plunder, as it carries a "no one cares" signal [40]. Thus, minor vandalism may begin and culminate in significant destructions. Disorder indicates that untended behaviors will likely lead to the breakdown of community controls. Vandalism occurs once communal barriers, i.e., a sense of mutual regard and civility obligations, are lowered by actions that seem to signal that no one cares.

Reference [38] mentioned that "foot patrolling" by police officers, while not having been proven to reduce the crime rates, has reduced the fear of crime, and improved trust in the police force, thus enhancing the police-citizens relationship. Due to the close contact between police officers and local residents, the "regulars", such as panhandlers, loiterers, and some strangers, would understand and agree that there are hidden "informal rules" to be observed by all parties, which will maintain order in the neighborhood. These informal rules form part of the custom of the local residents even without legal backing. This order maintenance would reduce the fear of crime and make it possible to integrate social cohesion in the community [41].

As explained by [38], social order maintenance is partly the role of the police officers in maintaining the local order in extension to fighting crime. People will have a good impression if they frequently meet the police officers on the street. However, suppose the police officers always arrive in a police car (i.e., motorized-patrol officers). In that case, people tend to have a negative impression that they are "acting" and not sincere in preventing or solving crime and helping the victims. Therefore, there is a relationship between crime prevention and order maintenance. This order maintenance has hidden, informal rules abided by the regulars, and it is viewed as "community relations building" activities that happen on the ground. It indirectly builds trust in the police force and boosts their image. This approach could be applied in the Safe City Program in Malaysia by involving police officers in frequent foot-patrolling activities and manning the police station or patrolling in vehicles. Another practice to learn from the broken windows theory is promoting community policing projects that benefit the police-citizen relationship. This is a form of informal social control mechanism, and it is suitable for building trust and developing better local order maintenance rules in Malaysia.

2.2. Formulating the Factors of a Safe City Program in Malaysia

According to the Royal Malaysia Police (RMP), the crime index rose significantly from 1980 to 2009. The worst index was recorded in 2007, in which RM2.04 billion was allocated for crime prevention programs in Malaysia [42]. After the March 2008 elections in Malaysia, the Federal Government, through its Government Transformation Program, took measures to address the people's demand for a safer environment urgently. In 2009, the Safe City Program was formally included in the Malaysia Government Transformation Program as one of the strategies under the National Key Results Areas (NKRAs). The Reducing Crime NKRA (CRI NKRA) was implemented to address public safety issues concerning crime and policing [43]. Two National Key Performance Indicators (NKPIs) were identified under the CRI NKRA, namely "reducing street crime through a safe city program" and "crime prevention through environmental design" [11].

Through the National Urban Policy, the Malaysian government has defined a safe city as "an integrated program to the creation of cities where the population is free from all physical, social, and mental treats" [44]. The safe city features that have been determined for crime prevention are environmental design, the roles of safety-related agencies such as the police force, and community development. In December 2009, the Safe City Program was redefined into three main strategies consisting of 15 steps from the 23 crime prevention measures in the first version that was introduced in 2004 [11]. This exercise was done after considering the effectiveness of the initiative at the local authority level as well as opinions of the Ministry of Home Affairs, the RMP, State Town and Country Planning Department, and members of the Crime Lab (NKRA). Academic studies on the Safe City Program in Malaysia have flourished since 2004. Most of the studies rate the effectiveness of the program as between intermediate and low, as well as highlighting citizens' perceptions on relying on the government as the party responsible for curbing crimes; undeniably, more efforts are needed to promote community participation, including community policing activities [45–47].

Following the review of the safe city programs that were launched in Malaysia in 2004 and 2009, and understanding on main actors in crime and fear prevention theories, the authors found these factors can be primarily grouped under the two main categories of CPTED and CPSD, and further divided into seven sub-categories and 27 indicators (Table 1). Under the category of CPTED, all factors are solely related to the role of the actor of guardian, i.e., the authorities, and none were related to the actors of victims and offenders. Under such grouping, four sub-categories derived included (a) real barriers design initiatives, (b) symbolic barriers design initiatives, (c) Information and Communication Technology (ICT) and mechanical surveillance design initiatives, and (d) image and human activities' legitimacy initiatives. On the other hand, under the category of CPSD, the prevention factors are under the role of the guardians (authorities) and potential victims/communities (engagement). Only one sub-category was derived under the role of guardians, such as the management's legitimacy. In contrast, two sub-categories were found under the community's role, such as community involvement and public awareness factors.

Table 1. Factors in a Safe City Program (source: items were derived from the Safe City Program (SCP) year 2004 and 2009 in Malaysia and regrouped with the insights from [2,5,16,38,48]).

Actor	Sub-Category	Item
1st Category: CPTED (territoriality control), with 18 items		
Guardians (Authorities)	Real barriers design initiatives	1. Separation of pedestrian walkways from motorized lanes
		2. Access control
		3. The appearance of building, street, and city
		4. Landscaping
	Symbolic barriers design initiatives	5. Safety Mirror
		6. Signage of location/direction
		7. Crime prevention signage
		8. Unobstructed view of public walkways
	ICT and mechanical surveillance design initiatives	9. Establish of GIS mapping for crime and SCP
		10. Safety alarm (Panic button)
		11. Installation of CCTV in commercial premises and public places
		12. Lighting
	Image and human activities' legitimacy initiatives	13. Generate appropriate activities at vulnerable crime spots
		14. Cleaning/tidying concealed and unkempt areas
		15. Mix development/land use
		16. Police post/mobile station/patrolling
		17. Security guard services
		18. Prohibition of business/parking on the walkways and pedestrian footpaths

Table 1. *Cont.*

Actor	Sub-Category	Item
2nd Category: CPSD (Social development and program), with 9 items		
Guardians (Authorities)	Management's legitimacy	1. Improve surveillance in the CBD areas
		2. Fixed agenda on safe city program at the full council meeting (inter agencies)
		3. Set up city status websites at local authority on safety issues
		4. Victimization/safety survey
Potential Victims/Communities (Engagement)	Community Involvement	5. Teenager development in fear and crime prevention activities
		6. Private and corporation participation
		7. Community policing
	Public Awareness	8. Education, public awareness, and publicity
		9. Watch group

Note: CBD stands for central business district, CCTV stands for closed-circuit television, CPTED stands for crime prevention through environmental design, CPSD stands for crime prevention methods through social development, GIS stands for geographic information system, ICT stands for information and communication technology, and SCP stands for safe city program.

2.3. A holistic Safe City Thesis

The authors have attempted to form a holistic safe city program thesis (Figure 2). In this thesis, the safe city program has the objectives of reducing crime that affects either individual victims or subjects such as properties, as well as the fear of crime.

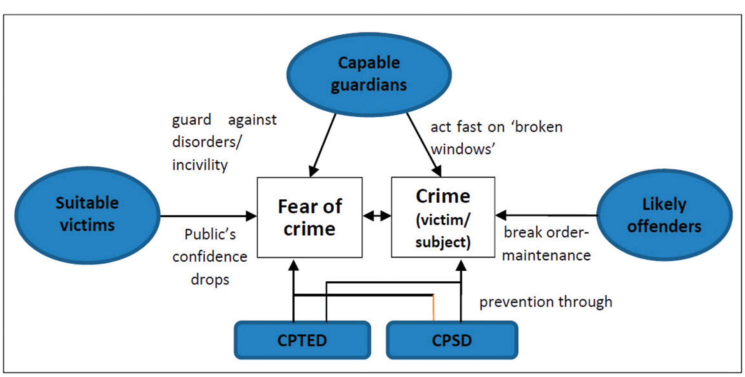

Figure 2. A holistic safe city thesis (source: authors).

The three major actors of likely offenders, suitable victims, and capable guardians posited by [2] form the foundation of this thesis's implicit concern. Subject to the right convergence of time and space, the prospective offenders could break the social order maintenance and commit crimes against the suitable victim(s) or properties such as a house. Whether the crime has happened or is likely to happen creates societal signals, mainly a phobic ambiance to the people living close to the crime scene. These decent people who are likely to turn into victims are exposed to the feeling of fear of crime, resulting in a drop of public confidence in the sense of safety. Within this cycle, the third-party guardians such as the police, head of household and community, local authorities, and other "public eyes", among others, play crucial roles in guarding against these disorders and incivility acts. Moreover, as posited by [38], the guardians and all society members should act fast on the "broken windows" or signs that criminal cases are left unattended to prevent further deterioration from occurring, which might culminate in an immense tragedy. Fear and crime are interconnected, since offenders can create and determine fear of crime, while victims can indirectly influence crime. Among the preventive measures suggested by [5], preventions through environmental design (CPTED) and social development (CPSD) are highlighted as suitable acts for curbing crime and the fear of crime.

2.4. Sustainability of Safe City Planning

Safety is an inherent feature in the creation of sustainable built-up environments. This was clearly stated in the United Nations (UN) policy New Urban Agenda (NUA), which advocated "creating safe, resilient, sustainable and inclusive cities" [49]. Meanwhile, the 11th Sustainable Development Goal (SDG) for 2015–2030 stated that the aim was to "make cities inclusive, safe, resilient and sustainable" [50]. Further evidence has identified safety as a continuous and significant indicator of a smart sustainable city when quality of life is measured [51–61].

The concept of safety is the ontological foundation of general and specific social sustainability [62]. In other words, under the umbrella of the sustainability concept, a socially safe environment is essential for existing and future generations. Without such an environment, cities, urban spaces, and streets will be unable to sustain human life. People would constantly migrate from those unsafe environments, cities, or particular streets. By extension, to sustain life, people have the right to not only remain safe but also adopt any measures such as safe city planning directed towards adaptation and security. Safety issues such as crime are framed as social problems of sustainability [36,63]. To investigate the aspect of sustaining urban security, the authors of this study attempted to ascertain the factors of fear and of crime prevention.

3. Methodology

By identifying factors contributing to crime prevention and fear of crime, this article aims to provide empirical evidence regarding a safe city program launched in Malaysia. A quantitative survey questionnaire methodology was employed, in which 400 pedestrians were asked about their perceptions of Kuala Lumpur's central business district. Survey research is probably the optimal method available to the social researcher concerned with collecting any original data that describes a population too large to observe directly [64] (p. 118), in this case, the 1.73 million inhabitants of Kuala Lumpur. The following subsections outline the site, population, and sample size; research framework, variables and research instruments; reliability test and data analysis; and research ethics.

3.1. Site, Population, and Sample Size

The site selection was based on the significance and importance of Kuala Lumpur to Malaysia, accounting for more than 40% of the country's urban population [59]. Kuala Lumpur has been selected as a policing model under Malaysia's new economic model. The police force intends to make Kuala Lumpur a safer city for locals and tourists alike [65]. Besides that, the greater Kuala Lumpur conurbation [66] has also been identified as a National Key Economic Area (NKEA) with projects and initiatives to enhance the city's competitiveness [67].

Recently, Kuala Lumpur has been ranked 35th in the Safe City Index 2019 [57], dropping four places from the year 2017, and most of the category ratings are below average compared to the other 60 cities in the world. Kuala Lumpur recorded approximately 24.37% of the national street crimes for the year 2016, and the Dang Wangi District is home to the main hot spots for street crimes, with about 37.86% of the overall street crime in Kuala Lumpur [68]. Due to such hot sport for street crimes, the Dang Wangi District was selected as the survey area, encompassing four streets: Sultan Ismail Street, Ampang Street, Raja Chulan Street, and Bukit Bintang Street and Imbi Street (Figure 3).

Figure 3. The central business district in Kuala Lumpur and pedestrian survey area (source: authors).

Survey personnel were stationed along these four streets with three survey points on each street during both day and night time and throughout weekdays and weekends. This method followed [69], which identified "day" interviews as occurring from 9 a.m. to 6 p.m. and "night" interviews as occurring from 7 p.m. and 10 p.m. In this study, "weekdays" was defined from Monday to Friday, and "weekends" from Saturday to Sunday. Sunday to Thursday nights were defined as "weeknights", while Friday and Saturday nights were "weekend nights".

According to Table 2, 400 samples were collected using proportionate stratified random sampling from June to December in 2017. The purpose of stratification is to categorize a population into subgroups based on homogeneity. Different subsets are heterogeneous. Next, a suitable number of units from each subset is chosen for sampling. The representative character of each sample is increased through this process, at least where stratification variables are concerned [64]. For each street, 100 samples were collected, with equal samples of 25 each during weekday and weekend, by day and night. In order to prevent bias, every 10th person in the stratified arrangement was selected for the sample. Those who confirmed that they had not visited the city previously were disqualified from the survey. Four hundred samples are adequate for study areas like Kuala Lumpur. A population of 1.73 million people requires a sample size of 386 people to represent the population at a 95% confidence level and a 5% error [70].

Table 2. Distribution of survey respondents (source: authors).

Study Area/Street	Weekday		Weekend		Total
	Day	Night	Day	Night	
Sultan Ismail	25	25	25	25	100
Raja Chulan	25	25	25	25	100
Ampang	25	25	25	25	100
Bukit Bintang-Imbi	25	25	25	25	100
Total	100	100	100	100	400

3.2. Research Framework, Variables, and Research Instrument

The survey questionnaire was designed mainly upon the effectiveness of the prevention items towards street crime and the fear of street crime.

Acknowledging that a cross-sectional survey can only measure the items at the occasion factor (i.e., at one point in time) [71], to measure the effectiveness (cause and effect), the items were designed such that respondents compared their experiences at the point of survey (the year 2017) with the previous year (2016 as the control variable). All variables which involve perceptions of fear or street crime in the Kuala Lumpur's central business district (KL CBD) are compared to the previous year (Table 3).

Each survey had an average duration of 20 to 30 min, including the time taken to explain the purpose of the survey to the respondent. The survey questionnaire was developed based on studies by [69,72], which are concerned with a safer city and have been proven to be effective.

The design of the questionnaire covered firstly the respondent's background. Five basic demographic items were included: gender, age, monthly income (in Ringgit Malaysia, RM), educational level, as well as their usual reason for visiting KL CBD.

Second, for the main research items, two dependent variables (DV) identified for securing a safe city program are Street Crime and Fear of Street Crime. For the first dependent variable, street crime was measured through the average perceived security level in the central city following time from 6 a.m. morning to after 10 p.m. for both weekdays and weekends, compared to last year. The 5-point Likert scale used ranged from 1 as being very dangerous to 5 as being very safe. While the second dependent variable, the fear of crime, was measured through the average perceived fear of crime compared to last year. The 5-point Likert scale used ranged from 1 as being much worse now to 5 as being much safer now.

Third, for the independent variables (IV), 27 items/factors, which are summarized in Table 1, were applied in this study, which also mainly comes from two main categories, namely the CPTED with 18 items, and the CPSD with nine items (Figure 4).

Table 3. Definitions and descriptive statistics of the variables (source: authors).

Variables		Description	Mean	S.D.	Skewness	Kurtosis
		Dependent Variable				
Street crime, Y1		The average perceived security level in the central city follows time from 6 a.m. morning to after 10 p.m. for both weekdays and weekends, compared to last year. The reference group is "last year."	3.52	0.88	−0.214	0.324
Fear of crime, Y2		The average perceived fear of crime compared to last year. The reference group is "last year."	3.11	1.01	−0.288	0.056
		Independent variables				
		CPTED				
Real barriers design initiatives, ×1	Separation of pedestrian walkways from motorized lanes, ×1	The reference group is "no separation of walkways"	3.75	0.98	−0.296	0.211
	Access control, ×2	The reference group is "no access control"	3.60	0.90	−0.116	0.345
	Appearance of building, street, and city, ×3	The reference group is "non-appearance of building, street, and city"	3.31	0.99	−0.151	0.086
	Landscaping, ×4	The reference group is "no landscaping"	3.26	1.02	−0.006	−0.057
Symbolic barriers design initiatives, ×2	Safety mirror, ×5	The reference group is "no safety mirror"	3.38	1.04	−0.040	0.901
	Signage of location/direction, ×6	The reference group is "no signage of location/direction"	3.53	0.96	−0.227	0.429
	Crime prevention signage, ×7	The reference group is "no crime prevention signage"	3.31	1.08	−0.179	−0.204
	Unobstructed view of public walkways, ×8	The reference group is "obstructed view"	3.61	0.96	−0.147	0.344
ICT design and development initiatives, X2	Establishment of GIS mapping for crime and SCP, ×9	The reference group is "non-availability of GIS mapping for crime and SCP"	3.46	0.95	−0.074	0.706
	Safety alarm (Panic button), ×10	The reference group is "no safety alarm"	3.90	0.95	−0.393	0.356
	Installation of CCTV in commercial premises and public places, ×11	The reference group is "non-installation of CCTV in commercial premises and public places"	4.04	0.99	−0.840	1.051
	Lighting, ×12	The reference group is "no lighting"	4.01	0.97	−0.668	0.747

Table 3. *Cont.*

Variables		Description	Mean	S.D.	Skewness	Kurtosis
Image & human activities' legitimacy initiatives, ×3	Generate appropriate activities at vulnerable crime spots, ×13	The reference group is "non-availability of appropriate activities at vulnerable crime spots"	3.49	1.01	−0.109	−0.151
	Cleaning/tidying concealed and unkempt areas, ×14	The reference group is "no cleaning/tidying concealed and unkempt areas"	3.45	1.03	−0.213	0.856
	Mix development/land use, ×15	The reference group is "singly land use development"	3.15	1.04	−0.031	0.345
	Police post/mobile station/patrolling, ×16	The reference group is "no police post/mobile station/patrolling"	3.95	0.99	−0.922	1.108
	Security guard services, ×17	The reference group is "no security guard services"	3.75	1.00	−0.495	0.807
	Prohibition of business/parking on the walkways and pedestrian footpaths, ×18	The reference group is "no control of business/parking on the walkways and pedestrian footpaths"	3.40	0.98	−0.124	0.635
		CPSD				
Management's legitimacy, X5	Improve surveillance in the CBD areas, ×19	The reference group is "non-improve surveillance in the CBD areas"	3.70	1.00	−0.394	0.322
	Fixed agenda on SCP at full council meeting (inter agencies), ×20	The reference group is "no fixed agenda on SCP at full council meeting"	3.33	0.98	−0.129	0.102
	Set up city status websites at local authority on safety issues, ×21	The reference group is "no set up of city status website at local authority on safety issues"	3.25	1.09	−0.115	0.099
	Victimization/Safety survey, ×22	The reference group is "no victimization/safety survey"	3.27	1.06	−0.087	0.412
Community Involvement, X6	Teenager development activities, ×23	The reference group is "no teenage development activities"	3.64	1.11	−0.471	0.536
	Private and corporation participation, ×24	The reference group is "no private and corporation participation activities"	3.49	0.97	−0.076	0.152
	Community policing, ×25	The reference group is "no community policing"	3.64	0.98	−0.394	0.456
Public Awareness, ×7	Education, public awareness, and publicity on safety issues, ×26	The reference group is "no education, public awareness, and publicity on safety issues"	3.78	0.95	−0.410	0.652
	Watch group, ×27	The reference group is "no watch group"	3.44	1.02	−0.406	0.411
N = 400						

Note: CBD stands for central business district, CCTV stands for closed-circuit television, CPTED stands for crime prevention through environmental design, CPSD stands for crime prevention methods through social development, GIS stands for geographic information system, ICT stands for information and communication technology, SCP stands for safe city program, and S.D. stands for standard deviation.

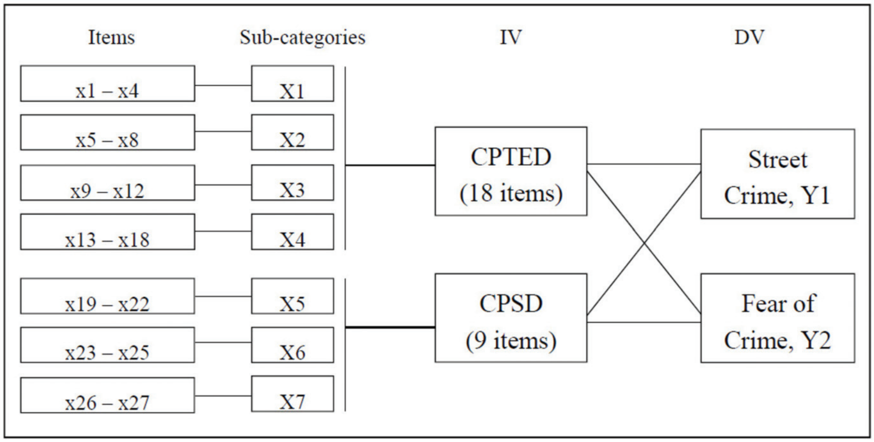

Figure 4. Relationships among variables (source: authors). Note: CPTED represents crime prevention through environmental design, CPSD represents crime prevention through social development, IV represents independent variables, and DV represents dependent variables.

