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Pedestrian activities: Enhancing knowledge and visibility of walking and place activities

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PREFACE

This PhD thesis entitled *Pedestrian activities: Enhancing knowledge and visibility of walking and place activities* is submitted in January 2025 to meet the requirements for obtaining the doctoral degree at the "Friedrich List" Faculty of Transport and Traffic Sciences, TUD Dresden University of Technology, Dresden, Germany.

The PhD thesis was supervised and assessed by Prof. Dr.-Ing. Regine Gerike (TU Dresden) and co-assessed by Prof. Dr.-Ing. Vanessa Miriam Carlow (TU Braunschweig).

The thesis is paper-based and consists of the chapters listed in the table of contents, including the chapters for each of the following papers:

Paper 1: Koszowski, Caroline; Wittwer, Rico; Hubrich, Stefan; Gerike, Regine (2024): Perceived importance of context-specific built-environment factors of walking: A new perspective for prioritizing policy measures for promoting walking. *International Journal of Sustainable Transportation*, *18*(3), 275–290. https://doi.org/10.1080/15568318.2023.2301372

Paper 2: Koszowski, Caroline; Hubrich, Stefan; Wittwer, Rico; Gerike, Regine (2024): From trips to stages: a methodology for Generating Stage Information in trip-level Household Travel Surveys. *Transportation*. https://doi.org/10.1007/s11116-024-10567-5

Paper 3: Koszowski, Caroline; Hubrich, Stefan; Wittwer, Rico; Gerike, Regine (under review): Streets as places – characteristics of place activities in the European context with the example of the City of Malmö (Sweden). Under review in *European Journal of Transport and Infrastructure Research*. Preprint. https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-971462

SUMMARY

of the dissertation by Caroline Koszowski, M.Sc.

Pedestrian activities: Enhancing knowledge and visibility of walking and place activities

Walking promotes sustainable urban and transport development and a healthy society. Together with place activities in public spaces (e.g., chatting, outdoor dining), pedestrian activities enhance the livability and vitality of streets. In addition, in Household Travel Surveys (HTS), walking appears consistently as a significant and stable component of urban transport. For these reasons, it is essential to elevate the visibility and understanding of pedestrian activities, both as a driver of urban vitality and as a key element in transport systems.

Despite the multiple benefits of pedestrian activities, significant gaps in knowledge and visibility persist:

- Trip-based HTS, such as the German city-based HTS SrV, collect data on the travel behavior of individuals on their daily trips mainly at the trip level and thus generate trip-based modal-split figures. Working with HTS mobility data, it can be assumed that especially walking stages of intermodal trips are often hidden in trip-level data. This limited visibility of walking in intermodal trips in the data may lead to an underestimation of its importance as a transport mode. This raises the following research questions: How can the visibility of walking stages be increased in HTS? Is it possible to develop a methodology to generate stage information from trip-level HTS? If so, what input data are required?
- Considering the limited visibility of walking stages in intermodal trips, it is equally important to examine how place activities influence and integrate into travel behavior. Place activities can either occur at destinations of trips (e.g., dining outside) or during trips (e.g., waiting at the bus stop). The existing definitions and terminology from the field of HTS only partially cover the mentioned types of place activities. This raises the research question of how these terms and definitions can be harmonized and consistently be linked.
- In addition, extensive studies on place activities from the transport planning perspective and in the European context are still missing. This means that typical key characteristics of place activities, such as their duration, variation across different times of day, and differences by gender and age, as well as correlates of street design, have not yet been adequately investigated. This leads to the research questions: What are the characteristics of place activities in general? How do place activities vary throughout the day? What are the characteristics of place activities by gender and age groups? What are the relationships between street characteristics and place activities?
- There is a lack of knowledge on context-specific determinants that motivate or inhibit walking, which could serve as a bridge between the individual and the street level. This raises the research questions: Which context-specific factors at the neighborhood and streetscape level correlate with leisure and utilitarian walking? Are there differences between frequent and less frequent walkers?

This thesis aims to shed light on the field of pedestrian activities and raise awareness of its importance within the transport planning community. Hence, this thesis presents three papers that collectively adopt a multi-data and multi-method approach to deepen insights into mobility and street user behavior.

Paper 1 identifies context-specific determinants for the frequency of walking for leisure and utilitarian purposes at the individual, neighborhood and street level. The results are representative for German cities with at least 100,000 inhabitants. By using Logistic Regression Models and additional descriptive analysis, the paper focuses on walking as an integral part of pedestrian activities.

Highlights of Paper 1 and main contributions:

- *Identification of context-specific determinants at the individual, neighborhood, and street level.*
- *Provision of representative results for German cities with at least 100,000 inhabitants.*
- *Emphasis on distance as a key determinant for the frequency of utilitarian walking.*
- *Demonstration of a higher relevance of built-environment characteristics for the frequency of leisure walking compared to utilitarian.*

Paper 2 is positioned at the individual level, aiming to develop a new methodology for generating stage information from trip-level HTS for German cities with at least 100,000 inhabitants, specifically focusing on inner-city trips. The methodology is based on two German HTS datasets (SrV 2018 and MiD 2017) and encompasses four steps: (1) calculation of the number of stages of all trips in SrV 2018, (2) estimation of the duration of walking stages in intermodal PT and car trips in MiD 2017 and the transfer to SrV 2018, (3) calculation of the distance of stages in SrV 2018, and (4) calculation of the modal-split figures at the stage level in SrV 2018.

Highlights of Paper 2 and main contributions:

- *Presentation of a "lean" methodology for the generation of stage information from trip-level HTS data.*
- *Calculation of stage-level modal-split estimates by number, duration, and distance for SrV 2018 (inner-city trips in cities with ≥ 100,000 inhabitants).*
- *Enablement of a first direct comparison between modal-split shares at trip level and the estimates at stage level.*
- *Presentation of results for cities with ≥ 500,000 inhabitants: in average more than three out of six stages per day are walked, with a duration of approximately 28 minutes and a distance of two kilometers.*

Paper 3, as an empirical street-level study, contributes to understanding the characteristics of place activities and explores their relationship with street characteristics. To provide a comprehensive analysis of place activities, the study employs descriptive analysis, GIS-based methods, and simple Linear Regressions to examine how streetscape features influence place activities. Based on a case study sample (n = 1,654 observations), the findings offer new insights into the duration, types, postures, and the daily profile of place activities.

Highlights of Paper 3 and main contributions:

- *Provision of a general characterization of place activities within the European context using the case study of the City of Malmö.*
- *Attribution of place activities to the quality of the design of street characteristics (e.g., personalization and permeability of facades/businesses).*
- *Identification of a strong effect of land uses (businesses and gastronomy vs. offices) on the duration, the type, and the daily profile of place activities.*

The presented papers close existing research gaps and address the introduced research questions. Beyond this, a glossary is developed that consolidates all relevant HTS and place-activity terms. This definitional framework aims to support methodological advancements in HTS and facilitates a more precise description of place activities in public spaces.

In conclusion, this thesis underscores the essential role of pedestrian activities in creating livable and sustainable cities. By identifying determinants on walking and place activities, enhancing the visibility of stages in intermodal trips, and providing a comprehensive definitional framework, this thesis establishes a foundation for seamlessly integrating pedestrian activities into transport planning. It equips researchers and practitioners with the knowledge needed to foster human-centered, sustainable urban and transport development.

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LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
BIC	Bayesian Information Criterion
GIS	Geographic Information System
HTS	Household Travel Survey
IPAQ	International Physical Activity Questionnaire
NEWS	Neighborhood Environment Walkability Scale
MiD	Household Travel Survey "Mobility in Germany"
PT	Public transport
RQ	Research questions
SDG	Sustainable Developments Goals
SrV	Household Travel Survey "Mobility in Cities – SrV"
UDQI	Urban Design Quality Index
WHO	World Health Organization
5 Ds	Framework by Ewing and Cervero (2010) that encompasses five dimensions: density, diversity, design, distance to public transport, destination accessibility

1 Introduction

1.1 Motivation

This thesis aims to enhance the visibility and knowledge of pedestrian activities, including walking and place activities. The motivation is twofold. First, walking promotes sustainable urban and transport development and a healthy society. Together with place activities in public spaces (e.g., chatting, outdoor dining), it enhances the livability and vitality of streets. Second, Household Travel Surveys (HTS) consistently highlight walking as a significant and stable component of urban transport. For these reasons, it is essential to elevate the visibility and understanding of pedestrian activities, both as a driver of urban vitality and as a key element in transport systems.

Based on the Sustainable Developments Goals (SDGs) introduced by the United Nations in 2015 (United Nations 2015), sustainable development has become a key political guideline within the European Union (Gerike and Koszowski 2017; Krombach et al. 2024). Transport plays a dual role in this context: on the one hand, it facilitates mobility, enabling social participation; on the other hand, it causes adverse effects across social, economic, and environmental dimensions (Gerike and Koszowski 2017; Krombach et al. 2024; Koszowski et al. 2019a). Therefore, promoting environmentally friendly modes of transport – including public transport (PT), cycling, and walking – is highly relevant for sustainable transport planning. Cycling and walking, as forms of active mobility, together with PT, fulfill nearly all mobility needs (Koszowski et al. 2019a). These modes not only enhance social participation, but are also considered space-efficient and flexible solutions for urban transport systems.

Beyond the promotion of sustainable transport development, from a public health perspective, integrating active mobility into daily mobility routines helps to increase individual physical activity levels. This way, the WHO-recommendation of at least 150 minutes of moderate-intensity aerobic physical activity per week can be achieved more easily (WHO 2018). Positive health benefits are the result, including a lower risk of non-communicable diseases (Guthold et al. 2018).

Although walking offers numerous benefits, it is often underestimated compared to other transport modes that, for example, enjoy greater visibility due to lobbying efforts or political support (Bauer and Dziekan 2019). Pedestrian activities, encompassing both movement on foot and place activities, play a crucial role in urban planning. Their presence in the streetscape enhances the livability of public spaces and contributes to the economic success of cities (Gehl 2010; Gerike et al. 2021b). Lower car traffic speeds allow pedestrians to fully enjoy attractive public spaces and spontaneously engage in place activities, such as chatting or outdoor dining.

Urban streets are contested spaces, as they are often narrow and serve multiple purposes. They accommodate (1) the movement of vehicles and people, (2) place activities on streets, (3) they serve as conduits for media, and (4) have ecological function (see e.g., Schönfeld and Bertolini 2017; Gerike et al. 2021b; Miura et al. 2024). Despite the essential functions of the street, the movement function of streets is often prioritized in urban streets, for example, by providing high Levels of Service for vehicle traffic or integrating cycling infrastructure. As a result, sidewalks are frequently treated as "left-over spaces" (Gerike et al. 2021a) and additional areas for place activities are even more neglected.

Pedestrian activities become visible at the street level through the measurement of pedestrian volume on specific streets. Place activities, on the other hand, can be recorded by mapping their location, number, duration, and type of activity (Mehta 2013). At the individual level, walking is captured as recorded trips in HTS aggregated for specific spatial units. These two levels are interconnected: when data show high shares of walking at the individual level, for example in a specific neighborhood, a higher pedestrian volume can typically be expected on the streets of that neighborhood. Conversely, high pedestrian volumes at the street level often reflect a higher share of walking in individual travel patterns (Koszowski et al. 2024).

Since 1972, the German city-based HTS SrV has been conducted every five years in many German cities and regions and displays travel behavior continuously over time at trip level (Hubrich et al. 2019; Wittwer et al. 2024; Gerike et al. 2020). Figure 1 shows the trip-based modal-split shares by number of East German cities, the so called "SrV-Städtepegel", in a time series (Gerike et al. 2020). It is evident that (monomodal) walking trips represent a constant and reliable parameter in urban transport, accounting for approximately 30 % of all trips. To meet all mobility needs, walking is often combined with PT or other transport modes. When multiple transport modes are used for a single trip, it is referred to as an intermodal trip. Each segment of an intermodal trip is referred to as a stage (Clifton and Muhs 2012; Hubrich et al. 2019; Nobis and Kuhnimhof 2018).

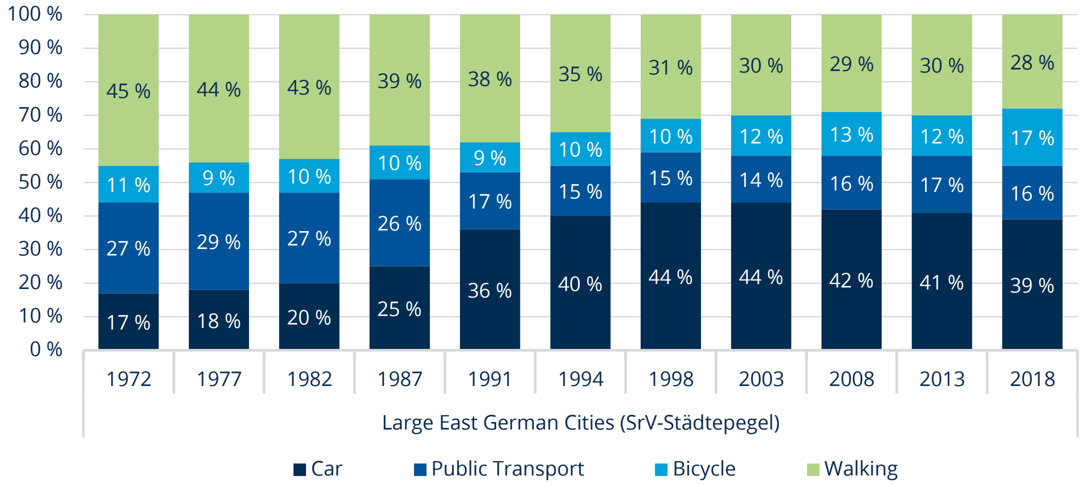


Figure 1: Trip-level modal-split shares by trip number 1972–2018 (Gerike et al. 2020, p. 15)

When working with HTS mobility data, it can be assumed that especially walking stages of intermodal trips are often hidden in trip-level data. This limited visibility of walking in intermodal trips in data may lead to an underestimation of its importance as a transport mode. Building on the limited visibility of walking stages in intermodal trips, it is also important to consider how place activities integrate into travel behavior. Place activities can either occur during trips (e.g., waiting at the bus stop) or at destinations of trips (e.g., dining outside). However, the existing definitions and terminology from the field of HTS only partially cover the mentioned types of place activities.

Despite the multiple benefits of pedestrian activities, significant gaps in knowledge and visibility persist. This thesis aims to shed light on the field of pedestrian activities and raise awareness of its importance within the transport planning community.

The remainder of this thesis is organized as follows: Section 1.2 provides an overview of the research gaps and research questions that form the basis for this thesis. As this is a paper-based thesis, Section 2 summarizes the three papers, highlighting their main results and contributions. Additionally, the main contributions of the papers are outlined when the research questions are addressed. Furthermore, this section introduces a new glossary that bridges the fields of HTS and place activities, aiming to enhance visibility and foster a common understanding of pedestrian activities. Section 3 discusses the main findings of the three papers, reflecting on the methodologies employed and the identified determinants of pedestrian activities. Finally, Section 4 summarizes the key characteristics of the papers and provides an outlook with recommendations for future research.

1.2 Research gaps and research questions

Research gaps arise when content is not yet sufficiently covered or information are insufficient. Overall, there are nine different types of research gaps (Baako et al. 2022; Islam 2024). In this thesis three types of research gaps are identified (Baako et al. 2022; Islam 2024; Miles 2017):

- Knowledge gap: There is a lack of knowledge in literature. Aspects of a specific topic are unexplored or underexplained.
- Methodological gap: Methodological approaches in literature are missing or are not appropriate and need development for transferability.
- Empirical gap: Research findings are not yet sufficiently evaluated and empirically verified.

As previously discussed, the limited visibility of pedestrian activities, including walking and place activities, represents a key issue from which several research gaps emerge. To address this challenge, it is essential to examine these research gaps at both the individual and street level, recognizing the interdependencies between them.

Table 1 provides an overview of the identified research gaps in the field of pedestrian activities and directly links them to the corresponding research questions (RQ). Additional information on the reference level and the type of research gap offers further orientation and highlights the relevance of each gap.

Table 1: Overview of research gaps and research questions

Reference Level	Type of Research Gap	Research Gap in Detail	Overall Research Questions	
Individual level	Knowledge gap	Limited visibility of pedestrian activities in HTS	>> **RQ 0:**	How can terms and definitions related to place activities and HTS be harmonized and consistently be linked?
			>> **RQ 1:**	How can the visibility of walking stages be increased in HTS?
	Methodological gap	Lack of a lean method for generating stage-level information	>> **RQ 2:**	Is it possible to develop a methodology to generate stage information from trip-level HTS? If yes, what input data are required?
	Knowledge gap	Lack of information on context-specific motivating or hindering determinants on walking	>> **RQ 3:**	Which context-specific factors at the neighborhood and streetscape level correlate with leisure and utilitarian walking? Are there differences between frequent and less frequent walkers?
Street level	Empirical gap	Lack of typical key characteristics of place activities	>> **RQ 4:**	What are the characteristics of place activities in general? How do place activities vary throughout the day? What are the characteristics of place activities by gender and age groups?
	Knowledge gap	Lack of information on motivating or hindering determinants on place activities	>> **RQ 5:**	What are the relationships between street characteristics and place activities?

On the individual level, three research gaps arise. The **first research gap** refers to the overarching issue of the limited visibility of pedestrian activities in HTS, including walking stages and place activities.

Trip-based HTS, such as the German city-based HTS SrV, mainly collect data on trip level and thus generate trip-based modal-split figures. One trip is defined as the relation from the origin to the destination with at least one transport mode (e.g., Federal Highway Administration 2009; Servizi et al. 2021; Follmer 2019). Additionally, a trip is assigned a specific trip purpose, determined by the activity at the destination (Primerano et al. 2007; Aschauer et al. 2018; Gerike et al. 2015; Ho and Mulley 2013).

Fundamentally, there are two concerns related to the limited visibility of pedestrian activities in HTS. First, when presenting trip-based modal-split figures, walking as a transport mode remains visible only if the trip is characterized as monomodal. Following the definition, a change of transport modes indicates an intermodal trip (Clifton and Muhs 2012; Hubrich et al. 2019; Nobis and Kuhnimhof 2018). In trip-level HTS, intermodal trips are typically assigned a primary transport mode based on a fixed hierarchy, such as the mode covering the greatest distance. HTS that give priority to walking over other modes are not known by the best of knowledge. Therefore, this approach decreases the visibility of walking in trip-based modal-split figures.

Second, because traditional trip-based HTS do not focus directly on activities and, mainly due to the expected burden for the respondents, collect data at the trip level rather than at the stage level, the visibility of place activities is reduced. Figure 2 shows that place activities can be categorized into two types. The first type of place activities occurs at destinations, such as when people dine outside at a restaurant or spend time at a playground. In HTS, those place activities at destinations of trips are by definition clearly distinguished by definition from the trip to the destination itself. The second type of place activities occur during trips and thus influence stage and trip durations, but they are not considered in trip-based HTS. Furthermore, HTS do not clearly distinguish between walking as a mode of transport and on-foot place activities as part of a trip. For example, place activities can occur between two stages in intermodal trips with walking stages acting as intermediate stops (e.g., parking a bicycle or waiting for the bus), where people pause before continuing their trip with another transport mode. Additionally, stops within stages may include place activities (e.g., having a short chat while sitting at the bench during the walking stage to the PT stop). To summarize these points, the visibility of place activities in HTS is overall limited.

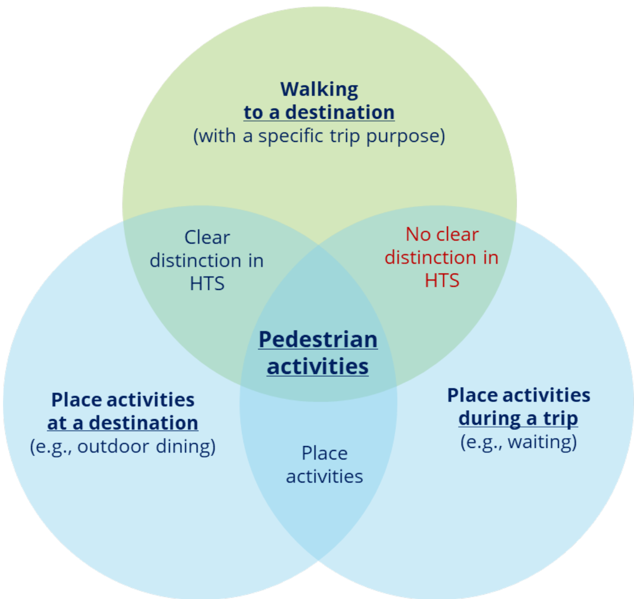


Figure 2: Dimensions of pedestrian activities and their coverage in HTS

Developing a glossary with a set of definitions that bridges the fields of HTS and place activities would foster a shared understanding, enhance the recognition, and improve the visibility of place activities both in HTS and in the field of transport planning.

This results in the basic research question (RQ 0):

- *How can terms and definitions related to place activities and HTS be harmonized and consistently be linked?*

The clear delineation of terms is a fundamental requirement and represents a cross-cutting task throughout this thesis, as well as an additional conceptual contribution. For this reason, this foundational research question is designated as RQ 0.

Walking is essential for accessing PT and other modes as well as for reaching the final destination of the trip (Lu et al. 2023; van Soest et al. 2020), which results in intermodal trips. The above-mentioned hierarchy-based assignment of the main transport mode causes walking stages in intermodal trips to be hidden by other transport modes. Consequently, trip-based modal-split figures only display (monomodal) walking trips. Although Figure 1 highlights that walking trips already form a reliable pillar of urban transport, it does not fully reflect the broader potential of walking within intermodal trips. This leads to the first research gap: the limited visibility of walking stages in trip-level data.

This results in the first research question (RQ 1):

- *How can the visibility of walking stages be increased in HTS?*

It is obvious that there is a lack of information. Hence the first research gap can be typed as a knowledge gap.

The **second research gap** is methodological. Collecting detailed information on stages (e.g., number, duration and distance) might be a promising option to (1) increase the visibility of walking and (2) to gain a broader understanding of walking in its various dimensions. However, collecting detailed stage-level information is associated with high costs and imposes a significant burden on respondents, which could negatively impact response rates. Currently, there is no suitable methodology to estimate detailed stage-level information from trip-level HTS data that include some information on stages (i.e., sequence of used transport modes; number of transfers in PT trips), highlighting an important gap in research methods.

This results in the second research question (RQ 2):

- *Is it possible to develop a methodology to generate stage information from trip-level HTS?*
- *If yes, what input data are required?*

The **third research gap** represents a knowledge gap. There is a lack of information on context-specific motivating or hindering determinants of walking, which could serve as a bridge between the individual and the street level. A brief review of the literature will help to illustrate this research gap.

For walking, studies on determinants of walking exist at two levels. There are studies on (1) walking that have a clear focus on analyzing walking behavior on an individual level (e.g., weekly walking duration) of selected person groups, e.g., of residents in a specific neighborhood (Gascon et al., 2019; Kerr et al., 2016; Wang et al., 2021). Walking behavior can be understood either as a component of active mobility, or as an independent mode of transportation (e.g., Gascon et al. 2019; Götschi et al. 2017; Gerike et al. 2021b; Koszowski et al. 2019a; Cervero and Kockelman 1997).

Furthermore, there are studies positioned at (2) the street level. Here, walking can be described by pedestrian volume or activities (see e.g., Lai and Kontokosta 2018; Kim et al. 2019; Fang et al. 2022; Ewing and Clemente 2013). Particularly in the first group of studies, determinants can be categorized into two groups: supply-side factors related to the built environment and person-related factors. Supply-side factors encompass characteristics of the neighborhood (meso-scale) as well as features of the streetscape (micro-scale). Person-related factors, on the other hand, include socio-demographic, socio-economic, and socio-psychological variables, such as values, perceptions, preferences, and norms (Götschi et al. 2017; Koszowski et al. 2019b).

The individual level focuses on built-environment characteristics of the neighborhood, particularly in relation to leisure and utilitarian walking. However, it can be assumed that streetscape characteristics also play a significant role, depending on the specific context of the walking trip (Hillnhütter 2021).

Insights into these contexts – such as leisure walking while promenading in the city or utilitarian walking during trips to the supermarket – are currently lacking. Bridging this gap would help to better understand the connection between residents' individual walking behavior and streetscape characteristics. Furthermore, little is known about the differences in characteristics, behavior, preferences, and perceptions between frequent and less frequent walkers in these specific contexts.

This results in the third research question (RQ 3):

- *Which context-specific factors at the neighborhood and streetscape level correlate with leisure and utilitarian walking?*
- *Are there differences between frequent and less frequent walkers?*

The last two research gaps refer to place activities and are clearly positioned at the street level. Basic empirical research is needed, since research findings are not yet sufficiently evaluated and empirically verified, especially in the European context.

The **fourth research gap** addresses the lack of typical key characteristics of place activities. Despite their importance for street life and livable cities, most studies focus on this topic from an urban planning perspective rather than a transport research perspective. This applies in particular to the work of Mehta et al. and related studies influenced by them (e.g., Mehta 2013; Barros and Mehta 2023; Mehta and Bosson 2021; Njeru and Kinoshita 2018). For each stay, individual data (apparent gender and age in categories), data on the posture (e.g., standing, sitting) and on the specific activity (e.g., conversing, eating/drinking, window-shopping, playing, smoking, vending) exist. Although waiting at the PT stop is part of street life, it is not recorded. In addition, the duration of place activities is only recorded in classified groups. From a transport planning perspective, Ewing and Clemente (2013) deal with pedestrian activities as a sum of moving pedestrians and place activities, but not exclusively with place activities. Both groups of literature are located in the U.S. Extensive studies on place activities from the transport planning perspective and in European context are still missing. Typical key characteristics of place activities, such as their duration, variation across different times of day, and differences by gender and age groups, have not yet been adequately investigated.

