urban science

Review

Status and Future Directions for Residential Street Infrastructure Retrofit Research

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Abstract: Residential streets, particularly in automobile-dependent suburban locations, have frequently been perceived as ecologically unsustainable, antisocial, unhealthy, and aesthetically dull from an urban design perspective. However, residential streets can be improved through infrastructure retrofits, particularly by combining green and grey infrastructures and integrating various functions and services. Using a systematic literature review and an adapted landscape services framework, the paper analyses the status of retrofit research and discusses existing composition and spatial integration of green, grey, and green-grey street infrastructure. Findings suggest changing infrastructure compositions in residential streets and a trend toward increased grey and green-grey infrastructure integration. However, functional connectivity is often lacking, and while barriers to implementation have been suggested, few have been tested. While retrofits are potentially able to increase the number and quality of landscape services that support human well-being, more—and possibly longitudinal—research is required to advance and analyze their implementation and provide evidence for their success.

Keywords: green infrastructure; grey infrastructure; green-grey infrastructure; landscape services; residential streets; street retrofits; infrastructure retrofits; urban design

1. Introduction

Streets within residential communities perform various infrastructure functions. They provide conduits for communication, electricity, stormwater, sewage systems (i.e., utilities), and for pedestrians, cyclists, and automobiles. Furthermore, residential streets can increase social inclusion [1] and social cohesion [2]. They contribute to neighbourhood vitality, diversity, and sense of place [3]. Green infrastructure, such as street trees, contributes to positive aesthetic experiences, physical, and mental health, and increased property values [4]. In addition to mitigating microclimate in support of user thermal comfort [5], green infrastructure helps cleanse the air [6], and sequester carbon mitigating climate change [7]. It also provides support for indigenous wildlife, e.g. [8], and stormwater management services beyond those of conventional pipes, curbs, and gutters [9].

Beginning in the early 20th century, many residents were able to adopt automobiles as their primary mode of transport [10]. This led to the development of large scale, low-density residential neighbourhoods on the outskirts of city centres, that were not within walking or cycling distance of public transit or supporting land uses, such as employment and commercial centres [11]. While there has been some variation in residential street widths through time and with context, since about the 1930s many suburban residential street and carriageway widths have become increasingly wide. For example, Ben-Joseph [12] argued that since 1930, in many American cities, streets have been designed to maximize the speed and safety of drivers, with rights of way ranging from about 15 to 18 metres (Figure 1). In many subdivisions, both right of way and carriageway widths have significantly increased through time. Segregated sidewalks as well as trees and shrubs in the public right of way have often disappeared from designs. At the same time, housing has become increasingly fronted with garages rather than porches and balconies that characterized earlier subdivisions [13]. This demonstrates the increasing priority given to the car over pedestrians in suburban street design.

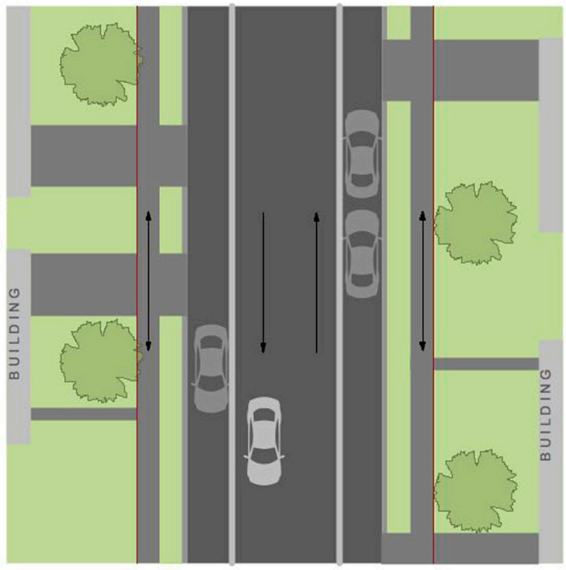

Figure 1. Example of a typical suburban street design (plan view; not to scale).

Such suburban neighbourhood designs are more and more considered ecologically and socio-economically unsustainable [14]. For example, their street designs have been associated with unsafe car speeds and high accident rates [15]. Their automobile-dependent transport patterns discourage walking and cycling and have been related to reduced physical and mental health, increased levels of obesity [16], and social isolation [17]. They are also associated with increased levels of air pollution and carbon emissions [18], accelerated rates of climate change [19], and health care costs [20]. Their lack of publicly-owned stormwater storage and cleansing services means that large quantities of polluted surface runoff is delivered to waterways, contributing to their erosion, pollution and downstream flooding, particularly in cities subject to high rain fall [21]. Unfiltered stormwater runoff is a potential groundwater pollution hazard. Retrofitting streets with green or green-grey infrastructure systems and technologies such as rain gardens would likely reduce pollution levels [22].

Currently, many cities are being planned to accommodate population growth through infill development within existing suburbs, rather than through new greenfield development [23]. The intent is to intensify suburbs, in support of a greater mixture of land uses, and increased public transit. However, their success relies on existing suburban streets being redesigned and retrofitted to reduce car dependency and increase pedestrian and/or cycling modes of transit. Thus, new street designs are being proposed that encourage street sharing between automobiles, bikes, and pedestrians [24], including a reduction of automobile carriageways and parking capacity, the introduction of speed limits and corresponding traffic calming features [25], the incorporation of dedicated bike lanes, and expanded pedestrian areas that encourage social interaction [26].

At the same time, care needs to be taken to ensure denser neighbourhoods do not lose or degrade their green areas and services through the infill process. Some neighbourhood infills have resulted in the loss of green space area, particularly within privately owned land [27]. This unintended result is likely to reduce the attractiveness of the compact city model and impedes its adoption. New green infrastructures, such as trees, planters, and rain gardens are being promoted to provide enhanced ecosystem services and integrate ecology with urban design [28]. Integrated green-grey services might serve to offset some of the negative aspects of densification and mitigate some of the impacts of increased frequency and severity of extreme weather events related to climate change.

To what extent can new grey and green infrastructures be accommodated within existing residential streets? Green functions of cities (e.g. urban agriculture, recreation, and nature conservation) and those grey (e.g. buildings, pavement, and utilities) have conventionally been viewed as competing in terms of both land use and access to (public) funding [29]. Additionally, more often, grey functions have often been prioritized. This has resulted in the loss or degradation of green functions through time [29]. However, Tjallingii [29] and others, e.g. [30], argue that mutually supporting designs of green and grey infrastructures can be achieved, and should be encouraged. The large widths of many existing residential streets may provide opportunities for accommodating multiple grey and green functions. Additionally, designing grey and green infrastructures at the same time could assist in minimizing spatial conflicts. Furthermore, retrofitting them together may be more cost effective then separately, and may reduce the annoyance associated with street repairs [31].

While studies have pointed to the need to retrofit existing residential streets and emphasized benefits of street reconstructions with regard to green infrastructure [32], little is known about whether it is occurring, what infrastructures are being implemented, how, and to what effect. The paper systematically analyses the literature on street infrastructure retrofits to uncover evidence in support of answers to five interrelated research questions: To what extent are street retrofits occurring, or being studied? Are compositions of green, grey and green-grey infrastructures in streets changing through retrofits? To what degree are infrastructure types being integrated spatially and temporally? To what extent are ecosystem services being studied? And, what are the key barriers to retrofit implementation and success? Results will assist in establishing the status quo of conventional suburban street retrofits and identifying research questions for advancing their transformation in support of multiple landscape services.

2. Materials and Methods

Our review uses an established systematic literature review methodology [33]. Papers, published in English-language academic journals were obtained from searches of these databases: Science Direct, Scopus, Web of Science, Avery and JSTOR. Each was searched from the earliest year of publication, which varied according to the journals; however, all searches covered the period from January 2000 to December 2015 (the agreed end of the 'search' research stage). Peer-reviewed academic journal articles rather than publications from grey literature were searched to ensure quality standards. Papers chosen dealt with residential street retrofits in North America, Western Europe and Australasia. Street retrofits were defined as changes to the designs of existing streets. Urban and suburban street contexts were both included, partly because terms such as suburban and urban are often not clearly defined in the literature and vary in their physical, functional, social or cultural dimensions [34]. The paper does not analyze and discuss planning frameworks such as zoning regulations that may have an influence on residential street designs and street infrastructure. We assume that residential streets provide mainly residential services. However, complementary (mixed) land uses such as small-scale retail, cafes, restaurants, offices, etc. make part of the functional diversity of residential neighbourhoods and support healthier lifestyles and active living [35]. More mixed-use development in residential areas would likely have an influence on residential street designs.