For independent variables, a 5-point Likert scale was used to measure the levels of effectiveness of the 27 items, ranging from 1 as being not at all effective to 5 as being extremely effective. The mean score range values of the scale ratings were used for the descriptive analysis and to identify the effectiveness of the crime prevention steps stated in the safe city program. From the sample of 400 respondents, all mean score for the effectiveness of initiatives in reducing street crime and fear of crime are above 3, which indicated that all respondents have agreed that all twenty-seven initiatives under the safe city program are effective (Table 3). Besides, most of the data showed a skewness or kurtosis value of less than 1.0. If the skewness or kurtosis value is between −1.0 and 1.0, the distribution is considered normal, and indicate that are almost preferred to be symmetrical [73]. Two exceptional cases of CCTV installation with kurtosis 1.051, and the existence of police post surveillance with kurtosis 1.108, were assumed to contain normal data since their skewness values were in the normal range. Furthermore, the authors intended to measure both of these items, as they are important features in CPTED, as highlighted in [16,33]. Assuming the sample size is sufficient in number, which in this study amounts to 400 samples, no serious issues should arise even if the normality assumption is violated. The implication is that parametric procedures can be used in this study, despite a lack of normal distribution of data [74].

3.3. Reliability Test and Data Analysis

All the collected data from the public survey involving 400 respondents were checked for quality using the Statistical Package for the Social Sciences (SPSS) software by conducting reliability tests to verify the consistency of all the measurements.

Cronbach's alpha (α) was utilized in running the reliability test. A Cronbach's alpha value < 0.6 is considered poor, 0.61–0.7 is considered questionable, 0.71–0.8 is acceptable, 0.81–0.9 is considered good, while more than 0.9 represents an excellent level with high reliability [75]. Based on reliability tests, all data used for measuring the effectiveness of Safe City initiatives in reducing street crime and fear of crime are excellent, with Cronbach's alpha values ranging from 0.912 to 0.959 (see Table 4). These values indicate that all the scales contain internal consistency, and are therefore considered reliable for use.

Table 4. Reliability and internal consistency of data in reducing street crime and fear (source: authors).

Variables		Cronbach's Alpha (α)	Reliability Level
CPTED			
Real barriers design initiatives, ×1	Separation of pedestrian walkways from motorized lanes, ×1	0.940	Excellent
	Access control, ×2	0.959	
	Appearance of building, street, and city, ×3	0.933	
	Landscaping, ×4	0.924	
Symbolic barriers design initiatives, ×2	Safety Mirror, ×5	0.913	
	Signage of location/direction, ×6	0.933	
	Crime prevention signage, ×7	0.955	
	Unobstructed view of public walkways, ×8	0.912	
ICT design and development initiatives, X2	Establish of GIS mapping for crime and SCP, ×9	0.937	
	Safety alarm (panic button), ×10	0.954	
	Installation of CCTV in commercial premises and public places, ×11	0.918	
	Lighting, ×12	0.912	
Image and human activities' legitimacy initiatives, ×3	Generate appropriate activities at vulnerable crime spots, ×13	0.920	
	Cleaning/tidying concealed and unkempt areas, ×14	0.934	
	Mix development/land use, ×15	0.936	
	Police post/mobile station/patrolling, ×16	0.926	
	Security guard services, ×17	0.914	
	Prohibition of business/parking on the walkways and pedestrian footpaths, ×18	0.941	
CPSD			
Management's legitimacy, ×5	Improve surveillance in the CBD areas, ×19	0.925	Excellent
	Fixed agenda on SCP at full council meeting (inter agencies), ×20	0.938	
	Set up city status websites at local authority on safety issues, ×21	0.951	
	Victimization/safety survey, ×22	0.945	
Community Involvement, ×6	Teenager development activities, ×23	0.937	
	Private and corporation participation, ×24	0.950	
	Community policing, ×25	0.951	
Public Awareness, ×7	Education, public awareness, and publicity on safety issues, ×26	0.937	
	Watch group, ×27	0.941	
Significant level of 0.000			

Note: CBD stands for central business district, CCTV stands for closed-circuit television, CPTED stands for crime prevention through environmental design, CPSD stands for crime prevention methods through social development, GIS stands for geographic information system, ICT stands for information and communication technology, and SCP stands for safe city program.

Subsequently, Pearson's Correlation through Bivariate Analysis was generated to test the relationship between the variables [75]. A value that measures the strength of a relationship is the correlation coefficient, r, otherwise known as Pearson's r. The r values between 0.3 and −0.3 indicate a weak relationship, values from 0.3 to 0.7 and from −0.3 to −0.7 indicate a moderate linear relationship, and values from 0.7 to 0.9 and from −0.7 to −0.9 are considered strong.

Next, inferential analysis in the form of regression analysis was performed to test the significant contributing factors of preventing crime and the fear of crime. The statistical significance was examined at the traditional *p*-value of less than 0.05. Multiple correlation coefficient, R, measures the quality of the prediction of the dependent variable. In other words, simple linear regression was used to estimate the dependent variables or outcomes of reducing street crime and fear of crime based on the Safe City initiatives as the independent or predictor variables. This analysis also determined the overall fit or variance explained of the model and the relative contribution of each Safe City initiative.

3.4. Research Ethics and Survey Research

In the majority of cases, survey research incorporates requests for respondents to offer personal information which is probably otherwise unavailable [64]. Furthermore, underage respondents were also involved in this study. Therefore, all the data collected from respondents will not be publicly disclosed in order to protect their privacy, and to avoid any possible psychological distress. Moreover, respondents were given an information sheet to read, and signed a consent form guaranteeing the confidentiality of data provided to this survey. The study received ethical approval from the Royal Malaysia Police.

4. Results

4.1. Pedestrian Profile

The respondents' background information reflects the commercial and business status of Kuala Lumpur and the variety of justifications or attractions for residents to reside in and for tourists to visit the city (Table 5).

Table 5. Respondents profile (source: authors).

Characteristics		**Frequency**	**%**
Gender	Male	189	47.30
	Female	211	52.70
Age	13–19	51	12.80
	20–29	198	49.50
	30–39	76	19.00
	40–49	44	11.00
	50–59	28	7.00
	60 and above	3	0.80
Monthly income (RM)	Less than 1000	57	14.30
	1001—2000	40	10.00
	2001—3000	140	35.00
	3001—4000	69	17.30
	4001—5000	53	13.30
	5001 and above	41	10.30
Education level	Primary school	2	0.50
	Secondary school	23	5.80
	College	99	24.80
	Undergraduate degree	227	56.80
	Postgraduate	47	11.80
	No qualification at all	2	0.50
Usual reason visits KL CBD	Work/business	160	40.00
	Shopping	70	17.50
	Entertainment/recreation	108	27.00
	Tourist/visitor	25	6.30
	Resident	24	6.00
	Other	13	3.30

Note: RM represents Ringgit Malaysia, KL represents Kuala Lumpur, and CBD represents central business district.

The male and female genders are almost equally represented at 47.3% and 52.7%, respectively. The 20–29 years old age group has the highest number of respondents (198 or 49.5%). For monthly income, the group with the highest number of respondents is the RM2001–RM3000 income group (140 or 35%). Most of the respondents hold at least a first degree (56.8%). The three most cited reasons for visiting Kuala Lumpur CBD are for work/business purpose (40%), followed by entertainment/recreation (27%), and shopping (17.5%).

4.2. Perception of Fear and Street Crime Level

The Safe City Program and its initiatives can be divided into two major categories, namely CPTED and CPSD. In correlation analysis, the authors found that CPTED had a stronger relationship with reducing street crime (0.592) compared to CPSD (0.562). CPTED and CPSD had the same level of moderate relationship with reducing fear of crime, with both obtaining a Pearson's correlation value of 0.628.

In detail, the results show that each of the independent variables had a significant relationship ($p < 0.01$) with the dependent variables, which are reducing crime and reducing the fear of crime. The three CPTED variables that had the strongest relationship with reducing street crime are landscaping (0.690), the appearance of the building, street, and city (0.686), and generate activities (0.675). Meanwhile, the three CPSD variables that had the strongest relationship with reducing street crime are full council meeting (0.654), watch group (0.653), and city status website (0.62). Overall, most of the relationships can be considered as moderately linear with the r values falling between 0.498 and 0.690.

Next, the three CPTED variables that had the strongest relationship with reducing the fear of crime are safety mirror (0.698), the appearance of the building, street, and city (0.692), and generate activities (0.679). Meanwhile, the three CPSD variables of city status website (0.673), watch group (0.656), and victimization/safety survey (0.653) had the strongest relationship with reducing the fear of crime. The range of r values for reducing the fear of crime (0.522–0.698) is slightly narrower than that for reducing street crime (0.498–0.690).

4.3. Effect of CPTED and CPSD

In regression analysis, the R values of 0.630 and 0.638 for reducing street crime and reducing the fear of street crime, respectively, indicate a moderate level of prediction. The coefficient of determination (R^2) is the proportion of variance in the dependent variable that can be explained by the independent variables. The R^2 value of 0.396 for reducing street crime indicates that the set of independent variables can explain only 39.6% of the variability in the dependent variable. Similarly, the R^2 value of 0.408 for reducing the fear of crime shows that the set of independent variables can explain only 40.8% of the variability in the dependent variable.

As for the results for the statistical significance of the regression models, the independent variables significantly predicted the dependent variables of reducing street crime ($F(27,372) = 9.047$, $p < 0.0005$) and reducing the fear of crime ($F(27,372) = 9.483$, $p < 0.0005$). Both regression models are a good fit for the data. However, the statistically significant level for the coefficient of each independent variable needs to be referred to.

Table 6 shows the estimated multiple regression model. Only three Safe City initiatives as the independent variables made a good prediction of Reducing Street Crime as the dependent variable, which can be statistically significantly predicted as:

> *"Reducing Street Crime," F (27, 372) = 1.124 + (0.109 × access control) − (0.091 × full council meeting) + (0.021 × city status website), with p < 0.05.*

Table 6. Multiple regression results (source: authors).

Independent Variables	**Reducing Street Crime**			**Reducing Fear of Crime**		
	β	**T**	**Sig.**	**β**	**T**	**Sig.**
CPTED						
Separation of walkways	−0.17	−0.447	0.655	0.048	1.251	0.212
Access control	0.109	2.794	0.005 *	0.031	0.800	0.424
The appearance of building/street	0.009	0.250	0.803	−0.026	−0.728	0.467
Landscaping	0.049	1.240	0.216	0.014	0.352	0.725
Safety mirror	−0.018	−0.454	0.650	0.006	0.151	0.880
Signage of location/direction	0.063	1.619	0.106	0.058	1.456	0.146
Crime prevention signage	0.015	0.445	0.656	0.029	0.814	0.416
Unobstructed view	0.052	1.506	0.133	0.019	0.514	0.608
GIS mapping	0.007	0.203	0.839	−0.046	−1.238	0.216
Safety alarm (panic button)	0.029	0.778	0.437	0.077	1.962	0.051
CCTV	0.026	0.656	0.512	0.053	1.504	0.133
Lighting	0.045	1.165	0.245	0.042	1.112	0.267
Generate activities	0.058	1.712	0.088	0.032	0.948	0.344
Cleaning unkempt areas	−0.007	−0.188	0.851	0.039	1.056	0.292
Mix development	−0.011	−0.281	0.779	0.074	1.959	0.051
Police post/mobile station	0.018	0.420	0.675	0.036	0.865	0.387
Security guard services	0.021	0.510	0.610	0.004	0.102	0.918
Prohibition of business/parking	0.061	1.854	0.065	0.036	1.037	0.300
CPSD						
Improve surveillance	0.043	1.110	0.268	0.020	0.486	0.627
Full council meeting	−0.091	−2.274	0.024 *	−0.007	−0.169	0.866
City status website	0.021	4.994	0.000 *	0.074	1.943	0.053
Victimization/safety survey	−0.049	−1.166	0.245	0.030	0.762	0.446
Teenager development activities	−0.024	−0.593	0.553	−0.036	−0.838	0.402
Private participation	0.008	0.209	0.835	−0.004	−0.117	0.907
Community policing	0.034	0.847	0.398	0.034	0.805	0.422
Education	−0.003	−0.073	0.942	0.031	0.734	0.463
Watch group	−0.016	−0.463	0.643	0.003	0.086	0.931
Constant		1.124			0.800	

Note: * significant level < 0.05. CCTV stands for closed-circuit television, CPTED stands for crime prevention through environmental design, CPSD stands for crime prevention methods through social development, and GIS stands for geographic information system.

Meanwhile, notably, none of the independent variables could make a good prediction of Reducing the Fear of Crime at a significant level > 0.05. Therefore, no regression formula was formed to predict the outcome of Reducing the Fear of Crime.

5. Discussion

5.1. Reduction of Crime at a Moderate Level

The Safe City Program is capable of reducing street crime at a moderate level and is less sensitive in predicting the outcome of all the good efforts made by various agencies. Amongst the 27 initiatives in the Safe City Program, only "access control","full council meeting", and "city status website" could predict the outcome of reducing street crime significantly. However, the impacts of these three initiatives were not powerful enough in reducing street crime with β coefficient values 0.109, −0.091, and 0.021, indicating low sensitivity. In detail, "access control" is an important concept emphasized in CPTED [18]. Controlling the accessibility of a road or an area contributes to a sense of territoriality, resulting in effective crime prevention [19]. This result is in line with [76], which tested the relative effects and found the strongest direct effect of territorial variables on crime prediction. Humans are used to establishing hierarchies or territories that range from private to semi-private to public space by marking their turf using fences, signs, and plain border definition. The most common are fencing and walling for separating physical space to create safety as well as a sense of safety [19].

For "full council meeting", the authors note that it is crucial to hold the meetings to sustain the Safe City Program because important decisions are usually made during council meetings. Out of the 27 initiatives, most of the respondents were unaware of the "fixed agenda on Safe City Program at full council meeting" at the local authority level as a platform for inter-agency discussions and collaboration planning. The Federal Government has defined the Safe City Program in Malaysia as city-based, involving cross-ministry and agency partnerships, being led by the mayor of each local authority with a fixed agenda for the monthly council meetings, and having the aim of reducing street crime through target hardening, physical initiatives, and public involvement [7]. For the "set up city status websites at local level", the result affirming its significant contribution to crime prevention suggests that this initiative should be included in future safe city programs, as this initiative was ignored in the second version of the Safe City Program 2009 in Malaysia. Besides, it can create online awareness by providing a long-term reference with favorable impacts.

5.2. Reduction of Fear of Crime at a Weak Level

None of the elements in the Safe City Program was able to predict the outcome of reducing the fear of crime significantly in multiple regression modelling. Hence, the study concludes that the Safe City Program is acceptable at a weak level in increasing perceived pedestrian safety and reducing the fear of crime, particularly among city users in the Kuala Lumpur CBD area.

The purpose of the study was to identify effective general factors concerning fear and crime prevention within a Safe City Program. Thus, demographic variables like gender were not set as control variables in the regression analysis, even though female respondents revealed higher levels of fear and tended to be actual victims of street crime.

Based on the holistic safe city program thesis formed in Figure 2, the authors suggest that the Safe City strategies should be well integrated since separate implementations of each initiative will not be able to reduce crime or the community's perception of disorder.

5.3. Offenders' Perspectives of Curbing Crimes and Fear of Crime

Among the three significant factors, i.e., "access control", "full council meeting", and "city status website", all of these are from the efforts of the guardians such as the local authorities, and police forces. In terms of efforts from the potential victims from communities, none of the strategies is significantly found in this study. Thus, a question arises to what other contributing factors that will be able to fill in the gap of sustaining safe city program. Since the factors in reducing fear and crime may not be lying under the factors of "capable guardians" (authorities), and "suitable victims" (community), but possible strategies could be view/search from the factors of "likely offenders". This suggestion is derived from [2] who mentioned that guardians, victims, and offenders are three important actors in everyday crime prevention theories. Thus, from the offenders' perspective, it could be divided into two groups, namely those are potential, and those already an offender. Education to the former group is essential, such as cultivating ideas of living in a harmonious life, family, and society, and understanding of the punishment to offenders and wrong social impression on those criminals. If lesser people do not/potentially perform crimes, then it will not/be less likely to impose fear to the community, or deeply commit any crimes. As for the already-offenders, support and rebuild after-criminal life is essential such as counselling support in jail, social support, acceptance, and opportunity in having decent jobs for everyday expenses and living [13].

5.4. Victims/Communities Perspective Needed to Be Enhanced

The authors posited that indicators for victims and communities might be under-explored in the limited literature covering CPSD [29–31,77]. The authors suggest that for those "already victims", society needs to study the social problems that lead to crime, build more robust psychological health, heal from fear, accept fear reality, positively face life after the crime, and help them back to a safe society. Since the deeper issue facing is although statistics showed that crime rate decrease, but fear is deepening. In other words, the real quantity of crimes happening might be low, but other none "real" crime or non-police reported cases such as harassment, threatening will "impact" on third parties. Meaning, a direct victim might be one single person, but the people around that victim, such as those family members, and the victims' communities, may face "fear in the heart", as though they will be mentally more cautious and preventing themselves from becoming a real victim. Thus, the topic of "fear of crime" should be highlighted more in a safe city program and solutions from responsible communities should be explored further than the existing superficial engagement of communities in sustaining a safe city environment.

6. Conclusions

It is not surprising that this study hardly obtained one or two individual initiatives which strongly influenced the dependent variables of reducing street crime and reducing the fear of crime. Cities exist in a dynamic, complex environment and securing their prosperity through protecting the population, assets, and reputation is a significant challenge [13]. Few strategies by guardian authorities are effective; however, they may not be total in curbing crime and fear of crime in the city. More strategies should be explored from the other actors such as victims/community and offenders. The Safe City Program works only when a combination of initiatives from all the perspective of guardians, victims, and offenders is integrated well.

There are several limitations to the present study. From a theoretical perspective, only routine activities and broken windows theories were selected for review. Other theories of crime opportunity such as rational choice, crime patterns, awareness, and crime opportunity theory might be explored in future studies to reveal evidence of fear and crime prevention items. From a methodological perspective, the data collection method is less likely to ascertain whether respondents were fully aware of all the measures included in the survey. This creates the potential for measurement bias if levels of familiarity relating to instrument items were not investigated. Further methodological limitations could arise from generalizing the effectiveness of the safe city program from the cross-sectional survey design at the occasion factor, although the respondents were asked to compare their perceptions of fear and street crime with the previous year.

From a practical point of view, this case study looked at only a part of (street crime in commercial area) the whole Safe City Program that integrates different strategies. Therefore, all the initiatives from different approaches and concepts need to be rethought to be more effective in reducing street crime and the fear of crime. Crime patterns are not static, and the Safe City Program needs to adapt its initiatives quickly to tackle new problems as they arise. In doing so, the Safe City Program aims to remain relevant to public concerns, thus alleviating the fear of becoming a crime victim.

The strength of the findings may depend on other factors beyond the scope of this investigation, such as the community's engagement and the offender's perspectives. CPSD is also notably a relatively young field of academic study, and it may take some time to learn how to execute the CPSD principles and obtain results. A suggestion for future research is to study the prevention strategies from community and offenders' perspective, the relationship between fear of crime, social interaction, and community configuration in different types of study areas. An additional suggestion is to develop and analyze longitudinal data from household structures or activities and to suggest more locational or temporal specific crime prevention solutions for local contexts. This study focused on the factors of a Safe City Program from the perspective of pedestrians without detailing the CPTED and CPSD specifically. There may remain many undecided hurdles in the effort to identify effective ways to approach the multiplicity of risk factors connected to crime and victimization, not to mention the fear of crime.

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Article

Does Facilitating Human–Place Bonds Alleviate the Negative Effects of Incivilities on Health?

Massoomeh Hedayati Marzbali [1,*], Mina Safizadeh [1], Mohammad Javad Maghsoodi Tilaki [2] and Aldrin Abdullah [1]

[1] School of Housing, Building & Planning, Universiti Sains Malaysia, Penang 11800, Malaysia; safizadeh.mina@gmail.com (M.S.); aldrin@usm.my (A.A.)
[2] School of Humanities, Universiti Sains Malaysia, Penang 11800, Malaysia; maghsoodi@usm.my
* Correspondence: hedayati@usm.my; Tel.: +60-17-447-1295

Abstract: The present study has two purposes—methodological and theoretical. The methodological purpose is to examine a method for the analysis of perceived incivilities and health in urban neighbourhoods. The current study investigates the direct and indirect relationships between the two variables. The theoretical purpose is to measure neighbourhood incivility as a second-order latent variable that represents physical and social incivilities, and investigates place identity and place attachment as mediators in the relationship between incivilities and health. Previous research has focused on a single dimension of incivility. By contrast, the current study considers a multidimensional form of incivility. This quantitative study comprises 265 residents from an urban neighbourhood in Penang, Malaysia. The results of the structural equation modelling suggest that perceptions towards neighbourhood play a mediating role in the relationship between incivility and health. The mediation roles of place identity and place attachment in the relationship between incivilities and health are also supported. Thus, facilitating human–place bonds alleviates the negative effects of incivilities on health in the study neighbourhood. Residents are less attached to neighbourhoods that are perceived as socially and physically deteriorated. Thus, reducing incivilities and improving place attachment may enhance neighbourhood health.