This results in the fourth research question (RQ 4):

- *What are the characteristics of place activities in general?*
- *How do place activities vary throughout the day?*
- *What are the characteristics of place activities by gender and age groups?*

The **fifth research gap** represents a knowledge gap. There is limited literature on validated street characteristics that include place activities as a dependent variable. Research groups such as Mehta et al. and Ewing et al. focus either exclusively on place activities or consider them a part of broader pedestrian activities. These studies present validated sets of street characteristics as independent variables from both urban and transport planning perspectives. However, studies focusing exclusively on place activities within a transport planning framework are still lacking, particularly from a European perspective. Additionally, there is insufficient information on the motivating and hindering factors influencing place activities.

This results in the last research question (RQ 5):

- *What are the relationships between street characteristics and place activities?*

2 Summary of papers and main contributions

2.1 Paper 1: Perceived importance of context-specific built-environment factors of walking: A new perspective for prioritizing policy measures for promoting walking

Paper 1 focuses on the individual level and is based on a cross-sectional survey with a representative sample (n = 4,637) from twelve German cities with at least 100,000 inhabitants each. The primary aim of this paper is to identify determinants of residents' walking behavior comparing frequent and infrequent walkers, across the individual, neighborhood, and streetscape level for two specific contexts: leisure walking (promenading in the city) and utilitarian walking (trips to the supermarket). The investigation of the two specific contexts allows to identify differences in respondents' perceived importance of built-environment characteristics and to bridge the gap between the individual level of residents' behavior and the streetscape level.

In order to identify the residents' walking behavior, Logistic Regression Models are computed with the dependent variable being the "frequency of walking in general". Walking behavior within the last twelve months was assessed in seven categories from "daily or almost daily" to "never". For the purpose of Logistic Regression, the dependent variable was recoded into a binary outcome variable (0/1), distinguishing between individuals who walk less than three to four days a week (43 %) and those who walk daily or almost daily (57 %).

The independent variables, selected based on a literature review, encompass three levels:

(1) Socio-demographic/economic variables at the individual level (e.g., children in household, number of cars in household, employment, gender)

(2) Built-environment variables at the neighborhood level (e.g., area type by predominant building type, accessibility of facilities of daily needs within a five-minute walk, accessibility of at least one PT mode within a five-minute walk)

(3) Built environment variables at the streetscape level (e.g., surface and width of sidewalks, street furniture, trees along sidewalks)

Given the focus of this study on the built environment, these variables are classified along the "5 Ds" framework (density, diversity, design, distance to public transport, destination accessibility) by Ewing and Cervero (2010). At the neighborhood level, a new variable, "area type by predominant building type," was developed to capture aspects of density and diversity. It was determined by asking residents to identify the predominant building type in their neighborhood (e.g., detached single family house on a single lot, semi-detached house, row house, rowed apartment houses), as well as to provide further details on land use. Thus, this variable reflects both population density and diversity. Accessibility-related variables in this study correspond to the "destination accessibility" and "distance to public transport" dimensions of the "5 Ds" framework. Streetscape variables, on the other hand, focus on streetscape design and are aligned with the "design" dimension.

Two Logistic Regression Models are computed, one for each context, after having tested the requirements for the application (test of nested structures, multicollinearity between variables). In order to examine the explanatory power of the three levels (individual, neighborhood, and streetscape level) on walking, thematic blocks of independent variables are added successively in each model. For model diagnostics and selection, in particular R^2 Nagelkerke as the goodness-of-fit criterion, alongside the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) are used (see e.g., Gehrke 2019; Wolf and Best 2010). The model results indicate stable effect directions and odds ratios across the given models. Beyond the fit of statistical parameters, the outputs are logically interpretable, which supports the explanatory power of the Logistic Regression Models. Additionally, descriptive analysis complements the models to provide deeper insights.

The results show that at the individual level, car availability and employment are the two consistently significant individual factors for both leisure and utilitarian walking. Both models indicate that each additional car in a household reduces the chance of (almost) daily walking by 1.3 times ($p < 0.001$), which aligns with findings from previous studies. (see e.g., Cervero and Radisch 1996; Haybatollahi et al. 2015; Kaplan et al. 2016; Wang et al. 2021). Regarding the effect of employment on the frequency of walking, non-employed persons are more likely to walk frequently than those in education (reference category). Effects for utilitarian walking are higher than for leisure. Conversely, employed persons (aged below 35 years and aged 35 years and above) are less likely to be frequent leisure walkers compared to those in education. This may be explained by time restraints, longer trip distances or complex trip chains by employed persons, making the model results consistent with theoretical expectations.

At the neighborhood level, built-environment factors, such as the predominant building type in the neighborhood and accessibility to facilities of daily needs and to PT stops, are of high relevance in both models. In dense, mixed-use areas the chance of frequent walking is twice as high compared to neighborhoods dominated by detached single-family houses (reference category). These findings align with existing literature on the influence of the built environment on walking behavior, highlighting the importance of urban density and mixed land use in promoting walking. (see e.g., Brüchert et al. 2020; Christiansen et al. 2016; Wang et al. 2021).

At the streetscape level, the models reveal significant differences between frequent and less frequent walkers. For utilitarian walking, attractive buildings and greenery play a notable role, while space availability and street furniture are particularly important for leisure walking. Descriptive findings further emphasize these results, showing even greater differences between the two groups. Interestingly, streetscape factors are far more influential for leisure walking than for utilitarian walking. Protection, associated with safety and security, is ranked highest by almost all respondents, followed by comfort, which encompasses variables like space and surface quality. Delight or amenities, including attractive buildings, greenery, and first-floor uses, are also important but rank slightly lower. For utilitarian walking, however, distance emerges as a key factor, underlining the pragmatic nature of such trips.

Paper highlights

- *Identification of context-specific determinants at the individual, neighborhood, and street level.*
- *Provision of representative results for German cities with at least 100,000 inhabitants.*
- *Emphasis on distance as a key determinant for the frequency of utilitarian walking.*
- *Demonstration of a higher relevance of built-environment characteristics for the frequency of leisure walking compared to utilitarian.*

This study contributes especially by providing new information on context-specific motivating or hindering determinants for walking, and thus to research question 3 (RQ 3).

The overall contributions of this paper, along with those of the other two papers, are described in detail in Section 2.4.

2.2 Paper 2: From trips to stages: A methodology for generating stage information in trip-Based Household Travel Surveys

Paper 2 is positioned at the individual level and presents a methodology for estimating detailed stage-level information for trip-level HTS.

The output of trip-level HTS are usually key figures on the travel behavior of individuals on their daily trips. Thereby, one trip is defined as one relation from one origin to a destination. A trip is undertaken for a specific purpose and involves at least one transport mode (walking or another transport mode). If multiple transport modes are used, the trip is classified as an intermodal trip. The segments of a trip are called stages. Each stage is associated with a single transport mode and ends when the transport mode changes (Clifton and Muhs 2012; Hubrich et al. 2019; Nobis and Kuhnimhof 2018). For the preparation of trip-level key figures, such as the modal split, HTS in Germany use a hierarchy of transport modes to assign a primary mode in the case of intermodal trips. As walking is often complemented with PT or other transport modes, it is represented in classic trip-level modal-split figures only through monomodal trips. Collecting data at the stage level, while potentially more detailed, poses significant challenges, including lower response rates, selectivity, or high costs. As a result, an efficient methodology for uncovering stage-level information from trip-level HTS is missing.

In this study a novel methodology is developed to generate stage information from trip-level HTS. This methodology is tailored to inner-city trips in larger cities with at least 100,000 inhabitants, ensuring comparable mobility conditions. The methodology includes four distinct steps:

1. The German city-based HTS SrV 2018 is a trip-level survey with information on the sequence of used transport modes and the number of transfers in PT trips. The calculation of the number of stages of all trips is thus possible (n = 289,156 trips; n = 452,898 stages, city group of at least 100,000 inhabitants).
2. For the calculation of walking stage durations, the sub-sample in the German National HTS MiD 2017 is used. Intermodal trips are predominantly composed of PT trips with walking stages and car trips with walking stages. To estimate the duration of walking stages in these cases, Multiple Linear Regression Models were calculated. The transfer of the estimates for the duration of walking stages on PT and car trips to the SrV 2018 database was achieved by using the regression equations from the models. This methodology addresses 27 % of intermodal PT and car trips with walking stages. When combined with the existing monomodal trips (71 %), the approach covers 98 % of all trips in the database. Heuristic estimation rules are used for the remaining intermodal two percent of all trips to ensure comprehensive coverage.
3. For the calculation of the distance of stages, the information from SrV 2018 on the average speed from monomodal trips (walking, cycling and car trips) is used. Since PT trips are intermodal by its nature with at least access and egress walking stages, the average speed was calculated using stage data from MiD 2017.
4. Based on all the information on the number, duration and distance for all stages, finally, stage-based modal-split estimates can be calculated for SrV 2018 (inner-city trips, cities with at least 100,000 inhabitants).

To directly compare trip-level modal-split shares with stage-level estimates, data were calculated for three city-groups (100,000 to < 200,000 inhabitants; 200,000 to < 500,000 inhabitants and ≥ 500,000 inhabitants). At the trip level, walking (monomodal) accounts for approximately 30 % of all trips across all groups, equivalent to 1.1 out of 3.6 trips per person per day. At the stage level, walking becomes even more prominent in inner-city trips: around 50 % of all stages are walking stages across the city groups. In cities with ≥ 500,000 inhabitants, this means that 3.2 out of 6 daily stages per person are walked.

The transfer of the walking shares from trip (30 %) to stage level (50 %) is mainly compensated by decreased shares of cycling and car stages, which were hidden intermodal trips at trip level, as well as from PT, an inherently intermodal transport mode.

Despite the high share of 50 % walking stages, the shares of trip duration and distance drop at the stage level. Around 38 % of total trip time is spent on walking stages. This is still the highest share among all transport modes (cycling: 17 %; PT and car 23 % each). In cities with ≥ 500,000 inhabitants, this means an average of 27.5 minutes of walking per person per day, covering nearly two kilometres. This corresponds to approximately eleven percent of stage-level modal-split shares by distance. Given that walking is the slowest mode of transport and highly distance-sensitive, these findings on duration and distance at stage level are plausible.

Paper highlights

- *Presentation of a "lean" methodology for the generation of stage information from trip-level HTS data.*
- *Calculation of stage-level modal-split estimates by number, duration, and distance for SrV 2018 (inner-city trips in cities with ≥ 100,000 inhabitants).*
- *Enablement of a first-time direct comparison between modal-split shares at trip level and the estimates at stage level.*
- *Presentation of results for cities with ≥ 500,000 inhabitants: in average more than three out of six stages per day are walked, with a duration of approximately 28 minutes and a distance of two kilometers.*

This study contributes to increasing visibility of walking stages (RQ 1) as well as to the development of a "lean" methodology for generating stage information from trip-level HTS (RQ 2).

The overall contributions of this paper, along with those of the other two papers, are described in detail in Section 2.4.

2.3 Paper 3: Streets as places – characteristics of place activities in the European context with the example of the City of Malmö (Sweden)

For a better understanding of place activities in relation to their characteristics and determining streetscape factors, Paper 3 is founded on extensive on-site observations in the City of Malmö (Sweden) as an example for the European context. Paper 3 thus presents an empirical approach and is located at the street level.

In the context of the EU-project *Multimodal Optimisation of Roadspace in Europe (MORE)*, the City of Malmö was one case study area and defined three future scenarios for the new development area of "Nyhamnen": the car-oriented city, the sustainable city, and the city of places. For the evaluation of those, the City of Malmö chose case study areas within the municipality as representatives for the three scenarios. The following serve also as case study areas for this study:

- "Mariedalsvägen" and "Sallerupsvägen" as representatives for the car-oriented city
- "Södra Förstadsgatan" and "Stora Varvsgatan" as representatives for the sustainable city
- "Regementsgatan" as a representative for the city of places

In the literature, studies related to place activities and validated sets of street characteristics are based on two main groups of authors: Mehta (2013) focusing exclusively on place activities, and Ewing and Clemente (2013), incorporating place activities as a part of pedestrian activities. In Paper 3, five street sections from five case study areas were divided into 16 blocks. Following the data collection protocols established by each of the author groups, a detailed dataset on supply-side characteristics was compiled for each block in the case study areas. To obtain demand-side data, extensive on-site observations were conducted with the block serving as the unit of analysis. To ensure consistency, the field manual by Mehta (2013) was applied. From a fixed observation point, detailed information was carefully mapped over a twelve-hour period (from 7 am to 7 pm), including:

- Type and duration of place activities (e.g., chatting, taking care of somebody, walking the dog, interaction with a bike or scooter, commercial activity such as window shopping, consuming as a representative for drinking and eating, smoking, interacting with the mobile phone, and waiting)
- Posture (e.g., standing, formal sitting, informal sitting, lying, or multiple movements)
- Person-related information, such as apparent gender and age group

Waiting at the bus stop was additionally recorded, which is not in line with the field manual of Mehta (2013). After data collection, all mapped place activities were transferred to a Geographic Information System (GIS). Descriptive statistics, GIS analyses, and simple Linear Regressions were computed to gain empirical insights into the spatial distribution, characteristics, and determinants of place activities.

With a sample of n = 1,654 valid[1] place activities, the results of the street sections in the City of Malmö show that the intensity, the type and the durations place activities are driven by the general land use in the neighborhood as wells as by the adjacent buildings. Although the overall number of place activities is in a similar range (40–50 place activities per h), activity characteristics differ

[1] Valid place activities include all mentioned information and have a minimum duration of 15 seconds, following Mehta 2013.

greatly in the case study areas. Regementsgatan and Södra Förstadsgatan as mixed urban neighborhoods with business-oriented services and gastronomy show high place-activity peaks during lunch and evening hours, with Regementsgatan also showing a morning peak. Both show higher activity levels and durations for socializing activities such as "chatting and taking care" – the most desirable place-activity type. In contrast, Stora Varvsgatan as a business district dominated by office use displays place-activity patterns typical for office workers. Place-activity peaks occur during lunch breaks and at the end of the workday, with occasional smoking breaks in between. Place-activity durations here are significantly shorter than those on Regementsgatan and Södra Förstadsgatan. In Sallerupsvägen, the social institution as the characteristic land use shapes the place-activity levels and types during office hours. The share of the peak hours is highest in the morning (23 %). However, place-activity durations are the shortest, and waiting activities or interactions with phones – categorized as lower-value activities – dominate overall.

Beyond the descriptive analysis, this study demonstrates a positive relationship between the street characteristics (e.g., personalization and permeability of facades/businesses) proposed by Mehta (2013) and place activities. The aggregated Urban Design Quality Index (UDQI) proposed by Ewing and Clemente (2013) is the sum of the five so called urban design quality factors (i.e., imageability, enclosure, human scale, transparency, complexity). It shows positive tendencies of correlation with activity numbers, but on a weaker level than the street characteristics by Mehta (2013). Since there are overlaps between the single variables of both author groups, the single variables by Ewing and Clemente (2013) seem to be specifically more insightful for place activities than the composed factors.

Spatial mapping of place activities offers valuable context, identifying local hotspots and primary attractors. Entrances to adjacent buildings (e.g., gastronomy, supermarket, office) emerge as key attractors. These are possible "destinations" for place activities in public space. Transport-related place activities, such as waiting at the PT stop or parking the bicycle, function as intermediate attractors during trips.

Overall, this paper delivers novel insights into the characteristics and spatial patterns of place activities in European context, using the City of Malmö as a case study. In addition, it provides more generalized correlations that describe the relationship between street characteristics and place activities. These findings offer a valuable foundation for designing livable streets and public spaces in the future.

Paper highlights

- *Provision of a general characterization of place activities within the European context using the case study of the City of Malmö.*
- *Attribution of place activities to the quality of the design of street characteristics (e.g., personalization and permeability of facades/businesses).*
- *Identification of a strong effect of land uses (businesses and gastronomy vs. offices) on the duration, the type, and the daily profile of place activities.*

This study contributes to increasing the empirical knowledge on place-activity characteristics (RQ 4) in the spatial context and during the day. Additionally, this paper gives insights on the relationships between street characteristics and place activities (RQ 5).

The overall contributions of this paper, along with those of the other two papers, are described in detail in Section 2.4.

2.4 Contribution to research questions

The following section outlines the contributions of each paper to answering the research questions. Given the relations between the papers, Table 2 provides a comprehensive overview of their overarching contributions. The extent to which the research questions are addressed by each paper varies and can be categorized as follows:

- The research question (RQ) is fully covered by a paper.
- The research question (RQ) is partially but directly covered by a paper.
- The research question (RQ) is partially but indirectly covered by a paper.
- The research question (RQ) is not covered by a paper.

Table 2: Contribution of the papers to the research questions

Overall Research Questions		Paper 1	Paper 2	Paper 3
RQ 0	How can terms and definitions related to place activities and HTS be harmonized and consistently be linked?	◔	◔	◔
RQ 1	How can the visibility of walking stages be increased in HTS?	○	●	◔
RQ 2	Is it possible to develop a methodology to generate stage information from trip-level HTS? If yes, what input data are required?	○	●	◑
RQ 3	Which context-specific factors at the neighborhood and streetscape level correlate with leisure and utilitarian walking? Are there differences between frequent and less frequent walkers?	●	○	◔
RQ 4	What are the characteristics of place activities in general? How do place activities vary throughout the day? What are the characteristics of place activities by gender and age groups?	◔	○	●
RQ 5	What are the relationships between street characteristics and place activities?	◑	○	●

Legend

● RQ fully covered ◑ RQ partially but directly covered ◔ RQ partially but indirectly covered ○ RQ not covered

This thesis aims to enhance the visibility and the knowledge of pedestrian activities, including walking **(RQ 1)** and place activities **(RQ 0)**.

Regarding **RQ 0**, all presented papers in this thesis partially address aspects of place activities. Paper 1 (see Section 2.1) investigates the relevance of street design factors, such as street furniture (e.g., seating options), green areas along the street, and the attractiveness of buildings for two specific contexts: leisure and utilitarian walking. Paper 2 (see Section 2.2) uncovers walking stages that are hidden behind trip-level data in trip-level HTS. Notably, intermodal PT trips with walking stages inherently include waiting at PT stops, which is closely linked to place activities. Furthermore, overlaps exist between activities at trip destinations and place activities; for instance, activities such as outdoor dining may occur as place activities in public spaces. Place activities are extensively examined in Paper 3 (see Section 2.3). Although content-related overlaps are evident, terms related to place activities and traditional HTS have not yet been consistently defined and linked.

This raises the research question of how terms and definitions in the fields of place activities and HTS could be harmonized and consistently be linked (**RQ 0**).

Based on the three included papers, the following Table 3 provides a comprehensive overview of all relevant HTS and place-activity terms. Definitions are compiled from references in the context of HTS and place activities and presented in a glossary.

The basic terms of HTS vocabulary (see Table 3, see origin, destination, trip, trip purpose, stage, trip chain, tour, round trip) are based on HTS glossaries and methodological reports (Federal Highway Administration 2009; Nobis and Kuhnimhof 2018; Hubrich et al. 2019; Follmer 2019) as well as scientific literature (Primerano et al. 2007; Clifton and Muhs 2012; Servizi et al. 2021; Ho and Mulley 2013). Servizi et al. (2021) and Shin et al. (2015) present definitions on terms that are primarily linked to vocabulary of smartphone tracking such as "stop".

As already mentioned, the term "activity" has at least two connotations and can be found in HTS literature as well as in the literature on place activities. Gerike et al. (2015) and Aschauer et al. (2018), in particular, focus extensively on the concept of activities in the context of HTS and Time Use Surveys. Activities occur between two trips (e.g., working, shopping) and can be derived from the trip purpose in HTS. These activities can be categorized into (1) mandatory, subsistent activities (e.g., work, school), (2) flexible, non-discretionary activities (e.g., shopping, errands), and (3) optional, discretionary activities (e.g., leisure activities) (Gerike et al. 2015; Primerano et al. 2007). Given the use of the term "activities", it is important to distinguish these from place activities. According to the literature around Mehta (2013), place activities can be described as place-bound stationary activities occurring in public spaces, characterized by a specific posture (e.g., standing; sitting) and a particular activity (e.g., chatting, outdoor dining) for a certain time period. In addition, Gerike et al. (2023) deal with place activities in vibrant streets.

Building on the findings of Paper 3 (see Section 2.3) and the critical reflection on HTS and place-activity terminology, the following descriptions are added:

- A place activity can occur in public space at trip destinations. In addition, individuals can be engaged in place activities during a stop within or at the end of a stage.
- Place activities include intermediate, transport-related place activities.
- Intermediate place activities occur during stops within a stage or at its end, or in between two stages.
- There are transport-related place activities, such as waiting at the PT stop; parking a car, bike or scooter; checking information on PT.
- Non-stationary activities take place in public space but are not place-bound (e.g., reading during sitting on a bus, phoning while walking, drinking coffee while walking). Such non-stationary activities are not classified as place activities. Non-stationary activities are part of trips.

Table 3: Glossary on relevant terms of HTS and place activities

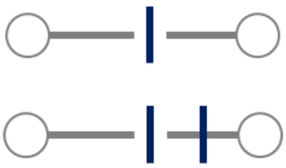
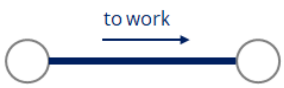
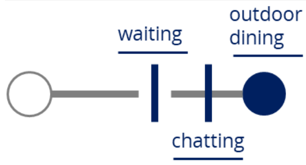
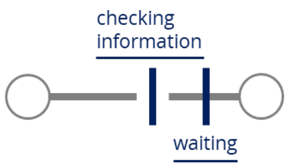
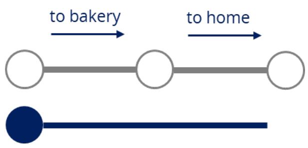
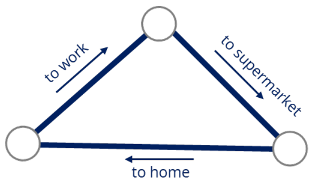
Term	Description	Schematic illustration
Origin	– The origin is a place where a →trip starts – The origin is a place where →activities may have occurred (before the trip)	
Destination	– The destination is a place where a →trip ends – The destination is a place where →activities occur	
Trip	– A trip is a travel or movement outside home from one place (→origin) to another (→destination) – A trip has one specific →trip purpose that motivates the trip – A trip includes the use of at least one transport mode – A trip consists of →stages if two or more transport modes are used – A trip with at least two →stages with different transport modes is called an intermodal trip	
Stage*	– A stage can be a →trip or a part of a →trip – A stage is a movement from one point to another in a network – A stage is associated with one single transport mode; the stage ends if the transport mode changes – A stage might include one or more →stop(s)	
Stop	– A stop occurs when the average speed of a transport mode goes down to zero for a certain time period – A stop can occur within a →stage or at the end of a →stage (but not at the end of the →trip) – During a stop, individuals can engage in →place activities	
Trip purpose	– The trip purpose is the reason that motivates the →trip – The trip purpose ends up in an →activity that takes predominantly place at the destination of a trip (e.g., trip to the place of work; trip to home) – In some cases, the trip purpose is fulfilled by the trip itself (→round trip)	
Activity	– Activities to be carried out at a destination motivate →trips; the type of activity determines the →trip purpose (e.g., activity: work, purpose: trip to work) – The classification of activities can be divided into the following three types: 1. Mandatory, subsistent activities as typically daily, time- and location-fixed activities (e.g., work, education) 2. Regular flexible, non-discretionary activities (e.g., shopping, errands) which can vary in time and location 3. Optional, discretionary activities (leisure activities)	

Table is continued

Term	Description	Schematic illustration
Place activity	– A place activity describes the stay of a person in the public space as a place bound, stationary →activity with a specific posture (e.g., standing, sitting) and defined →activity (e.g., chatting, outdoor dining) for a certain time period – A place activity can occur in public space at the →destination of a →trip; also, individuals can engage in place activities during a →stop within a →stage or at the end of a →stage – For place activities, the street functions as both a place and a →destination – Place activities include transport-related →intermediate place activities	
Intermediate place activity	– Intermediate place activities are transport-related →place activities, such as waiting at the PT stop; parking a car, bike or scooter; checking information on PT – Intermediate place activities occur during →stops within a →stage or at the end of →stages, or in between two →stages	
Non-stationary activity	– Non-stationary activities are →activities that occur in public space but are not place bound (e.g., reading during bus stage, phoning while walking; drinking coffee while walking) – Non-stationary activities are not →place activities, but are part of the →trips	
Trip chain	– A trip chain is a series of linked →trips between successive →destinations – A trip chain includes at least two →trips – The →origin of the first →trip is not necessarily the →destination of the last →trip	
Tour	– A tour is a →trip chain consisting of at least two trips, with one anchor point (e.g., home) as the →origin of the first →trip and the→ destination of the last →trip	
Round trip	– A round trip is a →trip in which the →origin and →destination are the same place (e.g., walking the dog, promenading) – The →trip purpose of the round trip is determined by the →activity	

* Leg can be used as a synonym

This definitional framework aims (1) to support methodological advancements in HTS and (2) facilitates a more precise description of place activities in public spaces.

Paper 2 fully addresses research questions **RQ 1** and **RQ 2**. Both research questions relate to each other. Developing a methodology to generate stage-level information from trip-level data is essential to increase the visibility of walking stages.

