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A systematic review of the scientific literature on the theme of multi-functional streets

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Abstract. Cities consist of 20-30% streets, a gigantic infrastructure that must be maintained and developed. As such, they have the potential to contribute to tackling contemporary challenges as the increasing urbanization and climate change which place higher demands on urban environments, from quality of life, health and safety to environmental sustainability. Multifunctional streets are introduced as an answer to these challenges, as they can fulfil this multitude of functions. This paper presents a state-of-the-art, quantitative systematic review of scientific literature on the theme of multifunctional streets. Scientific papers were filtered from Web of Science and Scopus. Only scientific papers of the last 10 years were included. We will first present a survey of the field and then focus on the empirical papers that help us identify the physical factors which have been proven to support and improve the different functions of streets, from the social and ecologic to the economic and technical. The empirical studies represent 24% of the scientific papers selected, where the social function is the one most frequently studied, followed by the ecologic and the economic function. Within the social function the empirical papers in relation to health (39%) and safety (21%) dominate, followed by the ones studying liveability (9%). We will focus on empirical studies on the themes of Liveability and Safety, two important variables of the Social function, interrelating yet often conflicting.

1. Introduction
Cities consist of 20-30% streets, a gigantic infrastructure that must be maintained and developed. As such, they have the potential to contribute to tackling contemporary challenges as the increasing urbanization and climate change which place higher demands on urban environments, from quality of life, health and safety to environmental sustainability. Multifunctional streets are introduced as an answer to these challenges, as they can fulfil this multitude of functions; they are not only traffic infrastructures, but also lively and inclusive public places, carriers of economic development, ecological corridors supporting ecosystem services and lines of technical infrastructures including street and traffic lighting, electrical power, signalization etc. This paper presents a state-of-the-art, quantitative systematic review of scientific literature on the theme of multifunctional streets. It is part of a 3-year research project (2019-2021) named: "Smart streets" (Smarta gator) led by Alexander Ståhle (KTH Royal Institute of Technology) and financed by Vinnova (Swedish governmental agency for Innovation systems). The research project aims to develop a Street Multifunctionality Index (Gatufunktionsindex) to assess how existing and designed streets combine five different street functions - Social, Ecologic, Economic, Technical and Traffic - and also produce design guidelines for the design and planning of future multifunctional streets, either in new infrastructure or via retrofits. Within this project, the aim of

the literature review is twofold: first, to assess the degree in which the multifunctionality of streets is addressed in recent literature and provide an overview of the field by identifying where the general literature on the subject is trending, which are the recurrent issues studied, which are the clusters of themes emerging, what themes are missing or being understudied; second, since an end product of the research project is to provide guidelines for urban design and planning practice, the review aims to identify the physical factors which have been empirically proven to support the different street functions, and especially those which support multiple functions. The second aim is pursued through focused thematic reviews, which complement the general overview of the field.

This paper will first shortly present the survey of the field. Then, it will present the thematic reviews on the themes of Liveability and Safety, two important variables of the Social function, interrelating yet often conflicting. The parallel focused reviews are particularly interesting as they bring forward the potentials and at the same time challenges of the multifunctionality concept and its potential practical application in future designs and retrofits. Multifunctionality implies the combination of street functions, which are nonetheless often conflicting. A case in point is the liveability-safety combination which will be presented here.

2. Review method

A first qualitative search in scientific literature, to set up the criteria for the systematic review, showed that there is no generally used term to describe multifunctional streets. Different terms are used depending on the geographical context. In the USA the term used is "Complete streets" and is associated with the Complete streets policy to create multimodal types of streets that include all modes of travel (e.g. private cars, public transport, walking and cycling) in an aim to promote active travel, walking and cycling. In Australia the term used is "Smart roads", while "City boulevards" and "Liveable streets" are often used in the European context. In all cases the focus is placed on multimodality and the gradual increase of street space allocated to pedestrians and cyclists, with the parallel discouraging of car use. All the other functions except transport (social, economic, ecologic, technical) are either missing or separately studied. An exception is the "High streets", an older concept developed in the UK, where the main function addressed is the economic. A broader term coming closer to addressing street multifunctionality is "Green streets", where the ecologic function is dominant, but the transport and social function are also addressed. In conclusion, the preliminary indication was that the multifunctionality of the streets is not a topic which has been studied a lot in scientific literature. Multimodality on the other hand appears to be a well-established subject especially in transport studies, where also topics related to future mobility (Autonomous vehicles, Vehicular ad-hoc networks VANET, Intelligent Transport Systems etc) are growing in interest.