The searches were conducted using Boolean functions to combine keywords and phrases (Appendix A). Searches included terms that defined the setting, e.g. 'street' or synonymous words, AND the term green infrastructure, or synonyms (e.g. green network), OR components of green infrastructure (e.g. tree); OR green infrastructure functions (e.g. biodiversity). Street grey infrastructure studies were identified in the same way with the term defining the context combined with the term grey infrastructure or synonyms (e.g., infrastructure), OR components of grey infrastructure (e.g., sidewalk) OR their functions (e.g., street calming). Searching ended when duplicates of previously downloaded citations dominated the search results [36]. The resulting 34 papers were screened using the PRISMA process described by Moher, et al. [37]. Figure 2 shows a diagrammatical representation of the methodology we applied

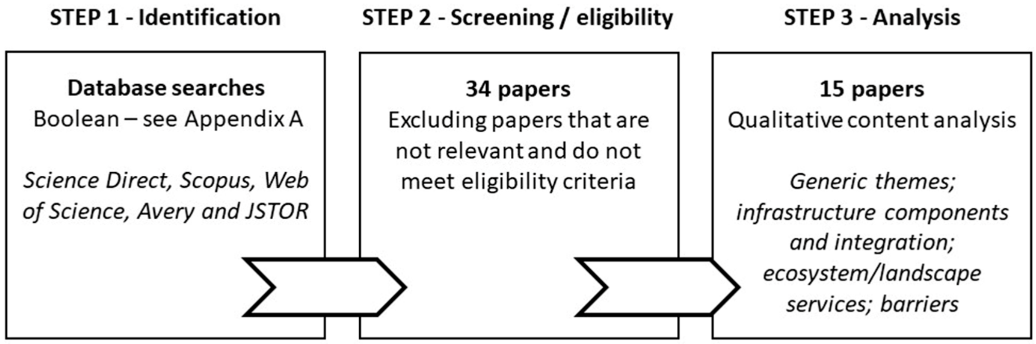

Figure 2. Diagrammatical representation of systematic literature review process.

The final selection of papers was analyzed for themes using qualitative content analysis assisted by the NVivo software package. Common review themes [33] were analyzed including year of publication, author, academic journal, academic discipline, geographical study location, climate zone, and topic of study. Journal titles were used to classify the research by discipline according to the SCOPUS subject classification system. The Trewartha climate classification system [38] was used to identify climate zones.

Additional themes were also identified including street infrastructure types (e.g., green or grey), components (e.g., sidewalks or trees), ecosystem services, scale of integration in streets, and enablers and barriers to infrastructure implementation. Definitions of the terms grey and green infrastructure were required to categorize street infrastructure components, systems and functions, and their level of integration within street retrofits. However, definitions in the literature varied widely across multiple disciplines. For example, the term "infrastructure" most frequently refers to human-made physical systems, such as transportation, electricity, communications, stormwater and sewage [30]. Social infrastructures are also sometimes included in definitions, such as education and healthcare. Such infrastructures have more recently been labelled as grey, and sometimes red [29] to distinguish them from newly conceived green infrastructure systems (e.g. [39]). Green infrastructure also has multiple definitions in the literature. Some focus on its components, particularly those providing hydrological functions (e.g. [40]), and others define it as ecological networks or systems without specifying system components or their spatial or temporal scales (e.g. [41]). Due to the uncertainty regarding these definitions, we developed our own definitions with respect to street infrastructure based on an analysis of the common characteristics of the infrastructure elements studied within the reviewed papers.

In terms of analysis of ecosystem services, various frameworks are available for use (e.g. [42]), but none fully captures the range of nature, human-nature and human-based services provided by street infrastructures. Streets are elements (and places) within spatial human-ecological systems. The concept of landscape services [43] rather than ecosystem services was considered more useful in a street specific framework. It was adapted from the most recognized urban ecosystem framework, TEEB [42] (see also Section 3.4). Based on this framework, we identified the services researchers have studied. Only landscape services mentioned as the focus of research question(s) were categorized within the framework, even though infrastructures could conceivably provide other services.

We evaluated the integration of grey, green and green-grey infrastructures in streets according to the extent to which they meet Hansen and Rall's [44] definition of urban integrated infrastructure as multi-scale, physically, and/or functionally connected.

3. Results

3.1. Overview of Findings

The review resulted in fifteen papers on green and/or grey infrastructure within urban or suburban residential street retrofits, published between 2009 and 2015 (Table 1). The majority (eleven papers) came from new world countries (United States, Australia and New Zealand), with five papers originating in Europe (UK and France). About half of publications arose from the U.S.

Ninety percent of the research was conducted in temperate subtropical climates characterized by warm to hot summers and cool winters, with the majority occurring in coastal sub-climate zones of the sub-tropics (Oceanic and Humid sub-climates). These sub-climates experience rain throughout the year, but particularly in winter, and have significant storm events over extended periods [45].

Table 1. Papers identified in systematic literature review.

Authors	Year	Journal	Name of paper	Method	Location of study	Climate zones
			USA			
Brown and Borst [46]	2014	Journal of Hydrological Engineering	Evaluation of surface and subsurface processes in permeable pavement infiltration trenches	Water flow monitoring	Louisville, Kentucky	Humid Subtropical (CFA)
Chapman and Horner [47]	2010	Water Environment Research	Performance Assessment of a Street-Drainage Bio-retention System	Water flow/ pollutant monitoring	Washington	Dry-summer temperate (CSB)
Church [48]	2014	Landscape and Urban Planning	Exploring Green Streets and raingardens as instances of small scale nature and environmental learning tools	Semi-structured interviews	Portland, Oregon	Dry-summer temperate (CSB)
Page et al. [31]	2015a	Journal of Hydrology	Retrofitting with innovative stormwater control measures: Hydrologic mitigation of impervious cover in the municipal right-of-way	Water flow monitoring	Wilmington, North Carolina	Humid Subtropical (CFA)
Page et al. [49]	2015b	Ecological Engineering	Soils beneath suspended pavements: An opportunity for stormwater control and treatment	Water flow/ pollutant monitoring	Wilmington, North Carolina	Humid Subtropical (CFA)
Page et al. [50]	2014	Journal of Environmental Engineering	Retrofitting Residential Streets with Stormwater Control Measures over Sandy Soils for Water Quality Improvement at the Catchment Scale	Water flow monitoring	Wilmington, North Carolina	Humid Subtropical (CFA)
Schlea et al. [51]	2014	Journal of Hydrological engineering	Performance and Water Table Responses of Retrofit Rain Gardens	Water flow/ pollutant monitoring	Westerville, Ohio	Hot humid continental climate (DFA)
Shu et al. [52]	2014	Transportation Research Part D	Changes of street use and on-road air quality before and after complete street retrofit: An exploratory case study in Santa Monica, California	Air quality, microclimatic data and traffic volume monitoring	Santa Monica, California	Dry-summer subtropical (CSA)
			UK			
Adams and Cavill [53]	2015	Journal of Transport & Health	Engaging communities in changing the environment to promote transport-related walking- Evaluation of	Pedestrian counts/ interviews	England	Oceanic (CFB)

			route use in the 'Fitter for Walking' project			
Coulson et al. [54]	2011	Health &Place	Residents' diverse perspectives of the impact of neighbourhood renewal on quality of life and physical activity engagement- Improvements but unresolved issues	Focus groups	England	Oceanic (CFB)
Curl et al. [55]	2015	Landscape and Urban Planning	The effectiveness of 'shared space' residential street interventions on self-reported activity levels and quality of life for older people	Questionnaire surveys, community meetings and information sessions.	England, Wales and Scotland	Oceanic (CFB)
			France			
de Larrard et al. [56]	2013	International Journal of Pavement Engineering	Removable urban pavements: an innovative, sustainable technology	Interviews	France	Oceanic (CFB)
			Australia			
Hatt et al. [57]	2009	Journal of Hydrology	Hydrologic and pollutant removal performance of stormwater bio-filtration systems at the field scale	Water flow/ pollutant monitoring	McDowall, Queensland	Humid Subtropical (CFA)
			New Zealand			
Charlton et al. [58]	2010	Accident Analysis and Prevention	Using endemic road features to create self-explaining roads and reduce vehicle speeds	Videos and resident questionnaire	Auckland	Oceanic (CFB)
Mackie et al. [59]	2013	Accident Analysis and Prevention	Road user behaviour changes following a self-explaining roads intervention	Videos	Auckland	Oceanic (CFB)

The fifteen papers were published in eleven different journals, spanning two out of the four SCOPUS field clusters: Physical science (eight papers) and social science (seven papers). No papers were published in the health science field cluster that has health professions as a major subject area; however, mental and physical health aspects of streets appeared to be covered within the social science field cluster, particularly in the transportation and health minor subject fields. Environmental science journals, and those dealing with environmental engineering, in particular, dominate publications followed by transportation-related journals (Appendix A).