For **RQ 2**, two prerequisites regarding suitable databases can be identified. First, trip-level HTS, such as the SrV, must include some stage-related information, such as the sequence of used transport modes and the number of transfers in PT trips. This enables the calculation of the number of stages of all trips. Second, the estimation of durations of walking stages requires a complementary database with stage information. In this case, the sub-sample in the German National HTS MiD 2017 serves as a suitable database.

The transfer of the estimated duration of walking stages from MiD 2017 to SrV 2018 is achieved using regression equations derived from Multiple Linear Regression Models for intermodal PT and car trips with walking stages. Since 98 % of all trips in SrV 2018 are monomodal, intermodal PT trips or car trips with walking stages, heuristic estimation rules are used for the remaining intermodal two percent of all trips. The final input required to estimate stage distances is the average speed of monomodal trips. Using this comprehensive methodology, modal-split figures can be calculated at the stage level. Uncovering stage data reveals that 50 % of all stages are walking stages, significantly increasing the visibility of walking. Adding stage-level modal-split estimates for duration and distance reveals walking stages in all their dimensions.

In conclusion, Paper 2 fully answers both research questions. Additionally, Paper 3 on place activities provides partial contributions. As previously noted, transport-related activities, such as waiting at PT stops, are examined in Paper 3 and are conceptually related to stages.

Paper 1 contributes to the third research question **(RQ 3)** and the discussion on differences in the relevance of built-environment factors and travel purposes. Studies based on the IPAQ-questionnaire already demonstrate distinctions between walking for transport and leisure. This study extends these findings and specifically asks respondents to report their preferences separately for the different contexts by using context-specific questions at the streetscape level.

This approach enables a deeper investigation into how much importance respondents place on built-environment characteristics. The data reveal that frequent leisure walkers, in particular, are more sensitive to features of the streetscape. These walkers tend to walk at a reduced speed, which may heighten their awareness of street characteristics. Additionally, the analysis of perceptions between frequent and less frequent walkers highlights that frequent walkers are especially demanding when it comes to streetscape attributes. This group should serve as the benchmark for urban street design, with the ultimate goal of increasing the number of frequent walkers and creating facilities that meet their needs.

The research questions **RQ 4** and **RQ 5** address the key characteristics of place activities and the street characteristics that correlate with place activities. Paper 3 contributes to answering both questions.

The empirical study is based on extensive on-site observations of place activities in five case study areas in the City of Malmö, serving as an example in the European context. Detailed data, including information on the duration, type, and posture of place activities as well as person-related details, enable a comprehensive characterization of place activities. Additionally, timestamp information allows the analysis of place activities in a daily profile.

The relationship between collected supply-side characteristics at street level and place activities is analyzed using simple Linear Regressions. The results indicate that the quality of the design of street characteristics (e.g., articulation and personalization and permeability of facades/businesses) influences place activities.

The insights into the characteristics of place activities and their correlates at street level are valuable for transport planners, particularly regarding the allocation of space within the cross-section of streets for place functions. More space should be allocated around adjacent buildings that attract place activities, such as gastronomy, supermarkets, office entrances, and PT stops. For practitioners, the derived key figures provide a basis for justifying planning measures.

3 Discussion

In this section, the results of the three presented papers are contextualized on the basis of a methodological and content-related reflection. In addition, arising limitations of the applied methods and possible directions for future research are outlined.

3.1 Methodological discussion

3.1.1 Representativeness of results

For a holistic view on the topic of pedestrian activities, this thesis addresses walking trips and walking stages at the individual level, and place activities at the street level. Papers 1 and 2 focus on the individual level, generating new insights into walking (RQ 1–4). Both are based on mobility surveys (Paper 1: survey on active mobility; Paper 2: HTS SrV 2018 and MiD 2017) with samples randomly drawn from population registers of participating municipalities to ensure representative results. Since Paper 1 and 2 focus on data on German cities with ≥ 100,000 inhabitants, the findings are representative of this specific urban context.

In contrast, Paper 3 examines place activities at the street level, conducting extensive twelve-hour on-site observations in five street sections in Malmö, Sweden (RQ 5–6), that are divided into 16 blocks. Hence, a full sample of place activities in these street sections builds the data basis. While the number of blocks may initially seem insufficient for broader generalizations, related studies, such as Mehta (2013), analyzed correlations with place activities using 15 blocks – a comparable scope. Paper 3 emphasizes its local focus through descriptive analysis and spatial mapping of place activities, representing a medium-sized European city. Additionally, by calculating correlations between street characteristics based on frameworks by Ewing and Clemente (2013) and by Mehta (2013), the study extends its relevance to a more generalizable context. Through its threefold analytical approach, Paper 3 bridges the gap between local observations and broader generalizations.

3.1.2 Balancing effort and data richness in mobility and pedestrian activity research

HTS commonly collect trip-based data on travel behavior. Meanwhile, some stage-based HTS surveys provide detailed information on trip stages, including mode, duration, and distance (see e. g. Kagerbauer et al. 2015; Kagerbauer and Stark 2018; Schmid et al. 2019). Researchers face a dual challenge: reducing respondent burden during survey completion and ensuring sufficient support and motivation throughout the survey process – both are closely tied to budget constraints. Therefore, Paper 2 introduces a new methodology for generating stage information from trip-level HTS for German cities with at least 100,000 inhabitants, focusing on inner-city trips.

This methodology is based on two HTS datasets – SrV 2018 and MiD 2017 – and involves four key steps: (1) Calculating the number of stages of all trips in SrV 2018, (2) estimating the duration of walking stages in intermodal PT and car trips using MiD 2017 and transferring this to SrV 2018, (3) calculating the distances of stages in SrV 2018, and (4) calculating modal-split figures at stage level for SrV 2018. The final step enables stage-level modal split comparisons by number, duration, and distance across three city groups (100,000 to < 200,000 inhabitants; 200,000 to < 500,000 inhabitants and ≥ 500,000 inhabitants). This "lean" methodology provides a systematic approach for extracting stage-level insights from trip-level HTS.

In contrast to Paper 2, which relies on existing mobility data, Paper 3 conducted extensive twelve-hour on-site observations to capture detailed place activities across five street sections with varying land-use characteristics (e.g., small service-oriented businesses and gastronomy vs. office-dominated areas). Here, the burden of data collection and maintaining data quality can be challenging, especially as the sample size increases. Although the manual static observation method for a period of twelve hours is intense, the method was found to be suitable. Video recordings with an automated extraction of the number and characteristics of place activities could reduce the burden of data collection, but while current technologies can count pedestrians (see e.g., Lee 2020; Fang et al. 2022), they cannot reliably distinguish movement and place activities.

3.2 Determinants of pedestrian activities

As outlined in Section 2.4, place activities are an integral part of trips and can occur (1) at trip destinations (e.g., outdoor dining), (2) at intermediate, transport-related facilities (e.g., bus stops, parking facilities) between two stages, or (3) as stops during stages or trips. Hence, overlaps between determinants on walking and place activities can be assumed. Given that Paper 1 and Paper 2 focus on different dependent variables (Paper 1: residents' walking behavior, i.e., frequent vs. less frequent walkers for leisure and utilitarian walking; Paper 2: duration of walking stages in PT trips and car trips), the determinants cannot be directly compared.

Taken together, however, they provide an overview of factors that motivate frequent leisure and utilitarian walking, as well as those that affect the duration of walking stages in intermodal trips. Paper 3 offers additional insights into motivating or hindering determinants of place activities.

The following sections discuss the determinants of pedestrian activities across the papers. First, socio-demographic and socio-economic factors at the individual level are examined. This is followed by an exploration of built-environment determinants.

3.2.1 Socio-demographics and socio-economics

In Paper 1, the method of one-level Logistic Regression is applied to identify the determinants of residents' walking behavior in two specific contexts: leisure and utilitarian walking. Results indicate that at the individual level, car availability and employment are significant factors for both types of walking. Specifically, car availability has a negative impact on walking. The chance of (almost) daily walking is reduced with each additional car in a household. This finding aligns with previous studies (see e.g., Cervero and Radisch 1996; Haybatollahi et al. 2015; Kaplan et al. 2016; Wang et al. 2021). Employment also influences walking frequency, with stronger effects observed for utilitarian walking than for leisure walking. Non-employment increases the chance of frequent walking compared to individuals in education (the reference category), while employment has the opposite effect. These model results are plausible, as employed individuals often face time constraints, longer trip distances, or more complex trip chains than those in education.

In Paper 2, occupation appears to have a marginal effect on the duration of walking stages in intermodal car trips. For walking stages in PT trips, this factor was not significant in the initial tests before running the Regression Models. These findings are consistent with van Soest et al. (2020), who reported that employment and education have only a weak effect on PT-related walking. Overall, employment significantly affects walking frequency (Paper 1), but has a negligible effect on the duration of walking stages in intermodal trips.

Gender does not appear to be a significant factor in either Paper 1 or Paper 2. This could be attributed to the fact that walking behavior is relatively comparable across all socio-demographic and socio-economic groups.

Paper 3, as an empirical street-level study, contributes to the understanding of place activities and their relationships with street characteristics. Using descriptive and GIS analyses, the study provides insights into gender and age patterns in place activities across five case study areas in Malmö.

Gender distribution in place activities varies by location: it is balanced in Mariedalsvägen and Stora Varvsgatan, whereas the share of women is higher in Sallerupsvägen and Regementsgatan but lower in Södra Förstadsgatan. These results align with previous case studies, which also report no clear tendencies (Gehl 2018; Shirazi 2019). Adults (18–64 years) represent the largest age group across all case study areas, while younger age groups are underrepresented, likely reflecting the absence of schools in the vicinity. This is in line with the literature (Gehl 2018; Shirazi 2019). Due to the observational method used in Paper 3, additional socio-demographic and socio-economic information, such as education or employment, could not be captured. Further surveys would be necessary to obtain a more comprehensive understanding of person-related factors.

3.2.2 Built environment at the neighborhood and streetscape level

As a key determinant, the built environment affects pedestrian activities at both the neighborhood and streetscape scales.

In the literature, the "5 Ds" (density, diversity, design, distance to public transport, destination accessibility) are consistently identified as key determinants for pedestrian activities at neighborhood level, particularly walking (Ewing and Cervero 2010; Götschi et al. 2017; Lai and Kontokosta 2018).

In Paper 1, these built-environment factors at the neighborhood scale were hypothesized to influence the frequency of leisure and utilitarian walking. The Logistic Regression Models tested three specific factors derived from the "5 Ds": predominant building type (combining density and diversity), accessibility to facilities of daily needs, and accessibility to PT stops.

The findings show that all three factors are consistently significant, with high odds ratios in the models. Notably, dense, mixed-use building structures double the chance of frequent walking in both leisure and utilitarian contexts, aligning with prior research (see Cervero and Kockelman 1997; Kang 2015; Stead and Marshall 2001). This demonstrates that the predominant building type factor is an effective proxy for density and diversity and offers a valuable tool for future questionnaire-based research. The factor on accessibility to facilities of daily needs is significant for leisure walking, for utilitarian close to significance, suggesting that proximity to such facilities within a five-minute walk significantly increases the chance of leisure walking. Similarly, the accessibility to PT within a five-minute walk positively impacts frequent walking across both contexts.

Paper 2 does not directly test these factors but sets the analytical framework for German cities with at least 100,000 inhabitants and inner-city trips, based on the assumption that larger cities feature denser and more walkable environments with better PT provision. The successful application of the new methodology supports the validity of this assumption.

Finally, Paper 3, focusing on the street scale, incorporates the "5 Ds" during the selection of the five case study areas. It is reasonable to assume that these variables influence place activities by underpinning "higher" or "lower" levels of place activity in terms of type, frequency, and duration. Papers 1 and 2 emphasize the significance of neighborhood-level built-environment factors for walking, while Paper 3 extends this understanding to street-level place activities.

As highlighted in the literature, built-environment variables at the neighborhood level also apply to the streetscape level (Ewing and Clemente 2013; Gerike et al. 2021b).

Papers 1 and 3 both address streetscape variables, but their reference level (individual vs. street level) and dependent variables differ (Paper 1: frequency of walking for leisure and utilitarian purposes; Paper 3: place activities). Consequently, the approaches to examining the impact of streetscape characteristics also vary.

In Paper 1, a questionnaire was developed based on a literature review and the standardized NEWS-questionnaire (Saelens et al. 2003) along with its variations (see e.g., Sallis et al. 2010). The questionnaire investigates determinants of residents' walking behavior for leisure and utilitarian walking. The descriptive analysis reveals that for frequent leisure walkers, streetscape design holds greater importance compared to utilitarian walkers. This group is particularly sensitive to features of the streetscape (e.g., importance of safety and security, space and surface quality, attractive buildings, greenery or first floor usages). The fact that leisure walkers move more slowly likely enhances their awareness of these characteristics. In contrast, utilitarian walking is primarily influenced by functional considerations, with distance emerging as a key determinant.

For Paper 3, the streetscape variables are founded on two groups of authors: Mehta (2013), who focuses exclusively with place activities and Ewing and Clemente (2013), who incorporate place activities as a part of pedestrian activities.

Simple Linear Regressions between the street characteristics by Mehta (2013) and the surveyed place activities reveal that, in particular, the variables of personalization and permeability of facades are positively associated with place activities. This means that the design and decoration of facades (personalization) and how well activities inside the buildings can be seen and experienced from the street (permeability) attract place activities. These variables refer to land-use qualities and are also significant in the literature by Mehta (2013).

Ewing and Clemente (2013), building on their urban design quality framework (Ewing et al. 2006), identified five composite urban design quality factors that influence pedestrian activities (imageability, enclosure, human scale, transparency, complexity) based on a literature review and expert ratings. These factors include more detailed variables measuring physical features of streetscapes. In the literature, some of the physical features, such as the proportion of windows, street furniture, and active uses, significantly influence pedestrian activities (Ewing et al. 2016). Physical features, such as the proportion of windows overlap with Mehta's framework – in this case, permeability. Both variables enhance the connection between indoor and outdoor spaces for pedestrians. Due to overlaps between the variables of both author groups, the single variables seem to be insightful for describing place activities in Paper 3. The aggregated Urban Design Quality Index proposed by Ewing and Clemente (2013) shows positive tendencies of correlation with activity numbers, but on a weaker level.

Beyond the tested correlations, Paper 3 highlights the essential role of land uses of the adjacent buildings in shaping the intensity, duration, and types of place activities. This is in line with Gehl (2018) and Shirazi (2019) where high activity levels are closely tied to intense commercial land uses. Additional spatial mapping in Paper 3 reveals three primary types of places for place activities:

– Adjacent buildings as key attractors of place activities. Entrances of adjacent buildings (e.g., gastronomy, supermarket, office) attract place activities as "destinations" in public space.
– Transport-related facilities attract place activities, such as waiting at the PT stop or parking the bicycle as intermediate place activities on intermodal trips.
– Street furniture (e.g., benches or playing grounds) as places for place activities. This is not an explicit result of Paper 3, since street furniture is underrepresented in the observed street sections.

In sum, Papers 1 and 3 illustrate the significant influence of built-environment characteristics on pedestrian activities at both the neighborhood and the street level.

4 Summary of content and outlook

This thesis aims to enhance the visibility and the knowledge of pedestrian activities, encompassing both walking for movement and for place activities. To achieve this, this thesis presents three papers that collectively adopt a multi-data and multi-method approach to deepen insights into mobility and street user behavior. Figure 3 summarizes the key characteristics of the papers, including their spatial context, the street function and the type of pedestrian activity, the reference level, the methodologies, and the statistical analysis methods applied in each paper.

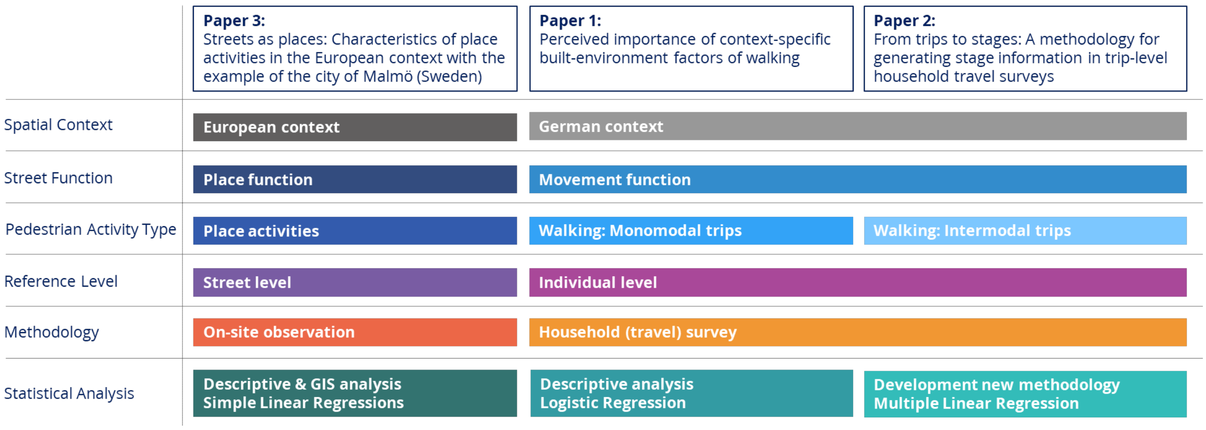


Figure 3: Summary of paper characteristics

Paper 1 identifies context-specific determinants for the frequency of walking for leisure and utilitarian purpose at the individual, neighborhood and street level. The results are representative for German cities with at least 100,000 inhabitants. By using Logistic Regression Models and additional descriptive analysis, the paper focuses on walking as an integral part of pedestrian activities.

Paper 2 is positioned at the individual level, aiming to develop a new methodology for generating stage information from trip-level HTS for German cities with at least 100,000 inhabitants, specifically focusing on inner-city trips. The methodology is based on two German HTS datasets (SrV 2018 and MiD 2017) and encompasses four steps: (1) calculation of the number of stages of all trips in SrV 2018, (2) estimation of the duration of walking stages in intermodal PT and car trips in MiD 2017 and the transfer to SrV 2018, (3) calculation of the distance of stages in SrV 2018, and (4) calculation of the modal-split figures at stage level in SrV 2018.

In the second step, Multiple Regression Models were calculated in MiD 2017 after preliminary statistical tests (e.g., U-Tests for selection of independent variables and checks for multicollinearity). The regression equation is subsequently used to transfer walking stage duration estimates to the SrV 2018 data base. This methodology is a "lean" methodology for generating stage information from trip-level HTS.

Paper 3, as an empirical street-level study, contributes to understanding the characteristics of place activities and explores their relationship with street characteristics. To provide a comprehensive analysis of place activities, the study employs descriptive analysis, GIS-based methods, and simple Linear Regressions to examine how streetscape features influence place activities. Based on a case study sample (n = 1,654 observations), the findings offer new insights into the duration, types, postures, and the daily profile of place activities.

The following table summarizes the key highlights of the papers and outlines their contributions to the literature:

Table 4: Highlights of the presented papers

Paper	Highlights
Paper 1	– Identification of context-specific determinants at individual, neighborhood, and street level. – Provision of representative results for German cities with at least 100,000 inhabitants. – Emphasis on distance as a key determinant for the frequency of utilitarian walking. – Demonstration of a higher relevance of built-environment characteristics for the frequency of leisure walking compared to utilitarian.
Paper 2	– Presentation of a "lean" methodology for the generation of stage information from trip-level HTS data. – Calculation of stage-level modal-split estimates by number, duration, and distance for SrV 2018 (inner-city trips in cities with ≥ 100,000 inhabitants). – Enablement of a first-time direct comparison between modal-split shares at trip level and the estimates at stage level. – Presentation of results for cities with ≥ 500,000 inhabitants: in average more than three out of six stages per day are walked, with a duration of approximately 28 minutes and a distance of two kilometers.
Paper 3	– Provision of a general characterization of place activities within the European context using the case study of the City of Malmö. – Attribution of place activities to the quality of the design of street characteristics (e.g., personalization and permeability of facades/businesses). – Identification of a strong effect of land uses (businesses and gastronomy vs. offices) on the duration, the type, and the daily profile of place activities.

The presented papers close existing research gaps and address the introduced research questions. Additionally, this thesis contributes by answering the overarching RQ 0.

A glossary is proposed that consolidates all relevant HTS and place-activity terminology. This definitional framework aims to support methodological advancements in HTS and facilitate a more precise description of place activities in public spaces. By enhancing the visibility of pedestrian activities in data, this framework has the potential to drive future methodological progress. However, the theoretical proposals require further elaboration and practical application in subsequent studies. This gap is identified as the "Theory-Application Void" (Baako et al. 2022; Islam 2024) , which underscores the necessity of transferring theoretical concepts into real-world experiments. Determining the appropriate format for this transfer remains a critical task.

The advantage of trip-level HTS with some information on stages, such as SrV 2018, lies in its "lean" methodology, which minimizes respondent burden. Expanding the questionnaire to include additional information on place activities could undermine this advantage, making questionnaires less suitable.

Therefore, the terminological integration can be sufficient to raise the awareness for place activities in HTS. In the future, stage-oriented applications – such as innovative survey approaches using smartphone-based methodologies – might provide a suitable platform for incorporating data on place activities. Such approaches could offer new insights, for instance, into implausibly long walking trips over short distances, where place activities are likely but remain unrecorded in current datasets.

A direct comparison of different data collection approaches would also be methodologically valuable. This could refine the understanding of walking behavior and help address potential over- or underestimation in existing datasets. For instance, the outputs from the stage-level information generation methodology (Paper 2) could be directly compared with findings from smartphone-based travel surveys, providing a more comprehensive perspective on walking behavior.

Furthermore, this thesis discusses the determinants of pedestrian activities (see Section 3.2). A comprehensive framework is needed to illustrate the key determinants on both the supply and demand side enabling a holistic understanding of the drivers for walking and for place activities. Notably, there remains a significant gap in understanding the impact of social determinants, particularly on place activities.

To address these knowledge and empirical gaps, several recommendations can be made. Studies should directly compare walking and place activities at the street level to disentangle the specific relevance of streetscape factors for each activity type. Such comparisons would allow for a nuanced understanding of similarities and differences between walking for movement and place activities. A comprehensive guideline compiling core findings on pedestrian activities could support urban and transport planners in designing livable public spaces.

Expanding the sample size would further enhance the generalizability of findings on place activities. This could be achieved by increasing the number of case study areas and the number of observations within each area. Such an approach would allow for the inclusion of additional explanatory variables, such as weather, seasonal variations, and differences between weekdays and weekends. Additionally, observations across cities of varying sizes could provide insights into how the built environment impacts place activities.

However, larger sample sizes pose challenges in data collection and maintaining data quality. Automated data collection methods, such as video recordings with software for extracting the number and characteristics of place activities could mitigate these challenges. Long-term observation through such methods could reduce the data collection burden while capturing rich datasets. Nevertheless, issues related to data protection must be carefully addressed. Future studies should also record place activities with precise duration measurements (e.g., by minute and second) to deepen the understanding of these activities in all their dimensions.

In conclusion, this thesis underscores the essential role of pedestrian activities in creating livable and sustainable cities. By identifying determinants of walking and place activities, enhancing the visibility of stages in intermodal trips, and providing a comprehensive definitional framework, this thesis establishes a foundation for seamlessly integrating pedestrian activities into transport planning. It equips researchers and practitioners with the knowledge needed to foster human-centered, sustainable urban and transport development.

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6 Original research articles in full-text

6.1 Paper 1

Koszowski, Caroline; Wittwer, Rico; Hubrich, Stefan; Gerike, Regine (2024): Perceived importance of context-specific built-environment factors of walking: A new perspective for prioritizing policy measures for promoting walking. *International Journal of Sustainable Transportation*, *18*(3), 275–290. https://doi.org/10.1080/15568318.2023.2301372

6.2 Paper 2

Koszowski, Caroline; Hubrich, Stefan; Wittwer, Rico; Gerike, Regine (2024): From trips to stages: a methodology for Generating Stage Information in trip-level Household Travel Surveys. *Transportation*. https://doi.org/10.1007/s11116-024-10567-5

6.3 Paper 3

Koszowski, Caroline; Hubrich, Stefan; Wittwer, Rico; Gerike, Regine (under review): Streets as places – characteristics of place activities in the European context with the example of the City of Malmö (Sweden). Under review in *European Journal of Transport and Infrastructure Research*. Preprint. https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-971462

6.1 Paper 1

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Perceived importance of context-specific built-environment factors of walking: A new perspective for prioritizing policy measures for promoting walking

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ABSTRACT

Walking as one type of physical activity generates benefits for personal health and contributes to sustainability in its environmental, economic, and social dimensions. Based on a cross-sectional survey for a representative sample of German cities with at least 100,000 residents, this study investigates determinants of residents' walking behavior. Two contexts of promenading in the city for leisure walking and the trip to the supermarket for utilitarian walking are distinguished in order to investigate differences in respondents' perceived importance of built-environment characteristics and to bridge the gap between the individual level of residents' behavior and the streetscape level. In addition, the analyses distinguish between frequent and less frequent walkers in order to understand differences in characteristics, behavior, preferences, and perceptions between these two groups. The results of this study with a sample of $n = 4{,}637$ respondents show that the relevance of the built environment is higher for leisure walking than for utilitarian walking and higher for frequent walkers compared to less frequent walkers. For leisure walking, "protection"-variables are ranked high (e.g. safety, security), followed by "comfort" (e.g. space, surface quality) and by "delight" (e.g. attractive buildings, greenery). Distance is key for utilitarian walking. Significant differences between frequent and less frequent walkers are identified mainly for the "Delight"-variables, this is attractive buildings and greenery for utilitarian walking, and space availability and street furniture for leisure walking. These differences should be considered in future research and street design practice which might preferably focus on the most demanding person group of frequent walkers.