Keywords: incivilities; health; Malaysia; place attachment; place identity; urban neighbourhood

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1. Introduction

In the past few decades, studies have identified positive and negative health determinants in urban neighbourhoods, such as physical and social incivilities, community events, and aesthetic issues. Studies have elaborated on the association between neighbourhood features and various affective variables, which can explain ties to the quality of wellbeing [1]. Neighbourhood incivility applies to features in physical and social dimensions that can indicate symptoms of a breakdown in social stability or order in neighbourhoods, resulting in a decrease in the quality of life of residents [2].

Evidence shows that place attachment mediates the influences of the perceived physical and social qualities of the environment on the wellbeing of residents [3]. This feeling of attachment is correlated with improved mental health and is negatively associated to depression [4,5].

Some reports have explored the influence of neighbourhood incivility on the spiritual wellbeing of residents, given the burden of neighbourhood incivilities [6], whereas others have focused on the role of the broken windows theory (BWT) [7,8]. Although the relevance of material and physical dimensions of neighbourhoods on residents' health has been generally recognised [9–11], few studies have considered the dimensions of physical and social incivilities on health simultaneously [2,12–15].

Studies on the relationship between incivilities and social relations are inconsistent. Although several researchers have reported a negative relationship between incivilities and social ties [16,17], some have argued that impoverished neighbourhoods are positively correlated with social relationships. For example, studies have found that people living in disadvantages neighbourhoods earn greater social assistance and more social cohesion compared with wealthier neighbourhoods [13,18]. In a similar vein, the reports in the literature on the relationship between incivilities and health are contradictory. In the study of Robinette et al. [14], no significant relationship was established between neighbourhood incivility and health, whereas several researchers have reported that social cohesion and an improved perception of neighbourhood environment have a significant relationship with the improvement of the quality of wellbeing [19–21]. Although these studies support the relationship, existing research on the effects of neighbourhood incivilities on health remains lacking in certain dimensions. Firstly, despite attempts to investigate the effects of neighbourhood incivilities on the health of residents, empirical studies that consider the mediating roles of the human–place bond and neighbourhood relationship are lacking. Notably, mediated relationships do not recognize the direct effects of incivilities on the perceptions of residents, and do not depend on BWT. However, in the present work, if incivilities diminish the human–place bond, then the ability of socialisation to improve residents' wellbeing is decreased. This latter step is successfully captured by social disorganisation theory. This interpretation aligns with a recent study [22] that focused on the ability of a neighbourhood to self-regulate.

Furthermore, contextual factors have been investigated in previous studies, focusing mostly on only one dimension of incivility in the neighbourhood environment. Therefore, concerns emerge from casual directions that require a thorough emphasis on the physical and social incivilities of neighbourhoods. However, causal relationships between the social relationship of a neighbourhood and residents' wellbeing have not been consistently evident. Furthermore, most studies in this field of research have been conducted in non-Asian contexts. In this sense, the relationship between neighbourhood incivility and health may slightly differ in Asian contexts, especially in rapidly urbanising and multi-ethnic societies, such as Malaysia; moreover, variables such as human–place bonds may play a mediating role in this relationship. The level of neighbourhood incivility and residents' view of incivility may differ across nations having various ethnic groups [14], a phenomenon that will be considered in the present study sample.

Seeking solutions to strengthen human–place bonds and health in the Malaysian society is crucial because of the country's various ethnic backgrounds [23]. To address the aforementioned research gaps, the present study mainly aims to investigate the relationship between perceived incivilities and health in urban neighbourhoods. Moreover, this work assumes that human–place bonds (i.e., place identity and place attachment) may mediate the relationship between incivilities and health. Two key issues are addressed in the study, which will be presented in the conclusion. Firstly, although studies on each dimension of incivility are comprehensive, only a few have explored the two dimensions simultaneously. This problem will be discussed with a multidimensional measure of incivility (i.e., physical and social incivilities) using structural equation modelling (SEM) in this study. Secondly, by considering the mediating role of human–place bonds, this study offers further insight into the relationship between health and place.

2. Literature Review

The neighbourhood or community environment has become a hot topic in the study of environmental and community psychology. Neighbourhoods that are recognized to have stronger social resources, such as social stability, lead to improved health; whereas those with more social and physical incivilities lead to a poor quality of wellbeing [14,19] and problems such as insomnia [24], binge drinking among youths [25], increases in blood pressure, cardio-metabolic diseases [14], obesity [26], and depression [27,28]. Perceived incivilities or other physical and social signs of unrest in neighbourhoods affect the rate of people's stress levels and, consequently, their health [27,29]; such incivilities also reduce contributions in local group events or even the tendency to walk outdoors [30].

Social incivility represents the undesirable behaviours that take place in public settings, such as disruptive disputes, careless neighbours, loitering, and alcohol consumption. By contrast, undesirable environmental conditions, such as vandalised structures, litter, and abandoned cars, are examples of physical incivility [2,31,32]. People who consider their neighbourhood an important part of their identity are likely to spend time outside or to develop closer bonds with their neighbours [33].

2.1. Social Disorganisation Theory

Physical and social incivilities have been widely used in research on people's assessments of crime and safety in urban areas [34]. Shaw and McKay [17] initiated a disorder model by testing the social disorganisation theory throughout Chicago. This theory focuses on the neighbourhood environment's physical and social conditions, suggesting that people avoid spaces with incivility indicators. It indicates that perceived incivilities gradually diminish the innate capacity of a group to handle behaviours. Studies on cues to care [35] and BWT support this result [36].

People feel less attached to neighbourhoods that are considered to be deteriorated or have high levels of incivility [37]. However, the extent to which perceived incivilities can reduce place attachments to the home (microscale) or the block (macroscale) is unknown [38]. Home bonds are highly valued when the local environment is seen to be deteriorating and crime-ridden. Therefore, perceived incivilities may diminish neighbourhood attachments, but leave home attachments intact or strengthen them. When people think that their neighbourhood is dangerous or undesirable, they minimise the time they spend outside and avoid public spaces, which decreases the time spent on active commuting [39,40].

2.2. Conceptual Framework

The theory of criminological social disorganisation has motivated public health researchers to test the effect of neighbourhood disorder on the health habits of residents [22]. Recently, sophisticated methodological studies related to how people interpret and communicate in the neighbourhood environment have gained considerable attention [22,32]. Certain social and environmental characteristics may lead to residents' interactions, which can be a foundation for individual health. O'Brien, Farrell, and Welsh [22] used a meta-analysis to study the theoretical and empirical evidence of the relationship between incivilities and health according to three main approaches. They suggested a theoretical framework that connects (directly and indirectly) the aforementioned variables and represents the possible influence of the human–place bond as a mediator in this relationship. As shown in Figure 1, the current study proposes a conceptual model for examining the direct and indirect relationships between incivilities and health. Neighbourhoods lacking human–place bonds may have to cope with incivilities in physical and social dimensions [41] in order to achieve a healthy living environment. The model implies that if the neighbourhood characteristics can influence residents' health, they will possibly do so by promoting or hindering the degree of place identity and place attachment. To ground our investigation of the association between neighbourhood incivilities and health, and to examine place identity and place attachment as mediators, this study put forward nine hypotheses, as explained in detail below.

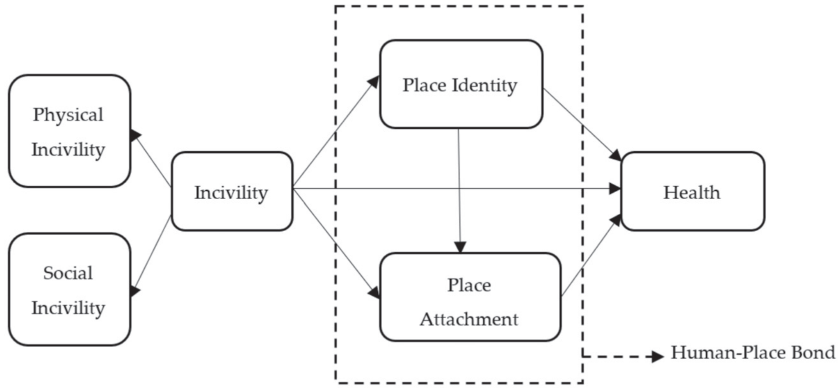

Figure 1. Conceptual pathways among the study variables.

2.2.1. Perceived Incivilities and Human–Place Bond

Neighbourhood incivilities refer to two types of incivilities, namely: (1) physical incivilities, characterised by observable incivilities (e.g., broken glass, vandalism, and litter), and (2) social incivilities, manifested by disruptive social behaviour (e.g., public drinking and lewd conduct) [42,43], which may also be seen in the physical environment. Neighbourhood incivility encourages residents to allow breaches against social order and be less likely to interfere to deter crime and incivility [44]. Residents thus tend to spend their leisure time at home, and they are unlikely to be in community relationships [45], suggesting low social regulation. Conversely, research on sense of place has provided insight into numerous meanings that people associate with their local surroundings.

Generally, sense of place is a broad attitudinal structure comprising three dimensions, namely: place attachment, place dependence, and place identity [46]. Schreyer et al. [47] and Williams and Roggenbuck [48] are the pioneers of the conceptualisation of place attachment; they determined the human–place bond in two components, namely, place identity and place dependence. Subsequent studies have revealed that affective and cognitive dimensions exist in the relationship between humans and their physical environment. Place attachment refers to an emotional bond towards places, whereas place identity refers to the self-cognition as a member of a place [49,50]. Place attachment can be described as the affective connection or bond formed between people and particular spaces where they remain and feel safe and secure [38]. Human–place bonds establish a form of “stickiness” [51], which increases the dependency and loyalty of residents to their living environment [52]. Therefore, the following hypotheses have been driven from the results of previous studies and the theoretical background.

H1. *Incivility is negatively associated with place identity.*

H2. *Incivility is negatively associated with place attachment.*

2.2.2. Perceived Incivilities and Health

Neighbourhood incivilities may discourage residents from engaging in neighbourhood spaces associated with physical and social activities concomitant with community health and wellbeing [53]. Therefore, social and environmental indicators of neighbourhood disorder are fundamentally associated with health and quality of life [34,54]. Residents suffer a burden on their wellbeing when they perceive more incivilities in their neighbourhood; by contrast, a friendlier and more supportive atmosphere can encourage residents to go out and engage in social activities [12]. For example, people may avoid green spaces that have vandalism, destroyed properties, or loitering youths [55]. In a review study, Gardener and Lemes de Oliveira [56] concluded that perceptions of the neighbourhood play a significant role in the health and well-being of the residents, and the elderly in particular. These include fear of crime, the presence of social and physical incivilities, sense of belonging, and neighbourhood cohesion. Furthermore, improving social and physical disorders in neighbourhoods could be a pivotal strategy for improving young children's physical activity and health [57]. Therefore, the following hypothesis has been developed to test this relationship.

H3. *Incivility is negatively associated with health.*

2.2.3. Human–Place Bond and Health

Evidence shows that place attachment is directly linked to health and wellbeing in various people, including adolescents [58], the elderly [11], ethnic groups [59], and households with different income rates [60]. The psychological literature has also found a relationship between considering an environment as an appropriate place to live in and place attachment, in which a higher place attachment is shown by those who indicate a more favourable assessment of that environment [50,61]. Place attachment is also linked negatively with depression [62]. In addition to a healthy and safe environment, aesthetic condition is associated with a stronger place attachment [63], and the perception of greater incivilities and physical degradation contributes to weaker place attachment [64]. On the basis of the above discussions, the following research hypotheses are drawn.

H4. *Place identity is positively associated with place attachment.*

H5. *Place identity is positively associated with health.*

H6. *Place attachment is positively associated with health.*

2.2.4. Potential Mediating Role of Human–Place Bonds

Extant empirical studies found that the neighbourhood environment has direct and indirect effects on residents' overall health. It seems that feeling part of the community is essential for maintaining residents' well-being, regardless of age, nationality, or income level. In their study, Jaśkiewicz and Wiwatowska [2] confirmed the mediating role of place identity in association with perceived incivilities and residents' health. Neighbourhoods with a high rate of incivility perception witness events that promote mistrust and lack of human–place bonds. The belief that other people are not trustworthy may limit social interactions between neighbours. Ross and Mirowsky [29] found that a lack of human–place bonds mediated the relationship between neighbourhood disorder and distress.

In another study by Zhang and Zhang [11], the results showed that sense of community mediated the effect of the incivilities of the neighbourhood on one's subjective health. Evans [65] concluded that a favorable neighbourhood environment could improve individuals' social interaction with people (making it easier to get social support from others) and lead to faster recovery from fatigue and discomfort, which could further enhance one's physical and mental health. Furthermore, similar studies concluded that the quality of public open space in neighbourhoods and shops was positively associated with human–place bonds, and could further affect one's mental health [66]. As mentioned above, the physical and social characteristics of the neighbourhood environment not only directly influence residents' mood and well-being, but also indirectly affect well-being by strengthening identification with or belonging to a residential neighbourhood [11]. Therefore, the following hypotheses are drawn based on the above discussions.

H7. *Place identity mediates the relationship between incivility and health.*

H8. *Place attachment mediates the relationship between incivility and health.*

H9. *The relationship between incivility and health is serially mediated by place identity and place attachment.*

2.2.5. Study Variables

The conceptual boundaries of the relationship between place attachment and place identity remain unclear and open from a theoretical point of view. Occasionally, these concepts are used interchangeably [67], as if they were synonyms. However, Lalli [68] and Puddifoot [69] incorporated place attachment under the concept of place identity. Hernández et al. [49] found that residents develop place attachment before place identity. However, Lewicka [70] argued that no agreement occurs on how the two concepts are correlated. The present work proposes that place identity and place attachment are different but related concepts, in which the former precedes the formation of the latter.

Neighbourhood incivility, as a multidimensional construct, including indicators of physical and social disorder [71], has the potential to decrease health behaviours (e.g., physical activity) among neighbourhood residents, as well as their physical and mental health [72]. It can be measured by physical and social incivilities [73]. Therefore, the proposed incivility variable is specified as a reflective second-order variable through the repeated use of all of the evident variables of the underlying first-order latent variable [74]. These hierarchical views have long been accepted in the current literature. In their study, Foster et al. [75] examined neighbourhood disorder items associated with fear of crime, through variables of physical incivilities and social incivilities. Jackson [76], in examining the social and cultural significance in the fear of crime, considered environmental incivilities using two sub-variables of physical incivilities and social incivilities. However, limited studies have empirically investigated the incivility variable using a second-order factor, because the aim is to examine the effects of the collective elements of social and physical incivilities on health.

Numerous studies have connected the concept of neighbourhood conditions to personal health. However, little research bears the theoretical framing of incivilities on the human–place bond that could undermine individuals' health. This study examines the idea that health is partially a feature of a residential neighbourhood's physical and social structures. The human–place bond has been recognized as a potential mediator between incivilities and health [22]. Although some variations are anticipated between the effects of the neighbourhood context and health, the degree to which this relationship differs depending on the level of place identity and place attachment among neighbours is largely unknown. Table 1 presents the definition of each dimension.

Table 1. Operationalisation of latent variables.

Dimensions	Definitions
Physical incivility	Residents' perceptions of physical incivility, such as trash and litter, and vacant houses in the neighbourhood environment.
Social incivility	Residents' perceptions of social incivility, such as loitering youths, inconsiderate neighbours and drugs, in the neighbourhood environment.
Place attachment	The extent to which respondents are fond of their neighbourhood; this involves caretaking and surveillance behaviours in the neighbourhood.
Place identity	The extent to which respondents convey and declare their identity in relation to their neighbourhood.
Health	The extent to which respondents convey the condition of their mental and physical health.

3. Materials and Methods

3.1. Site Selection

Penang was selected as the research location for this study. It is an island-state off the northwest coast of Peninsular Malaysia, and is one of the most developed Malaysian states with a population of 1.77 million [77]. This study contributes on the empirical examination and validation of social disorganisation theory by using multiple mediators. Countless aspects present across areas encompassing diverse cultures and neighbourhoods, such as physical and social factors, can be considered.

A survey conducted in Penang, Malaysia, covered a sample of 265 residents (after data cleaning) across a heterogeneous neighbourhood using a systematic sampling method. The study area is in the southeast part of Penang, Malaysia. It is built in on what used to be paddy fields in the mid-1970s, and was quickly converted into the residential neighbourhood that it is now. The location, which consists of landed properties, is a typical medium-class housing area with semi-detached terrace houses. A few condominium blocks and walk-up apartments have been constructed in the last decade at the boundaries of housing estates. This study focused on the landed properties, because they are the predominant types of dwelling in the area. This study used a systematic sampling procedure to select residents at intervals of every fourth unit in the study area.

3.2. Survey Instrument

In terms of research design, the current study is a cross-sectional design carried out in a residential housing neighbourhood. This research is based on a quantitative method, which prompted participants to respond to a series of questionnaires. The purpose of the study is not to develop a theory; however, the exploratory approach was used to bring new insight on the direct and indirect links between incivilities and health in residential areas. SEM was used to empirically test the conceptualised variables and framework.

The respondents provided their demographic information, as well as 25 statements that reflected physical incivility, social incivility, place identity, place attachment, and health. Incivility is a second-order construct created by considering social and physical incivilities of first-order constructs, and was extracted from an exploratory factor analysis.

Letters were sent to all of the selected houses a week before the first questionnaire interview was scheduled, informing them of the study. The letters ensured that the residents were aware of the study and that they would have already made up their mind whether to participate by the start of the interview. The response rate of the study was 62%. This study, as part of a larger project, was approved by the Ethics Committee of Universiti Sains Malaysia. Table 2 presents the study variables with their respective indicators.

Table 2. Study variables with respective indicators.

Construct	Item	Description
Physical incivility: Items were adapted from Foster et al. [78], Gibson et al. [79] (2002), Marzbali et al. [32], and Sampson and Raudenbush [16] (ranging from 1 = not an issue/no problem, to 7 = big problem)		
	PhysicInc1	Unkempt lawns and gardens
	PhysicInc2	Houses and fences not looked after (vacant houses)
	PhysicInc3	Upkeep of children's playgrounds
	PhysicInc4	Littering and dumping of rubbish in public areas
	PhysicInc5	Poor street lighting
	PhysicInc6	Vandalism or graffiti on public properties
	PhysicInc7	The condition of streets, sidewalks or road signs
Social incivility: Items were adapted from Foster, Giles-Corti, and Knuiman [78] and Sampson and Raudenbush [16] (ranging from 1 = not an issue/no problem, to 7 = big problem)		
	SocInc1	Inconsiderate or disruptive neighbours
	SocInc2	Noisy neighbours and loud parties
	SocInc3	Problems regarding selling and dealing of drugs
	SocInc4	Uncontrolled pets
	SocInc5	Teenagers hanging around the street
	SocInc6	Motorbike racing is high in this street
Place identity: Items were adapted from Kyle, Graefe, Manning, and Bacon [67]; Tournois and Rollero [50]; and Zhang et al. [80] (ranging from 1 = strongly disagree, to 7 = strongly agree)		
	PI1	This neighbourhood means a lot to me
	PI2	I am very attached to this neighbourhood
	PI3	I identify strongly with this neighbourhood
	PI4	I have a special connection to this area and my neighbours

Table 2. *Cont.*

Construct	Item	Description
Place attachment- Items were adapted from the work of Hipp and Perrin [81], Lewicka [70], Marzbali et al. [32], and Tournois and Rollero [50] (ranging from 1 = strongly disagree, to 7 = strongly agree)		
	PA1	I feel a sense of belonging to my neighbourhood
	PA2	I feel that I am a member of this neighbourhood
	PA3	I see myself as part of this neighbourhood
	PA4	I do keep an eye on what occurs in front of my house daily
	PA5	It would be very hard for me to leave this neighbourhood
	PA6	I feel comfortable when interacting with other races in this neighbourhood
Health: Items were adapted from Abdullah et al. [82], Baum et al. [83], and Wallace [84] (ranging from 1 = poor, to 5 = excellent)		
	Health1	Would you say that your mental health is poor, fair, good, very good, or excellent?
	Health2	Would you say that your physical health is poor, fair, good, very good, or excellent?

3.3. Statistical Analyses

The proposed model and hypotheses were tested by performing a partial least squares (PLS) analysis using SmartPLS3 software [85]. PLS was selected because of its suitability to the exploratory nature of this study, in which some of the hypothesised relationships amongst the variables had not been previously examined. Moreover, PLS is suitable when a research model is in its infancy, and it avoids the limitations of covariance-based SEM, such as sample size and restrictions, because of modelling complexity [74]. Nonparametric bootstrapping was utilized to assess the significance of the path coefficients amongst the latent variables, and between the latent and evident variables.