All different identified terms were used to define the search keywords of the systematic review. The search script was as follows: [[(Multifunctional OR Smart OR Green OR Complete OR Multimodal) AND (Road OR Street)] OR (City boulevard) OR (Livable street) OR (Sustainable street) OR (High street)], using truncation. The aim was to broaden the search enough to include literature from all geographic regions, and so escape the bias of using only, for example, US-based research. The databases used were Web of Science and Scopus to control for the quality of scientific papers and the search was done in Title, Abstract, Keywords [1]. Articles in scientific journals, papers in conference proceedings, books and book chapters were included in the search, to provide a more comprehensive review. The search was limited to the last 10 years (2009-2019), in order to focus on the most recent developments in the related fields of research and since the guidelines and conclusions need to be relevant for current and future planning. Although the time frame mostly used for the state-of-the-art reviews is 5 years, we decided to start with an expanded search of 10 years, since literature in urban design and planning is not so quickly updated as in other scientific fields.

The method followed was a series of screenings [2]. At first, 3782 unique scientific papers were filtered from Web of Science and Scopus. A screening of the titles followed based on the general relevance of the paper, which resulted to a shortlist of 1956 abstracts to be reviewed. The abstracts were classified depending on 1. the term used (figure 1), 2. street functions they addressed (figure 2) 3. type

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of study (figure 3), 4. geographical context. In the case of empirical studies, also the main societal, environmental or economical effect (e.g. health, microclimate, walkability) was recorded (figure 4). This method aimed to, first, systematically survey the field and then prepare sets of full papers to be synthesized in thematically focused reviews.

3. Results

3.1. Survey of the field

Out of the 1956 screened abstracts, 784 were assessed as irrelevant to the focus of the review (e.g. large-scale freight, route planning apps, smart tolls and pricing, in-vehicle support), resulting to a final set of 1172 full papers to be included in the survey of the field and eligible for further reading. Our preliminary observation that the multifunctionality of the streets has not been addressed adequately in scientific literature was confirmed. The notion of street multifunctionality seems to be rather new and although it is sometimes implied or presented as a general vision for future streets, it has not been systematically studied (figure 1). Only in papers from ecology the term multifunctionality is used to describe green areas, including green streets, where the technical, ecological, social and economic functions are intentionally combined.