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Introduction

Walking for transport is beneficial from various perspectives. It is a zero emission, space-efficient, flexible and environmental-friendly transport mode. In combination particularly with public transport, it can cover all daily mobility needs. Walking as a physical activity contributes to meeting the goal of at least 150 min of moderate-intensity aerobic physical activity per week as formulated by WHO (2018) and thus significantly reduces the risk of non-communicable diseases and premature death (Guthold et al., 2018). Furthermore, a high share of pedestrians in public spaces is one important driver of the economic success of cities and contributes to social and livable public spaces (Gehl, 2010).

Studies on determinants of walking exist at two levels, this is (1) walking behavior of selected person groups at the individual level, e.g. of residents in a specific neighborhood (Gascon et al., 2019; Kerr et al., 2016; Wang et al., 2021) and (2) pedestrian volumes and behavior at streetscape level (Ewing & Clemente, 2013; Ewing & Handy, 2009; Gehl, 2010; Mehta, 2014). Dependencies between the two perspectives exist: when residents in a neighborhood walk more (individual level), more people can also be expected in the streets (streetscape level), and vice versa. Both perspectives are needed in order to develop targeted approaches for promoting walking (1) for selected person groups or (2) in specific street sections. Determinants at both perspectives can be grouped into supply side factors of the built environment at neighborhood level (meso-scale) and streetscape level (micro-scale) as well as person-related factors including mainly socio-demographic, socio-economic, and socio-psychological variables such as values, perceptions, preferences and norms (Götschi, Nazelle, Brand, & Gerike, 2017; Koszowski et al., 2019). Studies at streetscape level hardly include socio-demographic or other person-related variables; studies on residents' walking behavior at the individual level hardly include built-environment factors at streetscape level; both types of studies usually include variables describing neighborhood characteristics.

Overall, more studies on determinants of walking behavior exist at streetscape level and in addition, these are less heterogeneous with their clear focus on pedestrian volumes as dependent variable (Cambra & Goncalves, 2017; Ewing et al., 2012; Hermida et al., 2019; Lai & Kontokosta, 2018).

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Studies at the individual level investigate (i) weekly walking duration for transport and for leisure based e.g. on the International Physical Activity Questionnaire (IPAQ) (Boakye et al., 2023; Cervero et al., 2009; Craig et al., 2003; Gascon et al., 2019) or (ii) trip numbers and their characteristics from travel diaries or questions on typical behavior from travel surveys (Cao, 2010; Carlson et al., 2016; Cerin et al., 2014; Cerin et al., 2009; Hsieh & Chuang, 2021; Liao et al., 2020; Sauter et al., 2016). Both types of studies at the individual level have varying foci on the whole population in specific cities or regions (Brüchert et al., 2020; Chan et al., 2021; Hermida et al., 2019; Larrañaga et al., 2016), on specific person groups (Guliani et al., 2015; Loh et al., 2022) or on specific trip purposes such as travel to school or to work (Guliani et al., 2015; Ribeiro & Hoffimann, 2018). Built-environment variables are mainly operationalized by objective indicators based on Geographic Information Systems (GIS). The Neighborhood Environment Walkability Scale (NEWS), developed in the IPEN-study (Saelens et al., 2003), and its abbreviated form (Cerin et al., 2013; Cerin et al., 2006; Kerr et al., 2016) are the most prominent survey instruments that use perceived built-environment characteristics. Saelens et al. (2003) compare objective GIS-based and perceived built-environment characteristics and demonstrate that the latter reliably represent the built environment.

This study is positioned at the individual level, it focuses on the built-environment determinants and particularly on the relevance of streetscape characteristics for residents' walking behavior. Our main research goal is to better understand what makes people walking with four main contributions to the existing literature: For the first time, (1) we do not only ask for general built-environment characteristics of the neighborhood but instead, we introduce two different specific situations to respondents, this is first promenading in the city for leisure (or discretionary) walking and second the trip to the supermarket for utilitarian walking. This approach is based on the hypothesis that different streetscape characteristics matter for the different walking trip contexts (Hillnhütter, 2021) and that these differences can only be identified with specific questions on these specific contexts. In addition, this context-specific approach also allows us to bridge the gap between the individual level and the streetscape level. This study investigates residents' walking behavior at the individual level but thanks to the context-based approach, we can ask micro-level questions on the relevance of specific streetscape characteristics. (2) We distinguish in our analysis between frequent and less frequent walkers in order to understand differences in characteristics, behavior, preferences, and perceptions between these two groups. This approach is based on the hypothesis that people who walk more often might be more observant and attentive while walking and might assign different priorities to built-environment characteristics compared to people who walk less. (3) We develop one single question on built-environment characteristics of respondents' neighborhood which should be simple but at the same time it should well differentiate neighborhoods in terms of population density and land use diversity. In addition, the question should well match with the typical building and urban structures in German cities which have not been fully covered in the mainly American studies yet. (4) We create representative evidence for residents in German cities with at least 100,000 inhabitants. With these four main contributions, this study should inform efforts in urban and transport planning as well as in public health for promoting walking, public life, and physical activity.

The remainder of this paper is organized as follows: The state of the art on determinants of walking is presented in the section "Literature" , based on a literature review at both the individual and the streetscape level. The section "Methods" describes the study design followed by section "Statistical Analysis" that introduces the methods used for statistical data analysis. Afterwards results are presented in the section "Results" including two models focusing on determinants of leisure versus utilitarian walking behavior and on the differences between frequent and less frequent walkers. The models are built up groupwise by thematic blocks, to investigate the explanatory power of individual, meso-scale and micro-scale factors on walking. The final section discusses the results, compares them with the state of the art, develops recommendations for policy making in urban and transport planning and reflects the methodological strengths and limitations of the study.

Literature

Characteristics of the built environment

For the built environment, the "5 Ds" (Density, Diversity, Design, Distance to public transport, Destination accessibility) are consistently significant in quantitative analysis at both the individual and streetscape level. Density, measured e.g. by floor area ratios or population densities, and diversity, captured by entropy measures describing the number and variety of different land use types in a given area, are of particular importance for pedestrian volumes at specific street sections (Ewing et al., 2016; Lai & Kontokosta, 2018) as well as for residents' walking behavior (Christiansen et al., 2016; Gascon et al., 2019; Liao et al., 2020; Sugiyama et al., 2012; Vos et al., 2023). Shorter distances, particularly to rail-based public transport, consistently and significantly increase pedestrian volumes at streetscape level (Ewing et al., 2016; Kim et al., 2019) and also residents' walking activity (Brüchert et al., 2020; Gascon et al., 2019; Knuiman et al., 2014; Lam et al., 2022; Paydar et al., 2020). Design variables such as the connectivity of the street network are significant in some studies but not in others (Ewing et al., 2016; Sugiyama et al., 2012). Destination accessibility shows an overlap with diversity and is significant mainly at the individual level (Christiansen et al., 2016; Sugiyama et al., 2012; Wang et al., 2021) but less in studies on pedestrian volumes at streetscape level (Ewing et al., 2012; Ewing et al., 2016).

The Ds also apply to the streetscape level but are used at this level almost only for studies investigating correlates of pedestrian volumes. Density, measured e.g. as the total building floor area for parcels abutting the street divided by the total area of tax lots, consistently impacts significantly on pedestrian volumes (Ewing et al., 2016). Imageability, enclosure, human scale, transparency, and complexity are further relevant design variables at streetscape level (Ewing et al., 2012; Ewing & Handy, 2009).

Gascon et al. (2019) investigate the impacts of built-environment variables both at the home location and at the study or work location on residents' walking behavior based on GIS-data, they find higher relevance for built-environment characteristics at the home location (see also Vale & Pereira, 2016). Blue and green infrastructures are relevant particularly for recreational walking (Christiansen et al., 2016; Wang et al., 2021). Liao et al. (2020) point out in their GIS-based study that particularly areas with residential land use and inland water have positive impact on walking frequency. Coverage with and characteristics of pedestrian infrastructure hardly gets significant at the individual level for residents' walking behavior (Sugiyama et al., 2012) but positively impacts on pedestrian volumes (Kang, 2015; Kim et al., 2019).

Christiansen et al. (2016), based on GAMM-models and GIS data, find a linear relationship between residents' weekly walking time and land-use mix but not for residential density. This leads to the question, whether tipping points might exist for some of the correlates of walking.

Built-environment variables are generated from GIS-data (Gascon et al., 2019) or from survey-based questions on perceived walkability (Vos et al., 2023). The NEWS-questionnaire (Saelens et al., 2003) and its variations (see e.g. Sallis et al. (2010) for PANES as a short form of NEWS) are the most frequently used instruments that operationalize built-environment determinants of residents' walking behavior based on a validated list of items to be surveyed in a standardized questionnaire (Cerin et al., 2018; Kerr et al., 2016; Sallis et al., 2020; Van Dyck et al., 2012). NEWS in its original form measures 68 perceived attributes on (1) residential density, (2) land-use mix—diversity, (3) land-use mix—access, (4) street connectivity, (5) infrastructure and safety for walking, (6) esthetics, (7) pedestrian traffic safety and (8) crime safety (Cerin et al., 2006). Walking levels in studies that investigate the impact of perceived built-environment characteristics are mostly measured based on the IPAQ-questionnaire. This questionnaire distinguishes between walking for transport and for recreation and thus generates insights on context-specificity of walking behavior. Residential density and land-use mix diversity apply for both walking purposes (Boakye et al., 2023; Cerin et al., 2014; Kerr et al., 2016) with a stronger effect for recreational walking (Lam et al., 2022). Crime and safety (Boakye et al., 2023) as well as esthetics are significant for recreational walking (Boakye et al., 2023; Van Cauwenberg et al., 2018). Hsieh and Chuang (2021) distinguish between purposive and discursive walking and find similar effects. Residential density, land-use mix diversity, and traffic safety are associated with purposive walking while esthetics and crime safety are associated with discursive walking. Land-use mix access and street connectivity are common correlates of both walking patterns. No studies could be identified that investigate the impact of built-environment characteristics on walking behavior separately for persons with low or high walking frequencies.

Person-related determinants of walking behavior

Younger and older person groups have higher walking frequencies compared to persons aged in between in some studies (Liao et al., 2020) while the age variable does not get significant in others (Gascon et al., 2019). Women tend to walk more than men (Wang et al., 2021; Wasfi et al., 2017). Van Dyck et al. (2012) investigate interaction effects with built-environment characteristics and find some significant effects. For example, men are shown to be more sensitive to land use mix-access than women in terms of walking. Gascon et al. (2019) find less walking with higher education levels but no effect of education was found in most other studies (Cerin et al., 2009; Wang et al., 2021; Wasfi et al., 2017). Income is included only in few studies with mixed findings. For example, Moudon et al. (2007) and Brüchert et al. (2020) find more walking with higher income whereas Wang et al. (2021) find the opposite effect. People not working walk more compared to working people (Gascon et al., 2019), people with access to a car consistently walk less (Gascon et al., 2019; Wang et al., 2021). The same holds for access to bicycles (Gascon et al., 2019). Mixed findings exist for the effect of household characteristics on walking behavior. Wasfi et al. (2017) find higher walking levels for people living alone than in couples for younger but not for older persons whereas Wang et al. (2021) find more walking for couples. People who are physically active in their leisure time walk more than people who are not (Wasfi et al., 2017) and also healthy people walk more than people who have any difficulties to walk (Moudon et al., 2007; Wasfi et al., 2017). Only few studies exist that analyze the associations between socio-psychological variables and walking behavior. Pro-walking social norm is consistently related to higher walking levels (Gascon et al., 2019; Moudon et al., 2007). Based on a principal component analysis, Gascon et al. (2019) generate composite factors and analyze their impact on weekly walking duration. They find significant increases of walking with higher importance of safe, healthy, sustainable, and private travel as well as decreases when short, flexible, and predictable travel times are important. They find positive impacts of good opinions on walking and in addition interdependencies between walking levels and the use of the alternative modes.

Methods

Study design and data structure

This study is based on a cross-sectional online-survey on active mobility conducted in 2017 in twelve German cities with at least 100,000 inhabitants. The survey aimed at collecting data that represents resident behavior for German cities of this size. The sample was therefore drawn in a two-stage process. First, eight German cities with different city size (100,000–200,000 inhabitants; 200,000–500,000 inhabitants; $\geq$ 500,000 inhabitants) and topography (flat and hilly) were selected randomly; four additional cities were set from the beginning because these had been chosen as living labs where measures to promote active mobility were foreseen.

The second stage included the random selection of residents $\geq$ 18 years of age from the registry of residents for each of the selected cities. Finally, 4,637 persons aged between 18 and 99 from the twelve German cities, grouped by city size and topography, provided a fully completed questionnaire. The characteristics of the sample are summarized in Table 1. They are presented in comparison with the results of the household travel survey "Mobility in Cities—SrV 2018" which reliably represents the population and their travel behavior in German cities (Hubrich et al., 2019). Official population statistics could not be used for comparison as these exist only for each individual city and because relevant variables such as car availability are missing.

The two samples match well for the variables gender, number of children in the household, and also for the accessibility of public transport. The sample in this study is in average younger than in SrV 2018, this is consistent with differences in the employment status. Car ownership is with 1.12 cars per household higher in this study than in SrV 2018 with 0.9 cars per household. One reason for this might be the bias of the sample in this study toward highly educated persons, the share of respondents with high school graduation is with 74% substantially higher in this study than in SrV 2018 with 53%. There is consensus in the literature that education levels relate to income and that income levels relate to car ownership respectively car availability (Buehler et al., 2017). It is thus very likely that the bias toward higher education levels impacts on car ownership (German Environment Agency, 2020; Hubrich, 2017). The number of bicycles per household in this study is with 2.19 bicycles per household higher than in SrV 2018 with 1.6. This indicates a possible bias toward persons who are interested and engaged in active mobility as the topic of this study. Descriptive statistics for the area type and accessibility of facilities for daily needs (food/supermarket, bakery, drugstore, pharmacy, parcel counter) are also presented but could not be compared to SrV 2018. There is a balanced distribution of area types, only 12% of respondents can reach all five facilities for daily needs within a 5-min walk.

Dependent variable for logistic regression models and model selection

The dependent variable for the logistic regression models in this study is the "frequency of walking in general" as the main target and ambition in urban and transport planning with substantial synergies to public health with its focus on the duration of walking and physical activity. Respondents stated their typical walking behavior within the last twelve months in seven categories ranging from "daily or almost daily" to "never" without any limitations in terms of time or distance. This question is consistent with standard household travel surveys (Hubrich et al., 2019). For this study, the dependent variable "frequency of walking in general" ($n = 4{,}637$) is binary coded (0/1) in

- Persons walking less than three to four days a week (share = 43%)
- Persons walking daily or almost daily (share = 57%)

This classification is chosen for two main reasons: First, both groups of frequent and less frequent walkers are represented with almost equal shares in the sample which is beneficial particularly for setting up the statistical models. Second, our initial tests of different possible groupings of this variable showed that a more detailed classification of

Table 1. Sample characteristics in this study in comparison to "Mobility in Cities – SrV 2018".

Variables	This study (weighted; $n = 4{,}637$) Mean (SD)/Share %	Mobility in Cities – SrV 2018 (weighted; $n = 22{,}999$) Mean/Share %
Age (Average Years)	46.55 (18.06)	51.13
Gender: Women	50 %	51 %
Gender: Men	50 %	49 %
Number of Children in Household		
No Children in Household	82 %	81 %
At Least one Child in Household under 16 years	18 %	19 %
Average Number of Cars in Household (Total Private and Business Cars)	1.12 (0.84)	0.9
Average Number of Bicycles in Household (Total Conventional Bicycles and E-Bikes)	2.19 (1.69)	1.6
Employment:		
In Education	16 %	9 %
Employed Persons Aged Under 35 Years	16 %	14 %
Employed Persons Aged 35 and More Years	41 %	41 %
Non-Employed Persons	5 %	5 %
Retired	22 %	31 %
High-School Graduation (Yes)	74 %	53 %
Area Type by Predominant Building Type		
Detached Single-Family Houses	23 %	No information
Detached Apartment Buildings	14 %	No information
Rowed Apartment Buildings in Residential Areas	34 %	No information
Rowed Apartment Buildings in Mixed Areas	29 %	No information
Accessibility		
Accessibility of 5 out of 5 Facilities of Daily Needs* in a 5-Minute Walk	12 %	No information
Less Than 5 Facilities of Daily Needs in a 5-Minute Walk Accessible	88 %	No information
Accessibility of at Least One Public Transport Mode (Bus or Tramway) in a 5-Minute Walk	81 %	77 %
No Public Transport Mode Accessible (Bus or Tramway) in a 5-Minute Walk	19 %	23 %

*food/supermarket, bakery, drugstore, pharmacy, parcel counter.

walking frequency does not yield significant differences between the groups. These differences seem to emerge only with the distinction between (almost) daily walking and all other walking practices.

We investigate built-environment determinants at the micro-scale for this dependent variable in the two different contexts of promenading in the city and of walking to the supermarket leading to the two different logistic regression models, each of them built-up by thematic blocks as introduced below.

Overview of independent variables for logistic regression models

The independent variables for this study as shown in Table 2 are chosen based on the literature review. They cover three levels: (1) socio-demographic/economic variables at the individual level, (2) built-environment variables at the neighborhood level (meso-scale) and (3) at streetscape level (micro-scale). Built-environment variables are the main focus of this study, they are classified along the 5 Ds as introduced above. For population

Table 2. Structure of independent variables and reference to D-variables.

Level	Set of variables		Reference to D-Variables
Individual Factors: (Socio-Demographic and Socio-Economic Factors)	Children in Household (Reference Category: No Children)		**D**emography
	Number of Cars in Household (Total Private and Business Cars)		
	Number of Bicycles in Household (Total Conventional Bicycles and E-Bikes)		
	Employment:		
	In Education (Reference Category)		
	Employed Persons Aged Under 35 Years		
	Employed Persons Aged 35 and More		
	Non-Employed Persons		
	Retired		
	Gender (Reference Category: Male)		
	High-School Graduation (Reference Category: No High School Diploma)		
Meso-Scale Factors (Neighborhood)	Area Type by Predominant Building Type		**D**ensity and **D**iversity
	Detached Single-Family Houses (Reference Category)		
	Detached Apartment Buildings		
	Rowed Apartment Buildings in Residential Areas		
	Rowed Apartment Buildings in Mixed Areas		
	Accessibility Factors		
	Accessibility of 5 out of 5 Facilities of Daily Needs in a 5-Minute Walk (Reference Category: Less Than 5 Facilities Accessible)		**D**estination Accessibility
	Accessibility of at Least One Public Transport Mode in a 5-Minute Walk (Reference Category: No Public Transport Mode Accessible)		**D**istance to Transit
Micro-Scale Factors (Streetscape)	**Model 1: Leisure Walking (n= 4,637)** *Imagine you promenade in the city. How important are the following characteristics for the attractivity of street space?**	**Model 2: Utilitarian Walking (n= 2,036; Only Persons Walking to Supermarket)** *What motivates you to walk to the grocery? I walk to the grocery because …***	Design
		Factors of Distance	
	–	The Walk Is Not Long**	
	–	It Goes the Fastest by Walking**	
	Factors of Comfort		
	–	It Is Not Hilly**(-)	
	High Surface Quality (Flat, Non-Slip, Without Damage)*	Sidewalks Are Easy To Walk On**(-)	
	Much Space to Walk*	Sidewalks Are Sufficiently Wide**	
	Street Furniture (e.g. seating, bins)*	Along the Walkway There Are Opportunities To Sit**	
	Public Toilets*	–	
	Good Lighting*	Sidewalks Are Well Lit**(-)	
	Factors of Delight		
	Trees and Planting Along Sidewalks*	Along the Walkway There Are Attractive Green Areas (e.g. parks, trees)**	
	First Floor in Adjacent Buildings With Shop Windows and/or Gastronomy Along the Sidewalk*	–	
	Attractive Buildings (e.g. Façade)*	Along the Walkway There Are Attractive Buildings**	
	Appropriate Height of Buildings in Relation to the Street Space (Streetscape Proportions)*	–	
	Factors of Protection		
	Low Vehicle Traffic*	Along The Walkway Traffic Is Low**	
	Low Speed of Vehicle Traffic*(-)	–	
	Crime-Related Security*	Along The Walkway It Is Secure (Crime-Related)**	
	Traffic Accident Safety*	Along The Walkway It Is Safe (Traffic-Related) **(-)	
	Safe Crossings*	–	

Scale:
*(Somewhat) unimportant, (Somewhat) important;
**I (somewhat) do not agree, I (somewhat) agree
(-)Variable was not included into model, because of multicollinearity (see Chapter of Statistical Analysis).

"Density" and land use "Diversity" at the meso-level, our ambition is to formulate one question that is simpler and easier to answer than the NEWS-questionnaire but still captures these two important variables for typical built-environment contexts in German cities comprehensively. Two questions on "Destination" accessibility and "Distance" to transit are added at the meso-level. Variables for "Design" are formulated at the micro-level of specific streetscapes for the two contexts of leisure and utilitarian walking. These variables are classified into the three groups of streetscape-level walking determinants developed by Gehl (2010), this is "Protection" as the basic requirements (e.g. safety, security), "Comfort" (e.g. space, surface quality) and "Delight" (also sometimes referred to as "Amenities" , including e.g. streetscape proportions, street furniture).

Meso-scale factors at neighborhood level

The concept for describing the built environment at neighborhood level is visualized in Figure 1. First, respondents were asked in question 1.1 to characterize the building types in their neighborhood. If in question 1.1 the category "rowed apartment houses" was ticked as a particularly diverse building type that can appear as parallel buildings or as blocks with backyards, and that fits in various types of areas (mixed or residential areas), respondents were asked to specify in a second question 1.2 the predominant type of rowed apartments in their neighborhood in more detail which corresponds to the diversity of land use in the neighborhood. In question 1.1, respondents had the possibility to check off multiple response categories in order to account for possible heterogeneity of building types within one neighborhood. For a distinct classification of the neighborhood type for each respondent within one variable, the multiple answers from question 1.1 were aggregated based on the potential number of persons per housing unit in each category into the new variable "Predominant Building Type—Ranked". The category "Rowed Apartment Houses" was expected to have the highest values in terms of potential number of persons, hence it got the highest rank (=5) whereas detached single-family houses were assigned the lowest rank (=1). Respondents who ticked "not present" or "all buildings correspond to this building type" for all categories in question 1.1 were excluded from further analysis for reasons of implausibility ($n = 62$). The final new variable "Area Type by Predominant Building Type" to be used for the analysis was finally built as a combination of the new variable "Predominant Building Type—Ranked (grouped)" and question 1.2 as shown in Figure 1 (see also Figure S1 and Table S1 in the Supplementary Material).

Micro-scale factors at streetscape level and model selection

Based on the literature review, we hypothesize that built-environment-walking factors at the meso-scale can be uniformly formulated for leisure and utilitarian walking purposes. Therefore, we use general variables at this level as introduced above. For the micro-level, for specific street sections, however, we hypothesize that the relevance of the different built-environment characteristics differs depending on the trip purpose. People might be more attentive to their environment when walking for leisure compared to utilitarian walking and particularly in cases when the boundary between walking to get to destinations and walking as an activity in its own gets blurred, when people come to streets as destinations and not to get to destinations. They might give particular relevance to esthetics and nice surroundings in these cases.

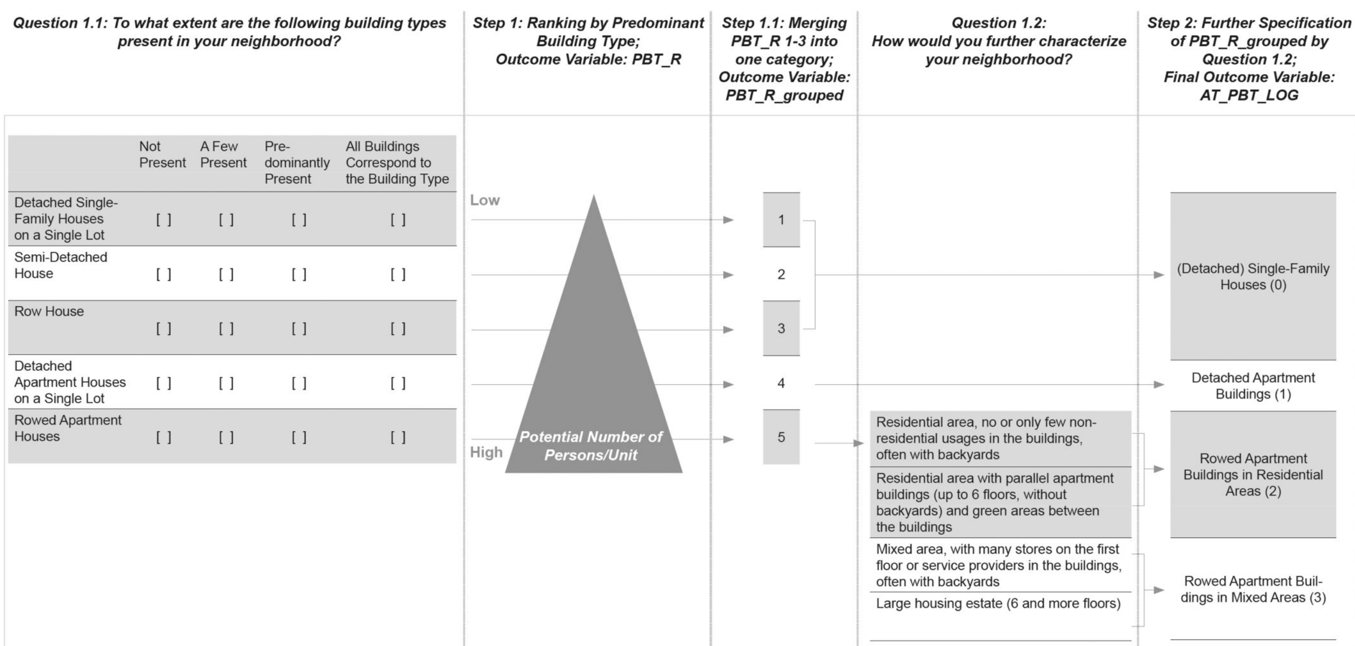

Figure 1. Procedure and composition of the new variable "area type by predominant building type".