4. Results

4.1. Data Cleaning and Respondent Profiles

Among the 280 collected responses, 15 were excluded from subsequent analyses because of missing values. Among the remaining 265 responses, all standardised values were within the range of −4 to +4, as suggested by Mertler and Reinhart [86], considering that no outliers were present in the dataset. The average age of the respondents was 46 years (standard deviation (SD) = 16), and they had lived at their current home for an average of 18 years (SD = 11). Table 3 shows the other sociodemographic characteristics of the respondents. From the table, the majority of the respondents were homeowners, male, had completed an undergraduate degree, were married, and were living with their family. Data based on the sociodemographic characteristics show that the residents in the study area were considered to be healthy households.

Table 3. Respondents' demographic characteristics.

Demographic Factors	Categories	Number	Percentage
Ownership	Owner	206	77.7%
	Tenant	31	11.7%
	Others	28	10.6%
Gender	Male	143	54%
	Female	122	46%
Marital status	Single, widowed, or separated	73	27.5%
	Married and living as married	192	72.5%
Education	University/college	139	52.5%
	Secondary education	104	39.2%
	Primary education	15	5.7%
	Non-formal education	7	2.6%

Table 3. *Cont.*

Demographic Factors	Categories	Number	Percentage
Occupation	Self-employed	43	16.2%
	Private sector employee	83	31.3%
	Public sector employee	26	9.8%
	Retiree	35	13.2%
	Unemployed	54	20.4%
	Others	24	9.1%
Length of residence	Less than 5 years	31	11.7%
	5–9 years	36	13.6%
	10 years and over	198	74.7%
Ethnicity	Malay	118	44.5%
	Chinese	116	43.8%
	Indian	31	11.7%

4.2. Measurement Model Results

To evaluate the hypotheses, PLS structural equation modelling was used. Multiple parameters were considered in order to assess the validity and reliability of the measurements. Outer loadings, convergent validity, composite reliability, and discriminant validity were required in order to evaluate the measurement model (Tables 4 and 5). As suggested by Hair et al. [87], the outer loadings should exceed 0.4. The smallest outer loading value was 0.556 (SocDis6; Table 4). In the testing reliability, the threshold value of Cronbach's alpha, rho-A, and composite reliability for a given construct is 0.7. All constructs had reliabilities of more than 0.70 (Table 4). Convergent validity was measured by the average variance extracted (AVE), the threshold value of which was 0.5 [88].

Table 4. Outer loadings and cross loadings of latent constructs.

	Health	Physical Incivility	Place Identity	Place Attachment	Social Incivility
Health1	**0.945**	−0.140	0.265	0.575	0.005
Health2	**0.954**	−0.254	0.309	0.635	−0.181
PI1	0.245	−0.311	**0.879**	0.248	−0.150
PI2	0.261	−0.329	**0.953**	0.279	−0.188
PI3	0.344	−0.323	**0.924**	0.335	−0.215
PI4	0.246	−0.301	**0.903**	0.258	−0.195
PhysicInc1	−0.195	**0.870**	−0.257	−0.241	0.606
PhysicInc2	−0.207	**0.888**	−0.226	−0.252	0.646
PhysicInc3	−0.229	**0.837**	−0.336	−0.213	0.532
PhysicInc4	−0.212	**0.886**	−0.325	−0.299	0.605
PhysicInc5	−0.104	**0.857**	−0.242	−0.235	0.634
PhysicInc6	−0.161	**0.871**	−0.331	−0.249	0.607
PhysicInc7	−0.174	**0.890**	−0.389	−0.284	0.605
PA1	0.587	−0.278	0.293	**0.896**	−0.230
PA2	0.564	−0.298	0.331	**0.912**	−0.244
PA3	0.562	−0.336	0.339	**0.911**	−0.287
PA4	0.586	−0.262	0.231	**0.893**	−0.232
PA5	0.540	−0.172	0.207	**0.858**	−0.124
PA6	0.561	−0.186	0.231	**0.851**	−0.167
SocInc1	−0.116	0.640	−0.169	−0.276	**0.891**
SocInc2	−0.063	0.640	−0.154	−0.212	**0.910**
SocInc3	−0.074	0.611	−0.222	−0.205	**0.860**
SocInc4	−0.148	0.519	−0.137	−0.165	**0.735**
SocInc5	−0.094	0.539	−0.246	−0.197	**0.787**
SocInc6	0.082	0.321	−0.014	−0.075	**0.556**

Notes: values in boldface are outer loadings, whereas others are cross loadings.

Table 5. Assessment of reliability and validity of constructs.

	Health	Physical Incivility	Place Identity	Place Attachment	Social Incivility
Health	**0.950**				
Physical Incivility	−0.210	**0.871**			
Place Identity	0.304	−0.345	**0.915**		
Place attachment	0.638	−0.291	0.309	**0.887**	
Social Incivility	−0.097	0.712	−0.206	−0.245	**0.799**
Average Variance Extracted	0.902	0.759	0.838	0.787	0.638
Composite Reliability	0.948	0.957	0.954	0.957	0.912
rho_A	0.897	0.948	0.946	0.948	0.903
Cronbach's Alpha	0.891	0.947	0.935	0.946	0.881

Note: The diagonals (in bold) represent the square root of the AVE.

Discriminant validity was examined using three criteria. Firstly, following Fornell and Larcker [88], the square root of the AVEs of each construct needed be greater than the correlation estimate among the constructs (Table 5). Secondly, the outer loading values on the respective constructs needed to be more significant than their cross-loadings on the other constructs (Table 4). Thirdly, the heterotrait–monotrait (HTMT) ratio and confidence interval needed to be less than 0.85 and 1, respectively [89]. The square root of AVE exceeded the intercorrelations of the constructs in the model (Table 5). This result suggests that the model had a sufficient discriminant validity [90]. The HTMT ratios and corresponding confidence intervals for each pair were less than 0.85 and 1, respectively (Table 6). Thus, the model possessed convergent and discriminant validities.

Table 6. Heterotrait–monotrait (HTMT).

	Health	Physical Incivility	Place Identity	Place Attachment
Physical Incivility	0.226 CI 90 (0.108, 0.364)			
Place Identity	0.327 CI 90 (0.192, 0.454)	0.367 CI 90 (0.238, 0.479)		
Place Attachment	0.694 CI 90 (0.582, 0.795)	0.303 CI 90 (0.182, 0.422)	0.322 CI 90 (0.183, 0.458)	
Social Incivility	0.148 CI 90 (0.103, 0.263)	0.770 CI 90 (0.686, 0.839)	0.219 CI 90 (0.116, 0.351)	0.257 CI 90 (0.146, 0.396)

Harman's one-factor test [91] was conducted to examine the potential for common method variance. Common method variance is observed when only one factor arises from a factor analysis, or when the first factor describes more than 50% of the variance. Therefore, all items for the constructs were introduced into the factor analysis. The unrotated matrix shows that the first factor explained 38% of the variance. Thus, common method variance was not an issue in this study.

4.3. Assessment of the Hierarchical Incivility Construct

Incivilities were treated as a second-order construct, comprising two first-order reflective constructs (physical and social incivilities) that represent 13 items. Physical incivilities (R2 = 90.6%) and social incivilities (R2 = 79.8%) reflected the degree of the explained variance of the hierarchical construct. The entire path coefficient from its incivilities to its dimensions was significant at $p < 0.01$.

4.4. Assessment of the Structural Model

4.4.1. Direct Effects

Table 7 shows the results of the path analysis, which was conducted to test the hypothesised direct effects amongst the latent variables. The effect of incivility on place identity ($\beta = -0.312$, $p < 0.01$) and place attachment ($\beta = -0.219$, $p < 0.01$) was negative and significant. In agreement with previous studies, the results suggest that high perceptions of social and physical incivilities were linked with a lower sense of place identity and place attachment. However, the direct association between incivility and health was insignificant ($\beta = 0.042$, $p > 0.05$). As hypothesised, place identity had a positive and significant effect on place attachment ($\beta = 0.241$, $p < 0.01$). Moreover, place identity ($\beta = 0.128$, $p < 0.01$) and place attachment ($\beta = 0.611$, $p < 0.01$) had positive and significant effects on health. Thus, participants who felt high levels of place identity and place attachment reported positively about their health. Therefore, the results supported H1, H2, H4, and H5, but not H3. The R2 value for health was 0.422.

Table 7. Path coefficient and hypothesis testing (direct effects).

Hs	Relationship	β	t Value	Decision	f2	VIF
H1	Incivility → Place identity	−0.312	4.950 ***	Supported	0.108 (Small)	1.000
H2	Incivility → Place attachment	−0.219	3.173 ***	Supported	0.050 (Small)	1.108
H3	Incivility → Health	0.042	0.987	Not supported	0.003	1.164
H4	Place identity → Place attachment	0.241	3.455 ***	Supported	0.061 (Small)	1.108
H5	Place identity → Health	0.128	2.008 **	Supported	0.024 (Small)	1.176
H6	Place attachment → Health	0.611	11.385 ***	Supported	0.556 (Substantial)	1.161

Beta = regression weight, t values are computed through bootstrapping procedure with 265 cases and 10,000 samples; ** $p < 0.05$, *** $p < 0.01$.

4.4.2. Indirect Effects

This study estimated three mediating relationships. Table 8 shows the results of the path analysis, which tested the hypotheses of the indirect effects. The t values were calculated using the bootstrapping procedure suggested by Hayes [92], with 10,000 samples by reading the specific indirect effect from the PLS output. Table 8 shows that the t values of two indirect effects (H6 and H7) were significant at the 0.05 and 0.01 levels, respectively. Therefore, H6 and H7 were supported.

Table 8. Hypothesis testing (indirect effects).

Hs	Specific Indirect Effect	Path Coefficients (O)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	*p* Values	Decision	VAF (%)
H7	Incivility → Place identity → Health	−0.043	0.024	1.784	0.075	Not supported	–
H8	Incivility → Place attachment → Health	−0.151	0.050	3.032 **	0.002	Supported	75.29
H9	Incivility → Place identity → Place attachment → Health	−0.055	0.020	2.714 **	0.007	Supported	25.93

** $p < 0.01$, VAF (variance accounted for) = indirect effect/total effect.

Calculating the intensity of mediation is crucial for making decisions relevant to mediation effects. Following Hair et al. [87], the strength of a mediation effect was calculated by considering the variance accounted for (VAF), where VAF > 80% implies full mediation, 20% $\leq$ VAF $\leq$ 80% indicates partial mediation, and VAF < 20% does not indicate any mediation. VAF was calculated to estimate the intensity of the indirect effect by dividing the indirect effect by the total effect [93]. The VAF value indicates that approximately 75% of the total indirect effect of incivility on health is explained by the partial mediating effect of place attachment (Table 8). Hence, the relationship between incivilities and health is serially and partially mediated by place identity and place attachment, given that the VAF value is greater than 20% (i.e., 26%). Thus, indirect-only mediation was assumed, because the indirect effects were significant, but not the direct effect [87].

The R^2 values suggest that incivility explained approximately 10% of the variance in place identity, whereas incivility and place identity explained approximately 14% of the variance in place attachment. However, incivility (indirectly), place identity, and place attachment reasonably explained 42% of the variance in health. Effect size (f^2) was calculated to estimate the extent of the effect of an independent latent variable on the dependent variable. It is based on the change in the coefficient of determination (R^2). According to Chin [94], 0.02, 0.15, and 0.35 represent a small, moderate, and substantial effect size, respectively. Table 7 shows that the f^2 values for place identity and place attachment on health were 0.024 and 0.556, respectively. Thus, place attachment has a substantial effect on health.

The multicollinearity amongst the variables in the model was also tested. The results did not emphasize any cause for concern in using variance inflation factor (VIF), the values of which were all below the suggested threshold of 5.00 (Table 7) [95]. Hair et al. [96] suggested that the predictive relevance of the model should be examined using a blindfolding procedure. The Q^2 values for social incivility (Q^2 = 0.476), physical incivility (Q^2 = 0.640), place identity (Q^2 = 0.073), place attachment (Q^2 = 0.100), and health (Q^2 = 0.356) were >0. Thus, the model had sufficient predictive relevance.

5. Discussion and Conclusions

This study aims to test a model on the neglected, but pivotal, mediating role of human–place bond on the relationship between incivility and health. Direct and indirect relationships between incivility and health were tested. Understanding how residents create human–place bonds, which can affect health outcomes, is crucial. The conceptual framework was formed based on social disorganisation theory. Data were collected from a heterogeneous neighbourhood in Penang, Malaysia, using a sample of 265 residents. In contrast to predictions, no significant direct relationship was found between incivility and health. This is not surprising, as previous literature reported inconsistent evidence for incivilities' impact on health and risky behaviours [22]. O'Brien and colleagues [22] found a quite weak impact of incivilities on general health.

The results further suggest that place attachment significantly mediates the relationship between incivility and health, whereas place identity does not mediate this relationship. This is an interesting finding and may refer to methodological inconsistencies undermining the study of BWT [22]. However, the relationship between incivility and health is serially mediated by place identity and place attachment. Thus, although place identity does not play a mediating role in the relationship between incivility and health, it promotes the sense of place attachment by integrating the place as part of one's self. Therefore, if residents' health and wellbeing are affected by their environment, then the effect is likely caused by promoting or decreasing the degree of human–place bonds.

As two research hypotheses were not supported, the results help to better understand the relationship between incivility and health. This result is inconsistent with previous studies, and may refer to employing a second-order factor for the incivility construct in the research model. Many neighbourhood characteristics, in particular social and physical incivilities, may not directly affect health [39]; however, these features may influence perceptions of place identity and place attachment towards the neighbourhood, and consequently health. This finding helps to better understand the cognitive and social mechanisms underlying health, and give some insight into the incivility–health relationship. Therefore, longitudinal studies would assist in cross-validating the findings and determining the generalisability of the study findings to other contexts.

In terms of theoretical implications, this study provides insight into the mechanisms that lead to the experience and perception of the environment. The study findings may improve the knowledge on how the dimensions of an urban environment (social and physical) can affect the manner in which individuals perceive and experience their living environment. On the basis of the study findings, a stronger identity and attachment to a place is attributed to individuals who experience less incivilities in their neighbourhood. The study improves the research on the human–place relationship, which remains unclear in the literature [70]. This study revealed a positive and significant relationship between place identity and place attachment. Place identity and place attachment are conjectured to two different, but related, concepts, in which high levels of place identification indicate high levels of place attachment.

Previous research has indicated that place attachment and place identity promote health and wellbeing [14,19,22,32]. Our findings extend on such research, by revealing that individuals with high levels of identification and attachment with place also show high levels of general health. By evaluating the serial mediating roles of place identity and place attachment, the study found that the human–place bond can alleviate the negative effects of incivilities on residents' health in neighbourhoods. An ideal neighbourhood for residents is one that is safe, clean, and stable, whereas social and physical incivilities are associated with a poor quality of the neighbourhood. In agreement with the literature [22], the results further suggest that incivilities can diminish place identity and place attachment, which decreases the ability of residents to improve their health and wellbeing.

The more people perceive their area of residency as being deteriorated, the less they report a place attachment to it in relation to estimating their general health. This finding is consistent with previous studies, which reported that disadvantaged neighbourhoods exacerbate the development process of social relationships [16]. By contrast, the human–place bond improves the perception of the environment as a safe place to live, where people choose to live in the same neighbourhood. People's experience of incivilities could have an even greater influence than the experience of crime, because of the higher feasibility of residents having behavioural reactions to physical or social disorders (by confronting offenders) compared with criminal offenders, who may be dangerous to confront. The findings of this study show that incivilities and place identity are the antecedents of place attachment.

The practical implication of the study is as follows. Local authorities may improve the living conditions of residents to strengthen their level of attachment and identification to their living environment, which may improve individuals' health. Local authorities have the responsibility to design and make beneficial use of public areas. Thus, they have a crucial role in improving the social and physical qualities of the environment. The result further suggests that the degree of attachment and identification considerably affects individuals' health. Residents' bonds to the neighbourhood affect their level of engagement in community events. Thus, by planning neighbourhood gatherings, local authorities or the neighbourhood committee can promote a sense of belonging and feelings of attachment among the residents. Therefore, effective communication between residents is crucial in order to promote the spirit of neighbourliness and the creation of human–place bonds, and consequently enhance individuals' health. This promotion can be achieved by organising (i) public meetings on neighbourhood development; (ii) community clean-up incentives; (iii) recreational, athletic, and social events; and (iv) other activities conducted in the neighbourhood aimed at persuading residents to participate and promote a sense of community.

6. Limitations and Directions for Future Research

The study has some limitations that also provide directions for future research. Firstly, the study concentrated only on a heterogeneous middle-class neighbourhood. Although the study area represents a typical neighbourhood in Penang, Malaysia, the findings might not necessarily be applicable to other homogenous low- or high-class neighbourhoods. Secondly, although incivility was measured with subjective scales that have been validated in previous studies [32], results could differ if incivility was measured using quantitative methods, such as observation checklists. As such, future studies can use different samples and measure incivility objectively in order to improve the external validity of the proposed model. Thirdly, based on the basis of social disorganisation theory, neighbourhood structures, such as socioeconomic factors, are powerful determinants of the perception of safety and health, regardless of the role of neighbourhood physical attributes [97,98]. Sampson and Raudenbush [16] hypothesise that physical and social incivilities are greater in neighbourhoods marked by instability, poverty, and high ethnic transition. Future studies may consider the effect of neighbourhood structural factors, such as neighbourhood socioeconomic status and residents' turnover, on the perception of safety, crime, and health. Lastly, a prevailing tendency among the research on place identity and place attachment is considering the neighbourhood scale as the main category of analysis [99]. However, Casakin et al. [100] have suggested a city scale as having a predominant effect on the development of human–place bonds. Thus, additional studies should be conducted in order to investigate the creation of human–place bonds at neighbourhood and city scales.

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sustainability

Article

Urban Transit Network Properties Evaluation and Optimization Based on Complex Network Theory

Guo-Ling Jia [1], Rong-Guo Ma [1] and Zhi-Hua Hu [2,*]

1 School of Highway, Chang'an University, Xi'an 710064, China; jgl@chd.edu.cn (G.-L.J.); mrg@chd.edu.cn (R.-G.M.)
2 Logistics Research Center, Shanghai Maritime University, Shanghai 201306, China
* Correspondence: zhhu@shmtu.edu.cn; Tel.: +86-021-3828-4613

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Abstract: Urban public transportation contributes greatly to sustainable urban development. An urban public transportation network is a complex system. It is meaningful for theory and practice to analyze the topological structure of an urban public transportation network and explore the spatial structure of an urban transportation network so as to mitigate and prevent traffic congestion and achieve sustainability. By examining the Xi'an bus network, the degree distribution, average path length, aggregation coefficient, and betweenness centrality of the bus station network were computed using models in complex network theory. The results show that the node degrees of the Xi'an bus network are unevenly distributed and present a polarization diagram with long average path length and high aggregation. A model based on betweenness and its solution method was developed to improve the public transportation network's sustainability and discuss the possibility of optimizing the sustainability by network analyzing methods.

Keywords: public transport network; complex network theory; network analysis; logistics management; sustainability

1. Introduction

Urban transit transportation plays an important role in the sustainability of the economy, environment, and even the whole society, as it helps to improve traffic resource efficiency and effectively alleviate the contradiction between traffic supply and demand [1,2]. In particular, reasonable network structures contribute to reduce road congestion, travel difficulties, and related environmental problems such as air and noise pollution [3,4]. With the reduction of traffic congestion, a lot of energy and non-renewable resources can be saved, and traffic accidents, related deaths and injuries, direct and indirect economy losses can be avoided [5,6].

Although the contributions of urban transit transportation to sustainability are significant, the holistic construction of a public transportation system for many cities is seriously lagging behind [7,8]. Especially, with the increasing number of private cars, the proportion of transit transportation has declined and been replaced by other modes with low resource utilization ratios. It therefore results in increasing travel time by public transportation and lowering the service level of it. This problem is extremely obvious in China, where the proportion of people choosing public transportation in the world's major developed cities is between 45% and 60%, while that in China is less than 30% [9].

The methods in the realm of complex networks and systems are well developed and applied in transport systems. System dynamics as an important branch of system science was used to consider the transportation supply and demand dynamic balance and their interaction with urban development [10]. Due to the comprehensive consideration of sustainability problems, modern control theory has been applied in the fields of transportation [11,12]. The former has applicability and superiority in dealing with complex interactions, especially urban traffic complexities. The latter plays an important part in transportation management control. These two methods inspire systematic studies on urban transit transportation networks.

An urban public transport network can be viewed as a complex system of the urban transport system and socio-economic environment. Both the transportation department administration and professional scholars are working hard to explore how to improve the performance of the system, so that it can provide transportation services that are smooth, convenient, and environmentally friendly [5]. Urban transit transportation networks present the characteristics of complex systems. Complex network theory is a favorable method for studying complex systems. It emphasizes the topological nature of system architecture; complex networks provide a theoretical approach to the study of complexity [13,14]. Complex theory based on multidisciplinary knowledge can be used to study the complexity of urban transit transportation networks, so a network's space–time complexity and evolution mechanism can be explored. It provides theoretical guidance for the scientific planning of urban public transport structures. Complex networks highlight the topological characteristics of the system structure. Because the geometric properties of complex systems play a primary role in the network's dynamic behavior, public transportation can be depicted by traffic flows on complex networks involving bus lines and docking stations. Therefore, the advantages and disadvantages of the public transport network's structure have greatly affected the efficiency of passenger transportation in the entire public transport system. The topology of the public transport network deserves further research. By analyzing the characteristics of the existing network, a better public transportation system can be designed, and thus its utility can be improved [15,16].