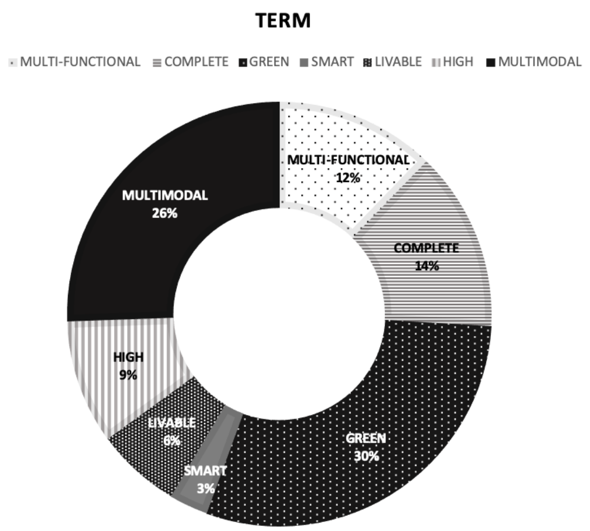

Figure 1. Terms used in the 1172 papers

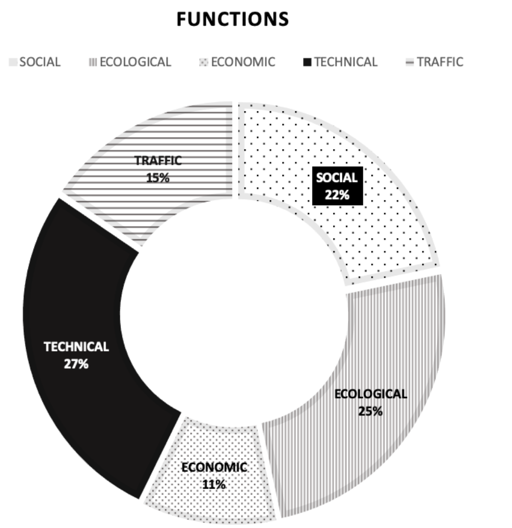

Figure 2. Functions in focus in 1172 papers

As was the initial indication, the different functions are addressed separately in literature (figure 2). The technical function appears dominant because it includes numerous studies focusing on street elements, as for example smart street lighting and smart materials (244 papers). Without these studies, the technical function would drop from 27% to 12%. The ecological and social function are often addressed in literature, the latter mostly in empirical studies, while the economic function remains understudied in comparison and is mostly represented by studies on UK's High streets. The traffic function is mostly represented by papers on multimodality (138 papers).

In relation to the type of study, we identify two main clusters of papers: one focusing on street design, usually referring to case studies (385 papers) and one of empirical studies focusing on streets' spatial, environmental and societal effects (311 papers) (figure 3). A third cluster of 244 papers focuses on smart street elements (e.g. street lighting). Further, 123 papers refer to related policies (e.g. Complete streets, Safe roads to schools); 78 refer to or introduce indices and scores (e.g. Smart Street Walk Score, Pedestrian Safety Index, Livability Index); 69 refer to future mobility systems (self-driving vehicles, VANET); while the rest 68 are general texts discussing ideas, visions and principles.

Of all the empirical studies (311 papers), the social function is most often studied where Health related to physical activity (e.g. active mobility, walkability, bikeability) (88 papers) and Safety (64) dominate, followed by Livability (28) and Security (14) (figure 4). The Ecologic function is also quite highly represented including Microclimate (37 papers) and Air-pollution (36). The Economic function is rather unexplored as already mentioned, and the economic effects of streets as land prices, housing prices and business developments are referred to in only 10 papers. Almost all geographic regions are represented, from USA (26%), Canada (12%), to different European countries (21%), China, Japan, India and other Asian countries (29%), Australia and New Zealand (8%), South American (2%) and African countries (3%). In the empirical studies a lot of attention is given to the different age groups, from small children, to youth, young adults, adults, middle-aged and elderly. Gender, physical disabilities, economic status and ethnicity are represented but to a much lesser degree.