We therefore distinguish in Table 2 two sets of micro-scale-built-environment factors, this is first "leisure walking" and second "utilitarian walking". The example of promenading in the city is used as the context for leisure walking and the weekly trip to the supermarket as the context for utilitarian walking, it seems to be most suitable in the context of local mobility, seeing that walking is a transport mode with highest sensitivity to distance and that hardly any respondent (only around 10% of our sample) walks all the way to work or to education. Micro-scale items for these two contexts are chosen as shown in Table 2 based on the following hypotheses: (1) the speed while walking for leisure is particularly low and the awareness of streetscape characteristics is higher than for utilitarian trips (Hillnhütter, 2021), (2) the relevance of distance is high for utilitarian walking trips but low for leisure trips, (3) different types of equipment of pedestrian facilities matter for utilitarian and leisure trips, e.g. public toilets are important for leisure but less for utilitarian walking whereas functional qualities of pedestrian facilities such as space availability or smooth surfaces might be more important for utilitarian walking.

Two models are developed based on these considerations, one for leisure walking and one for utilitarian walking. The "frequency of walking in general" is the dependent variable in both models. There is no difference between the two models in the person-related variables and the built-environment factors at the meso-scale but at the micro-scale as explained above. Micro-scale-built-environment factors are binary coded for leisure walking trips into 0= (somewhat) unimportant and 1= (somewhat) important; and for utilitarian walking trips into 0= I (somewhat) do not agree and 1= I (somewhat) agree. The full sample can be used for model 1. For model 2, only respondents are considered who state that they usually walk to the supermarket. Figure 2 gives an overview of the main characteristics of the two models.

Statistical analysis

Initial tests of data structures and model selection

Seeing that walking frequency is chosen as the binary coded dependent variable, binary logistic regression is the appropriate method for the modeling part of this study (see e.g. Hosmer et al., 2013). To legitimate the application of a "one level"-logistic regression and to obtain correct estimations for the regression coefficients, the independence of data structures and of the different levels of analysis has to be tested first (Ali et al., 2019; Austin & Merlo, 2017; Sommet & Morselli, 2017). Two levels need to be considered; this is first respondents' person and household characteristics (level 1: individual) and second their home location, by definition respondents live in either of the twelve German cities selected for this study as described above (level 2: context).

Multilevel logistic regression in the form of a Random Intercept-Only Model is applied without specific predictors (independent variables) to verify whether data structures are nested and to understand which proportion of the variance of the dependent variable can be assigned to the respondent (level 1: individual) respectively to the city (level 2: context) (Tausendpfund, 2020). The application of this model with the help of the generalized linear mixed-model package in SPSS Version 27 shows that the random intercept variance var(u_{0j}) is with 0.002 not statistically significant ($p > 0.05$). The Intraclass Correlation Coefficient (ICC) can be calculated based on this result as shown in Equation (1) below. The ICC quantifies the variance of the dependent variable at the context level 2. According to the literature, in social science cluster effects occur typically for ICC-values between 0.05 and 0.25 (Snijders, 2012; Tausendpfund, 2020).

$$ICC = \frac{var(uoj)}{var(uoj) + \pi^2/3} = \frac{0.002}{0.002 + \pi^2/3} = 0.0006 \qquad (1)$$

With an ICC of 0.0006 and the non-significant random intercept variance, data structures can be assumed as independent. This means, that the variance of the dependent variable can largely be explained by respondent characteristics, the context level does not need to be considered further (Tausendpfund, 2020). With this result, the first condition for running a "one-level" standard binary logistic regression is fulfilled.

Avoiding multicollinearity between independent variables is the second requirement for logistic regression analysis. It is tested with the Pearson-Product-Correlation Coefficient which is appropriate for testing the correlation of metric and dichotomous dummy-coded (0/1) variables (Bortz, 2010; Brosius, 2018). Predictors with strong correlations ($r \geq 0.5$) are excluded from logistic regression. The final correlation matrices of model 1 and model 2 are provided in the Supplementary Material (Tables S2–S3).

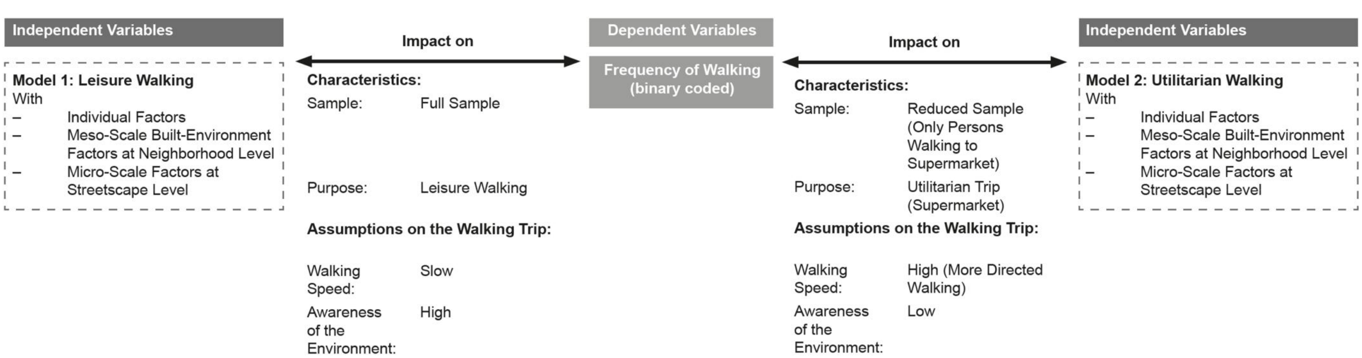

Figure 2. Comparison of characteristics of the two models.

Based on these two initial tests, a binary logistic regression analysis can be applied to estimate the impact of individual, meso-scale and micro-scale variables on the frequency of walking.

Model selection and diagnostics

Two models are computed using SPSS Version 27 as shown in Tables 3 and 4, the first one for leisure walking and the second one for utilitarian walking. Thematic blocks of independent variables are added one after the other for each of the two models in order to investigate the explanatory power of individual, meso-scale and micro-scale factors on walking.

The goodness of fit criterion R^2 Nagelkerke and the information criteria Akaike Information Criterion (AIC) as well the Bayesian Information Criterion (BIC) are used for model diagnostics and comparison. R^2 Nagelkerke as shown in Tables 3 and 4 is acceptable seeing that R^2-statistics are consistently lower in logistic regressions compared to linear regressions (Backhaus et al., 2018). Cao (2010) find in his binary logit model a comparable pseudo-R^2-value which he classifies as typical for disaggregated data with large sample sizes, this applies also for our study (see also Steyerberg, 2019). Higher numbers of explanatory variables also reduce pseudo-R^2-values (Wolf & Best, 2010). Backhaus et al. (2008) state that the explanatory power of models in social sciences with values from 0.5 can be interpreted as very good. Overall, our ambition is not to fully explain the variance in walking behavior with the models but rather to identify main mechanisms and significant effects in how built-environment characteristics impact on behavior. Seeing these specificities of R^2 Nagelkerke, we apply AIC and BIC as complementary criteria in order to ensure the comprehensive evaluation and comparison of the different models (Wolf & Best, 2010). Both information criteria consider the number of explanatory variables (k) as shown in the Equations (2) and (3) but only the BIC takes sample size into account and does thus better fit for studies with larger sample sizes.

$$AIC = -2LL + 2*(k+1) \tag{2}$$

$$BIC = -2LL + \ln(n)*(k+1) \tag{3}$$

With the increase of pseudo R^2statistics, both information criteria AIC and BIC should decrease so that models with the lowest values can be considered as most suitable (see e.g. Gehrke, 2019; Wolf & Best, 2010). In this study, in both models the negative tendency of AIC and BIC becomes visible with the successive addition of independent variables (see Figures 3 and 4).

Regarding the correct classification of the samples within the models, both show values above the random classification probability (see e.g. model 1.5: 63%; model 2.6: 73%). Both models are significant ($p < 0.001$), which is a result of the Likelihood-Ratio-Test and indicates that the models containing explanatory variables improves the fit in relative to their intercept-only models (see e.g. Crownson, 2020).

Besides parameters of goodness of fit, the stability of effect directions and Odds as well as the logical interpretability of models, which are all given in our models, also contribute to the explanatory power of the models.

Results

Descriptive statistics for micro-scale built-environment factors

Figures 5 and 6 show the importance and relevance of micro-scale-built-environment characteristics for leisure and for utilitarian walking. Overall, the relevance of the built environment is higher for leisure walking than for utilitarian walking and higher for frequent walkers compared to less frequent walkers. For leisure walking, traffic safety and security are paramount, between 95 and 97% of respondents indicate (somewhat) importance to these factors following by good lighting with 95% which concerns both, safety and comfort. High importance for leisure walking is also assigned to trees and planting along the sidewalk, space, surface quality, low vehicle traffic, street furniture and attractive buildings with 79 to 93% of respondents indicating (somewhat) importance to these variables. First floor usage (64%), streetscape proportions (61%) and public toilets (50%) get lowest levels of agreement. The low levels of agreement for public toilets might result from differences between age groups and respondents' health conditions. The availability of public toilets in general is (somewhat) important for about 64% of all respondents in the age-group of 65 years and older. Within the younger age groups the importance decreases. For 49% of the respondents in the age group of 35 to 64 years and for 44% of the 18 to 34 years old respondents, the availability of public toilets is (somewhat) important. Differences between frequent and less frequent walkers are generally low with highest values for "Lot of Space to Walk" and "Street furniture".

The relevance of built-environment characteristics looks different for utilitarian walking. Short distances to destinations are of highest relevance, 95% of respondents rank these as (somewhat) important. All other variables are less important. Walking to the supermarket as the fastest alternative is indicated by 79% and sufficient widths of sidewalks by 77% of respondents as reasons for choosing the walking mode, followed by crime-related security (51%), green areas (39%), low traffic (38%) and attractive buildings (34%). Differences between frequent and less frequent walkers mainly exist in the variables with overall lower levels of agreement, this is "Attractive Buildings" and "Attractive Green Areas" along the walkway. Differences between frequent and less frequent walkers are higher for utilitarian walking compared to leisure walking. Both person groups seem to be similarly attentive to their environment when they walk for leisure whereas for utilitarian walking, frequent walkers seem to be more attentive than less frequent walkers.

Models for leisure and utilitarian walking

Tables 3 and 4 show the final logistic regression models for leisure and utilitarian walking with five (model 1) respectively six stages (model 2). All coefficients and odds ratios

Table 3. Model 1 – determinants of walking frequency for leisure walking.

	Model 1.1		Model 1.2		Model 1.3		Model 1.4		Model 1.5	
Variables	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio
Constant	0.82***	2.26	−0.13	0.88	−1.04	0.35	−0.90**	0.41	−1.56***	0.21
Individual Factors: Socio-Demographical and Socio-Economical Factors										
Children in Household[a]	0.18 (1.00-1.45)	1.20	0.18 (0.99-1.45)	1.20	0.18 (0.98-1.45)	1.19	0.18 (0.98-1.45)	1.19	0.16 (0.96-1.43)	1.17
Number of Cars in Household (Private, Business)	−0.37*** (0.64-0.75)	0.69	−0.26*** (0.71-0.84)	0.77	−0.27*** (0.70-0.83)	0.76	−0.26*** (0.71-0.84)	0.77	−0.27***(0.70-0.84)	0.77
Number of Bicycles in Household (Conventional Bicycles, E-Bikes)	−0.02 (0.94-1.02)	0.98	−0.01 (0.94-1.03)	0.99	−0.01 (0.95-1.04)	0.99	−0.01 (0.95-1.04)	0.99	−0.01 (0.95-1.04)	0.99
Employment:										
Employed Persons Aged Under 35 Years[b]	−0.50*** (0.48-0.76)	0.61	−0.66*** (0.41-0.65)	0.52	−0.66*** (0.41-0.65)	0.52	−0.66*** (0.41-0.66)	0.52	−0.65*** (0.41-0.67)	0.52
Employed Persons Aged 35 and More[b]	−0.48*** (0.51-0.75)	0.62	−0.47*** (0.51-0.77)	0.63	−0.46*** (0.51-0.77)	0.63	−0.46*** (0.51-0.78)	0.63	−0.44*** (0.52-0.79)	0.64
Non-Employed Persons[b]	0.50** (1.13-2.40)	1.64	0.60** (1.23-2.67)	1.81	0.60** (1.23-2.70)	1.82	0.60** (1.24-2.71)	1.83	0.62** (1.26-2.76)	1.86
Retired[b]	−0.01 (0.79-1.24)	0.99	0.19 (0.95-1.52)	1.20	0.21 (0.97-1.58)	1.24	0.21 (0.97-1.58)	1.24	0.25* (1.01-1.65)	1.29
Gender[c]	0.06 (0.93-1.20)	1.06	0.08 (0.95-1.24)	1.08	0.04 (0.91-1.20)	1.04	0.03 (0.90-1.18)	1.03	0.01 (0.88-1.16)	1.01
High-School Graduation[d]	0.1 (0.94-1.29)	1.10	0.07 (0.91-1.25)	1.07	0.09 (0.93-1.29)	1.09	0.09 (0.93-1.29)	1.10	0.11 (0.94-1.31)	1.11
Factors on Meso-Scale at Neighborhood Level										
Area Type by Predominant Building Type										
Detached Apartment Buildings[e]			0.37** (1.15-1.82)	1.45	0.38** (1.17-1.84)	1.47	0.39** (1.18-1.87)	1.48	0.39** (1.17-1.86)	1.48
Rowed Apartment Buildings in Residential Areas[e]			0.38*** (1.22-1.76)	1.47	0.36*** (1.20-1.73)	1.44	0.37*** (1.20-1.74)	1.45	0.38*** (1.22-1.77)	1.47
Rowed Apartment Buildings in Mixed Areas[e]			0.37*** (1.91-2.87)	2.34	0.84*** (1.89-2.86)	2.32	0.85*** (1.89-2.87)	2.33	0.84*** (1.88-2.86)	2.32
Accessibility Factors										
Accessibility of 5 out of 5 Facilities of Daily Needs in a 5-Minute Walk[f]			0.43*** (1.22-1.92)	1.53	0.41*** (1.20-1.89)	1.51	0.42*** (1.22-1.92)	1.53	0.42*** (1.21-1.92)	1.52
Accessibility of at Least One Public Transport Mode in a 5-Minute Walk[g]			0.41*** (1.26-1.79)	1.50	0.43*** (1.29-1.83)	1.54	0.43*** (1.28-1.83)	1.53	0.43*** (1.29-1.84)	1.54
Importance of Micro-Scale Streetscape Factors										
Comfort										
High Surface Quality (Flat, Non-Slip, Without Damage)[h]					0.21 (0.98-1.56)	1.23	0.20 (0,96-1,54)	1.22	0.17 (0.93-1.50)	1.18
A Lot of Space to Walk[h]					0.45** (1.21-2.02)	1.56	0.48*** (1.25-2.09)	1.62	0.52*** (1.28-2.19)	1.68
Street Furniture[h]					0.30** (1.12-1.62)	1.34	0.32** (1.14-1.66)	1.38	0.34*** (1.17-1.70)	1.41
Public Toilets[h]					−0.14* (0.75-1.00)	0.87	−0.14 (0.75-1.00)	0.87	−0.15* (0.75-1.00)	0.86
Good Lighting[h]					0.11 (0.82-1.53)	1.12	0.11 (0.82-1.53)	1.12	0.06 (0.77-1.46)	1.06
Delight										
Trees and Planting Along Sidewalks[h]							−0.16 (0.64-1.13)	0.85	−0.16 (0.64-1.14)	0.86
First Floor Area With Shop Windows and/or Gastronomy Along the Sidewalks[h]							−0.06 (0.82-1.10)	0.95	−0.05 (0.82-1.10)	0.95
Attractive Buildings (e.g. Façade)[h]							0.03 (0.86-1.23)	1.03	0.04 (0.87-1.24)	1.04
Appropriate Height of Buildings in Relation to the Street Space[h]							−0.03 (0.84-1.12)	0.97	−0.02 (0.84-1.13)	0.98
Protection										
Low Vehicle Traffic[h]									−0.1 (0.76-1.08)	0.91
Crime-Related Security[h]									0.50* (1.09-2.51)	1.65
Traffic Accident Safety[h]									0.44 (0.98-2.46)	1.55
Safe Crossings[h]									−0.20 (0.58-1.15)	0.82
Model-Specific Parameters										
R^2 Cox&Snell | R^2 Nagelkerke | Chi^2 (Model)	0.04 | 0.06 | 177.8		0.08 | 0.11 | 320.3		0.09 | 0.12 |353.0		0.09 | 0.12 | 349.3		0.09 | 0.12 | 360.7	
Sample Size | Percentage of Correct Classification | Significance	3,884 |58 % | p < 0.001		3.884 | 62 % | p < 0.001		3.842 | 63 % | p < 0.001		3.811 | 63 % | p < 0.001		3.788 | 63 % | p < 0.001	
−2LL | df(x) | AIC | BIC	5,157 | 9 | 5,175 | 5,231		5,015 | 14 | 5,043 | 5,130		4,926 | 19 | 4,964 | 5,083		4,887 | 23 | 4,933 | 5,077		4,844 | 27 | 4,898 | 5,066	

Reference Categories:
[a]No Children;
[b]In Education;
[c]Male;
[d]No High School Diploma;
[e](Detached) Single-Family Houses;
[f]Less Than 5 Facilities Accessible;
[g]No Public Transport Mode Accessible;
[h](Somewhat) Unimportant;
*p-values: $p < 0.05$;
**$p < 0.01$;
***$p < 0.001$

Table 4. Model 2 – determinants of walking frequency for utilitarian walking.

	Model 2.1		Model 2.2		Model 2.3		Model 2.4		Model 2.5		Model 2.6	
Variables	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio	Beta (95% CI)	Odds ratio
Constant	1.00***	2.72	0.42	1.53	0.08	1.09	0.12	1.13	0.05	1.05	0.48	1.61
Individual Factors: Socio-Demographical and Socio-Economical Factors												
Children in Household[a]	0.07 (0.78-1.45)	1.07	0.06 (0.78-1.45)	1.06	0.04 (0.76-1.42)	1.04	0.08 (0.78-1.49)	1.08	−0.01 (0.71-1.38)	0.99	−0.10 (0.64-1.29)	0.91
Number of Cars in Household (Private, Business)	−0.17* (0.74-0.97)	0.85	−0.12 (0.78-1.02)	0.89	−0.13 (0.76-1.00)	0.87	−0.19*(0.72-0.96)	0.83	−0.19* (0.71-0.96)	0.83	−0.25** (0.66-0.92)	0.78
Number of Bicycles in Household (Conventional Bicycles, E-Bikes)	0.03 (0.96-1.10)	1.03	0.03 (0.96-1.10)	1.03	0.03 (0.97-1.11)	1.04	0.03 (0.96-1.11)	1.04	0.02 (0.56-1.10)	1.02	0.05 (0.97-1.14)	1.05
Employment:												
Employed Persons Aged Under 35 Years[b]	−0.54** (0.42-0.79)	0.58	−0.68*** (0.37-0.70)	0.51	−0.66*** (0.37-0.71)	0.51	−0.64*** (0.38-0.73)	0.53	−0.59** (0.40-0.78)	0.56	−0.47* (0.43-0.90)	0.62
Employed Persons Aged 35 and More[b]	−0.24 (0.59-1.05)	0.79	−0.31* (0.55-0.98)	0.74	−0.32* (0.54-0.98)	0.73	−0.25 (0.58-1.05)	0.78	−0.23 (0.58-1.08)	0.80	−0.26 (0.55-1.07)	0.77
Non-Employed Persons[b]	0.47 (0.87-2.92)	1.59	0.46 (0.86-2.93)	1.58	0.48 (0.87-2.99)	1.61	0.50 (0.89-3.07)	1.65	0.55 (0.91-3.33)	1.74	1.03* (1.23-6.34)	2.79
Retired[b]	0.47* (1.11-2.30)	1.60	0.54** (1.18-2.48)	1.71	0.64** (1.30-2.78)	1.90	0.68** (1.34-2.89)	1.97	0.89*** (1.60-3.69)	2.43	1.09*** (1.89-4.67)	2.97
Gender[c]	0.12 (0.92-1.39)	1.13	0.12 (0.91-1.40)	1.13	0.10 (0.89-1.37)	1.10	0.10 (0.89-1.37)	1.10	0.07 (0.85-1.34)	1.07	0.15 (0.91-1.48)	1.16
High-School Graduation[d]	0.00 (0.77-1.30)	1.00	−0.07 (0.71-1.22)	0.93	−0.07 (0.71-1.23)	0.94	−0.09 (0.69-1.21)	0.92	0.05 (0.78-1.41)	1.05	0.03 (0.76-1.42)	1.03
Factors on Meso-Scale at Neighborhood Level												
Area Type by Predominant Building Type												
Detached Apartment Buildings[e]			0.64** (1.21-2.96)	1.89	0.67** (1.23-3.08)	1.95	0.33 (0.99-1.94)	1.39	0.66** (1.19-3.13)	1.93	0.53* (1.01-2.85)	1.70
Rowed Apartment Buildings in Residential Areas[e]			0.33 (1.00-1.92)	1.39	0.35* (1.01-1.97)	1.42	0.64** (1.19-2.99)	1.89	0.35 (0.99-2.02)	1.42	0.21 (0.84-1.82)	1.24
Rowed Apartment Buildings in Mixed Areas[e]			0.68*** (1.41-2.77)	1.97	0.67*** (1.38-2.77)	1.96	0.66*** (1.36-2.75)	1.93	0.75*** (1.45-3.09)	2.11	0.66** (1.29-2.93)	1.94
Accessibility Factors												
Accessibility of 5 out of 5 Facilities of Daily Needs in a 5-Minute Walk[f]			0.32* (1.02-1.84)	1.37	0.35* (1.05-1.92)	1.42	0.40* (1.09-2.02)	1.48	0.38* (1.05-2.02)	1.46	0.33 (0.99-1.96)	1.39
Accessibility of at Least One Public Transport Mode in a 5-Minute Walk[g]			0.14 (0.84-1.57)	1.15	0.10 (0.80-1.52)	1.10	0.13 (0.82-1.57)	1.14	0.14 (0.82-1.63)	1.15	0.17 (0.82-1.71)	1.18
Relevance of Micro-Scale Streetscape Factors												
Distance												
The Walk Is Not Long[h]					0.44 (0.93-2.60)	1.55	0.44 (0.92-2.61)	1.55	0.24 (0.74-2.20)	1.27	−0.08 (0.49-1.72)	0.92
It Goes the Fastest by Walking[h]					−0.05 (0.71-1.26)	0.95	−0.06 (0.71-1.26)	0.94	−0.06 (0.69-1.28)	0.94	−0.09 (0.66-1.28)	0.92
Comfort												
Sidewalks Are Sufficiently Wide[h]							−0.03 (0.75-1.26)	0.97	−0.12 (0.68-1.17)	0.89	−0.06(0.70-1.27)	0.94
Delight												
Along the Walkway There Are Attractive Green Areas[h]									0.25 (1.10-1.66)	1.29	0.40**(1.12-1.97)	1.49
Along the Walkway Are Attractive Buildings[h]									0.30* (1.03-1.76)	1.35	0.34* (1.06-1.85)	1.40
Protection												
Along The Walkway Traffic Is Low[h]											−0.32* (0.56-0.95)	0.73
Along The Walkway It Is Secure (Crime-Related) [h]											−0.10 (0.70-1.16)	0.90
Model-Specific Parameters												
R^2 Cox&Snell | R^2 Nagelkerke | Chi^2 (Model)	0.03 | 0.04 | 53.1		0.05 | 0.06 | 83.4		0.05 | 0.07 | 91.1		0.05 | 0.07 | 92.3		0.06 | 0.09 | 108.1		0.08 | 0.12 | 122.9	
Sample Size | Percentage of Correct Classification | Significance	1,810 | 71 % | p < 0.001		1,810 | 71 % | p < 0.001		1,791 | 72 % | p < 0.001		1,748 | 72 % | p < 0.001		1,626 | 72 % | p < 0.001		1,475 | 73 %| p < 0.001	
−2LL | df(x) | AIC | BIC	2,129 | 9 | 2,147 | 2,197		2,099 | 14 | 2,127 | 2,204		2,060 | 16 | 2,092 | 2,180		2,000 | 17 | 2,034 | 2,127		1,835 | 19 | 1,873 |1,975		1,627 | 21 | 1,669 |1,780	

Reference Categories:
[a]No Children
[b]In Education;
[c]Male;
[d]No High School Diploma;
[e](Detached) Single-Family Houses;
[f]Less Than 5 Facilities Accessible;
[g]No Public Transport Mode Accessible;
[h](Somewhat) Unrelevant;
*p-values: $p < 0.05$;
**$p < 0.01$;
***$p < 0.001$

(OR) are plausible and stable for the different model stages which is an indication for their stability within the models and strengthens their explanatory power. Both models show comparable results for the socio-demographic and socio-economic factors and also for the built-environment variables at meso-scale due to the substantial overlap of the two samples. The reduced sample size in model 2 causes only minor differences.