Five research topics including eleven research questions have been studied with respect to street infrastructure. Most commonly asked questions concern the efficiency of stormwater infrastructure [31,46,47,49–51,57]. Most of these papers arose from countries experiencing significant rainfall (humid sub-climates). The second most commonly asked question concerns the effect street infrastructure have on pedestrians [53–55,59], and the third most popular question concerns the effects infrastructure has on the physical and mental well-being of residents [54,55] and road user behaviours [58,59].

3.2. Green, Grey and Green-Grey Street Infrastructures

Thirteen components of infrastructure were studied (Appendix B); however, none of the papers categorized their components as grey, green or green-grey infrastructure, or defined these terms. Two of the papers studying bio-retention areas and/or permeable pavements referred to their infrastructures as green infrastructure to differentiate them from (grey) storm-water management infrastructure, such as underground pipes [31,48]. However, a third paper on this topic suggested their bio-retention facilities (suspended pavements) were an integration of green and grey infrastructures due to their multiple green and grey services including water regulation, aesthetic and supporting (nature conservation) services [49]. No other papers identified their infrastructures as green, grey, or green-grey.

An analysis of infrastructure component characteristics revealed a continuum of green and grey components, ranging from infrastructures that had very little grey ingredients (or functional influence), like trees, to those having very little green ingredients (or influence), such as non-porous pavements. In between these two extremes are infrastructures that have more significant proportions of either green or grey. This continuum, at the scale of the city, was first described by Davies et al. [60].

To categorize street scaled infrastructures into green, grey and green-grey, we developed the following definitions. Green street infrastructures are components or networks consisting of a greater area or volume (>75 percent) of nature-made than human-made components (e.g., trees, plantings and planters (including their soils). Grey street infrastructures are components or networks consisting of a higher proportion (>75 percent) of human-made than natural components in area or volume (e.g. carriageways, curbs, sidewalks made of concrete, benches, or bicycle racks). Green-grey infrastructures are components and systems that have areas or volumes of 25 percent or more of either nature and human-made materials, or, where it cannot be determined from the study, comparable proportions of green or grey components (e.g. rain gardens). Potentially, networks could shift from one type to the other as their infrastructure components are retrofitted through time (e.g. a storm-water management system along a street could change from grey to green-grey infrastructure when pipes (grey infrastructure components) are replaced with bio-retention facilities (green-grey components).

We used these definitions to categorize the different street components into types of infrastructure (Appendix B). It shows that grey street infrastructure components, and particularly those that influence vehicular, pedestrian, and—to a lesser extent—cyclist's attitudes and behaviors dominate the research. Green-grey infrastructures are limited to bio-retention facilities and permeable pavements. Researchers used different terms referring to these infrastructure components including rain gardens, bio-swales, biofiltration systems, bio-retention cells, tree filter devices, suspended pavements, and permeable pavements. This may indicate a wide variety of facilities tested, but may also reflect different naming conventions. Green infrastructure components retrofitted into streets are limited to trees, plantings, and planters.

3.3. Integration of Green, Grey and Green-Grey Street Infrastructures

The integration or connectivity between green, grey and green-grey infrastructures occurs at multiple scales. Two scales are currently being studied: individual infrastructure components within streets (e.g. an individual biofiltration facility made up of green and grey infrastructures to form a combined green-grey infrastructure (Figure 3)) and networks of components across a street, e.g. biofiltration facility (green-grey infrastructure), planter, planting area and trees (green infrastructure), and street furniture and car parks (grey infrastructure) working together to provide street calming services. Exceptions were the studies by Page et al. [31,50] that evaluated surface water regulation facilities across two streets.

Infrastructure studied indicated two types of integration: physical (i.e. the extent to which infrastructures studied are physically linked or connected), and functional (i.e. the extent to which infrastructures studied contribute to the service being provided). We used Forman's [61] concepts of physical and functional connectivity within corridors and networks to determine whether infrastructure being studied were physically and/or functionally integrated or connected. Studies of physically integrated infrastructures evaluate those of more than one type (i.e. green and/or grey and/or green-grey infrastructures) that are linked or positioned closely together in or across the street (i.e. side by side without gaps, or with few and/or narrow and/or aggregated spatial gaps).

Studies of functionally integrated Infrastructures evaluate those of more than one type that work together to provide a service. Some physically integrated infrastructures are not functionally integrated in terms of how they are studied and/or may not function together to provide their intended service(s). For example, in Figure 3, the chicane and a biofiltration facility are physically integrated (i.e. they are positioned side by side with no gaps). However, in terms of how they are studied, they are not functionally integrated in the studies we reviewed. The chicane was not a component within biofiltration studies, even though it affects the function of the biofiltration facility. They are linked physically (side by side with no gap), but their two services (storm-water management and street calming) are studied separately.

Functionally integrated infrastructures closely rely on each other to perform a function, e.g. storm-water management, but do not necessarily have to be physically integrated or linked to provide this function. For example, street trees, planters and biofiltration facilities along a street could together provide supporting services (e.g. bird habitat), but they may not be physically linked. Finally, some infrastructure components and networks studied were both physically and functionally connected or integrated. For example, a tree filter device consists of both green and grey infrastructure components that together provide a function: Storm-water management. This can happen at the street scale, e.g. in the case of biofiltration swales within boulevards that are both physically connected by water along their length and work together to provide storm-water management.

Fourteen out of fifteen studies studied infrastructures that had, or assumed to have, some level of either functional integration (six studies), or physical and functional integration (eight studies). The remaining study only dealt with grey infrastructure [56]. Five of the studies looked at physically and functionally integrated components focusing on biofiltration facilities and areas of permeable paving. The components were characterized by high physical integration, with both green and grey infrastructure types linked without gaps, and both types making significant contributions to their water regulation services. Three studies dealt with physically and functionally integrated street networks of these components (e.g. Page et al. [31,50]. While the components were physically integrated as individual facilities, there were gaps between the facilities being studied and with adjoining infrastructures, such as curbs and gutters, which reduced their physical and functional integration as an infrastructure network. Finally, six studies dealt with what the authors assumed to be functionally integrated system of infrastructures, e.g. infrastructure types working together to calm street traffic and increase pedestrian and/or cycling (Figure 4).

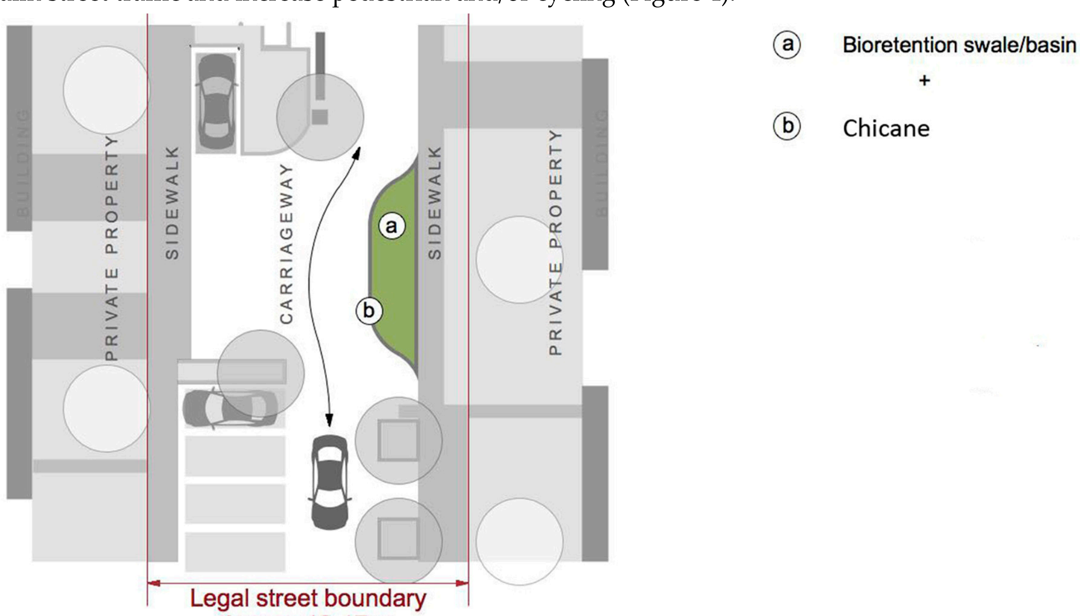

Figure 3. Example of physically integrated street infrastructure (plan view; not to scale).