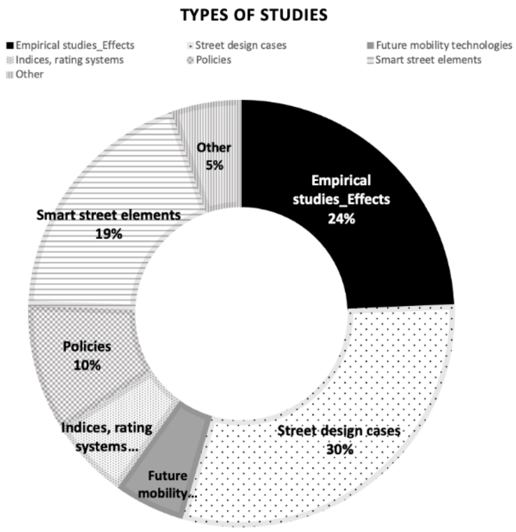

Figure 3. Types of studies in the 1172 papers

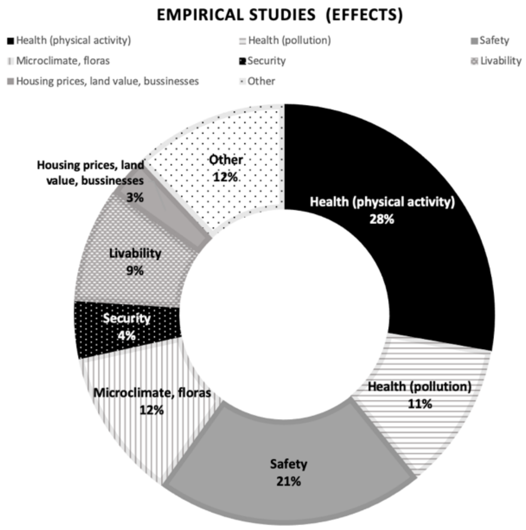

Figure 4. Themes in the 311 empirical papers

3.2. Focused reviews of empirical studies. Liveability and Safety

As already stated, a central aim of the review is to identify the physical factors which have been empirically proven to support not only separate street functions, but street multifunctionality. Thus, particular focus is placed on physical factors that support more than one street functions. As an example, we focus on physical factors which promote *Liveability* and *Safety*, two aspects of the social function, interrelating but often conflicting. For liveability, out of the 28 selected papers, 4 full texts were found irrelevant, 2 were missing and 2 did not study specific physical factors. For each of the remaining 20 papers [3] included in the focused review, the physical factors that were found to improve liveability are recorded and grouped. Next, the papers where each factor was mentioned in support of liveability were counted and the factors were ranked based on this count.

The empirical studies used both qualitative and quantitative and methods, including site observations, surveys, interviews, mappings, spatial analysis, as well as statistical analysis. Out of the 20 empirical studies, 45 physical factors were identified. 39 are related to the physical space of the individual street and 6 are related to the context or the network of streets. Throughout the 20 papers, liveability is strongly related to walkability and liveliness, meaning the presence of people on the streets as much and as long as possible, engaging in different activities (walking, sitting, dining, biking, playing, shopping etc). Connectivity and accessibility to diverse services and uses, safety, attractiveness and sense of place are also related qualities that increase liveability. Lastly, equal access to all people, no matter the age or mobility impairments (e.g. people in wheelchairs, visually impaired, people with strollers, elderly, children, injured) is high on the list of necessary factors for achieving liveability. What is also discussed is not only the liveability of the street based on different parameters, but also the perception of liveability from the people living and using the streets. In that sense, qualities such as safety have a two-way relationship with liveability because the feeling of safety increases the perception of liveability, but also high liveability means liveliness and 24/7 use of the street, which in turn increases the sense of safety.