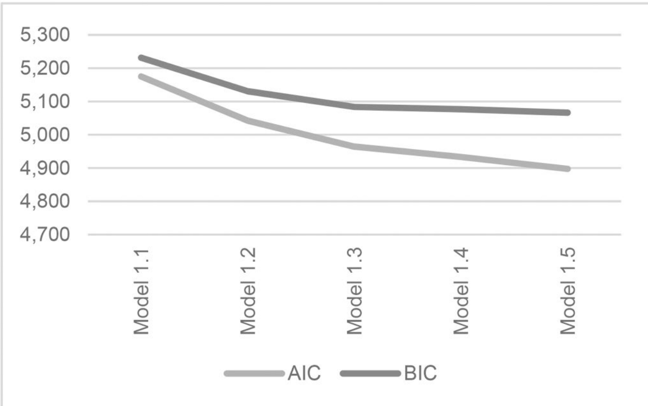

Figure 3. Model 1- model comparison with AIC and BIC.

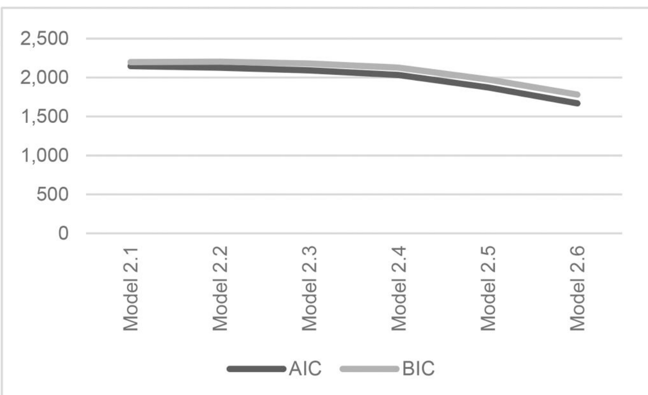

Figure 4. Model 2 - model comparison with AIC and BIC.

Car availability and employment are the two consistently significant individual factors both for leisure and for utilitarian walking. For each extra car within one household, the chance of (almost) daily walking ($y = 1$) is reduced significantly by 1.3 times ($p < 0.001$) in both models. This relationship can also be found in the literature (see e.g. Cervero & Radisch, 1996; Haybatollahi et al., 2015; Kaplan et al., 2016; Wang et al., 2021). The number of bicycles within households is not significant. The effect of employment is particularly strong for utilitarian walking for non-employed and retired persons who have a 2.8 respectively 3.0 higher chance of being a frequent walker than persons in education, the ORs are with 1.9 respectively 1.3 lower for leisure walking but still significant. Employed persons aged below 35 years have an almost two times lower chance of daily leisure walking (OR = 0.6 for utilitarian walking) than persons in education. Employed persons aged above 35 years show a 1.6 times lower chance for (almost) daily leisure walking and no significant differences to persons in education for utilitarian walking. These results are plausible, since employed persons tend to be busier, have longer trip distances (e.g. to their workplace) and more complex trip chains, these trip patterns are less suitable for walking as a mode of transport. In addition, non-employed or retired persons are more often subject to financial constraints and are thus, in combination with possibly more flexibility in choosing their destinations and time use, more affine to frequent walking.

Meso-scale factors include the predominant building type and accessibility to facilities of daily needs and public

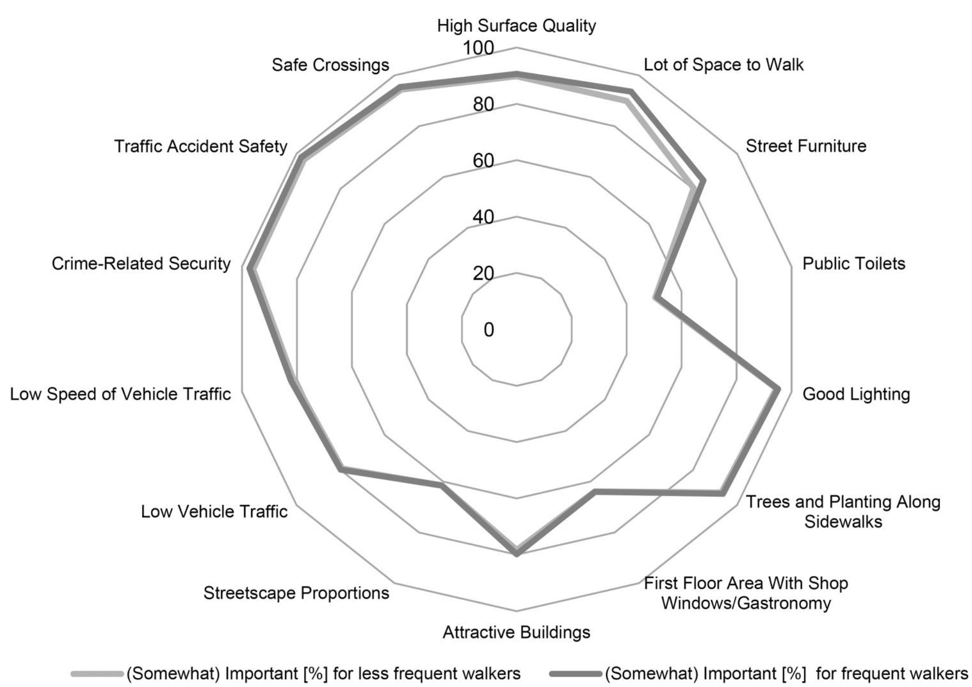

Figure 5. Importance of built-environment characteristics for leisure walking.

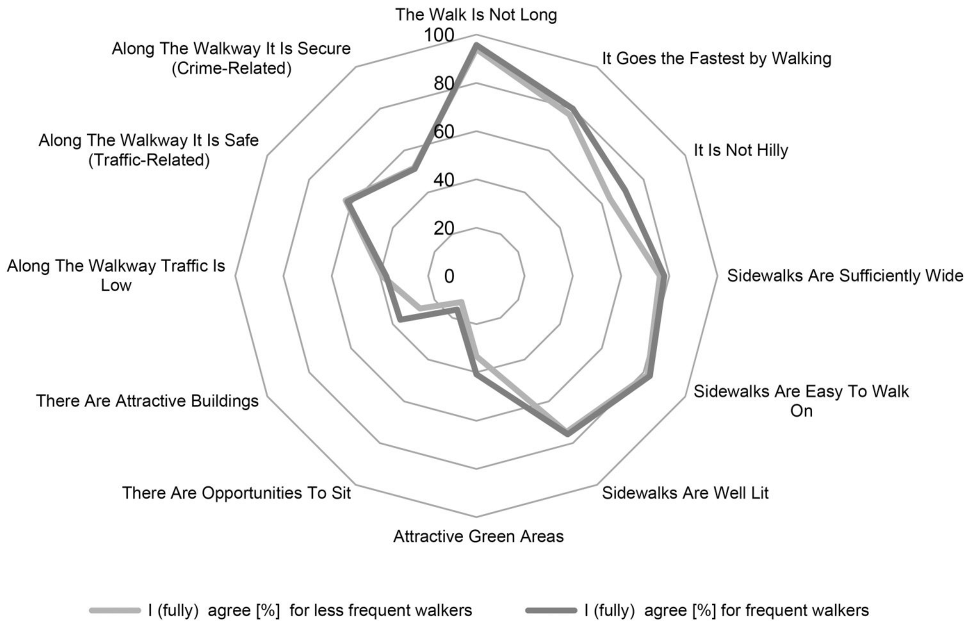

Figure 6. Motivational built-environment factors for utilitarian walking to the supermarket.

transport stops. They are consistently significant with high ORs in both models. The chance of walking frequently doubles in areas with rowed apartment buildings in mixed-use areas (Model 1.5: OR = 2.32, $p < 0.001$) compared to areas with detached single-family houses as the reference category. ORs are somewhat smaller but still significant and important for the factors "Detached Apartment Buildings" (Model 1.5: OR = 1.48) and "Rowed Apartment Buildings in Residential Area" (Model 1.5: OR = 1.47). ORs in model 2 are in the same range and also significant. These findings are consistent with the literature which shows consistently significant effects on walking for density, diversity and further D-variables (Cervero & Kockelman, 1997; Kang, 2015; Stead & Marshall, 2001). All accessibility factors are significant for leisure walking in model 1 and partly significant for utilitarian walking in model 2. The chance of (almost) daily walking increases significantly (Model 1.5: OR = 1.52; $p < 0.001$) for households that reach all five considered facilities of daily needs within a five-minute walk compared to those households that reach less facilities. The result remains insignificant in the second model but still, this variable is close to statistical significance ($p = 0.06$) and the model stages 2.2 to 2.5 show significant effects. Access to public transport within a five-minute walk significantly increases the chance of (almost) daily walking (see Model 1.5: OR = 1.54; $p < 0.001$). The significance of these two accessibility factors shows their complementary character to the predominant building type and confirms that all three meso-scale factors should be considered for further studies.

For interpreting model results at the micro-scale, it is important to remember that questions at this level address the importance of streetscape factors and not their existence or shape like this is the case at the meso-scale. Space to walk, crime-related security, and street furniture are the three significant micro-scale variables for leisure walking in model 1 with positive coefficients and ORs between 1.41 and 1.68 ($p < 0.05$). Public toilets are also significant (OR = 0.86; $p < 0.05$), their negative effect on walking prevalence is attributed to the relationship between age, walking frequency and the importance of public toilets. Public toilets are more relevant for people with lower health status levels, these persons tend to walk less. Different results were obtained for utilitarian walking. Attractive green areas along the walkway (OR = 1.49; $p < 0.01$), attractive buildings (OR = 1.40; $p < 0.5$), and low traffic (1/OR = 1.37; $p < 0.05$) are the three significant micro-scale factors in model 2. This means that frequent walkers assign higher relevance to greenery and buildings next to the street but less relevance to volumes of motorized traffic compared to less frequent walkers.

Discussion

The descriptive and model-based results confirm findings in the literature as well as the initial hypotheses for this study. Walking is a basic mode of transport, 57% of respondents in our sample walk on a daily or almost daily basis. People walk across all socio-demographic and socio-economic person groups, only car availability and employment status are found to significantly impact on walking prevalence. The distinction of employed persons by age below respectively above 35 years proved to be suitable, younger employed persons are significantly less likely to walk on a (almost) daily basis than employed persons aged above 35 years. Further variables such as gender, education or household type show no significant effects in the models, this is consistent with the literature (see e.g. Gascon et al., 2019; Wang et al., 2021; Wasfi et al., 2017). All three meso-scale built-environment factors are of high relevance, they include the predominant building type in the neighborhood as well as accessibility to facilities of daily needs and to public transport stops. The Ds and particularly density and diversity matter also in this study, this is consistent with the literature (see e.g. Brüchert et al., 2020; Christiansen et al., 2016; Wang et al., 2021) and shows that the variable on the predominant building type has been suitably developed to classify the different area types. Findings at these two levels of households respectively persons and meso-scale built-environment factors are similar for leisure and for utilitarian walking due to the overlap of the two samples.

Differences between leisure and utilitarian walking as well as between frequent and less frequent walkers were identified for the micro-scale built-environment factors. Interestingly, the importance of streetscape factors in the descriptive results is far higher for leisure walking compared to utilitarian walking. Respondents' answers match with the criteria as suggested by Gehl (2010). Almost all respondents rank "protection" very high in terms of safety and security, followed by "comfort" with slightly lower importance for the variables space and surface quality, and by "delight" ("amenities") with variables such as attractive buildings, greenery or first floor usages. The results look very different for utilitarian walking, distance is key here with 95% of respondents ranking this variable as relevant. Further variables follow with substantially lower levels of agreement. The logistic regression models show the differences between frequent and less frequent walkers in their assessment of the importance of all the different built-environment factors at the micro-scale. Significant differences between these two groups were identified mainly for the "Delight"-variables, this is attractive buildings and greenery for utilitarian walking in model 2, and space availability and street furniture for leisure walking in model 1.

The findings confirm the dominance of urban planning and of the D-variables at the meso-scale for utilitarian walking. Short distances to relevant destinations are the most important factor in our sample, all other variables are assessed substantially less important in the descriptive statistics. At the same time, the findings confirm the volatility of leisure walking. Respondents are far more demanding for these trips. More built-environment variables are assessed to be important and importance levels overall are substantially higher than for utilitarian walking. We need to invite people; we need to provide not only safe but also comfortable and attractive facilities before they come for leisure walking and street activities. The initial hypothesis that frequent walkers are more sensitive to their environment can also be maintained, they consistently assign higher importance to the "delight"-factors compared to less frequent walkers. This group should be our yardstick for urban street design with the final goal to increase the number of frequent walkers and to provide facilities that meet the needs of this most demanding and sensitive person group in our sample. The variables on public toilets (for leisure walking) and low traffic (for utilitarian walking) are also significant in some models with negative coefficients. This somewhat non-intuitive finding can be explained by dependencies with age for public toilets and with possibly actual lower sensitivities of frequent walkers for traffic volumes. In addition, 30% of those who agree on low traffic on the way of the supermarket are living in areas with lower density and less diversity. It is common sense, that in these types of areas traffic is low because of the design of the street network (e.g. cul-de-sac, no grid pattern), and because of (more likely) mono-functional land use (residential area).

Conclusions and outlook to further research

This study confirms and complements findings from the literature; it provides more detailed results at streetscape level than previous resident surveys on built-environment walking determinants; it is less detailed than previous street-level investigations with variables such as Transparency of adjacent usages or Imageability of streetscape (see e.g. Ewing et al., 2016). This study contributes to the discussion on differences in the relevance of built-environment factors for specific travel purposes and contexts. Existing studies that are based on the IPAQ-questionnaire on physical activity already distinguish between walking for transport and for recreation but they do not specifically ask respondents to report their preferences separately for the different contexts. Our context-specific questions at the micro-level of streetscapes allow to disentangle the different mechanisms that apply for utilitarian versus leisure walking with the latter being far more volatile and responsive to streetscape characteristics. In addition, this study distinguishes for the first time between frequent and less frequent walkers. It demonstrates differences in perceptions and preferences between these two groups which should be considered in future research and also in street design practice which might preferably focus on the most demanding person group of frequent walkers. The newly developed questions for characterizing the built environment at the meso-scale and for investigating the relevance of micro-scale factors proved to be suitable, they can be used in future surveys as the basis for prioritizing efforts from promoting walking but also for monitoring purposes.

The representative sample for German cities with at least 100,000 residents is a strength and limitation of this study, future similar investigations in other countries are encouraged for demonstrating the transferability of our findings. Similar representative investigations with the focus on smaller cities could also be insightful for urban and transport planners. The questions on the importance of micro-scale streetscape factors for leisure or utilitarian walking might also contain respondents' perceptions on whether these factors are actually present on their walking trips. The separation of the perceived existence and the perceived importance in future studies might help to better disentangle these two effects.

Disclosure statement

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6.2 Paper 2

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From trips to stages: a methodology for Generating Stage Information in trip-level Household travel surveys

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Abstract
Trip-level household travel surveys (HTS) are an efficient and widely used instrument in transport planning and research and are expected to remain in this role for at least the near future. Mode information is typically assigned to trips in these surveys based on a hierarchy of transport modes that hides important information on the individual stages which is particularly relevant for walking. This study develops a methodology for estimating detailed stage-level information for trip-level HTS that contain some information on stages, this is the sequence of used transport modes and the number of transfers in Public Transport (PT) trips. The methodology is developed based on detailed stage-level data from a sub-sample in the German National HTS MiD 2017 and directly applied to the German city-based HTS SrV 2018 which is a trip-level survey but contains stage-level information on modes and PT transfers. Linear Regression Models for estimating walking stage duration in PT and car trips are combined with simple heuristic estimations for the less frequent types of intermodal trips. Trip purpose, accompaniment and total trip duration are important predictors for walking stage duration. Trip-level and stage-level modal-split figures for the number, duration, and distance of trips and stages in SrV 2018 are computed with the developed methodology. About half of all stages and 30% of trips are done by walking. Walking stage duration is with around 38% considerable, this share drops to around 12% for walking stage distance.

Keywords Household travel survey · Travel diary · Intermodal trips · Walking · Public transport · Modal split

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Introduction

Household travel surveys (HTS) have a long tradition and are regularly conducted in many countries on the national level (National Household Travel Surveys, NHTS), and on regional and municipal levels. They are crucial for transport planning and modelling, for preparing decision-making processes, for the evaluation of transport policy measures, and also research on travel behavior heavily relies on this data. HTS can collect trip-level and/or stage-level data where trips are defined as the movement outside home from an origin to a destination for a specific purpose with one or more transport modes. Each segment of a trip covered by one single transport mode is called a stage (Clifton and Muhs 2012; Hubrich et al. 2019; Nobis and Kuhnimhof 2018). The following three main groups of HTS and particularly NHTS can be identified:

1. NHTS with information only on trips, such as NHTS Austria 2013/2014, NTS Canada 2022, NHTS South Africa 2020, and the main survey of the NHTS "Mobility in Germany (MiD) 2017" (Nobis and Kuhnimhof 2018; BMVIT 2016; Republic of South Africa 2021; Statistics Canada 2022)
2. NHTS with information at trip level which is complemented (a) by some information on stages for each trip such as the sequence of used transport modes or the number of transfers within Public Transport (PT) (German HTS SrV 2018 (Hubrich et al. 2019)), or (b) by data on access to and egress from PT stations (U.S. NHTS (Federal Highway Administration 2018, 2019, 2020)); HTS from this group are called "enhanced trip-level HTS" from now on
3. NHTS with detailed information on each stage of a trip including the transport mode, duration and distance; these data are collected for example in the Swiss NHTS (Schweizerische Eidgenossenschaft et al. 2021), the Dutch NHTS 2020 (Statistics Netherlands 2022, 2023) and in the non-representative stage-level sub-sample of the German NHTS MiD 2017 (Follmer 2019)

The majority of trips in HTS is monomodal, meaning that only one transport mode is used for the entire trip. Exemplarily for the city of Berlin, around 60% are monomodal trips (Gerike et al. 2019). These trips are well covered by the trip-level approaches in group 1. PT trips are by definition intermodal trips, meaning that at least two transport modes are combined within a single trip, but also trips by car or bicycle might have access and/or egress stages to/from car respectively bicycle (Jarass and Oostendorp 2017; Kagerbauer et al. 2015; Krygsman and Dijst 2001). In trip-level HTS, these intermodal trips are assigned to a main transport mode based on a predefined hierarchy of modes. This hierarchy is typically derived from stage-level investigations and usually assigns modes with longer distances in their stages a higher priority. PT is typically ranked highest, followed by car, bicycle, and walking (Hubrich et al. 2019; Nobis and Kuhnimhof 2018; Follmer 2019; Burke and Brown 2007). This means that in the commonly used trip-level statistics, walking as a transport mode only becomes visible for monomodal trips, when respondents completely walk from the origin to the destination without using any other mode because this other mode would automatically become the main transport mode for the entire trip. This limited visibility of walking as the core basis of our daily mobility in trip-level statistics is problematic because researchers cannot understand, planners cannot design, and politicians cannot prioritize what they do not see (Clifton and Muhs 2012; Burke and Brown 2007).

Stage-level HTS are a promising option for a better visibility of walking as the basis for a broader understanding of intermodal travel behavior and walking stages with their various positive effects also for urban planning and public health, these HTS can provide more detailed input data for transport modelling and better support integrated approaches in infrastructure planning. However, most existing HTS belong to group 1. They contain only trip-level information and are with this an efficient way to collect the data that cover most of the needs in research and practice.

Collecting detailed information on stage level as this is the case in group 3 increases respondent burden even when innovative survey approaches (i.e., smartphone-based) are applied. This leads to lower response rates, increased risks of selectivity and nonresponse bias, and finally to higher survey costs. For this study, we therefore assume that even in times of digitization and smartphone-based tracking technologies, "lean" trip-level HTS will continue to be a relevant survey method in the future, possibly in combination with innovative smartphone-based approaches, and that it is feasible and worthwhile to advance them towards group 2-designs and thus to uncover stage-level information.

Literature on stage-level travel surveys (Lu et al. 2023; van Soest et al. 2020) shows that PT trips have the highest proportion of intermodal trips followed by car. Walking is the most relevant mode for accessing the main mode vehicles and for getting to the final destination. Distance and duration of these walking stages are influenced by characteristics of the person, the built environment, PT supply, time of the day, and trip purposes (Jarass and Oostendorp 2017; van der Waerden et al. 2017; van Soest et al. 2020; Lu et al. 2023). Women and persons with higher income tend to have shorter walking stages to/from PT stages but findings are inconclusive and socio-demographic variables such as age, vehicle availability, driver license, household size, education, or employment hardly get significant or are even not considered in studies investigating first/last-mile stages in PT trips. People walk longer distances to rail-based PT vehicles than to busses and to PT services with higher frequency. In terms of trip characteristics, walking stages in work trips are longer than for other purposes in some studies but shorter in others. The reason might be opposite effects. People might prefer rail-based fast and reliable PT services for their trips to work with longer access/egress stages and at the same time, leisure trips might have less time pressure as well as a higher willingness to walk further. Walking stages are shorter in the morning than in the afternoon and for trips with less transfers between PT vehicles within one trip; they get longer with increasing distance of the entire trip. Typical durations of walking stages in PT trips vary between six and nine minutes per stage and 300 m to 800 m. Hardly any literature could be identified on typical characteristics of walking stages in intermodal trips with car or bicycle as the main mode (van der Waerden et al. 2017).

The literature review provides insights on the characteristics of walking stages in PT trips but at the same time, the following three main research gaps are identified: First, previous studies solely rely on descriptive statistics, no model-based analyses could be found. Second, only intermodal PT trips have been covered to far, empirical evidence on the characteristics of walking stages in intermodal car trips is missing. Third, no method could be identified for computing stage-level travel estimates based on enhanced trip-level HTS.

Against this background, three main goals are formulated for this study: (1) to investigate the characteristics of walking stages in intermodal PT and car trips with the help of descriptive and model-based statistics, (2) to develop, on this basis, a methodology for estimating the number, duration, and distance of stages for enhanced trip-level HTS from group 2 as introduced above and (3) to directly apply this methodology for German inner-city trips in cities with ≥ 100,000 inhabitants.

HTS in group 2 are trip-based and thus "lean" in their core approach but ask for the sequence of used transport modes in intermodal trips and also for the number of transfers within the same types of PT vehicles. The methodology in this study is developed based on detailed stage-level data from a non-representative sub-sample in the German NHTS MiD 2017 (Follmer 2019) for which detailed information for individual stages was collected in addition to the trip-level data that is available for the entire sample. The methodology is then directly applied for the German city-based HTS SrV 2018 (Hubrich et al. 2019) which belongs to group 2 in order to demonstrate the applicability of the methodology and also the scope of information that can be generated while still keeping the advantages of the mainly trip-level survey design with only slight modifications. The methodology to be developed in this study has a great potential to enrich existing trip-level HTS of group 2 and to generate key indicators of travel behavior at stage-level such as the modal split by number, distance, and duration as well as to provide adequate visibility particularly for walking.

The remainder of this paper is organized as follows: The subsequent section describes the two German HTS SrV 2018 and MiD 2017 and introduces the approach for computing stage durations for PT and car trips with walking stages based on stage-level data from MiD 2017. Linear Regression Models are estimated and integrated into a comprehensive methodology to compute duration and distance of all stages in SrV 2018. The developed methodology is finally applied to estimate trip-level and stage-level information for SrV 2018. The remaining section discusses and summarizes the results and gives an outlook for further research.

Data and overview of methodology

The German NHTS "Mobility in Germany (MiD) 2017" (Follmer 2019) is used in this study to estimate stage-level travel characterics. MiD 2017 is a nation-wide trip-level HTS which collects representative travel data for Germany as a whole. The MiD 2017 surveyed more than 316,000 people in 156,000 households, and it was the first German NHTS that collected stage-level data for a disproportional and non-representative sub-sample of respondents (aged 14 years and more). These respondents recorded stage characteristics for selected intermodal trips involving more than one mode to provide methodological insights and detailed contextual evidence on intermodal trips (Follmer 2019). In total, 4,465 trips with 11,000 stages were recorded in this sub-sample of MiD 2017 (Federal Ministry for Digital and Transport 2017).

SrV 2018 (Hubrich et al. 2019) is the enhanced trip-level HTS (from group 2) for which the methodology for estimating stage characteristics is developed in this study, based on the detailed information from the sub-sample in MiD 2017. SrV was developed at TUD Dresden University of Technology as a trip-diary based household survey (Wittwer et al. 2024). The SrV-sample is drawn from the population registers of the participating municipalities. All members of the randomly selected households who are willing to participate record their travel behavior at trip level on a randomly selected reporting day and provide in addition information about their individual socio-demographic and socio-economic setting as well as on the household structure. The reporting days are distributed over the entire field time of one year and are mainly average working days (Tuesday to Thursday, except vacations and bank holidays) (Hubrich et al. 2019; Wittwer et al. 2024).

In SrV 2018, 649,103 trips from 197,566 individuals out of 87,299 German households were recorded (TU Dresden 2018). In addition to the trip data, information on the sequence of used transport modes (for all trips) and on the number of transfers between different types of PT vehicles (for all PT trips) was collected in SrV 2018 which is a unique characteristic of this mainly trip-level survey. 916,489 stages were identified for the 602,691 valid trips, for which trip information was complete. Information on the duration and distance of individual stages was not collected in SrV 2018, this is added in this study based on data from MiD 2017 as introduced above. Out of the whole SrV 2018 dataset, only data on inner-city trips in cities with ≥ 100,000 inhabitants are considered for this study for the following reasons. First, it can be assumed that larger cities with ≥ 100,000 inhabitants have denser and more walkable building structures as well as a better PT supply with possibly different stage characteristics than smaller cities (Gerike et al. 2020). Second, limiting data to inner-city trips avoids biases from rare long-distance trips and ensures a consistent focus on intermodal trips as part of the typical daily travel behavior in urban environments.