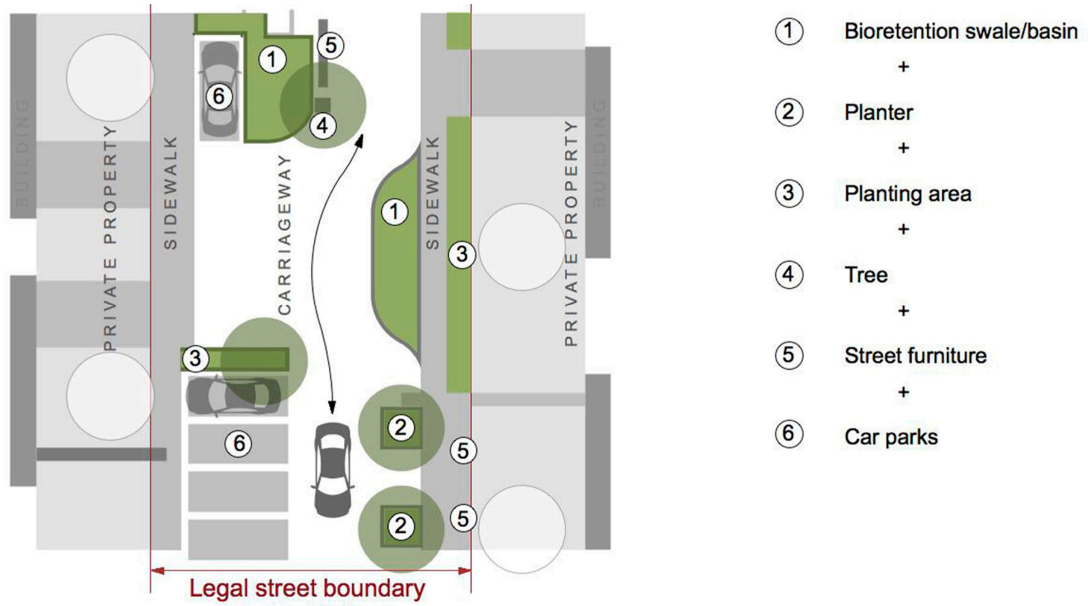

Figure 4. Example of functionally integrated street infrastructure (plan view; not to scale).

However, the extent to which components are physically connected was not indicated, nor the exact composition of networks in terms of proportions of green, grey and green-grey infrastructures. In addition, they provided little evidence in support of components operating together to perform the desired services. For example, none of the studies attempted to isolate the role of individual or groups of the infrastructure types or components studied in support of the attitudes or behaviours studied (Table 2).

Table 2. Integration of street infrastructure elements by scale.

Study	Infrastructure Components		
	Green	**Green-Grey**	**Grey**
Element Scale			
Physically and functionally integrated			
Brown and Borst 2014 [46]		parking lane permeable pavement	
Schlea et al., 2014 [51]		Kerbed boulevard bioretention cells	
Hatt et al., 2009 [57]		kerbed chicane bioretension cell	
Chapman et al., 2010 [47]		parking lane bermed bioretention	
Page et al., 2015b [49]		boulevard suspended pavement	
Network Scale			
Physically and Functionally Integrated			
Page et al., 2015a [31]; Page et al. 2014 [50]		bioretention cell, permeable pavement parking stalls, tree filters	
Church, 2015 [48]		bioretention facilities within kerbed boulevards along streets	
Mackie et al., 2013 [59]; Charlton et al., 2010 [58]	trees, plantings		cycle lane, pedestrian crossing, chicane
Shu et al., 2014 [52]	trees, plantings		sidewalks, street furniture, chicane
Curl et al., 2015 [55]	planter		chicane, bike racks
Adams and Cavill 2015 [53]	planting		street furniture, shared surfaces
Coulson et al., 2011 [54]	trees, planter, planting	bioretention cells	lighting, chicanes, shared space paving, artwork, cycle lane

3.4. Ecosystem / Landscape Services of Street Infrastructures

Definitions of green, grey and green-grey infrastructure components suggest that ecosystem services are provided not only by natural (i.e. non-human) agents of ecosystems (conventionally referred to in the literature as 'ecosystem' or nature's services), but also human agents. To categorize multi-agent services indicated in the papers, we adapted the ecosystem service framework of TEEB [42] developed for cities. It recognizes the increased number of sociocultural and economic services associated with urban ecosystems [62]. However, it still does not adequately recognize the services provided by human and human-nature agents within street infrastructures.

The landscape services concept developed by Termorshuizen and Opdam [43] recognizes these latter services as integral to urban ecosystems. Accordingly, we adopted a concept of 'street infrastructure landscape services'. Our adapted framework recognizes three categories. Nature-based services are those provided primarily by nature-fabricated components or systems of infrastructure (e.g. habitat services provided by a connected network of planted boulevards). Human-based services are those provided primarily by human-fabricated elements of infrastructure components or systems (e.g. aesthetic and functional services to pedestrians provided by pavements, lighting, and benches).

Lastly, there are nature/human-based services where they are provided by infrastructure components or systems made up of significant proportions of both human and nature-fabricated services (e.g. bio-retention facilities). Where researchers did not indicate the proportions of human and nature services within infrastructures, we categorized them as nature/human-based services.

According to the above framework, researchers are primarily studying cultural and regulatory services of retrofitted streets. Human and nature/human-based cultural services are being studied rather than nature-based cultural services (e.g. role of retrofitted street trees in support of street aesthetics). Six of the studies focused on testing recreational and mental/physical health support services [48,53–55,58,59]; however, three of these did not find evidence of these services [54,55,58]. Similarly, Church [48] did not find that bio-swales provided a connectedness to nature service. Infrastructure provided aesthetic services in three studies [53,54,58]; however, these services were not the primary focus of two of these studies.

Two potential cultural sub-services not identified by TEEB [42] were studied by researchers. Church [48] sought to determine if bio-swales contributed to resident education regarding storm-water management and provided evidence in support of this service. Although not a TEEB [42] sub-category, education is considered a cultural ecosystem service in the Millennium Ecosystem Assessment (MEA) [63], and it was added to the framework. De Larrard, Sedran and Balay [56] sought to determine if removable pavements reduced the cost of, and improved the ease of, street repairs. They provided evidence in support of this service. It could be argued that the ability to access and maintain infrastructure is an essential part of infrastructure systems and should be classified as a supporting service according to the Millennium Ecosystem Assessment (MEA) [63] definition of a supporting service.

In terms of regulatory services, only those nature/human-based are being studied, with a focus on water treatment sub-services (i.e. storm-water management). Bio-retention areas and porous pavement systems are primarily providing storm-water management services, with much evidence in support of quantity control services [31,46,47,51], and quality control of primarily suspended solids [47,49,51,57]. While air quality services of street infrastructure were studied, there was no evidence associating improved air quality with the street retrofit [52].

Appendix C lists the landscape services of street infrastructures according to the literature review using an adapted TEEB [42] framework. Service sub-categories are adapted from those of TEEB [42] unless otherwise indicated. Bold italicized font indicates a study that provides evidence in support of a landscape service. Where there is no bold or italicized font, there was a lack of evidence. An 'X' indicates no service has been studied to date.

3.5. Barriers to Street Infrastructure Retrofit Success and Implementation

Authors identified various barriers to street infrastructure retrofits which we discuss within six categories below. However, regarding their success, many studies on the effects of street scaled retrofits considered methodological weaknesses undermining their ability to test performance. In particular, there were concerns that studies did not allow sufficient time for behavior changes to occur following retrofits [55]. Authors called for more longitudinal studies, but acknowledged their drawbacks, "Ideally we would have waited five years to allow a direct comparison of the pre-and post-treatment crash rates. Practical considerations; however, dictated that we find a somewhat more immediate way of evaluating the effects of the treatments" [58] (p. 1997).

3.5.1. High Cost of Infrastructure Implementation

Six of the studies argued infrastructures may be costly to implement [31,50,51,53,56,59]. However, only one of these studies demonstrated that local governments considered implementation costs to be a barrier [56]. Page, Winston, Mayes, Perrin and Hunt [31] suggest costs may be reduced if retrofits were part of larger public infrastructure projects. Other researchers argued an incremental approach may facilitate implementation [53]. Three of the studies argued that they did not believe their infrastructures were expensive over their lifecycles relative to conventional infrastructures, calling for lifecycle assessments [31,50,51].

3.5.2. Insufficient Space

Research involving green-grey biofiltration and porous paving systems suggests a lack of publicly-owned space may be limiting their implementation [31]. The study demonstrates that the implemented infrastructure had significant capacity for managing storm-water generated by small to medium sized storm events. However, they did not have sufficient space and/or capacity as individual or grouped facilities to handle the amount of water arriving from large storm events. The authors argued that more biofiltration system capacity was required to improve their performance: "The decrease in Q_P [*peak discharge*] likely would have been greater if more than 52% of the DCIA [impervious area of catchment disconnected from conventional drainage pipes] had been retrofitted for hydrologic mitigation" [31] (p. 927).

3.5.3. Limitations in Infrastructure Performance

Implementation may be impeded by limitations to infrastructure performance. Biofiltration facilities and pavements are limited in their abilities to remove certain harmful substances (e.g. soluble phosphorus and dissolved copper [47]; nitrate/nitrite nitrogen [49], and ammoniacal nitrogen and orthophosphate [50]). While one study demonstrated variable results with respect to nitrogen removal depending on vegetation species [57], another argued the long-term effects of pollutants on vegetative components of facilities is unknown [49].