Research on the complexity of urban transportation networks generally focus on the structural characteristics of transportation networks' topology. Additionally, it is increasingly important to analyze the impact of network structure on traffic. Different urban transportation networks may call for specific theoretical guidance for planning, design, and management. Research on these areas help to explore general rules and special features for different types of cities. Evolutionary mechanisms of urban transportation networks can be achieved, and the time and space complexity of networks can be explored [5].

In summary, the research on urban public transport networks' complexity is still in its early stage. Although the research on urban public transport network models have provided the basic statistical characteristics of the network, the models rarely consider the spatial features of the transit transportation network. This study looks at the urban transit network's topology features from the perspective of complexity, measures the hierarchical relationship of nodes in the network, develops an optimization method based on complexity features presenting an effective method to improve the utilization rate of the urban public transport system, cut down traffic congestion, and reduce environmental pollution. The Xi'an urban bus network was chosen for its representation. Due to the presence of historical reasons, the layout of the road network in Xi'an is believed to be unreasonable. The population in the central area of the city is dense; the distribution of the population and road space is extremely uneven; the construction of transportation facilities is restricted; and the transit network has serious structural defects [17]. Additionally, the total construction of the public transportation system is seriously lagging behind, and the proportion of the structure is out of balance. Compared with other developed and advanced large cities around the world, Xi'an, as a new rising first-tier large city in China, is going to achieve a large increase in economy and transportation which means the public transportation is going to face challenges as well. How to optimize the network structure and make it consistent with economic and social development is not only meaningful and valuable for Xi'an, but for similar urban transportation systems around the world.

The rest of the manuscript is organized as follows: Section 2 presents a review on related studies; Section 3 introduces the methods used for urban transit network properties analysis; Section 4 explains the data sources and network construction images, and presents the urban public transportation network's features; Section 5 focuses on the formulation and optimization of the sustainable public transportation network design. Section 6 demonstrates the discussions on improvement of sustainable public transportation networks. Finally, conclusions and further research prospects are presented in Section 7.

2. Literature Review

Complex network theory can be used to capture and describe the evolutionary mechanisms, laws and functions of systems by means of graph theory and some statistics methods [13,18]. At the end of the 20th century, the study of complex network theory was no longer limited to the field of mathematics. Scholars began to consider the overall characteristics of a large number of actual networks with complex connections. Two groundbreaking articles have been recognized as the beginning of a new era of complex network research. One is entitled "Collective Dynamics of 'Small-world' Networks" [19]. The other is entitled "Emergence of Scaling in Random Networks" [20]. These two articles reveal the small-world characteristics and scale-free nature of complex networks, and establish corresponding models to illustrate the mechanisms of these characteristics. With the extensive research on complex systems, the research on the real world from various perspectives has spread to many disciplines and fields, such as cooperation networks in social networks, company directors' networks, research citation networks, language networks, and computer technologies networks, the neural network, the power network, telephone networks, and urban transportation networks, etc. [21].

Applying complex network theory to analyze the complexity of urban transportation network topology is a key to the study of complex urban transportation networks, and it is also one of the basic issues of urban transportation network research. It has been gradually realized that it is not enough to use some local data for traffic analysis and road planning to solve traffic congestion in cities. It is necessary to conduct a comprehensive analysis of the routes or the road network.

In recent years, research on weighted networks have been rapidly developed. Weighted networks introduce weight as a dimension to distinguish the difference between edges, as the strength between network nodes may be different. In 2006, Boccaletti [22] published the latest review on complex network research. Complex weighted networks can describe actual complex systems. At present, the research work on weighted networks mainly focuses on modeling research [23], complex characteristics [24], and dynamics on complex-weighted networks [22]. The results of some studies in many practical weighted networks have shown that vertex weight and edge weight also follow the power-law distribution. After giving weights to the connections, it provides a new method for characterizing the system. Adjusting the weights also provides a new means for optimizing the nature of the network and its functions. Complex networks are also important for the prediction and processing of emergencies. The network is found to be stable after the nodes are randomly deleted, but if the key connectivity nodes in the network are deleted, the network is easily destroyed [18].

Many scholars have conducted a lot of theoretical studies and empirical analyses of complex networks. The existing research mainly focuses on the empirical analysis of subways, streets, and public transportation networks, and studies the basic topology of the network, like the degree distribution, mean shortest distance, clustering system, etc. Latora and Marchiori carried out a preliminary study of the network characteristics of the Boston Metro [25]. Sen et al. studied the small-world characteristics of the Indian railway network [26]. Seaton et al. calculated the small world effect of the railway line network between Boston and Vienna [27]. Sienkiewicz analyzed the topological characteristics of the bus transportation network in 22 cities in Poland, and then further analyzed the clustering, match degree, and median characteristics of the Polish urban public transportation network [28]. The complex-weighted network has also received widespread attention in recent years. Li et al. [29], Bagler et al. [30], Barrat et al. [31], and Guimera et al. [32] studied the weighted network characteristics of airports in China, India, and the world, respectively. Among them, Barrat et al. [31] used real-world data to deeply explore the correlation between weights and topologies in weighted networks, and introduced the definition of some characteristics in weighted networks. Domestically, the complexity of urban transport networks has just begun. Wu and Gao [33] carried out theoretical and empirical research on complex networks earlier, and analyzed the scale-free characteristics of the Beijing public transport network. Wei et al. [34], Di [35], Zhao et al. [36], Zhang [17], and Zheng et al. [37] carried out empirical studies on urban transit transportation networks in Chengdu, Tianjin, and Xi'an based on complex network theory. These studies have shown that urban transportation networks have the structural characteristics of complex networks.

To sum up, although the research on networks has developed rapidly [38,39], it still faces many challenges in the study of urban public transportation. As far as urban public transportation is concerned, the existing research has just started, and there are still many problems to be solved. The characteristics of different network topologies need to be further analyzed. In particular, it is necessary to theoretically explore models that can optimize the network.

3. Method

The nature of the network that does not depend on the specific location of the node and the specific form of the edge can be described by the topological property. The corresponding structure is called the topology of the network. Topological parameters, also known as the static geometry of the network, are the basis for studying complex networks [13]. This study focuses on the four most important topological parameters of the network according to complex theory: degree distribution, path length, clustering coefficient, and betweenness. Two software, UCINET [40] and Netdraw [41], are used to obtain the regarding results and visual picture. The former is one of the most popular social network analysis software tools. It includes centrality analysis, cluster analysis, and statistical analysis, etc. Netdraw is generally used for visualization. It is integrated within UCINET software.

3.1. Node Degree

Node degree k is defined as the number of connections to the node and is the basic parameter for studying the topology of a complex network [24,42], as denoted by Equation (1). In Equation (1), N is the total number of nodes, θ_{ij} indicates whether node v_i and v_j are connected or not. Here, $\theta_{ij} = 1$ means that v_i and v_j are connected, while $\theta_{ij} = 0$ means no connection. The average node degree of the network composed of N nodes is given in Equation (2). If the node is randomly selected from the network, the probability of degree k is P. Then, denote $P(k)$ as the network degree distribution, which shows the change of P according to the value of k.

$$k(v_i) = \sum_{j=1}^{N} \theta_{ij} \tag{1}$$

$$\bar{k} = \frac{1}{N} \sum_{i=1}^{N} k(v_i) \tag{2}$$

In the actual bus network analysis process, the node degree indicator indicates the number of bus routes directly connected to the station. The greater the node degree, the more bus lines are connected. This indicator describes the extent to which the site has a direct impact on other connected lines. The results of complex network research indicate that subsequent bus routes tend to be connected to sites with higher node degrees.

3.2. Path Length

In a complex network, the number of edges included in a route between any two points represents the path length of these two points. The average of the shortest path lengths between any two points reflects the size of the network, called the feature path length. If there is no path between the two points, the path length between the two points is infinite.

The length of the feature path is computed by Equation (3). In Equation (3), l is the length of the network feature; N refers to the number of network nodes; and d_{ij} is the path length between two points. The maximum path length between all pairs of nodes represents the diameter of the network. The path length and network diameter measure the transmission performance and efficiency of the network.

$$l = \frac{1}{N(N-1)} \sum_{i \neq j} d_{ij} \tag{3}$$

3.3. Clustering Coefficient

Given a node i in the network, all nodes associated with the node i form a sub-network. c_s is the ratio of the number of arcs in the sub-network to the number of all possible arcs in the sub-network, and c is the average of all c_s.

The clustering coefficient can show the aggregation of nodes in the network, i.e., how close is the network. In real-world networks, especially in specific networks, nodes tend to establish a tight set of organizational relationships due to the relative high-density connection points. In public transportation networks, the distribution of the clustering coefficient means the bus lines' intensity near each station, and the average of the clustering coefficient depicts the intensity of the bus lines in the entire transportation network. Doragovtsev [43] pointed out that there are three different parameters for measuring cohesion characteristics, namely:

(1) Local clustering coefficient $C(k)$. In Equation (4), $\langle m_{nn}(k) \rangle$ denotes the average connections between neighbors of the node with degree k.

(2) Average clustering coefficient. In Equation (5), $P(k)$ is the distribution of the node degree k.

(3) Clustering coefficient. In Equation (6), $\langle k^2 \rangle$ shows the second moment of node degree, while $\overline{k}$ indicates the average node degree. This manuscript uses the average clustering coefficient to measure the aggregation characteristics of urban public transit networks.

$$C(k) = \frac{\langle m_{nn}(k) \rangle}{k(k-1)/2} \tag{4}$$

$$\overline{C} = \sum_k P(k) C(k) \tag{5}$$

$$C = \frac{\sum_k P(k) \langle m_{nn}(k) \rangle}{\sum_k P(k) k(k-1)/2} = \frac{\sum_k k(k-1) P(k) C(k)}{\langle k^2 \rangle - \overline{k}} \tag{6}$$

3.4. Betweenness (b)

The betweenness of node i is defined as Equation (7), where n_{jk} is the number of all the shortest paths connecting the nodes j and k, and $n_{jk}(i)$ is the number of paths passing through the node i among these paths. Similarly, the number of shortest paths through a certain edge can be used to define the betweenness of the edges.

$$b_i = \sum_{j \neq k \neq i} \frac{n_{jk}(i)}{n_{jk}} \tag{7}$$

4. Evaluation of Transportation Network Properties

4.1. Network Data

4.1.1. Assumptions

Some hypotheses are made before the study, as follows:

(1) Sites with the same name are treated as one docking site, and sites with different names are treated as different docking sites. Ignore the case where the individual docking sites have the same name but different docking locations.

(2) Ignore the situation that the uplink and downlink lines are different, and abstract the urban bus network into an undirected network. That is, if the site A can be reached from the site B through a certain line, the site B can also be reached from site A along the same line.

(3) Regardless of the difference in the frequency of vehicle departures and the number of bus lines connecting the two stations, that is, regardless of the connection weight problem in the network, the network is abstracted into an unweighted network.

(4) Due to the intersection of urban roads, T-junctions, etc., there are many places where bus lines meet. The point at which the bus line space intersects is not necessarily the bus stop site, so different bus lines are not connected here.

4.1.2. Data Selected

The public transport network consists of two basic elements: the station and the route. A line consists of several sites. This manuscript analyzes the Xi'an public transportation system. According to the above assumptions, the network includes 473 lines and 2808 docking stations.

4.1.3. Bus Network

The idea of establishing a bus station model is to use a docking station as a node. Since the geographical location of the bus stop was not considered, the cyclic operation of the bus line was ignored in the statistical process, and the first and last bus stops on each line were not connected. The shortest path length between the two nodes represents the minimum number of bus stops that pass from the point of departure to the destination.

According to the above modeling method, all stations were numbered, and 0/1 adjacency matrix of 2808 × 2808 was generated using Python, and UCINET and Netdraw drew the network topology map of the bus stations. Then, we performed the centrality analysis, selected "centrality measures" in the menu of "analysis", and chose "degree" when setting the node size. The connection represents the direct connection between the sites. The size of the point reflects the importance of the node. The final bus network is visualized in Figure 1.

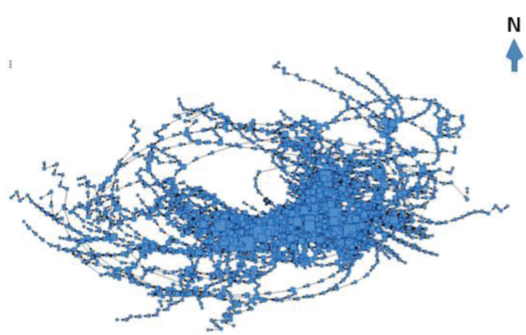

Figure 1. Topology of Xi'an bus network.

4.2. Evaluation Results of Transportation Network Property

This part uses complex network theory and UCINET, and takes the Xi'an bus station network as an example to calculate and analyze the characteristic and topological properties of the network.

4.2.1. Degree of the Network

For a weightless network, the node degree represents the number of connected edges between nodes. The greater the degree of node, the higher the connectivity, the better the traffic conditions in the actual geospatial space, or it is more likely to be the hub or transfer station in the actual bus network. The node degree statistics in the bus complex network are shown in Figure 2 and Table 1 below, and some nodes are shown in Table 2.

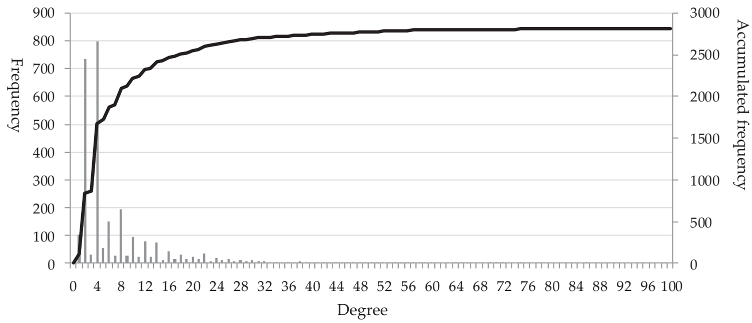

Figure 2. Node degree distribution of the Xi'an public transit network.

Table 1. Statistics of the partial node degree for the Xi'an public transit network.

Node Degree	0	1	2	3	4	5	6	7	8	9	10
Number of Node	3	101	735	30	799	56	149	28	194	27	93
Proportion (%)	0.1	3.6	26.2	1.1	28.5	2.0	5.3	1.0	6.9	1.0	3.3
Node Degree	11	12	13	14	15	16	…	72	75	86	99
Number of Node	24	78	22	74	13	56	…	1	1	1	1
Proportion (%)	0.9	2.8	0.8	2.6	0.5	2.0		0.04	0.04	0.04	0.04

Table 2. Docking stations with a high degree for the Xi'an public transit network.

No.	**Name**	**Degree**	**No.**	**Name**	**Degree**
1	Wu Lu Kou	99	16	Xiao Zhai	57
2	Bei Men	86	17	Zhi Yao Chang	56
3	Bei Guan	75	18	Bei Da Jie	56
4	Min Le Yuan	72	19	You Jia Zhuang	55
5	Long Shou Village	71	20	No. 6 Bus Company	55
6	Da Chai Shi	70	21	Wei Er Jie	55
7	Bei Shao Men	70	22	Ya He Garden	55
8	Da Yan Ta	66	23	Xi men	55
9	Tu Men	65	24	Xian Shao Men	54
10	Shi Tu Shu Guan	64	25	Yan Ta Xi Lu Dong Kou	54
11	Yu Xiang Men	60	26	Huo Che Zhan Dong	54
12	Wei Qu Bei Zhan	60	27	Hu Jia Miao	54
13	Feng Cheng Wu Lu	59	28	North Fang Xin Village	53
14	Dong Chang'an Street West Exit	58	29	Nan Shao Men	52
15	Duan Lv Men	58	30	Xi Kai Gong Si	52

Note: Name = Station name; Degree = Node degree.

The above table indicates that the highest value of node degree in the Xi'an public transport complex network is 99, with an average of 8.047, indicating that there are eight lines per site, the intensity distribution is extremely uneven, and the number of nodes with intensity below 10 is 2215, accounting for 78.9% of the total, the ratio of high nodes intensity above 52 is 1.1%.

4.2.2. Path Length

The shortest path represents a path from one node to another with the fewest edges. The average shortest path is the average of the shortest paths between all the nodes in the network. In the network model based on the adjacent site, it reflects an average number of sites between any two stations in the bus network, an elementary indicator for evaluating the convenience of the bus network model. After calculation, the average path length l is 28.455, the distance-based cohesion is 0.035, and the distance-weighed fragmentation is 0.965, which means that the degree of isolation between nodes is higher. Xi'an residents take an average of 28 stations per one trip.

4.2.3. Clustering Coefficient

For the bus station network, the clustering coefficient reflects the intensity of the bus lines near each station, and the network is analyzed. The average clustering coefficient of the bus station network in Xi'an is $C = 0.223$, and the low clustering coefficient indicates less neighbor node connection. Therefore, when the traffic flow of neighbor nodes passes through the node, it is easy to cause the node to be heavily loaded and congested. Figure 3 presents the clustering coefficient value of different nodes.

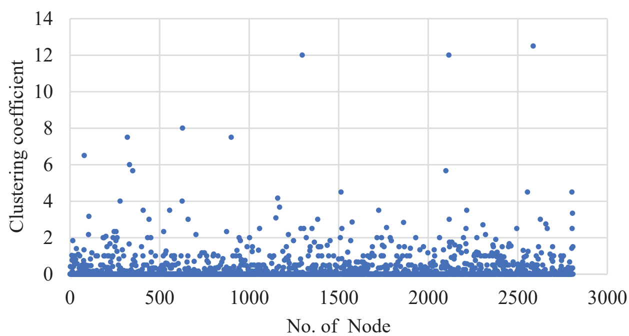

Figure 3. Clustering coefficient of the Xi'an public transit network.

4.2.4. Betweenness

The betweenness of node is defined as the number of shortest paths passing through a node in the network, reflecting the impact of the node on the network. It is calculated that the minimum betweenness of the bus station in Xi'an is 0, the maximum is 1,283,175.750, and the average is 54,134.063, Figure 4 shows the betweenness value of different nodes.

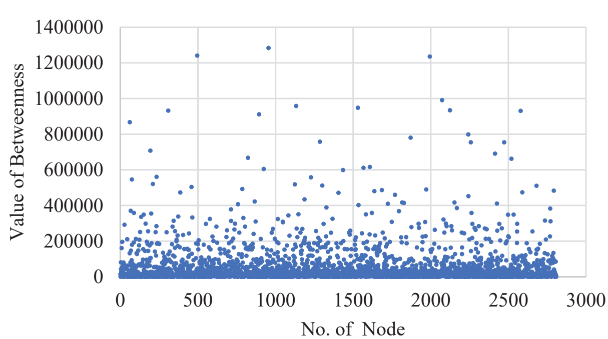

Figure 4. Node betweenness of the Xi'an public transit network.

A bus stop with a high betweenness is close to the topology of many other sites. It is usually a more important bus transfer site and has a greater influence in the network. As can be seen from Table 3, the betweenness and the number of bus routes that have passed are seemingly not correlated. In the planning of public transportation, it is necessary to recognize the importance of high degree or high betweenness sites, and improve the passenger flow and vehicle throughput performance of these stations, which have a very significant effect on improving the entire public transportation efficiency.

Table 3. Bus stops with high betweenness and passing routes.

Station Name	Betweenness	Passing Routes Number
Xiao Zhai	1,283,175.750	26
Ji Xiang Cun	1,240,683.875	19
Dian Zi Er Lu	1,235,358.375	16
Dian Zi Zheng Jie	990,928.688	15
Bei Da Jie	957,912.000	34
Wei Er Jie	948,115.063	19
Xi Wan Lu Kou	933,948.563	19
Chang'an District Government	932,379.750	25
Nan Shao Men	930,438.875	32
SaiGe Computer City	911,219.188	1

A bus stop with a high betweenness is close to the topology of many other sites. It is usually a more important bus transfer site and has a greater influence in the network. As can be seen from Table 3, the betweenness and the number of bus routes that have passed are seemingly not correlated. In the planning of public transportation, it is necessary to recognize the importance of high degree or high betweenness sites, and improve the passenger flow and vehicle throughput performance of these stations, which have a very significant effect on improving the entire public transportation efficiency.

5. Sustainable Transit Transportation Network Optimization

Research on the application of complex networks in public transportation systems showed that a scale-free network (BA network) has more adaptability. A few nodes have large degrees and the distribution of betweenness is not even. Links with high betweenness are responsible for the main passenger flow transportation, and are normally the public transportation hub points in the L-space public transportation network. The general bus congestion is also gathered on the links with high betweenness. The solution may focus on optimization of these key links. So, in order to solve urban public transportation congestion and maximize the capacity of the network, it is better to adopt the scale-free network topology structure. Whether in early planning or in later optimization, the corresponding driving mechanism can be used and the scale-free network topology developed to increase the capacity and sustainability of transportation networks.