The methodology to calculate stage characteristics for the enhanced trip-level HTS SrV 2018 consists of four main steps which are introduced below (see also Fig. 1). Detailed information on data processing will follow in the subsequent section.

1. **MiD 2017 data processing:**

   Consistency checks were carried out as the first step of data processing for the stage-level sub-sample in MiD 2017. Only stages with complete information on the transport mode, duration, and distance were retained for further analysis. Stages with ≤ 100 m are systematically not included in the MID 2017 stage module (Follmer 2019). Missing access and egress stages for PT trips were therefore imputed with a standard duration of one minute, in order to account for the fact that access and egress stages can be assumed to exist for all PT trips. After having completed these two steps of data processing, the data frame included 3,581 trips with 10,166 stages. In the next step, data were filtered by city size and trip distance, only respondents from cities with ≥ 100,000 inhabitants, and inner-city trips with ≤ 30 km were retained leading to a final sample of 1,674 trips with detailed information on 5,237 stages. The threshold of ≤ 30 km in MiD 2017 was set to ensure comparability between MiD 2017 and SrV 2018. 99.8% of all inner-city trips in SrV 2018 (n = 289,156 trips; n = 452,898 stages, city size group of ≥ 100,000 inhabitants) have a distance ≤ 30 km. Therefore, this value was used to define inner-city trips in MiD 2017 which does not distinguish between inner- and intercity trips in the own survey variables.

2. **Estimation of stage duration for MiD 2017 and application to SrV 2018:**

   The majority of intermodal trips (around 90%) in the MiD 2017 stage-level sub-sample are PT trips with walking stages followed by car trips with walking stages. Hence, for these two most relevant types of intermodal trips, Multiple Linear Regression Models were set up to estimate the duration of walking stages as the dependent variable. In the

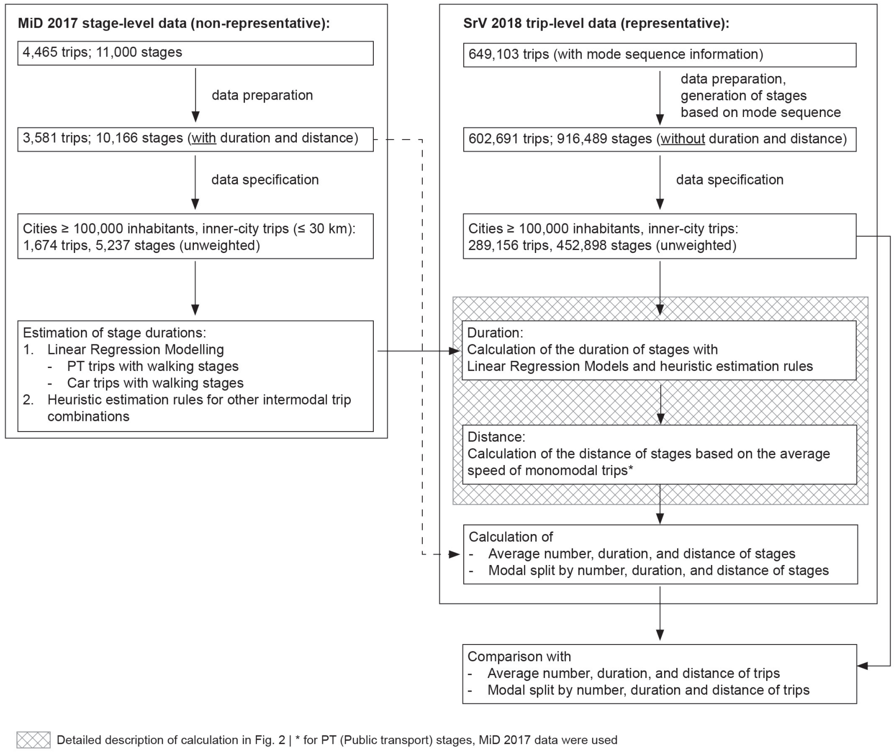


Fig. 1 General overview of the methodology for estimating stage-level information from the enhanced trip-level HTS SrV 2018

SrV 2018 sample, 98% of the trips are monomodal or covered by the Multiple Linear Regression Models. For the remaining intermodal 2% of all trips, heuristic estimations based of other combinations of transport modes in MiD 2017 were developed.

3. **Calculation of stage distance for SrV 2018 using the average speed from monomodal trips:**

   For calculating the distances of walking, cycling, and car stages, the average speed of monomodal trips in SrV 2018 was used. The average speed of PT stages in MiD 2017 was used for calculating distances of PT stages because there are no monomodal PT trips by definition and thus, the trip-level data from SrV 2018 could not be used.

4. **Calculation of stage-level modal-split values for SrV 2018:**

   Finally, the number, duration and distance of stages can be computed for SrV 2018. Based on this, stage-level modal-split proportions and travel characteristics can be calculated.

Development of a methodology for estimating stage-level information from enhanced trip-level HTS

The methodology to be developed in this study foresees the estimation of walking-stage durations for *PT trips with walking stages* as well as for *car trips with walking stages* in MiD 2017 as the two most relevant types of intermodal trips. The selection of independent variables was done based on the initial literature review which was complemented by own assumptions particularly for intermodal car trips for which literature rarely could be found. Two traditional OLS Linear Regression Models were set up (Bortz and Schuster 2010) with duration as the metric dependent variable and dummy-coded (0/1) independent variables. For statistical analysis, IBM SPSS Statistics Version 28 was used.

Initial statistical tests with MiD 2017 data

Multicollinearity of dummy-coded explanatory variables was checked in the first step to ensure the suitability of the MiD 2017 data for computing the Multiple Linear Regression Models. Pearson correlation coefficients show values of $r<0.5$ for all independent variables (Bortz and Schuster 2010) which means low to moderate correlation. U-tests have less strong assumptions than their parametric counterpart (t-test) (Chang et al. 2016). They are thus preferable for comparing differences of two subsamples (0/1-coded factors) in MiD 2017 and were applied to test for the statistical significance of differences between specific person groups and types of trips which are desirable for subsequent regression modelling.

Table 1 shows the results of these comparisons. For *PT trips with walking stages*, the share of walking stages in the total trip duration differs significantly for the variables *trip purpose* and *trip with accompaniment*. These results are in line with other studies that show longer durations of walking stages in PT trips for leisure (van Soest et al. 2020). It seems like people have more flexibility in these trips and accept or even appreciate higher shares of the slow walking stages. For example, Wang et al. (2021) show in their study for couples with and without children that accompanied leisure trips have a positive effect on daily walking trip time measured in minutes per person (Wang et al. 2021). There are no statistically significant differences between the shares of walking stages for the variables gender, occupation, or educational degree which is also in line with the literature (van Soest et al. 2020). The correlation between *total trip duration [min]* and the *duration of walking stages [min]* was tested with the Pearson correlation coefficient and is highly significant ($r=0.601$) which is again in line with the literature (van Soest et al. 2020) and a core input for setting up the Multiple Linear Regression Models.

For *car trips with walking stages*, the variables *trip purpose, trip with accompaniment* and *occupation* show significant differences in this comparison. For trip purpose and accompaniment, we assume similar mechanisms as for PT trips. Longer distances to parking garages or on-street parking locations for people with no occupation might be possible reasons behind the significant differences for this variable. Similar to PT trips, a strong correlation between the *total duration of a trip [min]* and the *duration of walking stages [min]* was found for car trips with walking stages ($r=0.638$).

Table 1 Relationship between independent variables and the share of the duration of walking stages of the total trip duration in MiD 2017 [%]

PT trips with walking stages					
		Share of the duration of walking stages of the total trip duration [%]			
		Mean (%)	Median (%)	p-value	n
Gender	Man	31.9	28.6	0.210	1,141
	Woman	33.5	30.0		
Drivers license	No	32.8	28.6	0.849	1,101
	Yes	32.7	28.6		
Occupation	No	32.6	28.6	0.462	1,141
	Yes	32.7	30.0		
Trip purpose	Leisure	34.6	30.0	0.004**	1,140
	Utilitarian	29.5	28.2		
Trip with accompaniment	Yes	36.5	33.3	0.003**	1,138
	No	31.5	28.6		
Education degree	Other degrees	33.3	30.0	0.058	1,141
	High school diploma	30.2	25.9		
Pearson Correlation r: Total duration of the trip [min] * duration of walking stages [min]		0.601		< 0.001***	1,141
Car trips with walking stages					
		Share of the duration of walking stages of the total trip duration [%]			
		Mean (%)	Median (%)	p-value	n
Gender	Man	25.1	16.7	0.138	424
	Woman	27.5	19.4		
Drivers license	No	22.6	15.5	0.448	423
	Yes	26.3	18.2		
Occupation	No	32.9	23.1	< 0.001***	424
	Yes	23.2	16.7		
Trip purpose	Leisure	28.6	20.0	< 0.001***	424
	Utilitarian	19.9	14.3		
Trip with accompaniment	Yes	29.6	23.1	< 0.001***	424
	No	23.5	16.7		
Education degree	Other degrees	26.6	20.0	0.174	424
	High school diploma	24.5	16.7		
Pearson Correlation r: Total duration of the trip [min] * duration of walking stages [min]		0.638		< 0.001***	424

p-values: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Multiple linear regression models for estimating stage-level information from MiD 2017 data

Multiple Linear Regression Models are applied to estimate durations of walking stages in PT trips (Model 1) and in car trips (Model 2) (see Table 2). This applies to 14% of all trips as intermodal PT trips with walking stages and to 12% of all trips as intermodal car trips with walking stages in the SrV 2018-database.

Before running the statistical models, the assumptions of OLS regression models were carefully checked. Linearity in parameters is only relevant for non-categorical variables. Linearity between walking duration and the total duration of the trip is sufficiently met within the range of our data points (≤30 km). A normal distribution of residuals in our outcome variables (duration of walking stages in PT and car trips) can be assumed based on visual checks of the residual histograms and Q-Q-Plots. Deviations in the histogram of residuals are reasonably small, deviations in the Q-Q-Plots were mainly found at the lower and upper ends which is acceptable. Observations are not fully independent, as trips are nested within individuals. However, since we treated intermodal PT and car trips separately, the intra-cluster correlation is negligible. Multicollinearity was checked by calculating the correlation matrix of potential predictors but is not present. The assumption of homoscedasticity was tested which is a typical problem in cross-sectional data (Long and Ervin 2000). Heteroscedasticity may lead to wrong standard errors and p-values in OLS Regression Models. For dealing with this problem, the approach of "Heteroscedasticity Consistent Standard Errors" is recommended for estimating robust values. In MiD 2017, the assumption of homoscedasticity is violated. Therefore, HC3 was used for calculating standard errors in the Multiple Linear Regression Models in this study (Long and Ervin 2000).

Two HC3 Linear Regression Models were computed (see Table 2). Model 1 for *PT trips with walking stages* and Model 2 for *car trips with walking stages*. For both models, only

Table 2 Linear Regression Models (HC3) on the impact of individual and trip characteristics on the duration of walking stages in PT trips (Model 1) and in car trips (Model 2)

Dependent variable: Duration of walking stages [min]	Model 1: PT trips with walking stages		Model 2: Car trips with walking stages	
	Modell 1.1 Reduced Model (HC3)	Modell 1.2 Full Model (HC3)	Modell 2.1 Reduced Model (HC3)	Modell 2.2 Full Model (HC3)
	Beta (95% CI)	Beta (95% CI)	Beta (95% CI)	Beta (95% CI)
Intercept	8.8373*** (8.2–9.5)	-3.5053 (-8.2–1.2)	4.4900*** (3.5–5.5)	-8.4358 (-18.7–1.8)
Occupation: No (Ref. Yes)	–	–	5.6123* (0.5–10.7)	2.6923 (-0.9–6.3)
Trip purpose: Leisure (Ref. Utilitarian)	0.0586 (-0.9–1.0)	2.1934*** (1.0–3.4)	1.2150 (-1.3–3.7)	6.5322*** (2.9–10.1)
Trip with accompaniment: Yes (Ref. No)	3.0235** (1.0–5.0)	2.3616** (1.0–3.7)	4.4473* (0.4–8.5)	1.8413 (-1.0–4.7)
Total duration of trips [min]		0.3757*** (0.2–0.5)		0.3555* (0.0–0.7)
Adjusted R^2	0.013	0.382	0.034	0.444
n	1,137	1,137	424	424

p-values: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

significant variables were introduced in Table 1. The *total duration of trips* is found to be the main predictor for the duration of walking stages for both PT trips and car trips. The significant influence of this variable on walking stage duration in intermodal PT trips has been shown in the literature before (van Soest et al. 2020). We assume two possible reasons for this: Persons in the less dense outer parts of a city might have longer distances to their next PT stop and longer total PT trip distances. Persons in any part of the city might be willing to walk longer to PT stops for longer trips. We calculated a full model with and a reduced model without variable *total duration of trips* to facilitate, based on the comparison of these two models, the assessment of the explanatory power particularly for this variable.

As a result, controlling for occupation, trip purpose, and accompaniment, the total duration of trips [min] substantially contributes to the explanatory power in both models. The goodness of fit criterion "Adjusted R^2" increases in Model 1.2 up to the value of 0.382. In Model 2.2, 44.4% of the variance can be explained when adding this variable. Besides the adjusted R^2-statistics, the stability of signs of regression coefficient as well as the logical interpretability of the Beta-coefficients show a sufficient explanatory power of the presented models.

In Model 1.2, *trip purpose* as well as *accompaniment on trips* contribute as reasonably significant predictors to the model. The duration of walking stages extends by about 2.2 min for leisure PT trips with walking stages in contrast to utilitarian trips, for accompanied trips by around 2.4 min compared to trips without accompaniment. The duration of walking stages proportionally increases by around 0.4 min with an increase of one minute in the *total duration of PT trips* which confirms the high relevance of this variable in the model.

In Model 2.2, *trip purpose* emerged as a particular strong and significant predictor with an extension of 6.5 min of walking stages for leisure car-trips compared to utilitarian car-trips. In contrast to utilitarian trips, these trips are probably less time constrained. The duration of walking stages increases by around 0.4 min for each additional minute in the *total duration of car trips* which is very similar to the results for PT trips. *Occupation* and *trip accompaniment* remain statistically insignificant within the full model 2.2. Those factors seem to have only a marginal effect on walking stage duration in intermodal car-trips.

Integration of the models into a comprehensive methodology to estimate duration and distances of all stages in SrV 2018

The developed Multiple Linear Regressions were integrated into a comprehensive methodology to estimate duration and distances of all stages in the SrV 2018 database. Multiple Linear Regression Models are valid for most of the trips in this database but do not produce meaningful results for very short stages and trips and in addition, they only cover intermodal PT trips and car trips with walking stages. Heuristic simple rules were therefore defined to complement the Multiple Linear Regression Models and to estimate characteristics also of stages that were not covered so far. This approach is illustrated in Fig. 2 and described in detail below:

I. **Calculation of stage duration based on the Linear Regression Models and heuristic estimations:**

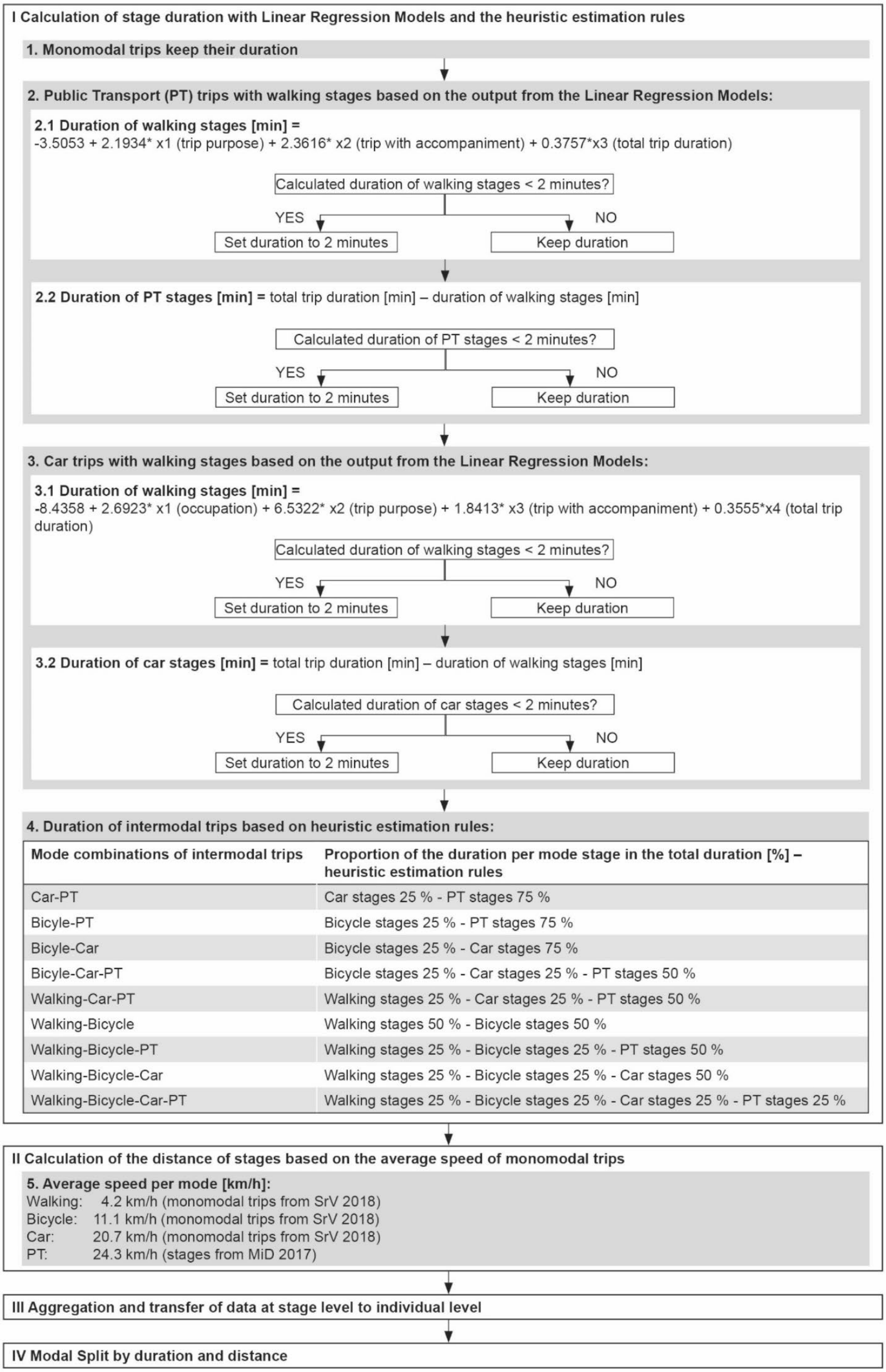


Fig. 2 Detailed overview of the methodology for computing stage durations and distances

For estimating the durations of stages in SrV 2018, all different combinations of transport modes within one trip need to be considered and rules needed to be defined for how to deal with them.

1. In cities with ≥ 100,000 inhabitants, about 70% (n = 205,288) of the trips are monomodal trips with only one stage (walking, bicycling, car trips). The original duration of these trips in SrV 2018 can be retained directly.
2. PT trips are, by definition, intermodal trips as they always include access and egress stages. The Multiple Linear Regression Models developed above were used for PT trips with walking stages as shown in general terms in Equation 1 (see e.g. Bortz and Schuster 2010):

$$\hat{y} = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 + \cdots + \beta_k * x_k \tag{1}$$

Using the intercept β_0 and the regression coefficients $\beta_{1...k}$ allowed to easily apply the regression coefficients from the full models from Table 2 to SrV 2018 and to estimate the duration of walking stages. For trips with short durations, the models generated very low values for walking stage duration which are not plausible. Two minutes were considered as a minimum value for walking stage duration, based on the assumption, that even short PT trips have walking stages and that one minute for each access to and egress from PT might be a suitable lower threshold. This assumption corresponds to a minimum distance for walking stages of 70 m per stage with an average walking speed of 4.2 km/h. This minimum value of two minutes was also applied for PT stages if these fall below this value when being computed as the difference between total trip duration and the duration of the walking stages within these trips.

3. The procedure described in step 2 was similarly applied to car trips with walking stages.
4. Only 2% (n = 5,344) of all inner-city trips in SrV 2018 (cities with ≥ 100,000 inhabitants) are "other" intermodal trips, which are not covered by the model estimations yet. For these trips, a simple heuristic estimation with 25 % - increments was applied with faster modes (and possibly longer distances) being assigned higher shares of the total duration.

II. **Calculation of the stage distance based on the average speed of monomodal trips:**

Stage distances were calculated by multiplying stage duration by the average speed by mode. For walking, bicycling and car stages, the distances were computed based on the average speed of the respective monomodal trips in SrV 2018. Distances of PT stages were determined based on the average speed of PT stages in MiD 2017 since there are no monomodal PT trips by definition.

III. **Aggregation from stage level to individual level:**

Stage-level information on duration and distance were aggregated to the individual level in the next step.

IV. **Modal split by duration and distance:**

Finally, the weighted shares of the modal split at the stage and trip level by number, duration, and distance, as well as the absolute values of these indicators, could be calculated.

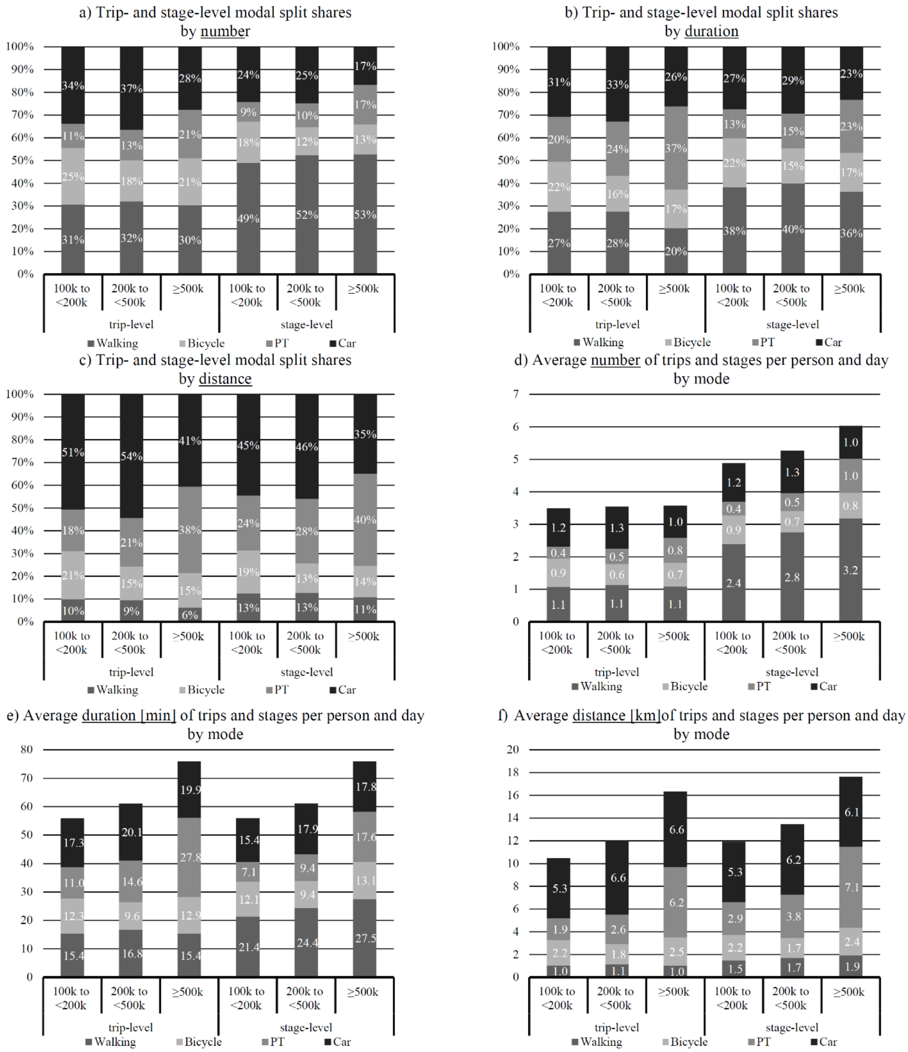
Application of the developed methodology to estimate trip- and stage-level information for SrV 2018

Figure 3a–f show trip- and stage-level estimates by number, duration, and distance for three different city size groups (100,000 to < 200,000 inhabitants; 200,000 to < 500,000 inhabitants and ≥ 500,000 inhabitants) for inner-city travel as it can be now computed with the help of the newly developed methodology.

The comparison of trip-level and stage-level modal split proportions by number (Fig. 3a) confirms the high relevance of walking in stage-level analysis. Around 30% of trips and 50% of all stages are done by walking. The increased shares of walking in stage-level analysis compared to trips are compensated by decreased shares particularly for bicycle and car which are the typical monomodal trips. PT trips have transfers also within the PT mode and thus show less distinct differences between trip-level and stage-level analysis. The comparison of city size groups in Fig. 3a shows similar tendencies for trips and stages. The shares of walking are surprisingly similar across city size. The shares of car and PT are quite similar for cities with < 500,000 inhabitants and decrease only for the largest cities with ≥ 500,000 inhabitants. The shares of bicycle are higher for the smallest cities < 200,000 inhabitants but quite similar for the two higher city size groups. Better PT supply seems to have a significant effect particularly in the biggest city size group. It reduces trips and stages both with bicycle and car whereas walking remains similar in its shares.