3.5.4. Poor Network Connectivity

Three authors [31,53,54] argued infrastructure performance was limited by insufficient physical and/or functional connectivity with supporting components. For example, conventional curbs and gutters did not support water management functions of adjacent permeable pavements [31]. Coulson, Fox, Lawlor and Trayers [54] claimed that the use of retrofitted streets by pedestrians and cyclists was impeded by a lack of street connectivity to desirable destinations: "Importantly, a need for connectedness also compromised motivation for using the cycle-walkway […] residents simply lacked a purpose to use it" (p. 309). Adams and Cavill [53] argued that infrastructure use was impeded by a lack of sufficient cycle network connectivity to public transit networks. Involving communities would improve the design: "Engaging communities in identifying barriers to walking on local routes in their local neighbourhood, and asking them to suggest solutions, was a successful approach for instigating environmental improvements which were undertaken by both the communities themselves and by local disadvantaged communities" (p. 586).

3.5.5. Lack of Sensitivity to Local Biophysical and Social Conditions

Several studies indicated that a lack of knowledge of, or inadequate consideration given to, local conditions may impede infrastructure implementation. For example, researchers of biofiltration and porous pavement infrastructures indicated their application to other streets might be limited by insufficient attention given to their different soil and hydrological conditions [29,42,45,50]. Lack of sufficient consideration of neighbourhood socio-economic factors, such as the level of deprivation and associated safety concerns, was also considered a significant barrier to the pedestrian use of retrofitted streets: "[S]ome felt threatened by close proximity to young people. A fine line seemed to exist between anti-social behaviour and normal, healthy play" [47] (p. 308). In addition, lack of sufficient attention to the needs of particular population segments was a barrier. For example, Curl, Ward Thompson and Aspinall [49] found a retrofitted street did not meet the needs of residents 65 years of age and older, "In order to have significant changes on the health and wellbeing outcomes of an ageing population, there may be a need for more drastic changes to the environment" (p. 124).

3.5.6. Inadequate Policy and Program Support

Six studies [46,48,49,54–56] suggested that local government or community support would assist in overcoming barriers to implementation. A study on removable pavers [56], and two biofiltration studies [46,49] suggested that specifications, guidelines and/or improved government policy support might increase their adoption, "Further research is needed to refine design guidance and provide a regulatory framework for the use of soil beneath suspended pavements to meet storm-water treatment and tree health goals" [49] (p. 47). Three studies [48,54,55] argued the importance of securing supportive social, and community programs. For example, it was suggested that government social programs could assist in supporting the use of streets among the elderly, "The impact on older people may be limited and more dramatic street design changes or other support, such as social support alongside environmental change, may be needed to effect such change" [55] (p. 124).

In addition, government programs were considered as important for resident education in support of the retrofit. For example, Church [48] found that some residents thought their street biofiltration swales not sited or functioning properly and this reduced their level of support for the retrofit. He argued that government needs to play a role to improve resident education: "This points toward a need for a more visible and transparent strategy to communicate stormwater policies, how Green Streets are sited, and a more visible reporting mechanism on facility monitoring" (p. 238). It was suggested that policies in support of biofiltration facilities should require multiple services as outcomes, such as improved aesthetics and wildlife habitat, not just storm-water management, in order to support human-nature connectedness services and expanded resident support for facilities. Coulson, Fox, Lawlor and Trayers [54] pointed to the role education programs might play in overcoming car-dependent behaviours, "As vehicle-centred issues were much more predominant in residents' minds, strategies to increase activity may need to challenge these issues first. Careful thought and planning is undoubtedly necessary for active travel policies" (p. 10).

4. Discussion

Based on our review, published scholarly research on street infrastructure retrofits (in terms of the implementation of new components and services) has not occurred until about ten years ago. Authors of four of the studies commented they believed their results may have been affected by an insufficient amount of time between the completion of the retrofit and their data collection. Authors indicated many barriers to the success and/or implementation of the infrastructures studied. Such barriers may be less present when novel infrastructures are considered for new streets; we found more papers on this topic during our literature review which, however, did not meet the selection criteria 'retrofit'. The cost of implementation within new streets is likely to be less and therefore more attractive to local governments and private developers. Similarly, barriers impeding retrofit implementation could be avoided in new streets through careful design. For example, the necessary space, connectivity and integration with other infrastructures could be designed into new streets and subdivisions, while retrofits within existing neighbourhoods must work within the confines of existing systems.

It is also possible that retrofits have occurred but have been studied infrequently. While scholars have recognized the need for research that leads to better real-world solutions among practitioners [64], this does not always occur. For example, the argument could be made that landscape architects, as designers of outdoor spaces, should be involved in researching street infrastructure retrofits; however, the literature review suggests they may not be playing a significant role. The disciplines, fields of study, journal titles and research questions suggest that retrofit research is dominated by engineering and transport planners. A study regarding the research of landscape architecture academics and its impact on practitioners found that while practicing landscape architects most frequently applied scholarly information concerning sustainable design, site engineering, construction technologies, plants and materials, and grading and circulation [65], academic landscape architects were publishing mostly in the area of landscape history, theory, perception, and education [66].

Meanwhile, Ahern [67] questions whether evaluative research is being conducted frequently in the urban design and planning fields. He argues that planners, designers and engineers are not embracing the concept of adaptive planning and design where implemented novel solutions to problems are tested, evaluated and improved in order to advance urban sustainable and resilient form. Practitioners may be concerned that implementing infrastructure that is innovative, but possibly risky and unsuccessful, may associate them with failed projects and possibly liability. Ahern [67] advocates designing these projects as "safe to fail" design experiments so that practitioners feel safe to evaluate their projects and publish the results. However, further research is required to determine the attributes of a "safe to fail" design experiment.

Infrastructure components and corridors studied suggest the composition of green, grey and green-grey infrastructures are beginning to change through retrofits. The changes appear to be occurring in response to two issues:

Firstly, there is concern about excessive storm-water runoff quantity and poor quality within neighborhoods with insufficient storage and filtration capacities. A majority of these studies are being conducted in New World countries with climate zones experiencing significant rainfall (Oceanic and Humid sub-climates), particularly in coastal areas that may be concerned about an increase in the frequency and severity of storm events and tidal rise related to climate change.

Secondly, there is concern about negative impacts of automobile dominated streets, such as their effects on mental and physical health (e.g. [15]) and social isolation [17]. In response, studies are focusing on how to increase pedestrian (and cycling) activities and reduce the use of automobiles, which corresponds to best-practice urban design. Some retrofits continue to follow a conventional segregation strategy, increasing the area and connectivity of cycling and pedestrian over automobile networks [54,58,59]. However, other retrofits follow the more 'radical' shared street strategy being promoted by the urban design and traffic planning literature (e.g. [24]). Papers evaluating the former strategy indicate grey infrastructure in support of automobiles is being reduced in area and/or connectivity in order to reduce speed. For example, in some streets, carriageway lanes are removed or narrowed (e.g. [59]), in others they are being reshaped from linear to curvilinear through chicanes (e.g. [52,55,58,59]). Studies evaluating shared space strategies (e.g. [55]) suggest grey infrastructure is being extended and made more complex to suit the needs of multiple user groups and activities. This is supported by studies that indicate slowing traffic (e.g. through use of Chicanes) is insufficient to increase pedestrian activities in streets [26]. New grey infrastructure components in support of improved pedestrian street habitats are required (e.g. street furniture such as benches, pedestrian scaled lighting, bollards and new street signage), however, supported by green and green-grey components such as plantings, planters, bio-retention facilities, and areas of porous pavement.

Studies indicating green-grey infrastructures are being retrofitted into streets suggest a trend toward increased infrastructure integration. In addition, studies introducing new infrastructures to alter street user behaviours suggest integration of green, grey, and in some cases, green-grey infrastructures. However, the types and quantities existing in streets prior to the retrofits are infrequently described. Therefore, it is difficult to determine the extent to which proportions of green and grey infrastructures have changed within these streets. Retrofit studies indicate that most new infrastructures are grey, with few green components. Furthermore, some of the new green-grey infrastructures (i.e. biofiltration facilities) are replacing green (e.g. trees and grass) within pedestrian-focused areas such as boulevards. This suggests that the trend noted by Tjallingii [29] toward the gradual replacement of green with grey in cities may be continuing with street retrofits. Further study is required to determine the extent to which this is occurring, and its consequences in terms of green infrastructure ecosystem services, particularly in cities undergoing intensification with loss of privately-owned green infrastructure [27].