The bus network optimization model is developed based on complex network theory. The complex network topology parameter is set as the objective, with the constraints of evaluation index of real bus network.

5.1. Objective

The link betweenness is the sum of the ratio of the shortest path number to the shortest path number between all the two nodes in the network. It characterizes the influence of nodes or edges on the whole network. The minimum number of edges is the smallest, which can effectively ensure that the shortest path of the network is small (Equation (8)). This goal indirectly shortens the total travel time of passengers and ensures the efficiency of the network. In Equation (8), n is the number of arcs between (N_o, N_d); B_i refers to the betweenness of arc i; and r_i is the resistance of arc i.

$$\min Z = \sum_{i=1}^{n} B_i r_i \tag{8}$$

5.2. Constraints

The influencing factors and constraints of urban public transportation network planning are multi-faceted, and they can generally be divided into two categories: the constraints of a single line and the constraints of the overall line network.

As for single line, the manuscript presents the following constraints.

(1) Line Length

The length of the line is related to factors such as the size of the city, the distance traveled by residents, and the speed of bus operation. Long line will inevitably increase its operating costs; otherwise, it will make the dispatching difficult, and increase the number of transfer times for public transportation, so there must be a reasonable range of line lengths, as denoted by Equation (9), where, l_{min} is normally set as 5 m in Equation (10). Here, v refers to the average speed of a bus, the value depends on the specific situation of each city, and T_{ma} means the maximum travel time that depends on the city scale.

$$l_{min} \le l \le l_{max} \tag{9}$$

$$l_{max} = \frac{vT_{max}}{60} \tag{10}$$

(2) The Non-linear Coefficient of Line

The non-linear coefficient of line refers to the ratio of line distance and the linear length of the city bus line. Equation (11) calculates the non-linear coefficient. Here, l_i is the distance of bus line i, d_i is the linear length of the bus line. According to the regulation of urban traffic planning and design, the maximum of the ratio is 1.4.

$$\left[\frac{l_i}{d_i}\right] < \left[\frac{l}{d}\right]_{max} \tag{11}$$

(3) Station Capacity

The capacity of the station depends on the stopping capacity of the station, its size, and the bus stop time, etc. In an actual urban public transport network, stations often serve multiple lines, and the total number of passengers carried by these lines should not exceed the capacity of the station, as constrained by Equation (12). Here, S_c is the capacity of the station; Q_i is the passenger volume of line i in the station; γ is the coefficient considering the number of multiple lines and the actual impact of traffic around the site. γ is decided considering actual cases.

$$\sum_i Q_i \le S_c \gamma \tag{12}$$

(4) Road Section Unevenness Coefficient

Road section unevenness coefficient K_i refers to the ratio of the flow of a certain section and the average flow of the line, as denoted by Equation (13), where Q_i is the flow of a certain section and $\overline{Q}$ is the average flow of the line.

$$K_i = \frac{Q_i}{\overline{Q}} \tag{13}$$

The total network is constrained by Equations (14)–(18):

(1) The Density of the Transportation Network

The density of the transportation network (ρ_{min}) refers to the bus line length. It directly reflects the degree of proximity to the line when the residents travel by bus. For the urban central area, Equation (14) is met, while for the downtown area, Equation (15) is met.

$$3 \leq \rho_{min} \leq 4 \tag{14}$$

$$2 \leq \rho_{min} \leq 2.5 \tag{15}$$

(2) The Average Transfer Coefficient

The average transfer coefficient $\overline{T}$ is the ratio between the sum of the bus trips number and transfer passengers number and bus trips number, which is computed by Equation (16). Here, $\overline{T}$ is the average transfer coefficient, Q_{ij}^{0} is the number of direct trips from site i to j; Q_{ij}^{1} is the number of trips with one transfer from site i to j; Q_{ij}^{2} is the number of trips with two or more than two transfer from site i to j; Q_{ij} is the number of total trips from site i to j. Normally, for large cities, Equation (17) is met and for medium and small cities, Equation (18) is met.

$$\overline{T} = \frac{\sum_{ij}\left(Q_{ij}^{0} + 2Q_{ij}^{1} + 3Q_{ij}^{2}\right)}{\sum_{ij} Q_{ij}} \tag{16}$$

$$\overline{T} \leq 1.5 \tag{17}$$

$$\overline{T} \leq 1.3 \tag{18}$$

5.3. Solution

A four-step solution procedure was developed to solve the model defined in Equations (8)–(18).

Step 1. Take one origin and destination (OD) pair (v_o, v_t) to be optimized. The Dijkstra shortest-path algorithm is used to search for the shortest route, r_1. If r_1 can meet the line length constraints, it will be used as the alterative line and then choose the next OD pair. Otherwise, go to Step 2.

Step 2. Search for r_k after r_{k-1} is confirmed. Mark the node and as for any node, $v_h \in V_o$. Its mark value is computed by Equation (19), where S_k is given in Equation (20)

$$P_h = \min_{m=1\ldots k-1, i\in V, j\in V_m} \left(L_i + L_{ij} + S_m - L_j\right) \tag{19}$$

$$S_k = \min_{h\in V_s} P_h \tag{20}$$

If $P_h = S_k$ and r_k go through node v_h, then refresh the mark of v_h. If there is no adjacent point at this point, the mark is updated to infinity. V_m is the set of points through which the shortest path passes. V is the set of nodes on the shortest route. L_i is the distance between node i and starting point o; L_{ij} is the distance between neighbor nodes i and j; and S_m is the length of m shortest route.

Step 3. Check whether r_k meets the line length constraints. If it does meet it, it can be chosen as the alternative route; otherwise go back to Step 2.

Step 4. Check if all the OD pairs are searched. If found, the alterative line set R is obtained; otherwise, go back to Step 1.

6. Results and Discussion

The main purpose of the experimental study is to investigate the properties of an urban public sustainable transportation network and optimize it. Complex network theory was used to construct the neighboring site-type undirected network model. An urban sustainable public transportation network was optimized based on the betweenness. The urban transit network's properties were evaluated by complex network theory and related methods, and the possibility of optimization was formulated as Equations (8)–(20), with a solution procedure. Weaker sustainability gives rise to quite a lot of problems in the current urban transit system. Therefore, sustainable development should be highlighted when conducting the optimization of public transport networks. In the experiments, we analyzed three scenarios. First, the optimization model based on the betweenness centrality helped cut down the path length and improved sustainability. Second, the constraints of a single line and the overall line network were analyzed and compared. Finally, the Dijkstra algorithm in an effort to easily obtain an effective solution and its implementation steps were analyzed. Sustainability analysis was embedded in the above scenarios and discussed in the following.

(1) In the results of the network analysis, the degree distribution of the bus transportation network in Xi'an was uneven, showing obvious polarization. The number of nodes with intensity below 10 was 2215, accounting for 78.9% of the all nodes, and the proportion of nodes with intensity above 52 was nearly 1.1%. High valuable sites are often assumed to be important transfer hub functions. Thus, they deserve to be the focus of construction, and the surrounding road surface needs to be widened as well. Traffic congestion will accordingly be reduced and the speed of bus traffic will be improved.

(2) From the average path length, the average value was 28.445. The maximum value was 80. The results mean that residents of Xi'an travel about 28.445 bus stops on average when taking a bus. By contrast, the maximum value of path length for the Shanghai bus network is only 32, and the average value is 7.585; while the maximum for Beijing is 103, and the average is 17.3866. As for such large cities as Shanghai and Beijing, the number of bus stations is several times more than that of Xi'an, and the average path length is smaller than that of Xi'an, indicating that the bus systems in these two large cities are more developed than the Xi'an bus network. Although the average distance of Beijing bus stations is smaller than that of Xi'an, the bus number in Beijing is three to four times larger than that in Xi'an. On the other hand, the scale of Chengdu's public transport network is similar to that of Xi'an, but the average path length is 10.81, which is smaller than that of Xi'an. It can be seen from these data that the average path length of the bus network in Xi'an is relatively large, which is closely related to the lack of public transportation routes to the outer suburbs and the unreasonable layout of Xi'an bus lines, which means that the convenience of Xi'an citizens is not high. What is more, the convenience of citizens also depends on the traffic flow and non-linear coefficient. The non-linear coefficient refers to the ratio of the actual traffic distance between the starting points of the road and the linear distance between the two points.

(3) The clustering coefficient was used to describe the aggregation of nodes in the network, that is, how close is the network. The average clustering coefficients reflect the intensity of the bus lines in the entire bus network. The clustering coefficient of each station in the Xi'an bus station network was calculated, and the values of 1934 stations were found to be 0, indicating that there are many neighboring stations in Xi'an that are not connected with each other. As the clustering coefficient of the station is relatively low, the connection between its neighbors is sparse, and most of the traffic between these neighbors has to pass through the station, resulting in its heavy load. Thus, stations with a high clustering coefficient are more likely to be blocked than stations with a low clustering coefficient. The number of stations with a high clustering coefficient in the bus network of Xi'an is small, and only 208 of them have clustering coefficients of 1 or above. Therefore, the average clustering coefficient of the whole network is not high, which is 0.223. However, it is higher than that of Shanghai and Beijing, which is respectively 0.064 and 0.14. This indicates that the bus lines in Xi'an are relatively denser.

(4) The betweenness characterizes the influence of nodes or edges on the entire network, and has a strong practical significance for solving real network problems. The betweenness of the Xi'an bus station network was calculated. The bus stations with larger betweenness were compared. It was found that the larger betweenness and number of bus lines passing through were not correlated. Increasing the traffic and bus throughput performance of these nodes had a very significant effect on improving the operational efficiency of the entire network. Thus, the urban sustainable transportation network optimization model was established and solved based on betweenness.

(5) From the data visualization results, we found that one of the most obvious features of the Xi'an bus lines was that the lines are too long. The lines pass across three districts or even more to connect the urban center to the suburbs. Long-distance travel cannot ensure full loads and so decreases the sustainability of the routes. In experiments we found that the line detour time can be reduced when the regular bus lines were shortened. The regular buses in the suburban–urban–suburb areas should be adjusted to the suburban–suburban and suburban–urban edge as much as possible. By such a method, the sustainability of the bus lines and tours can be improved. At the same time, some small-bus routes leading to the outer suburbs are considered to be restricted to enter the urban area and just reach the bus hub in the suburbs. This can reduce the repeated and disorderly crossing of buses, and reduce the occupation rate of buses on major roads, thereby reducing traffic congestion and improving the overall operational efficiency and sustainability of the public transportation system.

(6) We also considered the network resilience in the experiment analysis by simulating node failures and through time. That is to say, it was able to provide and maintain an acceptable level of service in the face of faults and challenges to normal operation. A local failure of the network will increase the burden on other parts of the network, especially the key nodes and branch lines. Their faults are likely to cause the entire network to collapse. Congestion and its spread have a greater impact. The overall stability of the public transport network is robust and fragile due to its heterogeneity in scale-free performance. The key nodes and branch networks play a vital role in the connectivity of the entire network, reflecting the complexity and intrinsic dynamics of the public transport network. Relevant literature [15,17] also confirms that improving the capabilities of key nodes and the micro-circulation capability of the feeder roads is an important approach for improving the overall network capabilities.

(7) From the perspective of complex networks, it is feasible to split the central hub, so that the work originally undertaken by one node is decomposed into several interconnected nodes, and the synchronization capability of the network is significantly enhanced. This feature is also tested by visualization and simulation upon the network. When the bearing capacity of the original single station is weakened, a new station can be set up at intervals of about 100 m, and the bus lines that are docked can be diverted to reduce the queue waiting for the bus, which can enhance the network transportation capacity.

7. Remarks and Conclusions

Complex network theory offers meaningful ideas for urban transit network studies. With the extensive development and application of the theory, increasingly more scholars are interested in deep study on complexity of transportation engineering. Urban transportation network design and optimization requires a combination of application and actual operation. It should not be limited to the topological structure analysis, instead, a concentration on the guidance of planning and design should be highlighted. The ultimate purpose is to actually improve the efficiency and sustainability of the network and society.

Firstly, this study used the complex network theory method and conducted a practical study on the urban transit network in Xi'an. The topological properties of the network were investigated and showed some insights into the public transportation network.

Secondly, a betweenness-based model and solution method was developed to improve the public transportation network's sustainability.

Thirdly, discussions on the features of the Xi'an transit network were presented. Some problems of public transportation were discovered from the perspective of sustainable development.

Urban traffic network structures have numerous impacts on traffic congestion and related challenges. Apart from network design optimization, possible directions of future policy could help maintain the network and avoid potential problems. First, the government should clarify the principle of prioritizing the development of public transportation and enhancing the ability of public transportation to lead the city's development. Second, infrastructure construction needs to be highlighted. In the bus hub station, charging facilities and other supporting facilities ought to be equipped to facilitate the use of trams. Simultaneously, the connection between urban public transportation and other modes can be strengthened to improve interchange efficiency. Third, investment in intelligent bus systems should be stressed and the application of information technology in urban public transportation operation management, service supervision, and industry management should be promoted. Guidance on improving information sharing and resource integration of urban public transportation and other modes needs to be strengthened. Fourth, measures incorporating urban logistics into urban transit are to be encouraged. With online shopping and e-commerce growing tremendously, express delivery vehicles are crowding urban traffic. In case some urban transit facilities are not well utilized, they can be used to share some urban logistics contributing to less traffic congestion.

To sum up, this study constructed the bus transit network of Xi'an, analyzed the topological characteristics of its complex network, and proposed an optimization model based on betweenness centrality and policy guidance. However, further research should be carried out considering the weight and directionality of the edge, the traffic flow, and robustness. Additionally, a novel trend combining complex network theory and data mining will be prospected. Furthermore, due to data acquisition problems, we could not obtain the flow data at each leg between any pair of bus stations in each bus line; we also did not use the spatial properties of the bus stations and attached communities. When we are able to obtain the related data, the limitations of this study will be further studied. First, the optimization procedure will be improved to consider the above origin–destination flow and spatial data. Second, the sustainability instruments will be examined by considering the impacts of node and edge dynamics on the network's structures. As so the infrastructure, development strategies will be tested upon the network. Third, due to the openness of the study on network optimization, interviews and grounded studies will be conducted as a base of network simulation and analysis.

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From Transfer to Knowledge Co-Production: A Transdisciplinary Research Approach to Reduce Black Carbon Emissions in Metro Manila, Philippines

Liina Tõnisson [1,*], Yvonne Kunz [2,*], Simonas Kecorius [1], Leizel Madueño [1], Everlyn Gayle Tamayo [3], Dang Marviluz Casanova [3], Qi Zhao [4], Tamara Schikowski [4], Anna-Katharina Hornidge [2], Alfred Wiedensohler [1] and Andreas Macke [1]

1 Leibniz Institute for Tropospheric Research, 04318 Leipzig, Germany; kecorius@tropos.de (S.K.); madueno@tropos.de (L.M.); ali@tropos.de (A.W.); macke@tropos.de (A.M.)
2 German Development Institute, 53113 Bonn, Germany; anna-katharina.hornidge@die-gdi.de
3 Clean Air Asia, Pasig City 1605, Philippines; everlyn.tamayo@cleanairasia.org (E.G.T.); dang.espita@cleanairasia.org (D.M.C.)
4 Leibniz Institute for Environmental Medicine, 40225 Düsseldorf, Germany; Qi.Zhao@IUF-Duesseldorf.de (Q.Z.); Tamara.Schikowski@IUF-Duesseldorf.de (T.S.)
* Correspondence: tonisson@tropos.de (L.T.); Yvonne.Kunz@die-gdi.de (Y.K.)

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Abstract: Air pollution, which kills an estimated 7 million people every year, is one of the greatest environmental health risks of our times. Finding solutions to this threat poses challenges to practitioners and policymakers alike. Increasing awareness on the benefits of transdisciplinary research in solution-oriented sustainable development projects has led to the establishment of the research project "A Transdisciplinary Approach to Mitigate Emissions of Black Carbon" (TAME-BC). This paper introduces the TAME-BC research setup that took place with Metro Manila, Philippines, case study. The approach integrates BC measurements with technological, socio-political, and health aspects to improve the scientific state of the art, policymaking, transport sector planning, and clinical studies related to air pollution health effects. The first pillar in the setup presents an (1) air quality assessment through aerosol measurements and instrumentation, complemented by a (2) description and assessment of the current policies, technologies, and practices of the transport sector that is responsible for pollution levels in the Philippines, as well as a (3) BC exposure and associated health impacts assessment. The fourth pillar is intercrossing, fostering (4) knowledge co-creation through stakeholder involvement across scales. We argue that this transdisciplinary approach is useful for research endeavors aiming for emission mitigation in rapidly urbanizing regions beyond Metro Manila.

Keywords: transdisciplinary collaboration; sustainability; sustainable development; air quality; black carbon; knowledge-transfer; innovation; measurement technology; emissions mitigation

1. Introduction

It is widely acknowledged that research for sustainable development has to be context-oriented to reflect the diversity, complexity, and dynamics of the processes involved, as well as their variability between specific problem situations. Moreover, the interests and knowledge of stakeholders involved have to be considered. Sustainability research covers a wide spectrum of socio-ecological challenges, from the over-exploitation of natural resources, for example, to biodiversity loss to climate change adaptation and mitigation. In this approach, we address specific air quality challenges.

Atmospheric aerosol particles originating from the incomplete combustion of fossil fuel or biomass are proven to cause severe health issues. Particulate air pollution is currently one of the world's largest environmental health risks [1]. There is vast evidence on the negative health effects of each air pollutant, which may have synergistic effects when exposed to a mixture of ambient pollutants. Some of the most prominent health impacts of air pollution are respiratory and cardiovascular diseases, lung cancer, diabetes, and stroke [1–3]. The latest Global Burden of Disease study estimated that 4.9 million premature deaths occurred in 2017 due to exposure to air pollution [4]. Air-pollution-associated adverse health effects create large economic costs through hampered human capital formation [5] and increasing health costs [6]. Apart from negatively affecting health and the economy, absorbing aerosols, such as black carbon, contribute to rising temperatures and lead to regional climate effects [7,8]. These consequences taken together create a growing awareness for the topic of air pollution within sustainability science.

Although poor air quality remains a concern in many countries in the Global North, it poses an even bigger health risk in Asia, particularly among lower- and middle-class income population groups in Southeast Asian countries [1,9]. Compared to countries in the Global North, various low- and middle-income countries in Southeast Asia have experienced rapid urbanization, accompanied by rampant economic and industrial developments. This process comes with the trade-off of air-pollution-related complications and air quality management systems are unable to keep up with the challenges [10,11].

One striking example of rapid economic growth and rampant urbanization rates that are accompanied by high levels of air pollution is the Philippines [12]. Metro Manila, the capital region of the Philippines, is composed of 16 cities and one municipality. It is one of the biggest and most densely populated megacities in Southeast Asia, with around 13 million inhabitants [13]. An insufficient public transport system and the accelerating increase in the private vehicular fleet resulted in congested roads being filled with private cars, taxis, old buses, public utility jeepneys (PUJs), and trucks [14]. Jeepneys are a modified version of old military jeeps left behind by Japanese and U.S. soldiers. The jeepney is not only the most affordable option for getting around, it is also iconic, known as the "king of the road" and part of Filipino identity [15]. Equipped with pre-Euro standard diesel engines, PUJs are one of the responsible sources of high concentrations of combustion-generated black carbon (BC) particles, which in turn became a dominant aerosol constituent in the urban atmosphere [16]. There is limited knowledge on the characterization of air pollutants in rapidly urbanizing countries, on its health impacts to the public, as well as on measures contributing to a solution in consideration of the dynamic socio-political institutional frameworks in the country [17]. To address this knowledge gap, a transdisciplinary framework was developed called TAME-BC (i.e., Transdisciplinary Approach to Mitigate Emissions of Black Carbon). This paper introduces the TAME-BC framework in the context of Metro Manila, Philippines, and is intended to be utilized by other projects with similar goals. To do so, the paper starts by providing a brief background on one strand of sustainability research, structuring the research approach. Ensuing, the disciplinary approaches by the various institutes (pillars one to three) involved are explained before bringing them together through the integrative part of the project (pillar four).

2. Literature Review: Sustainability Research

Sustainability research concepts require understanding the interconnected challenges and managing unprecedented problems [18]. The broad base of various scientific approaches for sustainability research can roughly be divided into "descriptive–analytical" and "transformational" approaches [19].

"Descriptive–analytical" approaches are methodologically characterized when systems thinking and/or modeling methods are applied. These methods usually analyze sustainability problems through their past or current frameworks, correlations, and cause–effect dynamics [20–23].

A transformational approach is the second strand in the current state-of-the-art sustainability research. This framework is used for developing evidence-supported solution options for sustainability problems [19,24,25]. Working toward an evidence-based sustainability solution that meets the interests of various stakeholders requires a "transdisciplinary" research approach [26].