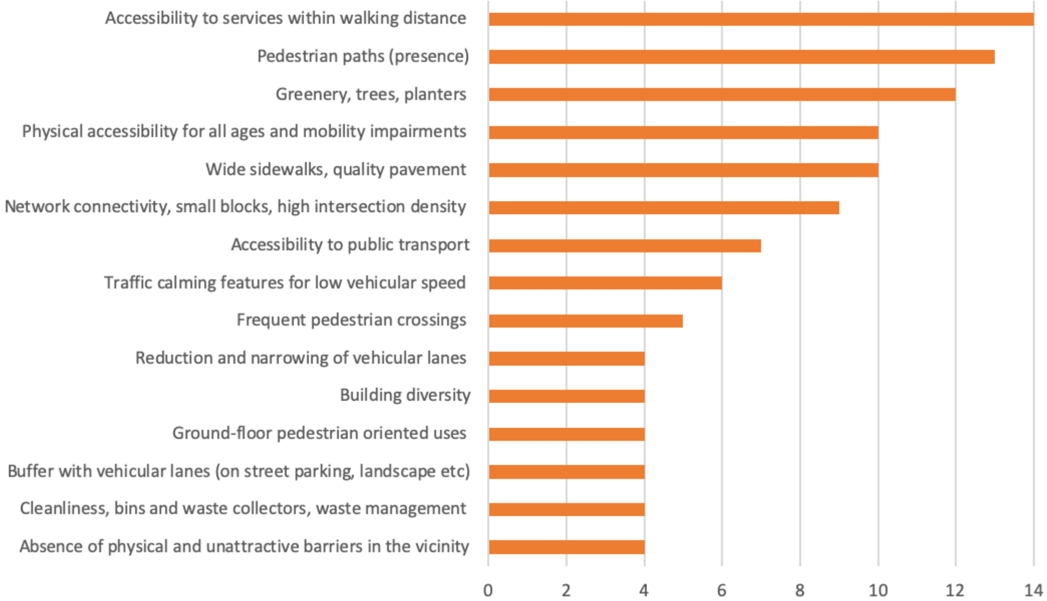

Figure 5. Ranking of physical factors that support Liveability based on the amount of empirical papers that have found them significant.

Figure 5 shows the ranking of the physical factors that are used in more than 4 papers, both related to context and to individual streets. The ranking is based only on the amount of papers that have studied each factor and have found it relevant or significant for liveability. It does not take into account the relative importance (e.g. statistical correlation) of each factor in comparison to other factors, as the variables that are compared in each paper vary, and so does the dependent variable and the method of assessment, correlation or association.

In similar ways as described above for liveability, for Safety 64 full papers were assessed, but 26 were found irrelevant (e.g. simulation and user behavior modelling, security, traffic signals, lighting) and did not refer to physical factors. Out of the 38 final papers, 28 physical factors were identified. Since often different papers focused on different road users (i.e. pedestrian safety, cyclist safety, driver safety), this information was also documented. Many papers on multimodality are included in this review and thus most studies focus on pedestrian and cyclist safety, as opposed to driver safety which is usually the focus of broader traffic engineering studies. In addition, the indicator of safety, or more precisely, of unsafety, also varies. A measure of the unsafety of a street can be the number of vehicular crashes, the severity of crashes or the number of fatalities in each street. Apart from vehicle-to-vehicle crashes, vehicle-to-pedestrian or to-bike crashes and bike-to-pedestrian crashes are used to measure pedestrian and cyclists' unsafety. The perception of safety is also studied mostly from pedestrians and cyclist [4].

Figure 6 shows three main categories of physical factors which have been shown to improve pedestrian and cyclist safety. The first category is related to the main cause of unsafety, which is vehicular speed. What is empirically confirmed in most papers is that the lowering of vehicular speed, either by speed limits or by traffic calming features and other physical factors, greatly improves safety. The second category is related to limiting the exposure of vulnerable users to vehicles and assuring their temporal (i.e. short crossing distance) or physical separation (e.g. low traffic volume, sidewalks and separate bike lanes, buffers and barriers, narrow car lanes). The third category is less studied but still identifiable as a separate theme of study. The physical factors of this category are not related to the separation of the different users, but to their safe interaction (e.g. mutual awareness and visibility of road users, legible intersections, crosswalks).

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Interestingly, the thematic review not only extracts the significant physical factors for safety, but also highlights their overlaps and conflicts, something particularly important for their practical application in design. Some factors improve safety for all users, while others are conflicting. For instance, the use of roundabouts instead of regular intersections has been proven to reduce car accidents, but by creating illegible crossings for pedestrians can hinder their safety [5]. Some factors affect the number of crashes, while others the severity of injuries, the number of fatalities or the number of potential conflicts. A case is point is the Proximity to the city center and the Traffic volume [6]. These might be related to increased number of crashes, but their severity and number of fatalities is decreased because they are associated to lower vehicular speed. Other factors improve all indicators of safety, such as Network connectivity [7]. Often the empirical results are also conflicting, such as the impact of the presence of buffers between vehicle lanes and sidewalks (e.g. on-street parking). Such buffers might protect pedestrians by physically separating them [8] but have been reported to increase crashes in uncontrolled crossings, because they decrease mutual visibility and awareness between drivers and pedestrians [9].

Figure 6. Three main categories and ranking of physical factors that support Safety based on the amount of empirical papers that have found them significant.