The review suggests integration or connectivity is lacking in terms of the physical and functional connectivity of green, grey and green-grey components within street networks. For example, most studies of storm water management infrastructure in streets focus on evaluating individual components (e.g. of one biofiltration facility). Few studies evaluate multiple physically and/or functionally connected green-grey infrastructures across streets or catchments, or their relationships with other green and grey components within storm-water networks. This lack of connectivity at the network scale also was apparent in studies evaluating retrofits of multiple components for altering street user behaviours. Few of these studies provided evidence of functional connectivity between components in support of changes in behaviour. Authors argued that changes in behaviour were impeded by a lack of connectivity between street scaled components and networks within the greater community. Further research is required to evaluate the physical and functional connectivity of street infrastructure networks to identify enablers and barriers to their implementation.

The review indicates some retrofits, such as those designed to alter street user behaviors, are temporally integrated, i.e., their green, grey and green-grey infrastructures are being retrofitted at the same time. While some authors argue this may offer benefits over implementing infrastructure types or components at different times (e.g., Reference [31]), further study is required to determine their relative costs and benefits.

Services within the cultural and regulatory landscape service categories and services provided by human and human/nature-based components of street infrastructure retrofits rather than their nature-based components were of particular interest in reviewed studies. Therefore, using an adapted landscape service framework, which recognizes all three agents of service (nature, human, and nature/human) has been suitable. In order to advance healthier infrastructures in support of human and non-human wellbeing, all infrastructure types, components and networks need to be inventoried and analyzed for their contributions. To assist with this process, we propose the use of a landscape services framework (Appendix C) as a tool.

In terms of cultural services, studies indicated that new green, and particularly grey, infrastructures provide aesthetic services. However, the evidence in support of mental or physical health services was less substantiated, largely due to inadequate attention to the socioeconomic conditions within neighbourhoods and/or lack of functional connectivity with infrastructure networks within the wider community. Further research is required to identify enablers and barriers to achieving these services through retrofits in order to advance their implementation. In terms of regulatory services, improved storm-water management, particularly quantity control, has been the focus of many studies, and is being achieved; however, further research is needed to identify ways to improve water quality services beyond the removal of suspended solids. Few studies evaluate services of biofiltration facilities.

One author found that facilities provided environmental education services to some residents. However, she also argued that facilities are not being designed for services beyond storm-water management and this is impeding retrofits. Further research is required to determine design objectives beyond storm-water management, whether they are being achieved, and their importance to implementation. In the context of the many services the literature attributes to green infrastructure in cities, the review suggests that many green infrastructure services that could be provided by street infrastructures, such as microclimate mitigation or wildlife habitat services, are not being studied, or being retrofitted. Further research is required to determine why these services are not being studied and/or retrofitted.

Authors suggested many barriers to implementation and/or success including the high cost of infrastructure implementation, insufficiency of space, limited infrastructure performance, poor network connectivity, lack of sensitivity to local biophysical and socioeconomic conditions, limited policy and program support and faulty research methods. However, only four of these barriers (limited infrastructure performance, lack of network connectivity, and lack of sensitivity to local biophysical and socioeconomic conditions) were supported by evidence within the studies. Further research is required to evaluate if barriers identified by authors are significant determinants of implementation and success and to suggest appropriate ways to overcome such barriers.

5. Conclusions

Green, grey, and green-grey infrastructures provide relevant landscape services within urban landscapes. While there is an opportunity to retrofit existing residential streets with improved infrastructures and services in support of increased environmental and socio-economic benefits, research indicates their transformation is just beginning and barriers to implementation may be substantial. Our systematic review of the existing literature shows that the number of scholarly publications regarding retrofits of urban streets is limited. It is important to acknowledge that this is a limitation of this study. We identified relevant scholarly retrofit studies that were conducted within the targeted regions until 2015; however, more research is required to announce a changing trend with confidence and to advance retrofit implementation and success within streets. Therefore, we suggest performing a follow-up systematic literature review following the same methodology and including papers published from 2016 onwards. Furthermore, other countries with significant areas of suburban, particularly post-World War II residential streets, beyond those targeted, need to be included in future reviews. We found that established ecosystem service frameworks did not adequately recognize all services within street infrastructures. Therefore, we propose an adapted landscape service framework in addition to landscape ecology-based spatial analysis concepts, to advance future research on residential street retrofits.

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Appendix A

Table A1. Disciplines studying street infrastructure categorized according to SCOPUS.

Field Cluster	No. of Papers	Minor Field	No. of Papers	Journal	No. of Papers
Physical Science	8	Environmental engineering	7	Journal of Hydrology	**2**
				Journal of Hydrological Engineering	**2**
				Water Environment Research	**1**
				Journal of Environmental Engineering	**1**
				Ecological Engineering	**1**
		Materials science (Miscellaneous)	**1**	International Journal of Pavement Engineering	**1**
Social Sciences	7	Geography, planning and development	**2**	Landscape and Urban Planning	**2**
		Transportation	**4**	Transportation Research Part D	**1**
				Journal of Transport & Health	**1**
				Accident Analysis and Prevention	**2**
		Health (Social Science)	**1**	Health &Place	**1**

Appendix B

Table B1. Continuum infrastructure element types from green to green-grey to grey.

Infrastructure Categories	Definition	Times Studied
	Green Infrastructure	**9**
Tree	Trees, either stand-alone or in groups	3
Planting	Trees, shrubs, herbaceous plants and/or bulbs	5
Planter	Raised man-made structure with planted trees, shrubs, herbaceous plants or bulbs	1
	Green-Grey Infrastructure	**9**
Bioretention areas	Facilities that store, infiltrate or treat stormwater runoff	7
Permeable pavements	Paved surfaces that infiltrate stormwater runoff	2
	Grey Infrastructure	**27**
Chicane	Elements that slow down traffic including street narrowing, changing streets from two to one-way streets, bump-outs, build-outs, raised tables, bollards, raised centre medium	8
Shared space/street	Mixed-use area shared by different street users with no sign or spatial elements that communicate it is to be used for vehicle, pedestrian or cyclist activities only.	1
Sidewalk	Linear pathway exclusively for pedestrian use	2

Pedestrian crossing	Street crossing points delineated by road marking, signage, and/or pedestrian refuges	2
Street furniture	All street furniture (includes lighting, bike racks, art)	6
Cycle lane	Pathway exclusively for bicycle use	3
Novel pavements	New types of pavements that are not shared spaces	1
Street signage	Painted symbols, beacons, flashing lights and placards	4

Appendix C

Table C1. Street retrofit infrastructure landscape services.

Landscape Service Category	Landscape Service Sub-Category	Literature-based Street-specific Landscape Service	Green Service Infra-structure	Green-Grey Service Infra-structure	Grey Service Infra-structure	Authors
Cultural Services						
Nature-Based Cultural Services						
	Aesthetics and inspiration	x	x	x	x	x
	Recreation; mental/ physical health	x	x	x	x	x
	Tourism	x	x	x	x	x
	Spiritual experience; sense of place	x	x	x	x	x
Human-based Cultural Services (1 Services)						
	Aesthetics and inspiration	***Improved street aesthetics***			***Street furniture, shared surfaces, planting***	***Adams and Cavill, 2015 [53]***
	Recreation and mental and physical health	***Improved pedestrian habitat/movement***				
		Improved pedestrian habitat/movement			***Chicane, street signage, planters, bike racks***	***Curl et al., 2015 [55]***
	Tourism	x	x	x	x	x
	Spiritual experience; sense of place	x	x	x	x	x
Nature/Human-based Cultural Services (4 Services)						
	Aesthetics and inspiration	***Improved street aesthetics***		***Cycleway, sidewalk, street furniture, plantings;***		***Coulson et al. 2011 [54]***
		Improved street aesthetics				***Charlton et al. 2010 [58]***
	Recreation and mental and physical health	***Improved pedestrian habitat/movement***		***Trees, plantings, street signage or removal of, cycle lane, pedestrian crossing, chicane***		***Mackie et al. 2013 [59]***
		Feelings of connectedness to nature		Bioretention area		Church 2015 [48]
		Improved physical activity; reduced automobile use for transport; improved feelings of safety		Cycleway, sidewalk, street furniture, plantings		Coulson et al. 2011 [54]
		Improved		Trees,		Charlton et

	pedestrian/cyclist perception of physical health/safety		plantings, street signage or removal of, cycle lane, pedestrian crossing, chicane		al. 2010 [58]; Mackie et al. 2013 [59]
Tourism	x	x	x	x	x
Spiritual experience; sense of place	x	x	x	x	x
Education (MEA 2005)	***Knowledge/ Appreciation of street stormwater management***		***Bioretention area***		***Church 2015 [48]***
Regulating Services					
Nature-based Regulating Services					
Air quality regulation	Improved air quality	x	x	Sidewalks, street furniture, trees, street signage, Chicane, planting	Shu et al., 2014 [52]
Climate regulation	x	x	x	x	x
Carbon sequestration and storage	x	x	x	x	x
Moderation of extreme events	x	x	x	x	x
Waste water treatment	x	x	x	x	x
Erosion, soil and fertility protection	x	x	x	x	x
Pollination	x	x	x	x	x
Biological control	x	x	x	x	x
Human-based Regulating Services					
None of the above	x	x	x	x	x
Nature/Human-based Regulating Services					
Air quality regulation	x	x	x	x	x
Climate regulation	x	x	x	x	x
Carbon sequestration and storage	x	x	x	x	x
Moderation of extreme events	x	x	x	x	x
Waste water treatment	***Infiltration of water***		***Permeable pavement***		***Brown and Borst 2014 [46]***
	Infiltration of water, filtration of suspended solids/heavy metals with variable removal of phosphorus, not nitrogen		***Bioretention area***		***Hatt et al. 2009 [57]***
	Infiltration/Retention of water runoff, phosphorus,		***Bioretention area***		***Chapman and Horner***