Solutions to environmental problems are mostly not just technical fixes or policy procedures [27,28]. Solutions for lowering pollution levels are usually as complex as the problems themselves. Therefore, sustainability research frameworks in the context of air quality management require long-term processes that involve real-world experimentation, collective learning, and continuous adaptation [19,29]. Thus, a long-term transdisciplinary approach is a key component of sustainability science when developing evidence-supported pollution mitigation options [30].

The methodological requirements necessary for transdisciplinary sustainability research are transparent, structured, and replicable sequences of steps generating knowledge as ingredients to solution finding [29]. The solutions should be based on a broad understanding of the problem (descriptive–analytical/system analysis) by considering know-how from various sets of stakeholders (scientists, decision-makers, NGOs, practitioners, etc.) [28–30]. They should further work toward a clearly stated sustainability-inspired project goal (normative/target knowledge) and outline change adaptation and transition management strategies, i.e., roadmaps for resolving the problem (instructional/transformation knowledge) [31]. Thus, transdisciplinary research needs to apply frameworks combining different types of methods and expertise to generate multidimensional applicable knowledge synergies or co-produced knowledge.

The transformational sustainability research framework, TRANSFORM, synthesizes the key features of the aforementioned frameworks [29]. TRANSFORM integrates transparent, structured, and replicable sequences of steps that generate knowledge, in which researchers

1. analyze and assess past and current states of the environmental problem,
2. trace solution-orientated project goals back to the current state of the problem, and
3. contribute to mitigating the current (pollution) problem.

Working along these steps with scientists from various disciplines and non-academic stakeholders allows for co-produced knowledge compared to knowledge produced by scientists only that is then transferred to non-academic stakeholders. The knowledge produced in such a silo is prone to overseeing certain context-specific aspects that might be of relevance to the solution.

3. The Metro Manila Air Pollution Case Study

The cooperation between institutes in Metro Manila and the Leibniz Institute for Tropospheric Research (TROPOS) started in 2014. An Aerosol Instrumentation and Physics Course was held at the University of the Philippines. This course led to the formation of a transnational research collaboration between TROPOS and partners from academia and NGOs in the Philippines called Researchers for Clean Air (RESCueAir). Only one year later, in 2015, the Manila Aerosol Characterization Experiment (MACE 2015) was conducted in Metro Manila to extensively characterize air pollution in three locations in the megacity.

For this purpose, an aerosol measurement container was brought from Germany to the Philippines in 2015, equipped with state-of-the-art aerosol instrumentation, to measure air pollution levels at a roadside in Quezon City, Metro Manila. The measurements focused on the physical-chemical properties of particulate pollution (for further information see Figure 1). A special focus of the measurement campaign was put on quantifying BC particles, which act as a carrier of toxic and carcinogenic components of particulate matter (PM), e.g., polycyclic aromatic hydrocarbons (PAHs) [32]. It was found that the BC levels at the roadside measurement location were up to 50 times higher than in European or North American urban areas [33]. Results also showed that the regulated levels of PM_{10} from the public transport sector and particularly the BC mass concentrations are up to 70 times higher than in Europe, the USA, and other Asian countries [16]. Results from complementary mobile measurements indicated that the concentration of BC is significantly high along the roads and in areas with very high transport activities [33]. The study further concluded that jeepneys contribute to up to 94% of the overall BC emissions [16]. Based on this finding back in 2015, TAME-BC, the transdisciplinary project launched in 2019, identified jeepneys as the mode of transport under consideration.

Figure 1. Map of Metro Manila with the approximate locations of the intensive measurement campaigns during TAME-BC (red triangle) and MACE2015 (black cross) using state-of-the-art aerosol measurement instrumentation.

While the first data were gathered on the characterization of pollutants and marginally on health impacts (during the MACE 2015), less is known about the practices in the transport sector influencing BC emissions. Although technological solutions have been tested in many countries of the Global North, sustainable technological innovations concerning the practices in the transport sector in the tropics are yet to be tested and implemented in Metro Manila. A publication by the Blacksmith Institute and Clean Air Asia [34] has summarized the cost–benefit analysis of different technology alternatives for PUJs (compared to their pre-Euro 4 diesel engines) and recommended several action points. Those action points were discussed with government agencies, industries, and transport groups. The recommendation to adopt e-jeepneys in short, fixed routes has been implemented by some local governments, but the rest of the action points were met with financial, technical, and other implementation challenges. The government of the Philippines, having recognized the public transport sector as contributing to air pollution, among other shortcomings in the sector, has launched the Public Utility Vehicle Modernization Program (PUVMP). The program introduces a suite of measures to make public transport more sustainable [35]. One of the program components is the phasing out of conventional PUJs to have them replaced with Euro 4 compliant vehicles. As the drivers are expected to incur the costs of new units with only partial support from the government, and most PUJ drivers are part of the low-income sector, mostly without formal working contracts and their benefits, the program is facing public resistance. This discordance necessitates further efforts to understand the institutional implications of proposed solutions if inclusive and integrative sustainable actions are aimed for.

The broadened interest in developing a research project to support solution-oriented knowledge production led to the planning stage for the research project TAME-BC, which focused on a transdisciplinary approach. The novel approach that was launched in 2019 integrates the natural, health, and social sciences in addressing the perennial problem of air pollution in Metro Manila.

The transdisciplinary research setup provides a platform to gain a better understanding of the environmental impacts of BC and how to overcome the negative consequences by finding answers to the following research questions:

- What are the main sources of BC and how can we determine practices and technologies in the transport sector contributing to BC emissions?
- How can we assess the air quality regulation system, including the institutional work, the interplay of actors and institutions, and their rules and norms?
- How can we analyze and describe the potential health effects of human exposure to BC?
- How can we integrate various sets of knowledge toward air quality improvement?

The methodology presents how theoretical approaches are translated into scientific practices through an integrated transdisciplinary sustainability research approach. The following sections describe the detailed methods of the various disciplines, as well as the attempt to integrate them toward a solution orientation.

4. Methodology

Researching real-world challenges in the context of sustainability studies requires a co-produced knowledge process, allowing for various stakeholders from both the scientific world and the non-scientific world to be part of the research setup. In the context of air pollution in Metro Manila, previously mentioned studies found that PUJs are amongst the main polluters in the transport sector. Regarding the input into decision-making processes that impact the transport sector, participation from practitioners, such as jeepney drivers, is needed for the process of achieving sustainable solutions. Based on our literature review, the state of the art for setting up sustainability research projects is the TRANSFORM approach that we combined with the concept of "follow the innovation" (FTI). While TRANSFORM was already depicted earlier, the FTI approach allows for "joint experimentation and learning by [...] fostering participatory processes of testing, jointly with local stakeholders, institutional and technical innovations and adapting them to the local" [36]. Methodologically we follow the three TRANSFORM and FTI approach requirements. By combing both methodologies, we apply the following transparent, structured, and replicable sequences of three steps:

1. Current problem assessment from specific expertise areas.
2. Solution-orientated goals that reflect on the current state of the problem.
3. Combine local knowledge with specific expertise areas for the reduction of BC emission levels.

Working on air quality management in Metro Manila, the research setup described here is an innovative package of technological, socio-political, and health interventions for decision-makers to mitigate BC emissions. In detail, this is put together by a first pillar, which assesses BC pollution levels and adaptation strategies in the transport sector. The second pillar aims at understanding the institutional environment of air quality regulations, including the local and national governance structures in the Philippines. The third pillar reflects on the assessment and current state of the problem of human exposure to BC and related potential health effects. Finally, the fourth pillar analyzes the institutional workings of the air-pollution-related innovation system to effectively integrate the knowledge obtained from the findings into sustainable solutions (Figure 2). The complexity of the pollution problem "requires the constructive input from various communities of knowledge" [37], which involves a scientific inquiry approach that cuts across disciplines, synthesizes theory and methodology, and co-creates solutions. Expectations concerning the exchange of knowledge between science and policy, including knowledge coproduction [38] and local embedment, were assured by the research approach [26,27,39].

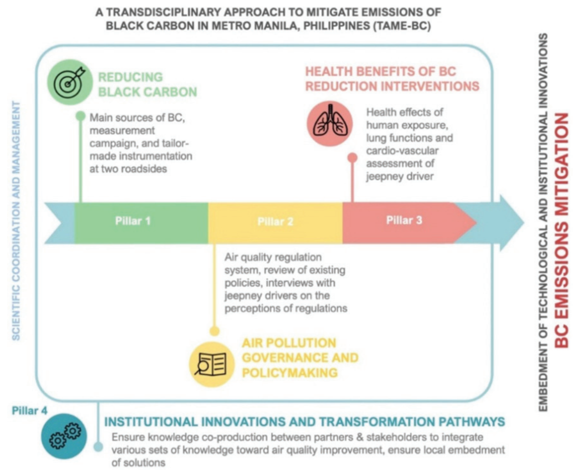

Figure 2. Setup of a transdisciplinary approach to mitigate emissions of black carbon (BC) in Metro Manila.

The goal of this paper then was to provide an overview of a novel transdisciplinary research framework in the context of emissions reduction that was initiated in 2019 while the implementation is ongoing. While the overall research design is a collaborative process, knowledge is also generated at a disciplinary level to then be integrated toward inclusive solution processes. The three disciplinary pillars are framed by the fourth pillar on innovation and transformation pathways, ensuring local embedment and the creation of shared knowledge. All pillars together lead to the overall aim (arrow) toward BC emission mitigation (see Figure 2).

4.1. Measurement Campaign: Instrumentation for Tracing Black Carbon

This component of the sustainability research setup aims at cooperation with local partners for optimal air quality measurement campaigns with innovative technologies. The optimal technology selection for a measurement campaign should be made based on previous research [13,32] and keeping in mind the sustainability goals. If no previous research exists, it is suggested the technology selection adopts well-known world standards. When working in the Global South, it is important to apply state-of-the-art instrumentation that can be developed remotely and does not necessarily need to be produced at the measurement location, since economically less developed regions cannot afford the state of the art and there could be an issue of available expertise to do high-quality research.

In the framework of the TAME-BC campaign in 2019–2020, a measurement container was employed to determine the particulate air pollution in the Manila North Port and East Avenue (Figure 1). To ensure the gathering of high-quality measurement data, aerosol instrumentation was handled according to recommendations provided by the World Calibration Centre for Aerosol Physics (WCCAP) in the frame of the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) Programme. The sampling was done following the recommendations described by the GAW report 227 [40] to minimize the particle losses due to diffusion, impaction, and settling. Furthermore, the relative humidity was kept below 40% for the measurement, employing a Nafion®Permapure dryer [41] and by keeping the temperature in the air-conditioned measurement container at 27 °C.

The aerosol instrumentation used in TAME-BC measurement campaign includes mobility and aerodynamic particle size spectrometers (MPSS—TROPOS-type and APSS—model 3221, TSI Inc., USA, respectively), absorption photometers, such as the aethalometer and the multiple angle absorption photometer (MAAP, model 5012, Thermo Inc., Waltham, MA, USA), a volatility-tandem differential mobility analyzer (V-TDMA, TROPOS-type), an aerosol chemical speciation monitor

(ACSM, Aerodyne Research Inc., Billercia, MA, USA) to measure the aerosol particle size distribution, absorption coefficient, volatility properties, and online chemical composition of aerosol particles, respectively, and an automated weather station. Aside from the custom-made state-of-the-art measurement container, which stayed in a single location for a set time, a complimentary state-of-the-art portable aerosol backpack was developed to investigate BC exposure concentrations along the streets and in different locations that require mobility. The instrumentation inside the backpack includes an optical particle size spectrometer (OPSS, model 3330, TSI Inc., Minnesota, MN, USA) and a micro aethalometer (microAeth® AE51, MA200; AethLabs, San Francisco, CA, USA). Measurement data, such as the particle size distribution, BC mass concentration, and geospatial position, are handled by a single board computer.

Within a transdisciplinary approach, technological solutions need to be planned and applied in cooperation with local partners. Therefore, the whole measurement campaign technology selection process was a collaboration with local experts.

Theory to Measurement Practice: Appropriate Embedment in Metro Manila

The first research pillar was dedicated to the assessment of pollution levels. Considering the local conditions, it was necessary to use tailor-made instrumentation in Metro Manila that nevertheless followed world standards for high-quality data collection. The exact composition of the measurement technologies was chosen based on experiences from previous measurement campaigns in Metro Manila.

Planned measurements and investigations took place in Manila North Port and East Avenue roadsides in Quezon City (Figure 1). Air pollution sampling in East Avenue allowed for investigating the pollution at the source point. The measurements done during TAME-BC are expected to provide an accurate source apportionment and information on how the particulate air quality is influenced by different sources in Metro Manila [42]. Such systematic pollution characterization gives the necessary additional insight into the health risks of exposed populations.

The establishment of long-term air-pollution-monitoring sites is vital for tracking the changes in BC concentrations. Long-term monitoring ensures tracing solution-orientated project goals back to the current state of the problem. Assessment and tracking project realization was the aim of the air quality measurement practice within this project. The long-term air-pollution-monitoring site was suggested to be located at the Manila Observatory (MO), where MACE2015 previously stationed aerosol instrumentation as a representative of urban background pollution level. Such a continuous scientific monitoring component is important because it can provide high-quality and long-term data to validate the effectiveness of technological, socio-political, and health innovations and transformations in reducing the emissions of BC in the course of this project and beyond.

The measurement and investigation stages executed in Metro Manila, Philippines, relied on the literature review and on the methods that were proven to provide comprehensive information on the pollution properties in TROPOS's previous studies in Metro Manila involving container measurements (e.g., estimating the emission factors) [16,43] and in mobile measurements studies [33]. Although the air pollution data is not presented in this manuscript, the goal of pillar one is to perform a thorough air quality assessment. The Metro Manila case study example that focused on BC emissions aimed at a scientific collaboration with the local science institutes by doing container measurements as part of pillar one. Measurements through the TROPOS Aerosol container were performed in the port from 19 December 2019 to 25 January 2020. Measurements in East Avenue right outside the Quezon City Hall ran from 30 January 2020 to the end of 25 February 2020. Compared to the port, higher BC concentrations were observed in East Avenue, which was heavily influenced by local heavy vehicle traffic emissions. Such a setup involving placing a measurement container in two various places provides the local transport planning authorities and policymakers with quality data for better decision-making. Container measurements provide the most accurate data on air pollution (compared to mobile sensors), and for the specific Metro Manila case study, the BC values in 2019 were observed to be higher than what was measured by Alas et al. in 2015 [33] in Taft and Katipunan Avenue.

This component of the setup focuses on applying the TROPOS measurement container and is a valuable scientific addition to the TAME-BC, as it serves as a quality assurance for all measurements made within the project. Policy assessment, coordination, and health awareness pillars draw their conclusions based on the aerosol characterization done in this pillar. Therefore, air pollution measurements should be covered in the first pillar to serve as a starting point for further actions.

4.2. Air Quality Management and Policy Implications

Investigating the institutional settings of past and current states of air pollution challenges by applying a case study approach in Metro Manila represents the second pillar. The problem of air pollution was already assessed and recognized by the government of the Philippines in the 1990s. Even though air pollution measurements were not as detailed back then as under the current project, it led to the issuance of the Philippine Clean Air Act in 1999. The Department of Transportation (DoTr) recently initiated the already mentioned PUVMP, mainly aiming to modernize the public transport fleet toward Euro 4-compliant engines for all public utility vehicles, where the obvious targets among those are also the unique jeepneys. Such a decision created division: Some of the affected groups oppose the modernization program arguing that it threatens transport cooperatives and single-unit jeepney owners. The government, however, remains committed to the phase-out of vehicles using older engines to ensure safety and decrease pollution, despite strong resistance. Lack of scientific knowledge in implementing environmentally and socially sustainable solutions may result in a failure of the PUVMP, which will affect the livelihoods of many people.

To gain a deeper understanding of the institutional environment surrounding air quality management in the Philippines, the two-fold approach that is taken must be highlighted. As suggested by the selected TRANSFORM methodology, foresight and back-casting methods adopted to FTI were applied. On the one side, a thorough content analysis of the regulations in place and how they evolved was conducted. On the other side, discrepancies between the de jure and de facto regulations can only be unraveled by understanding how those regulations are embedded in a wider institutional context on the local level. This means that interviews with those affected by the regulations are conducted.

Theory to Policymaking Practice: Appropriate Embedment in Metro Manila

While the political and public awareness toward air pollution-related problems in Metro Manila is increasing, this fosters de jure governance responses by state institutions and de facto mechanisms of the public down to the individual behavior level. However, fairly little is known about current management mechanisms that deal with increasing emission levels [17].

The second goal of TAME-BC, therefore, was to investigate and systematically map the dynamically evolving local institutional environment. It includes the evaluation of policies, rules, norms, and values that determine the current state of air quality in Metro Manila. This supports examining knowledge flows on air pollution and its mitigation management, based on local case studies.

In assessing the de jure governance responses to the decreasing air quality in the Philippines, a systematic mapping of governmental regulations served as the first step of the investigation toward air-quality-management-related policies. Starting with an analysis of the Clean Air Act from 1999, relevant ensuing regulations were investigated as well. This was done through the investigation of the national governmental authorities' homepages. The main contributions were from the Department of Environment and Natural Resources (DENR) and the DoTr. The most relevant documents were listed and analyzed through a qualitative content analysis using ATLAS.ti (version 8.4.16, Scientific Software Development GmbH, Berlin, Germany). The regulations on the PUVMP were furthermore considered, even though the program was not implemented in the context of air quality management in the first place [14]. Nevertheless, as the program aims to replace the old diesel engines with at least Euro 4 standard engines, it was of importance to the overall analysis. Based on the review of air quality management regulations, qualitative semi-structured interview guidelines were developed. The interviews were conducted to study the local level response to policies. Open-ended questions avoided collecting biased pre-formulated answers [44]. Jeepneys are over-proportionately contributing to air pollution. The drivers are over-proportionately exposed to pollutants. Therefore, the target group of the interviews was the jeepney drivers. Various jeepney driver associations serve different routes within Metro Manila. As the jeepney drivers themselves are a very heterogeneous group, they have different perspectives on air pollution, as well as on the modernization program. The different jeepney drivers often position themselves toward the modernization program along the line of opposing the project toward more moderate positions. Within the frame of the TAME-BC project, we interviewed three jeepney driver associations, representing different positions toward the modernization program. One group interviewed rejects the modernization program. A second group interviewed had a moderate stance, while the third group interviewed already participated in the modernization program. This variety allowed for a comprehensive information collection framework. The groups were further selected in regard to the area they worked in. One group interviewed passed the TROPOS container on their route. An additional overlap was created as jeepney drivers were also investigated by the mobile backpack measurement team.

The interviews were conducted with one driver at a time while being on the moving jeepney during usual business hours. A total of approximately 10 interviews per group was conducted (n = 30), where an interview lasted for an hour on average. This also allowed for participatory observation during the time on the jeepneys. Additional interviews were conducted with government representatives from the DENR, the DoTr, a local government unit, and NGOs working in the field of air quality. All interviews, but especially the ones with jeepney drivers, were conducted together with a local research assistant. The research assistant guaranteed ease of the interview situation, mainly by allowing the interview partner to interview in her or his preferred local language. Interviews were recorded and transcribed when permission was granted. The researchers also took notes during the interviews. After each interview, the notes were typed up and discussed among the research team.

Combining interview results with the mobile and stationary measurements can be used for a comprehensive analysis that serves the goals of pillar two. By having identified the exact pollution levels on various routes that were complementary to interviews with the jeepney drivers, the de jure and de facto policy assessment implications of pillar three have a strong basis for producing better local transport sector guidelines.

4.3. Awareness Building: Health Effects Estimation

The third pillar of TAME-BC was conducted in close cooperation with local hospitals for building health awareness with regard to air pollution problems. The health component of the project aims to increase knowledge of adverse health effects caused by ambient air pollution, as suggested in the following paragraph.

The exposure to BC has to be measured ideally for the main polluters and for those who are the most affected. Measurements of BC inside jeepneys was conducted by using portable instruments (backpack measurements) used at different locations during different days and times to allow for a more precise picture of the BC exposure levels for the drivers. Ideally, such measurements are done at various times of the day, weeks, and months such that comparisons can be presented. Further, the lifestyle and health conditions of the main polluters and those who are most affected should be assessed using the Burden of Obstructive Lung Disease (BOLD) study questionnaire. The BOLD study is an already existing cross-sectional survey that assesses the prevalence and burden of chronic obstructive pulmonary diseases (COPDs) in the Philippines, which developed a validated questionnaire. The lung functions of the main polluters and those who are most affected should be examined, ideally using pre- and post-bronchodilator spirometry measurements. Additionally, a cardiovascular assessment should be performed. This includes an electrocardiogram and blood pressure measurements. Lastly, the association between BC and health outcomes can therefore be analyzed using linear or logistic regression models depending on the classes of the outcome variables (e.g., continuous or binary variables). A set of previously selected covariates are recommended to be included to control for their potential confounding effects, such as age, sex, and socioeconomic and lifestyle variables.