3.3. Combining functions. Overlaps and conflicts.

The parallel focused reviews of liveability and safety are particularly interesting as they bring forward the potentials and at the same time challenges of the multifunctionality concept and its potential practical application in future designs and retrofits. Multifunctionality implies the combination of street functions, which are nonetheless often conflicting. A case in point is the liveability-safety combination. Although safety and the perception of safety is a necessary factor for achieving liveability, liveable streets also require 24/7 liveliness of the street, active travel, utilitarian and recreational walking and biking, multimodality, diversity of uses, sharing of space, inclusion and meeting of different users, all of which place potential threats to safety, which from a traffic engineering perspective, is related to the separation of users and modes of travel (whether temporal or spatial), rather than their combination. Even the notion of multimodality that is closely related to street liveability, puts pressure on traditional approaches to road safety, let alone the multifunctionality concept which goes even further to include a multitude of functions than mere transport (e.g. seating, resting, shopping, socializing, outdoor eating, strolling, running, recreational walking and biking, meeting, exercising). As the Safety review showed, a main strategy which promotes safety, is the separation of street users, temporal or spatial, and their limited exposure to each other [10]. What emerges is the tension between the desire to increase the active travel modes, like walking and biking, and the overall liveliness of the streets and at the same time ensure the safety of the co-present street users; a safety that is arguably threatened by their exposure to each other. The underlining challenge and question is: How can we have street sharing and co-presence of the different street users and at the same time eliminate the situations of potentially dangerous conflicts that can lead to accidents? On the other hand, the parallel review of empirical papers on liveability and safety also highlighted physical factors which support both and thus have an additive positive effect for street multifunctionality. Cases in point are network connectivity, physical factors which reduce car speeds, wide sidewalks, separate bike lanes, presence of commercial and pedestrian oriented uses, frequent and safe pedestrian crossings, narrow car lanes and short crossing distance.

4. Conclusions and discussion

The systematic review showed that the multifunctionality of the streets as a subject has not been addressed adequately in recent scientific literature. The notion of street multifunctionality seems to be rather new and although it is sometimes implied or presented as a general vision for future streets, it has not been systematically studied. The different street functions are studied separately, with the economic function to be relatively understudied. The ecological and social function are well-studied, with the latter being the dominant theme in empirical studies. What is missing is studies on the combined effects, conflicts or overlaps of the different street functions; an issue especially important as it is both a potential and a challenge for the practical application of the multifunctionality concept.

This need became clearer from the parallel focused reviews of empirical studies on liveability and safety, presented in this paper. Two functions that are necessary for the well-functioning of streets can also be very much conflicting. Physical factors that support one can hinder the other, placing increased pressure for sophisticated design solutions. On the other hand, with such parallel reviews there is also the opportunity to identify physical factors that improve both functions and can be promoted in the design guidelines for multifunctional streets. This idea can be further extended outside the social functions to include more. For example, greenery is not only important for street liveability but a necessary element and a carrier of the ecological function with positive effects on microclimate, tackling air-pollution, supporting urban floras and faunas. In addition, pedestrian oriented uses, such as shops, cafes and restaurants, can support both the social function of the street, with outdoor eating, strolling or shopping, have been proven to increase walkability, and also, they greatly support the economic function. The same goes for network connectivity which, as the empirical studies showed [7], improves both walkability, liveability and safety and has also been associated with the economic development of the street, especially with pedestrian oriented uses (e.g. food, retail) [11].

Lastly, when identifying the physical factors that improve liveability and safety according to the empirical studies, the importance of the context and the physical factors related to that was evident. A case in point is network connectivity and accessibility to services which are the decisive factors for street liveability. However, the role of such contextual effects has not been studied as well as more local street factors in scientific literature. Studies including contextual factors could give input for the application of the multifunctionality concept and the prioritizing of future streets and retrofits, as some streets have greater multifunctionality potential than others based on their location, centrality, accessibility, network connectivity or land uses of their context.