	dissolved copper, motor oil				***2010 [47]***
	Infiltration of water		***Bioretention area***		***Schlea et al. 2014 [51]***
	Infiltration of water; filtration of phosphorus, suspended solids, copper, lead and zinc.		***Bioretention areas, permeable pavement***		***Page et al. 2014 [50]***
	Infiltration of water runoff				***Page et al. 2015a [31]***
	Filtration of pollutants		***Suspended pavement systems***		***Page et al. 2015b [49]***
Erosion, soil and fertility protection	x	x	x	x	x
Pollination	x	x	x	x	x
Biological control	x	x	x	x	x
Provisioning Services					
Nature-based Provisioning Services					
Food	x	x	x	x	x
Fresh water	x	x	x	x	x
Raw materials	x	x	x	x	x
Medicinal resources	x	x	x	x	x
Ornamental species and/or resources	x	x	x	x	x
Human-based Provisioning Services					
None of the above	x	x	x	x	x
Nature/Human-based Provisioning Services					
None of the above	x	x	x	x	x
Habitat or Supporting Services					
Nature-based Habitat or Supporting Services					
Habitat for species	x	x	x	x	x
Maintenance of genetic diversity	x	x	x	x	x
Human-based Habitat or Supporting Services					
Reduced cost/Improved ease of service provision	***Increased access to utilities; Reduced cost/ increased infrastructure replacement speed***			***Novel pavement (removable)***	***De Larrard et al. 2013 [56]***
Nature/Human-based Habitat or Supporting Services					
None of the above	x	x	x	x	x

References

1. Sauter, D.; Huettenmoser, M. Liveable streets and social inclusion. *Urban Des. Int.* **2008**, *13*, 67–79, doi:10.1057/udi.2008.15.
2. De Vries, S.; van Dillen, S.M.; Groenewegen, P.P.; Spreeuwenberg, P. Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Soc. Sci. Med.* **2013**, *94*, 26–33, doi:10.1016/j.socscimed.2013.06.030.
3. Watson, G.B.; Kessler, L. Small Changes—Big Gains: Transforming the Public and Communal Open Spaces in Rundown Neighbourhoods. *J. Urban Design* **2013**, *18*, 565–582, doi:10.1080/13574809.2013.824368.

4. Wolch, J.R.; Byrne, J.; Newell, J.P. Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landsc. Urban Plan.* **2014**, *125*, 234–244, doi:10.1016/j.landurbplan.2014.01.017.
5. Klemm, W.; Heusinkveld, B.G.; Lenzholzer, S.; Jacobs, M.H.; Van Hove, B. Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. *Build. Environ.* **2015**, *83*, 120–128, doi:10.1016/j.buildenv.2014.05.013.
6. Nowak, D.J.; Crane, D.E.; Stevens, J.C. Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Green.* **2006**, *4*, 115–123, doi:10.1016/j.ufug.2006.01.007.
7. Demuzere, M.; Orru, K.; Heidrich, O.; Olazabal, E.; Geneletti, D.; Orru, H.; Bhave, A.G.; Mittal, N.; Feliu, E.; Faehnle, M. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *J. Environ. Manag.* **2014**, *146*, 107–115, doi:10.1016/j.jenvman.2014.07.025.
8. Fernández-Juricic, E. Avifaunal Use of Wooded Streets in an Urban Landscape. *Conserv. Biol.* **2000**, *14*, 513–521, doi:10.1046/j.1523-1739.2000.98600.x.
9. Keeley, M.; Koburger, A.; Dolowitz, D.P.; Medearis, D.; Nickel, D.; Shuster, W. Perspectives on the Use of Green Infrastructure for Stormwater Management in Cleveland and Milwaukee. *Environ. Manag.* **2013**, *51*, 1093–1108, doi:10.1007/s00267-013-0032-x.
10. Southworth, M.; Ben-Joseph, E. *Streets and the Shaping of Towns and Cities*; Island Press: Washington, DC, USA, 2003; pp. 17–42.
11. Newman, P.W.G.; Kenworthy, J.R. The land use—transport connection. *Land Use Policy* **1996**, *13*, 1–22, doi:10.1016/0264-8377(95)00027-5.
12. Ben-Joseph, E. Changing the Residential Street Scene: Adapting the shared street (Woonerf) Concept to the Suburban Environment. *J. Am. Plan. Assoc.* **1995**, *61*, 504–515, doi:10.1080/01944369508975661.
13. Southworth, M.; Owens, P.M. The Evolving Metropolis: Studies of Community, Neighborhood, and Street Form at the Urban Edge. *J. Am. Plan. Assoc.* **1993**, *59*, 271–287, doi:10.1080/01944369308975880.
14. Burton, E.; Jenks, M.; Williams, K. *Achieving Sustainable Urban Form*; Routledge: New York, 2013.
15. Dumbaugh, E.; Rae, R. Safe Urban Form: Revisiting the Relationship between Community Design and Traffic Safety. *J. Am. Plan. Assoc.* **2009**, *75*, 309–329, doi:10.1080/01944360902950349.
16. Garceau, T.; Atkinson-Palombo, C.; Garrick, N.; Outlaw, J.; McCahill, C.; Ahangari, H. Evaluating selected costs of automobile-oriented transportation systems from a sustainability perspective. *Research in Transportation Business & Management* **2013**, *7*, 43–53, doi:10.1016/j.rtbm.2013.02.002.
17. Dobson, J.; Sipe, N. *Unsettling suburbia- The new landscape of oil and mortgage vulnerability in Australian cities*; Griffith University: Brisbane, 2008.
18. Cervero, R.; Murakami, J. Effects of Built Environments on Vehicle Miles Traveled: Evidence from 370 US Urbanized Areas. *Environ. Plan. A* **2010**, *42*, 400–418, doi:10.1068/a4236.
19. Dulal, H.B.; Brodnig, G.; Onoriose, C.G. Climate change mitigation in the transport sector through urban planning: A review. *Habitat Int.* **2011**, *35*, 494–500, doi:10.1016/j.habitatint.2011.02.001.
20. Kim, D.-W.; Deo, R.C.; Chung, J.-H.; Lee, J.-S. Projection of heat wave mortality related to climate change in Korea. *Nat. Hazards* **2015**, *80*, 623–637, doi:10.1007/s11069-015-1987-0.
21. Liu, W.; Chen, W.; Peng, C. Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study. *Ecol. Model.* **2014**, *291*, 6–14, doi:10.1016/j.ecolmodel.2014.07.012.
22. Malaviya, P.; Sharma, R.; Sharma, P.K. Rain Gardens as Stormwater Management Tool. In *Sustainable Green Technologies for Environmental Management*; Shah, S., Venkatramanan, V., Prasad, R., Eds.; Springer: Singapore, 2019; pp. 141–166.
23. Dorsey, J.W. Brownfields and greenfields: The intersection of sustainable development and environmental stewardship. *Environ. Pract.* **2003**, *5*, 69–76.
24. Karndacharuk, A.; Wilson, D.J.; Dunn, R. A Review of the Evolution of Shared (Street) Space Concepts in Urban Environments. *Transp. Rev.* **2014**, *34*, 190–220, doi:10.1080/01441647.2014.893038.
25. Zalewski, A.; Kempa, J. Traffic Calming as a Comprehensive Solution Improving Traffic Road Safety. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *471*, 062035, doi:10.1088/1757-899x/471/6/062035.
26. Biddulph, M. Radical streets? The impact of innovative street designs on liveability and activity in residential areas. *Urban Des. Int.* **2012**, *17*, 178–205, doi:10.1057/udi.2012.13.
27. Haaland, C.; van den Bosch, C.K. Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban For. Urban Green.* **2015**, *14*, 760–771, doi:10.1016/j.ufug.2015.07.009.