4.3.1. Theory to Awareness Building Practice: Appropriate Embedment in Metro Manila

Exposure to pollution has several negative associated health effects, as described above. The theory described in the section above was applied in Metro Manila for the goal of BC emissions reduction via awareness building.

(1) The exposure of BC in jeepney drivers was quantified using personal measurements collected with mobile instrumentation inside the moving jeepney. TROPOS backpacks with portable instruments (consisting of (a) an AE51 Aethalometer, (b) an optical particle sizer, (c) Crowdsense, and (d) a personal air sampling monitor) was used for exposure measurements from January to February 2020 in two different locations. This approach provided an opportunity to compare the spatial distribution of BC between two different environments in Quezon City. Furthermore, the weekdays versus the weekend BC concentration levels were compared. A portable BC instrument in a backpack was used in two jeepney routes, with different microenvironments (Arayat, Cubao-Quezon City Hall (QCH), and UP Ikot (University of the Philippines, *ikot*= to go in circles), with sampling done during the morning, midday, and afternoon.

(2) The lifestyle and health conditions of the jeepney drivers were assessed using the BOLD study questionnaire. The BOLD study (https://www.boldstudy.org/) is an already existing cross-sectional survey that assesses the prevalence and burden of COPDs in the Philippines, which developed a validated questionnaire.

(3) The lung function of jeepney drivers (the same cohort interviewed under pillar two) was examined in the Lung Center of the Philippines (LCP) using pre- and post-bronchodilator spirometry measurements. Additionally, a cardiovascular assessment was performed, which included an electrocardiogram and blood pressure measurement.

(4) The association between BC and health outcomes was assessed using linear or logistic regression models depending on the classes of outcome variables (e.g., continuous or binary variables). A set of previously selected covariates was included to control for their potential confounding effects, such as age, sex, and socioeconomic and lifestyle variables.

We foresee that such data obtained will be vital to health outcome studies. Such studies are being conducted at the LCP to assess the health effects of BC, as BC particulates are known carriers of toxic substances. The data collected in pillar three will also be useful as much-needed evidence to aid policymaking regarding measures to address air pollution, especially now that the public is more conscious of taking care of their respiratory health.

BOLD Questionnaire Investigation

Between January 2020 and March 2020, approximately 100 jeepney drivers were investigated by trained personnel using the BOLD questionnaire at the LCP. The BOLD questionnaire collects information on occupations, indoor/outdoor environmental exposures, socioeconomic status (e.g., income), health conditions (e.g., cardiorespiratory symptoms, and sleeping and breathing disturbance), lifestyles (e.g., smoking), physical activities, and other issues.

Lung Function and Cardiovascular Measurements

Between January 2020 and March 2020, 100 jeepney drivers were invited to the LCP where measurements on lung and cardiovascular functions took place. Lung functions were measured using the spirometer EasyOne Air (Medizintechnik AG, Zurich, Switzerland) by trained personnel in line with the American Thoracic Society/European Respiratory Society [45]. Briefly, a questionnaire was performed before the measurements to exclude drivers with pre-existing contraindications. For each participant, at least three but not more than eight trials were performed under the guidance of a professional to obtain the optimal spirometric values. Subsequently, each participant inhaled a bronchodilator (e.g., salbutamol) using a metered-dose inhaler. The lung functions were re-measured 15 min later to get the post-bronchodilator measurements. For participants with successful spirometric measurements, the electrocardiogram and blood pressure were measured according to the manufacturers' instructions.

Although the exact result of pillar three will be discussed in a complementary manuscript, by doing the spatiotemporal analysis, it was possible to show that the mean and median BC concentrations varied between different routes for different times of the day. The pillar three actions help to identify air pollution levels in various locations. Namely, it was recorded that for the Arayat, Cubao-QCH route, the median measurement was ≈53.5 $\mu g\ m^{-3}$, while the mean was 68.4 $\mu g\ m^{-3}$. Additionally, the preliminary results showed that higher values were measured in the morning, before 10 a.m. Such results were obtained by conducting a total of forty runs of around 13 km jeepney-travel distance, which lasted 1–2 h per ride. Thirteen drivers participated in the measurements. Additionally, spatial analysis plots showed that equivalent black carbon (eBC) concentrations were higher along QMC and East Avenue, which had higher traffic volume compared to the rest of the route, and were at a minimum in the Arayat market area. In comparison to the UP IKOT route, where 42 runs were accomplished around the 5 km loop (≈25 min per loop), with around ten participating drivers, the median value recorded was 31.0 $\mu g\ m^{-3}$. The mean value there was 41.5 $\mu g\ m^{-3}$ for this specific route. Higher values were observed in the afternoon after 3 p.m. Furthermore, several pollution hotspots could be identified along the C.P. Garcia Avenue, which is a busy thoroughfare that experiences higher traffic volumes compared to inside the UP campus when using the mobile sensors on moving jeepneys. The two routes experience different traffic and environmental characteristics, which also has different implications for regular drivers and commuters of the routes. Such variations provide important input for clinical studies and health-related local research.

4.4. Coordination: Innovation Embedment via Stakeholder Engagement

The fourth pillar of the project cuts across disciplines and integrates non-academic partners into the research project for tracing solution-orientated project goals back to the current state of the problem. As the project focuses on the innovation potential and capacity development concerning the mitigation of BC emissions through an assessment of regulatory measures, involving stakeholders from the administration, economy, and science sectors, as well as practitioners from the transport sector, is crucial.

Involving a wide spectrum of stakeholders can be achieved through a series of participatory workshops that consciously avoid disciplinary expert jargon. Local stakeholder involvement provides empirical insight into air-quality-specific innovation opportunities. The project aims at developing recommendations for the further development of air-quality-specific capacities. This can be achieved by bringing together local knowledge of practitioners and other stakeholders involved with experiences of adaptation and innovation potential toward an improved air quality situation.

The transdisciplinary FTI approach is followed using a manual by [46], where the local coordination is in charge of ensuring the success of the fourth pillar. The emphasis in this context is put on the participatory process of identifying, testing, and adapting innovations with stakeholders from different sectors. By following the steps of the FTI approach and applying the TRANSFORM approach, the fourth pillar of the TAME-BC project focuses on systematic and strategic stakeholder engagement toward collective agreement to collaborate and co-create solutions [46] and on testing transition and intervention strategies [29].

4.4.1. Theory to Local Coordination Practice: Appropriate Embedment in Metro Manila

To root the technological, political, and health awareness practices into the local environment, a local NGO served as the coordinator on the ground. Building on its already established network and the trust of stakeholders in this network allowed for promising cooperation within the expanding network.

Appropriate embedment in Metro Manila started with cooperation among policy- and decision-makers to strengthen air quality management systems and identify spaces within institutional frameworks for innovation development and adaptation in air quality improvement, including BC mitigation. The goals were achieved by a series of capacity development workshops for innovation-based change adaptation.

Building the Stakeholder Network as a Dialogue Platform for Collective Learning and Change Adaptation

According to Lang et al. [37], building a collaborative research team is the first step in conducting a transdisciplinary research project. This was followed by the creation of a joint understanding of the real-world problem the consortium had broadly identified. For TAME-BC, this meant developing a communication strategy and approaches that matched the local context and reflected the priorities of the partners and stakeholders. Building on the NGO's existing network of contacts, key stakeholders, in addition to those already engaged by the project, were identified and mapped. With the help of other partners, institutional and operational links between government and non-government agencies were specified, together with the most efficient and strategic mechanisms of engaging them. A communication platform was established through internal and external directories, for ease of communication with all groups involved. Ensuring clear communication systems was necessary for a smooth transition for the identification of change adaptation potential once the findings from the study are consolidated.

Identifying a Methodological Approach to Combine Collective Reflection, Learning, and Air-Quality-Related Innovation Development

As the list of stakeholders ranges from scientists to jeepney driver association representatives to NGOs and local government representatives, it is a prerequisite to find a way to include all members of the team in the dialogues. Further following Lang et al. [37], a methodological framework for collaborative knowledge production was of crucial importance within the process of moving from knowledge transfer toward the co-creation of knowledge. For the identified stakeholders, regular group meetings are required. In parallel, discussions between various groups were facilitated and the results were shared within the wider stakeholder group. Workshops were conducted to encourage the transdisciplinary approach and further stimulate the development of air-quality-related innovations. Resources, such as publications, reports, and relevant news, were continuously disseminated through the communication platform established as a first task. For the stakeholders not directly involved in the interviews and workshops, leaflets were developed. The figure below (Figure 3) presents one example. At the beginning of the project, after agreeing on a shared problem definition, a leaflet summarizing the main research questions was prepared. It reflects on the four pillars and the overall goal of the project. This was presented in a graph and in simple language (in Tagalog, the local language in Luzon, the research area) to allow for ease of interaction with the information.

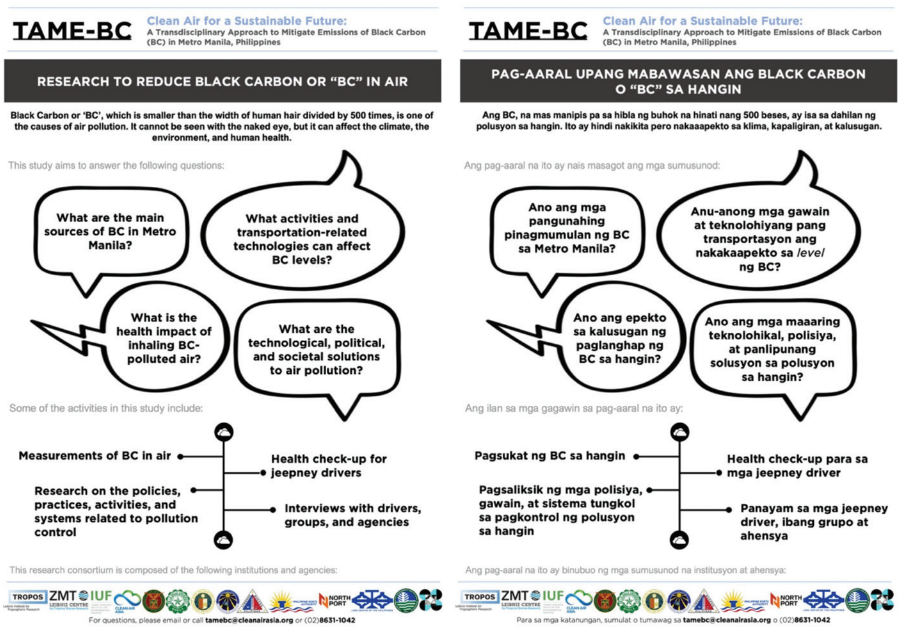

Figure 3. Leaflet in simple terms in the local language (right panel) to involve all stakeholders in the process.

Localizing a Concept for Innovation-Based Change Adaptation and Transition Management

Input from the technology, policy, and health effects practices was consolidated. Methodological needs and gaps from that input were identified. The input was improved for the development of innovation-based change adaptation and management. A research implementation roadmap was created that identified appropriate partners, most central project activities, and timelines. Throughout the process, there was a consistent reporting and documentation process in place to support the shared learning processes.

Developing Reports on Transdisciplinary Workshops and Process Documentation

Workshop and meeting reports, project reports, and other outputs must be continuously consolidated and shared with concerned partners and stakeholders. In all related documentation and reporting activities of the project, it was ensured that inputs from all stakeholders, especially PUJ drivers and government agencies, were valued. The outcomes of the various steps of the innovation embedment methodology were presented as a knowledge brief, policy assessment report, and a report on possible technological innovations. A draft action team and project roadmap were jointly developed, paving the way for innovation development.

5. Discussions and Limitations

For solving complex real-world sustainability problems, as outlined above, it is vital to bring together a broad range of researchers, practitioners, and stakeholders with a shared vision and goal. Collaborative research endeavors are challenging since this requires cooperation across disciplines and scales; therefore, the effectiveness of such research can be hard to measure in the short-term. At the same time, we regard the network that the project was able to build so far and its communication strategy as a major contribution toward a potential solution. Bringing stakeholders from the physical sciences, the social sciences, and the health sciences, as well as non-government and government representatives and practitioners, in our case, the jeepneys driver association representatives, together to discuss air pollution is a novelty in itself. To then follow a systemic approach in which the problem was collectively defined and agreement on the search and development for potential solutions was achieved is the basis for further collaboration. The Department of Transportation, a major stakeholder, agreed to work closely with the team and to become a part of it. In Figure 4 below, the TRANSFORM and FTI approaches applied for TAME-BC are displayed. Assessment and analysis (step one of the TRANSFORM approach's requirements) of the air pollution levels (Port, Quezon City (QC), and background BC levels) is the work conducted in pillar one. In pillar two, by incorporating de jure governance responses by state institutions and de facto mechanisms of the public, we study past and current states of the environmental problem (step two of TRANSFORM: provide solution-orientated goals that reflect the current state of the problem). Pillars three and four contribute to the mitigation of the air pollution problem by building awareness among the PUJs and by involving important local stakeholder networks. Pillar four is crucial for local embedment. The fourth pillar ensures that solution-oriented results from all other pillars are locally adopted and embedded in Metro Manila (step three of TRANSFORM: contribute to mitigating the current (pollution) problem).

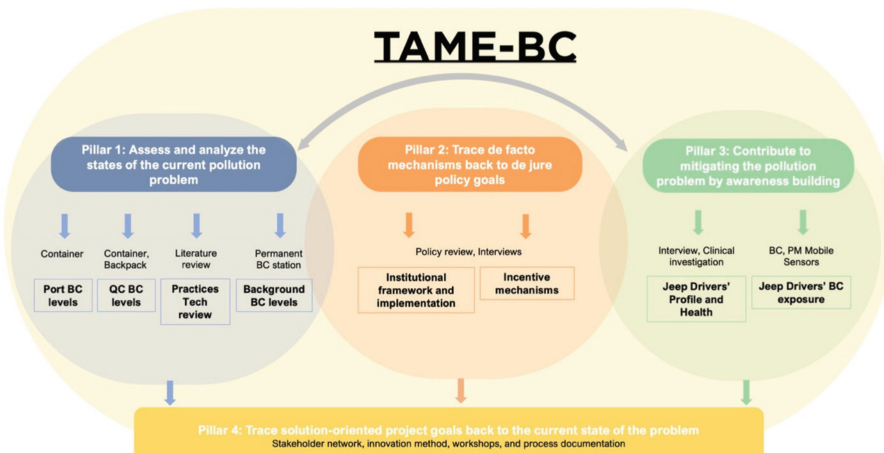

Figure 4. The "follow the innovation"(FTI) and TRANSFORM methodology steps displayed using the four pillars of the TAME-BC set-up.

For solving sustainability problems, tailor-made approaches are needed. Since every scientific attempt has a different method for tackling sustainability problems, it is hard to compare the methodologies. The state of the art on transdisciplinary research processes for more sustainability is still in the early stages. Although there is a growing number of publications on the topic, it is not possible to compare the research setup in this manuscript with a similar scientific approach in the past. TRANSFORM and FTI provide a scientific basis for conducting air pollution mitigation research. Nevertheless, due to changing local conditions and different sustainability goals, no comparable scientific approach has been taken before, according to the knowledge of the authors. If a similar scientific transdisciplinary approach emerges in the future for addressing sustainability problems, it is recommended to compare the results and effectiveness of the practices applied.

6. Summary

The procedural method presented is a novel approach in the context of sustainability research without presenting measurement or analysis results for each pillar. The four pillars bring together researchers from the environmental, social, and health sciences for assessing air quality challenges and solution-oriented goal setting. The setup includes stakeholders from science, non-governmental organizations, and government agencies to allow for local innovation development.

The methodology applied in TAME-BC follows the TRANSFORM and FTI approaches. This transdisciplinary approach consists of (1) the measurement of air pollutants, (2) the study of policy implications for air quality management, (3) exposure-related health effects estimations, and (4) local coordination and knowledge production. The TAME-BC approach provides a systematic integrative approach that aims at BC reduction. This setup starts by jointly defining the existing pollution challenges (complex problem constellation) and investigating solution-orientated goals (plausible future constellations) that reflect the current state of the problem (sustainable constellation) by involving various stakeholders (transition strategies).

Applying this approach to air quality challenges in Metro Manila highlights (1) the importance of novel and custom-built measurement technologies for scientific air quality measurement campaigns; (2) the necessity to involve local-level stakeholders to establish a response to policies aiming at BC emissions reduction processes, as well as the prerequisite of innovation roadmaps via attractive legal frameworks; (3) awareness-building processes among healthcare systems and local infrastructures. Finally, the paper emphasizes (4) the need to involve a broad set of stakeholders, including the identification of a shared language and shared goals. Instead of presenting results for all four pillars, this paper suggested that information collected via such a setup can be used for improvements in transport sector planning, policymaking, clinical studies, and state-of-the-art scientific studies. (see Figure 5).

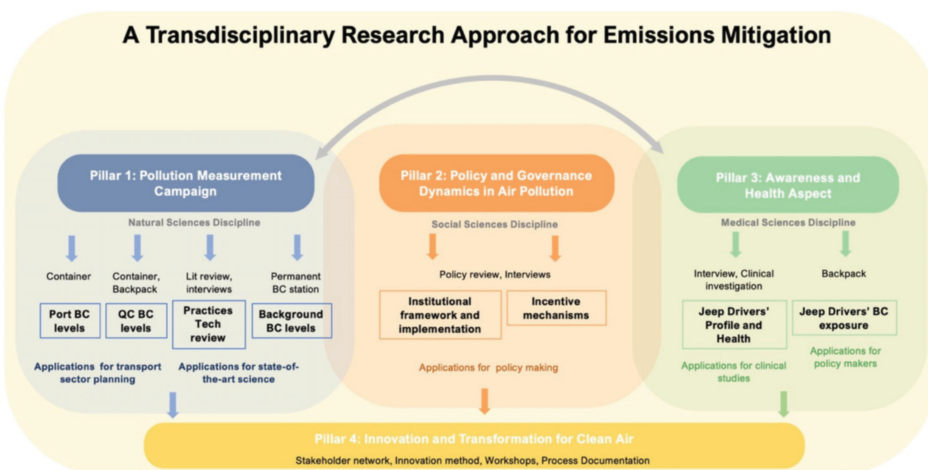

Figure 5. Visualization of a novel approach for sustainability research in the context of air quality management.

Bringing the four pillars together by following the FTI and TRANSFORM approaches in Metro Manila proved that custom-built technological solutions are necessary for high-quality data collection regarding air pollutants. Additionally, the high-quality data needs to be translated into the local context by analyzing de jure governance responses by state institutions and de facto mechanisms of the public down to the individual behavior of jeepney drivers. Third, awareness-building via knowledge on health effects needs to also be built with local stakeholders to guarantee sustainable change adaptation. Finally, these three scientific steps for BC emissions reduction need to be translated well into local networks, and therefore, a local partner is essential for innovation embedment via stakeholder engagement. These steps ensure a successful transdisciplinary approach for improved air quality and sustainable change-making. Such a setup has an impact on the local scientific state of the art (pillar one) through scientific emissions assessment, together with local partners. Applying the policy fore-, and back-casting assessment and awareness building pillars (pillars two and three) is also done. The fourth pillar has the potential to combine the knowledge produced toward the development of pollution mitigation.

This transdisciplinary approach aiming at reducing emissions in Metro Manila combined the FTI and TRANSFORM approaches and contributes to the sustainability science by developing and validating a novel approach for sustainability research in the context of air quality management.

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Abbreviations

BC:	Black carbon
NOx:	Nitrogen oxides
O3:	Ozone
CO:	Carbon monoxide
Pb:	Lead
PAHs:	Polycyclic aromatic hydrocarbons
TAME-BC:	Clean Air for a Sustainable Future: A Transdisciplinary Approach to Mitigate Emissions of Black Carbon in Metro Manila, Philippines
ZMT:	Leibniz Centre for Tropical Marine Research
IUF:	Leibniz Institute for Environmental Medicine
DIE:	Deutsches Institut für Entwicklungspolitik/ German Development Institute
TROPOS:	Leibniz Institute for Tropospheric Research
BMBF:	German Ministry for Education and Research
DOTr:	Department of Transportation
PUVMP:	Public Utility Vehicle Modernization Program
PUV:	Public Utility Vehicle
PUJ:	Public Utility Jeepney
DENR:	Department of Environment and Natural Resources
BC:	Black carbon
NOx:	Nitrogen oxides
O3:	Ozone
CO:	Carbon monoxide
Pb:	Lead
PAHs:	Polycyclic aromatic hydrocarbons
QC:	Quezon City
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TROPOS: Leibniz Institute for Tropospheric Research
BMBF: German Ministry for Education and Research
DOTr: Department of Transportation
PUVMP: Public Utility Vehicle Modernization Program
PUV: Public Utility Vehicle
PUJ: Public Utility Jeepney
DENR: Department of Environment and Natural Resources

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