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References

[1] Bettany Saltikov J 2010 *Nursing standard* (Breat Britain:Royal College of Nursing) **24** 51 p 47
Boote D and Beile P 2005 *Educational Researcher* **34** 6 pp 3-15
Crisp B R 2015 *Australian Social Work* **68** 3 pp 284-295.
Pickering C, Grignon J, Steven R, Guitart D, Byrne J 2015 *Studies in Higher Education* **40** 10
[2] Moher D, Liberati A, Tetzlaff J, Altman D G and The PRISMA Group 2009 *PLoS Med* **6** 7
[3] Anderson J K and Ellis J 2014 *J. Public Transportation* **17** 3
Appleyard B 2017 *J. Transport and Health* **5**
Bandarabad A and Shahcheraghi A 2012 *Adv. Env. Biology* **6** 3 pp 1063-67
Choi J, Kim S, Min D, Lee D and Kim S 2015 *J. Advanced Transportation* **50** 1
Conteh F M and Oktay D 2016 *Open House International* **41** 2 pp 23-30
Curl A, Thompson C W and Aspinall P 2015 *Landscape and Urban Planning* **139** pp 117-125
Dumbaugh E and King M 2018 *J. Planning Literature* **33** 4
El-Din R 2015 Int. Trans. J. Eng.Manag. Sci. Tech. **6** 3
Fauzi A F and Aditianata A I 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **123**
Fu B 2013 *Progress of Environ. Sci. Engin.* **1** 4
Hardy D and Hunter B 2017 *Transportation Research Record* **2609** 1
Holzer R and Lockrem Z 2011 *J. Green Building* **6** 3 pp 21-32
Lethco T, Davis A, Weber S and Sanagavarapu S 2009 *Transportation Research Record* **2119**
Li M and Li J 2017 *Urban Transitions Conference* **198** pp 790-801
Mackett R L Achuthan K and Titheridge H 2008 *Urban Design International* **13** 2
Mahmoudi M, Ahmad F and Abbasi B 2015 *Cities* **43** pp 104-14
Marshall W E and McAndrews C 2017 *Transportation Research Record* **2605** 1
Martincigh L and Di Guida M 2016 *TECHNE J. Techn. Archit. Environ* **11** pp180-7
McAndrews C and Marshall W 2018 *J. American Planning Association* **84** 1 pp 33-44
Norouzian-Maleki S, Bell S, Hosseini S, Faizi M 2018 *Urban Forestry and Urban Greening* **35**
O'Connor D M, MacLaughlin P, Angus J and O'Rourke V 2014 *Edulearn14: 6th Int. Conf. on Education and New Learning Technologies*
[4] Lawson A R, Pakrashi V, Ghosh B, Szeto W Y 2013 *Accident Analysis and Prevention* **50** p 499
[5] Marshall W. E 2018 Accident Analysis and Prevention **111** pp 251-265
[6] Marshall W E and Garrick N W 2011 *Accident Analysis and Prevention* **43** pp 769-781
[7] Guo Q, Pei X, Yao D Y and Wong S C 2015 *J. Central South University*, **22** 6 pp 2216-22
Marshall W E and Garrick N W 2011 *Accident Analysis and Prevention* **43** pp 769-781
Marshall W E and Garrick N W 2010 *Urban Design International* **15** 3 pp 133-147
Mecredy G, Janssen I and Pickett W 2012 *Injury Prevention* **18** pp 81-7
[8] Hanson C S, Noland R B and Brown C 2013 *J. Transport Geography* **33** pp 42-53
[9] Congiu T, Sotgiu G, Castiglia P, Azara A, Piana A, Saderi L, Dettori M 2019 Sustainability **11**
[10] Islam M S, Serhiyenko V, Ivan J N, Ravishanker N, Garder P E 2014 *J. Transportation, Safety and Security*, **6** 4 pp 335-355
MacLeod K E, Sanders R L, Griffin A, Cooper J F, Ragland D R 2018 J. Transp. Health **8** p 15
Lawson A R, Pakrashi V, Ghosh B, Szeto W Y, 2013, *Accident Analysis and Prevention* **50** p 499
[11] Scoppa M D and Peponis J 2015 *Environment and Planning B* **42** 2 pp 354-378
Hillier B, Penn A, Hanson J, Grajewski T, Xu J 1993 *Environment and Planning B* **20** pp 29–66