28. Ahern, J. Urban landscape sustainability and resilience: The promise and challenges of integrating ecology with urban planning and design. *Landsc. Ecol.* **2013**, *28*, 1203–1212, doi:10.1007/s10980-012-9799-z.
29. Tjallingii, S. Green and Red: Enemies or Allies? The Utrecht Experience with Green Structure Planning. *Built Environ.* **2003**, *29*, 107–116, doi:10.2148/benv.29.2.107.54466.
30. Wise, S. Green infrastructure rising. *Planning* **2008**, *74*, 14–19.
31. Page, J.L.; Winston, R.J.; Mayes, D.B.; Perrin, C.; Hunt, W.F. Retrofitting with innovative stormwater control measures: Hydrologic mitigation of impervious cover in the municipal right-of-way. *J. Hydrol.* **2015**, *527*, 923–932, doi:10.1016/j.jhydrol.2015.04.046.
32. Boyle, C.; Gamage, G.B.; Burns, B.; Fassman-Beck, E.; Knight-Lenihan, S.; Schwendenmann, L.; Thresher, W. *Greening Cities: A review of Green Infrastructure*; University of Auckland: Auckland, New Zealand, 2014.
33. Gough, D.; Oliver, S.; Thomas, J. *An introduction to Systematic Reviews*; Sage: London, UK, 2012.
34. Forsyth, A. Defining Suburbs. *J. Plan. Lit.* **2012**, *27*, 270–281, doi:10.1177/0885412212448101.
35. Sallis, J.F.; Spoon, C.; Cavill, N.; Engelberg, J.K.; Gebel, K.; Parker, M.; Thornton, C.M.; Lou, D.; Wilson, A.L.; Cutter, C.L.; et al. Co-benefits of designing communities for active living: An exploration of literature. *Int. J. Behav. Nutr. Phys. Activity* **2015**, *12*, 30, doi:10.1186/s12966-015-0188-2.
36. Petticrew, M.; Roberts, H. *Systematic Reviews in the Social Sciences: A Practical Guide*; Blackwell: Malden, MA, USA, 2006.
37. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. The PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine* **2009**, *6*, e1000097, doi:10.1371/journal.pmed.1000097.
38. Trewartha, G.T.; Horn, L.H. *An Introduction to Climate*; McGraw-Hill: New York, NY, USA, 1980.
39. Benedict, M.A.; McMahon, E.T. *Green Infrastructure: Linking Landscapes and Communities*; Island Press: Washington, DC, USA, 2006.
40. EPA. What Is Green Infrastructure? Available online: https://www.epa.gov/green-infrastructure/what-green-infrastructure (accessed on 16 March 2017).
41. Tzoulas, K.; Korpela, K.; Venn, S.; Yli-Pelkonen, V.; Kaźmierczak, A.; Niemela, J.; James, P. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landsc. Urban Plan.* **2007**, *81*, 167–178, doi:10.1016/j.landurbplan.2007.02.001.
42. TEEB. TEEB Manual for Cities: Ecosystem Services in Urban Management. Available online: http://www.teebweb.org/publication/teeb-manual-for-cities-ecosystem-services-in-urban-management/ (accessed on 17 January 2017).
43. Termorshuizen, J.W.; Opdam, P. Landscape services as a bridge between landscape ecology and sustainable development. *Landsc. Ecol.* **2009**, *24*, 1037–1052, doi:10.1007/s10980-008-9314-8.
44. Hansen, R.; Rall, E. *Green Surge—Analytical Framework Milestone 34: Overview of Analytical Framework, Selected Cases and Planning Documents*; TU Munich: Munich, Germany, 2014.
45. Peel, M.C.; Finlayson, B.L.; Mcmahon, T.A. Updated world map of the Köppen-Geiger climate classification. *Hydrol. Earth Syst. Sci. Discuss.* **2007**, *11*, 1633–1644.
46. Brown, R.A.; Borst, M. Evaluation of Surface and Subsurface Processes in Permeable Pavement Infiltration Trenches. *J. Hydrol. Eng.* **2014**, *20*, 04014041–04014041 - 04014041-04014012.
47. Chapman, C.; Horner, R.R. Performance Assessment of a Street-Drainage Bioretention System. *Water Environ. Res.* **2010**, *82*, 109–119.
48. Church, S.P. Exploring Green Streets and rain gardens as instances of small scale nature and environmental learning tools. *Landsc. Urban Plan.* **2014**, *134*, 229–240, doi:10.1016/j.landurbplan.2014.10.021.
49. Page, J.L.; Winston, R.J.; Hunt Iii, W.F. Soils beneath suspended pavements: An opportunity for stormwater control and treatment. *Ecol. Eng.* **2015**, *82*, 40–48, doi:10.1016/j.ecoleng.2015.04.060.
50. Page, J.L.; Winston, R.J.; Mayes, D.B.; Perrin, C.A.; Hunt Iii, W.F. Retrofitting Residential Streets with Stormwater Control Measures over Sandy Soils for Water Quality Improvement at the Catchment Scale. *J. Environ. Eng.* **2014**, *141*, 04014076, doi:10.1061/(ASCE)EE.
51. Schlea, D.; Martin, J.F.; Ward, A.D.; Brown, L.C.; Suter, S.A. Performance and Water Table Responses of Retrofit Rain Gardens. *J. Hydrol. Eng.* **2014**, *19*, 05014002, doi:10.1061/(ASCE)HE.
52. Shu, S.; Quiros, D.C.; Wang, R.; Zhu, Y. Changes of street use and on-road air quality before and after complete street retrofit: An exploratory case study in Santa Monica, California. *Transp. Res. Part D Transp. Environ.* **2014**, *32*, 387–396, doi:10.1016/j.trd.2014.08.024.

53. Adams, E.J.; Cavill, N. Engaging communities in changing the environment to promote transport-related walking: Evaluation of route use in the 'Fitter for Walking' project. *J. Transp. Health* **2015**, *2*, 580–594, doi:10.1016/j.jth.2015.09.002.
54. Coulson, J.C.; Fox, K.R.; Lawlor, D.A.; Trayers, T. Residents' diverse perspectives of the impact of neighbourhood renewal on quality of life and physical activity engagement: Improvements but unresolved issues. *Health Place* **2011**, *17*, 300–310, doi:10.1016/j.healthplace.2010.11.003.
55. Curl, A.; Ward Thompson, C.; Aspinall, P. The effectiveness of 'shared space' residential street interventions on self-reported activity levels and quality of life for older people. *Landsc. Urban Plan.* **2015**, *139*, 117–125, doi:10.1016/j.landurbplan.2015.02.019.
56. De Larrard, F.; Sedran, T.; Balay, J.-M. Removable urban pavements: An innovative, sustainable technology. *Int. J. Pavement Eng.* **2013**, *14*, 1–11, doi:10.1080/10298436.2011.634912.
57. Hatt, B.E.; Fletcher, T.D.; Deletic, A. Hydrologic and pollutant removal performance of stormwater biofiltration systems at the field scale. *J. Hydrol.* **2009**, *365*, 310–321, doi:10.1016/j.jhydrol.2008.12.001.
58. Charlton, S.G.; Mackie, H.W.; Baas, P.H.; Hay, K.; Menezes, M.; Dixon, C. Using endemic road features to create self-explaining roads and reduce vehicle speeds. *Accid. Anal. Prev.* **2010**, *42*, 1989–1998, doi:10.1016/j.aap.2010.06.006.
59. Mackie, H.W.; Charlton, S.G.; Baas, P.H.; Villasenor, P.C. Road user behaviour changes following a self-explaining roads intervention. *Accid. Anal. Prev.* **2013**, *50*, 742–750, doi:10.1016/j.aap.2012.06.026.
60. Davies, C.; MacFarlane, R.; McGloin, C.; Roe, M. *Green Infrastructure Planning Guide Project. Final Report*; NECF: Annfield Plain, UK, 2006.
61. Forman, R.T. *Land Mosaics: The Ecology of Landscapes and Regions*; Cambridge University Press: Cambridge, UK, 1995.
62. Fagerholm, N.; Käyhkö, N.; Ndumbaro, F.; Khamis, M. Community stakeholders' knowledge in landscape assessments—Mapping indicators for landscape services. *Ecological Indicators* **2012**, *18*, 421–433, doi:10.1016/j.ecolind.2011.12.004.
63. Millennium Ecosystem Assessment (MEA). *Ecosystems and Human Well-being: Synthesis*; Island Press: Washington, DC, USA, 2005.
64. Clark, W.C.; Dickson, N.M. Sustainability science: The emerging research program. *Proc. Natl. Acad. Sci.* **2003**, *100*, 8059–8061, doi:10.1073/pnas.1231333100.
65. Chen, Z. The Role of Research in Landscape Architecture Practice. Ph.D. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, 2013.
66. Milburn, L.-A.S.; Brown, R.D. Research productivity and utilization in landscape architecture. *Landsc. Urban Plan.* **2016**, *147*, 71–77, doi:10.1016/j.landurbplan.2015.11.005.
67. Ahern, J. From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. *Landsc. Urban Plan.* **2011**, *100*, 341–343, doi:10.1016/j.landurbplan.2011.02.021.