Duration and distance of trips and stages in Fig. 3b and c show significantly different magnitudes but similar tendencies in the comparison between trips and stages and also between city size groups. The proportion of walking drops from around 50% for trip numbers to around 38% for the duration and 12% for the distance. Walking as the slowest mode with the shortest distances is thus most sensitive to the different indicators but still covers a substantial share of the overall trip duration. Interestingly, the share of walking drops for duration and distance between the two smaller and the biggest city size group. The reason for this might be the better PT supply in cities with ≥ 500,000 inhabitants; distances to PT stops and walking stages are possibly shorter on average so that the share of walking drops even though the PT share increases. The drop from trips to stages across all city size groups is most substantial for PT, this shows the substantial share of walking in these trips. Distance-based modal split values in Fig. 3c show the least differences between trips and stages. Walking matters for the number and duration of stages but hardly makes a difference in terms of distance.

Figure 3d–f with the average values of number, duration and distance for trips and stages per mode, person and day are interesting in the comparison of trips and stages but particularly also in the comparison between the city size groups. The overall number of trips is very similar for all three city size groups whereas the number of stages increases substantially in the largest group with ≥ 500,000 inhabitants. These differences are mainly caused by walk-



Abbreviation: 100k = 100,000 inhabitants; PT = Public Transport
n (100 to < 200k) = 12,017 trips//58,657 stages | n (100 to < 200k) = 22,151 trips//116,592 stages | n (≥ 500k) = 46,069 trips//277,769 stages

Fig. 3 **a**–**f** Comparisons of trip- and stage-level estimates by number, duration, and distance for cities with ≥ 100,000 inhabitants (weighted, inner-city travel)

ing stages and PT stages. The number of PT stages doubles from the second group (200,000 to < 500,000 inhabitants) to the third group (≥ 500,000 inhabitants) with higher PT usage and more transfers within PT trips in this group being the main reasons. The number of trips and stages per person are almost the same for all city size groups for car and bicycle as the two typical monomodal transport modes.

For duration and distance in Fig. 3e and f, differences between city size groups are apparent for trips and stages. People in cities with ≥ 500,000 inhabitants travel longest both in terms of duration and distance. Differences mainly come from PT. Trip durations for PT are substantially longer for cities with ≥ 500,000 inhabitants than for smaller cities, the difference is less distinct for stages because parts of PT trip duration are now included in walking stage duration. Differences between city size groups are less distinct for distance in Fig. 3f, but still the increased overall distances of trips and stages for cities with ≥ 500,000 inhabitants are mainly caused by PT.

Overall, the analyses reveal interesting pattern in the comparison of trips and stages in terms of number, duration and distance and also of the city group sizes. Sensitivity analysis shows the stability of the results. Important parameters from Fig. 2 were varied, such as the threshold of two minutes for very short stages of walking for PT and car (step I.2 and I.3), the simplified heuristic estimates for other intermodal trips (step I.4), as well as the average speed per mode (step II). Deviations in all indicators are marginal in these sensitivity analyses, they reach from – 0.8 to + 0.8 percentage points.

Discussion and conclusion

This study has generated methodological insights and in addition, it contributes to a better understanding of travel behavior in cities with ≥ 100,000 inhabitants. The Linear Regression Models confirm the high relevance of the overall trip distances for the distances of walking stages in intermodal trips. This is in line with the literature (van Soest et al. 2020) but has not been demonstrated based on model-based analysis before. We controlled for sociodemographic attributes and trip characteristics but still, the overall trip distances are most relevant for understanding walking at the stage level. These mechanisms hold similarly for intermodal PT trips and car trips which is an important contribution to the literature where hardly any study on intermodal car trips could be identified. The Linear Regression Models are complemented by simple heuristic estimates for the less frequent combinations of transport modes in intermodal trips. This approach is reasonable and robust because the proportion of these trips is small.

Overall, the developed methodology for estimating stage information for enhanced trip-level HTS proves to be viable and insightful. It increases the level of detail in the travel data substantially with only slight increases in respondent burden and survey costs. The methodology can be directly applied to any specific German city or region because it was developed based on the stage module of the German NHTS MiD 2017 which should be valid across the entire country. Future studies could estimate Linear Regression Models for stage-level surveys in other countries and thus investigate the transferability of the mechanisms that have been identified in this work for the German context. The average speed of each transport mode as the basis for deriving stage distances from durations needs also to be verified but apart from these possible differences in travel characteristics between countries, the overall scheme for computing stage characteristics should be transferable to any other context.

It would be also interesting to adapt the developed methodology to rural areas and to include also trips between municipalities. However, the relevance of stage-level analysis is expected to be lower here, mainly because of lower PT use compared to cities with ≥ 100,000 inhabitants which are in the focus of this study. The combination of enhanced (but still lean) trip-level HTS with smartphone-based tracking studies is promising. Regression models (Linear Models or more complex models such as Generalized Linear Models or Generalized Linear Mixed Models) on the duration of walking stages in intermodal trips similar to this study might be computed based on the detailed stage-level smartphone-based tracking data, they can be used then in the enhanced trip-level HTS which at least to date are less costly than their smartphone-based counterparts. They could be run with far larger sample sizes but still provide stage-level information. Larger stage-level samples would also allow to distinguish between road- and rail-based PT vehicles in the statistical models and might add valuable information. The use of Large Language Models (LLMs) to study walking in intermodal trips is unchartered territory and might open up new avenues for future research.

In terms of content, this study provides insights on the number, duration and distance of trips and stages in absolute values and in proportions by transport mode. Walking trips and PT trips are particularly sensitive to the two analysis-levels of trips and stages. About half of all stages and 30% of trips are done by walking. Walking stage duration is with around 38% still significant, this share drops to around 12% for walking stage distance. In absolute numbers, this means that on average 3.2 out of 6.0 stages are being walked per mobile person and day with an average duration of 27.5 min and an average distance of two kilometres. The high proportion of walking stage duration was not expected before. Travellers spend substantial shares of their time for walking which is good because walking is space-efficient, supports lively streets and cities and is beneficial for public health.

Differences between city size groups are also interesting. The shares of walking for trips and stages in terms of number is almost the same for all groups even though PT usage is substantially higher in the largest cities with ≥ 500,000 inhabitants. This means that people have a similar number of walking stages but that these stages belong more to monomodal walking trips in smaller cities and to intermodal trips mainly in combination with PT or car in the larger cities. The interactions between the modes in the different city size groups show that better PT supply reduces the use of the car but also of walking (and bicycling) as monomodal trips. It is therefore essential to plan for the environmentally friendly modes walking, cycling and PT in an integrated way and in combination with restrictive policy measures for the car.

Besides these contributions to the scientific literature, this study provides insights for practical survey designers and transport planners outside academia: First, the developed methodology for computing stage-level information based on enhanced HTS can be directly applied to any German region and also to regions outside Germany if the statistical models are checked before for their applicability. Second, this study directly provides new empirical evidence on walking at stage level in German cities, it demonstrates the high relevance of this mode which is less visible in the trip-level statistics that are commonly used in transport planning so far. This evidence can be used to support initiatives to promote walking as a mode of transport, as a physical activity and also as an effective way to populate streets and public spaces with people which is essential for improving the quality of life and the economic success of cities.

The results of this study are encouraging for survey designers to go for enhanced trip-level HTS, possibly in combination with stage-level smartphone-based surveys. The additional insights on detailed stage-level travel characteristics that can be gained compared to traditional trip-level HTS approaches clearly outweigh the additional costs and provide valuable information for research and for planning practice.

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Author Contribution The authors confirm contribution to the paper as follows: study conception and design: C. Koszowski; S. Hubrich; analysis and interpretation of results: C. Koszowski, S. Hubrich, R. Wittwer and R. Gerike; draft manuscript preparation: C. Koszowski, S. Hubrich, R. Wittwer and R. Gerike. All authors reviewed the results and approved the final version of the manuscript.

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Data availability Data is available upon request for SrV and can be requested from the German Transport Ministry for MiD.

Declarations

Conflict of interest The authors declare no competing interests.

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6.3 Paper 3

Koszowski, Caroline; Hubrich, Stefan; Wittwer, Rico; Gerike, Regine (under review): Streets as places – characteristics of place activities in the European context with the example of the City of Malmö (Sweden). Under review in *European Journal of Transport and Infrastructure Research*. Preprint. https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa2-971462

Streets as places – characteristics of place activities in the European context with the example of the city of Malmö (Sweden)

Preprint (Version: 29 November 2024)

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Streets as places – characteristics of place activities in the European context with the example of the city of Malmö (Sweden)

Abstract

Pedestrian activities, as an umbrella term for the movement of people on foot and for the so-called place activities that take place directly on the street such as chatting or having a coffee, have received increasing attention in transport and urban planning research in recent years. Based on a case study of the City of Malmö (Sweden), this study is, to the best of our knowledge, the first in the European context to specifically examine place activities, taking into account a wide range of variables describing street characteristics and use. Research questions for this study include the general characteristics of place activities in terms of number, duration, type, posture, user group, daily profile, mapped location in the street space, and their relationship with street characteristics. Data on place activities and street characteristics are collected for 16 blocks at five street sections in the City of Malmö based on on-site observations and GIS-data provided by the city administration. The overall number of place activities is found to be in a similar range in all five case study areas but activity characteristics differ greatly. General land use in the neighborhood and in the buildings adjacent to the street shape user groups, activity types and daily profiles with substantial differences, e.g., between streets in neighborhoods with more office-focused versus more diverse land use types. Street characteristics are more influential on activity durations and postures, but also on activity types, if attractive destinations directly in adjacent buildings and well-designed streetscape attract higher-level place activities such as chatting or consuming, rather than just waiting for a bus or parking a bicycle. The behavioral and methodological insights from this study provide the ground for designing livable streets in evidence-based approaches and also for future research adding further case studies or extending the scope of the analysis.

Keywords: street design, urban design, pedestrians, walking, place activities

1 Introduction

Urban streets serve multiple functions: As a network and as specific street spaces, they are key features of any city; they enable the movement of people and vehicles as a basis for the functioning of societies; they are places and destinations for street activities; they are conduits for media such as water, electricity or communications; and they perform environmental functions such as mitigating heavy rain events or regulating air quality and climate. The task of urban street design is to prioritize and balance these functions for each case study anew, a thorough understanding of each type of street activity and its determinants is the basis for evidence-based and well-informed street designs. This study is based in transportation research and focuses on sidewalks and pedestrian activities which typically have received less attention in previous studies compared to the motorized modes and increasingly also cycling and micro mobility.

Pedestrian activities are used in this study as an umbrella term to cover both the movement of people and activities that take place directly on the street, such as talking to others or having a coffee, which are referred to as place activities. Pedestrian movement activities, which are also called walking activities, can be distinguished into walking trips, when people walk completely from an origin to a destination, and walking stages, when people walk from their origin to a public transport stop to take e.g. a bus and to walk then from the final public transport stop to their destination. Place activities are defined as activities that take place directly on the street, for which the street is not a 'conduit' that enables movement, but a destination in itself. The target functions for movement and place activities in urban street design differ substantially: Street users (here: pedestrians) should get to their destinations safely, quickly, reliably and comfortably to serve the movement function well, while for the place function urban street designers aim to attract many street users who stay on the street for a long time and engage in higher value activities such as socializing as opposed to lower value activities such as just waiting for a bus. Despite the different characteristics and target functions of movement and place activities, pedestrians switch between them spontaneously. They might come for the movement function to walk to a destination but then receive a phone call, need to check their route, meet someone or see something interesting – and engage in a (previously unplanned) place activity. These spontaneous changes between movement and place activities are a specific characteristic of pedestrians, making the analysis of pedestrian activities particularly challenging and interesting.

Three groups of studies investigating pedestrian activities can be identified in literature. First, there are studies on pedestrian volumes, which focus on the movement function by counting the number of pedestrians crossing an imaginary line on a sidewalk (Lai and Kontokosta 2018; Kim et al. 2019; Fang et al. 2022; Ryus et al. 2022). Second, there are studies that investigate pedestrian activities as the sum of movement and place activities (Ewing and Clemente 2013; Ameli et al. 2015; Ho et al. 2021; Hooi and Pojani 2020; Park et al. 2019). For example, Ewing and Clemente (2013) record all visible people in the study area who move (e.g. walking, running) or engage in place activities (standing or sitting, except outdoor dining) (see also Purciel and Marrone 2006). Third, there are studies that focus only on place activities (Mehta 2006, 2013; Barros and Mehta 2023; Mehta and Bosson 2021; Miura et al. 2024; Mehta 2019). For example, Mehta (2013), based on walk-bys and observations from a fixed point, record the location and number of all "stationary and lingering social activities" on the streets, while people passing by or entering a premise without stopping should not be recorded.

Only very few studies could be identified in group three (Mehta 2013; Mehta and Bosson 2021; Hall and Ram 2019; Njeru and Kinoshita 2018), which are mainly published or influenced by the group around Mehta et al. In addition, the literature in this third group is mainly based in urban planning research and separated from studies in the groups one and two, which are mainly based in transportation research. For example, Mehta (2013) instructs the field work staff to record all stationary activities except people waiting for a bus, they also do not consider the existence of a bus stop in a study area as an independent variable in their investigation of the place activities. Ewing and Clemente (2013), on the other hand, do not distinguish between pedestrian movement and place activities and consider the use of the adjacent buildings in less detail than the studies published by the group around Mehta et al. In addition, previous studies were mainly conducted in the USA and to a lesser extent in Asia, while studies in the European context are still lacking.

This study addresses these research gaps. Based on a Swedish case study in the City of Malmö, we investigate place activities at a level of detail that goes beyond previous studies and considers independent variables from both transportation and urban planning, combining the two "schools" of Ewing et al. and of Mehta et al. and including further relevant variables from other previous studies. With this approach, we extent the research on place activities from Mehta et al. by considering further streetscape characteristics and we also test the suitability of the independent variables from Ewing et al., which were developed for pedestrian activities as the sum of movement and place, for investigating place activities only. In order to meet these research objectives, the following research questions are formulated for this study:

- What are the characteristics of place activities in general?
- How do place activities vary over the day?
- What are the characteristics of place activities by gender and age groups?
- What are the relationships between street characteristics and place activities?
- Which specific local patterns of place activities can be identified with map-based visualizations?

To answer these research questions, we choose an empirical approach. Data on place activities and relevant characteristics of the street space and its environment are collected for 16 blocks at five street sections in the City of Malmö (Sweden). Data are processed following the protocols from previous studies from Ewing et al. and Mehta et al., so that detailed characteristics of activities and the street environment can be analyzed in combination with the aggregated variables from previous studies such as the Liveliness Index (LI) (Mehta 2013) or the Urban Design Quality Index (UDQI) (Ewing and Clemente 2013).

In what follows, we first give an overview of related research in section two. Section three introduces the case study areas as well as the methods for data collection and analysis. Results are presented in section four which is organized along the research questions as introduced above. The remaining section five discusses and summarizes the results and gives an outlook for further research.

2 Literature

2.1 Impact of the built-environment and streetscape characteristics on pedestrian activities

Neighborhood characteristics in previous studies from group one and two as introduced above are classified typically by the so-called "5 Ds" (density, diversity, design, distance to public transport, destination accessibility) or even "7 Ds" (add demand management and demographics), these variables are consistently relevant for pedestrian activities overall and also specifically for pedestrian movement activities (Ewing and Cervero 2010; Götschi et al. 2017; Lai and Kontokosta 2018; Toralles 2023). Ewing et al. (2013; 2016) measure density with the two variables floor area ratio (FAR) and population density within a quarter mile of their case-study streets and find significant influences of these variables on pedestrian activities in their models. Diversity describes the mixture of different land use types in a neighborhood, it is usually captured by entropy measures such as the number and variety of different land use types in a given area (Ewing and Cervero 2010; Lai and Kontokosta 2018). Diversity is found to be significant in Ewing et al. (2013) but not in Ewing et al. (2016). Lower distances particularly to rail-based public transport consistently and significantly increase pedestrian activities (Ewing and Clemente 2013; Kim et al. 2019). Design variables describe the characteristics and more specifically the connectivity of the street network, measured, e.g. as intersection density or as the share of 4-way intersections (Ewing and Cervero 2010; Berrigan et al. 2010). Intersection density is often significant but with small coefficients, while the share of 4-way intersections rarely gets significant in models of pedestrian volumes (Ewing et al. 2013; Ewing et al. 2016). Typical destinations in the accessibility variable include the number of nearby amenities and stores weighted by their distance (Ewing and Clemente 2013; Vale et al. 2013); these variables rarely get significant in Ewing et al. (2013; 2016) and show an overlap with diversity.

The neighborhood variables as introduced above are also applied to the street level (Ewing and Clemente 2013; Gerike et al. 2021). Ewing and Clemente (2013) compute density as the average floor area ratio (FAR) along the street (computed as the total building floor area for parcels abutting the street, divided by the total area of tax lots) and diversity for the ground floor area with the proportion of retail in the block face. They find both these variables significant in their models of pedestrian activities even when controlling for the D-variables at the neighborhood level. Ewing et al. (2006) (see also Ewing and Handy 2009; Ewing and Clemente 2013) identify, based on a literature review and subsequent expert ratings, the five composite urban design quality factors shown in Table 1 to characterize the attractiveness of street spaces. Each of these urban design quality factors is computed as the product of single variables, which are also shown in Table 1 (except the variable "people" because of its redundancy with the dependent variable of pedestrian volumes) and for which the weights are assigned based on the expert ratings (Ewing et al. 2006).

The five urban design quality factors are validated against counted pedestrian activities in subsequent studies (Ewing et al. 2013). Controlling for the D-variables at neighborhood level as introduced above, on the street level, only transparency is found to significantly influence pedestrian activities. This is consistent with findings from other studies that apply the same framework (Ameli et al. 2015; Hamidi and Moazzeni 2019). Ameli et al. (2015) find imageability to be also significant in their models. Ewing et al. (2016) split the five urban design quality factors as introduced above and analyze the influence of more detailed variables measuring physical features of streetscapes on pedestrian activities. They find the following three significant variables: proportion of windows, street furniture, and active uses. Street furniture includes any object in the street that increases its complexity with examples such as signs, benches, parking meters, trash cans, newspaper boxes, bollards and street lights. Public seating is found to be of particular relevance. The variable of active uses includes shops, restaurants, public parks, and further uses that generate significant pedestrian traffic. Blank walls, driveways, parking lots, vacant lots, abandoned buildings, and offices with no apparent activity are examples for inactive uses.

Kang (2015) and Kim et al. (2019) add more detailed variables on the street layout itself. They find significant positive impacts of sidewalk widths, crosswalks, trees and negative impacts of slope on pedestrian movement activities. The number of traffic lanes is significantly positive in their models but highly correlated with the distance to public transport. Lai and Kontokosta (2018) compute a composite variable, which they call streetscape, as the product of sidewalk coverage, pavement quality, and street amenity. They find this variable to be significant for pedestrian movement activities on weekends but not on working days.

Studies from group three as introduced above only investigate place activities which are operationalized either by the sheer number of people who perform these activities (Njeru and Kinoshita 2018; Hall and Ram 2019) or by the Liveliness Index as the product of the number of people with place activities and the duration of their activities (Mehta 2013). Mehta and Bosson (2021) classify the recorded place activities into activity types (e.g. talking, eating, reading, sunbathing) and postures (e.g. ambling, standing, sitting, lying, sleeping).

There is a substantial overlap between the determinants of these place activities with those found in the studies on the overall pedestrian activities in groups one and two. Table 1 lists the determinants of place activities as used by Mehta (2013). The existence of community places such as stores or other facilities where one can meet neighbors, friends or strangers is most relevant for the Liveliness Index, followed by the provision of seating, both commercial and public (Mehta 2007). Personalization is also significant, it describes how the interface of a building and business with the street (building façade, entrances, shop-windows, etc.) is embellished with personal touches such as displays, decorations, signs, banners, planters or flowerboxes. The variables permeability and variety of businesses are only significant in one study each (Mehta and Bosson 2021; Mehta 2007). Sidewalk widths are only significant in Mehta (2007); they seem to be a mediating variable that is less relevant on its own but rather allows to put facilities such as seating on the sidewalk that foster place activities. No significant influences on the Liveliness Index are identified for shade provided, the existence of street furniture besides seating, the articulation of façades, and the degree of independence of the adjacent stores. Mehta (2013) finally groups these variables, based on a factor analysis, into three types of qualities: land use, physical and social. These qualities are also shown in Table 1.

Table 1: Urban design quality factors by Ewing and Clemente (2013) and street characteristics by Mehta (2013)

Ewing and Clemente (2013)		**Mehta (2013)**	
Factor	**Street Characteristic** *(measurement)*	**Street Characteristic** *(measurement)*	**Factor**
Imageability	Number of accessible courtyards, plazas, parks, and gardens *(count, both sides, within study area)*		
	Number of visible/prominent major landscape features *(count, both sides, beyond study area)*		
	Proportion of historic buildings *(estimation .10-intervalls, both sides, within study area)*		
	Number of buildings with identifiers *(count, both sides, within study area)*	Degree of personalization of store front on the block segment *(1 to 10 rating scale)*	Land use qualities
	Number of buildings with nonrectangular shapes *(count, both sides, within study area)*		
	Presence of outdoor dining *(N=0/Y=1; your side, within study area)*	Number of public (non-commercial) seats on the block segment *(Number)**	Physical qualities
		Number of commercial seating (chairs) on the block segment *(Number)**	Physical qualities
	Noise level (1-5 rating scale, both sides, within study area)		
Enclosure	Number of long sight lines *(count, both sides, beyond study area)*		
	Proportion of street wall *(estimation .10-intervalls, your side, within study area)*		
	Proportion of street wall *(estimation .10-intervalls, opposite side, within study area)*		
	Proportion of sky *(estimation .05-intervalls, ahead, beyond study area)*		
	Proportion of sky *(estimation .05-intervalls, across, beyond study area)*		
Human scale	Number of long sight lines *(count, both sides, beyond study area)*		
	Proportion of windows *(street-level; estimation .10-intervalls, your side, within study area)*	Degree of permeability of street front on the block segment *(1 to 10 rating scale)*	Land use qualities
	Average building heights *(average, your side, within study area)*		
	Number of small planters *(count, your side, within study area)*		
	Pieces of street furniture and other street items *(count, your side, within study area)*	Number of other street furniture and physical artifacts on block segment *(Number)**	Physical qualities
Transparency	Proportion of windows *(street-level; estimation .10-intervalls, your side, within study area)*		
	Proportion of street wall *(estimation .10-intervalls, your side, within study area)*		
	Proportion of active uses *(estimation .10-intervalls, your side, within study area)*		
Complexity	Number of buildings *(count, both sides, within study area)*		
	Number of basic building colors *(count, both sides, within study area)*		
	Number of accent colors *(count, both sides, within study area)*		
	Presence of outdoor dining *(N=0/Y=1; your side, within study area)*	Number of public (non-commercial) seats on the block segment *(Number)**	Physical qualities
		Number of commercial seating (chairs) on the block segment *(Number)**	Physical qualities
	Number of pieces of public art *(count, your side, within study area)*		
		Variety of goods and businesses/services on the block *(Number)**	Land use qualities
		Number of independent stores/businesses on the block *(Number)**	Land use qualities
		The average sidewalk width at the block segment *(Average)***	Physical qualities
		Percentage shade and shelter from trees and canopies on block segment *(Percent converted to score 1 to 10)****	Physical qualities
		Percentage articulation of street front on the block segment *(1 to 10 rating scale)*	Physical qualities
		Number of community gathering places on the block segment *(Number)**	Social qualities
*Measurement in this study (see also section 3.3): * Number per 100 m block length | ** Average of 3 measurements in [m] per block | *** GIS-Shapefile tree coverage + percentage of elements providing shade and shelter*			

Gehl (2010) also works on place activities only, he proposes twelve quality criteria for pedestrian facilities which are grouped into the three categories of (1) protection as the prerequisite for movement and place activities including e.g. objective and subjective (perceived) safety against traffic and traffic accidents, (2) comfort including characteristics going beyond protection such as sufficient space void of obstacles and good surface quality, and (3) delight describing the design of the street space with respect to details, materials and green structures that should promote place activities and the enjoyment of the street. Gehl (2010) does not provide any quantitative validation for these criteria, based, e.g. on a comparison with empirically measured place activities. However, he lists various examples for the successful application of these criteria in projects for redesigning streets and public spaces all over the world (see also Gehl and Svarre 2013).

The comparison of the determinants of the overall pedestrian activities (e.g. Ewing and Clemente 2013) and of only place activities (see e.g. Mehta 2013) shows differences and similarities. Both groups include variables describing façades, and further characteristics of adjacent buildings and the street space. Mehta (2013) and related studies are far more detailed in land use variables such as the number of independent stores and businesses, Ewing and Clemente (2013) and related studies are more detailed in the physical characteristics of the buildings next to the street and their relation to the street space. Compared to the three groups of "qualities" as defined by Mehta (2013), Ewing and Clemente (2013) mainly focus on the physical qualities where their variables are more detailed than the ones from Mehta (2013), while the variable set from Mehta (2013) is overall broader in its scope, especially for the land use and social qualities. The variable "noise" as used by Ewing and Clemente (2013) is the only variable that considers negative impacts from motorized traffic. The double use of single variables (column 2 in Table 1) for computing the composite factors (column 1 in Table 1) needs to be considered in the interpretation of the composite factors.

2.2 Characteristics of place activities

There is only limited literature regarding general characteristics of place activities in public spaces. Case studies predominate in this specific research topic (Mehta 2006, 2007, 2013; Mehta and Bosson 2021; Gehl et al. 2004; Gehl 2018; Miura et al. 2024; Sarvari and Esnaashari 2018; Sharifi and Boland 2017; Istrate 2023; Ridings and Chitrakar 2021; Shirazi 2019). While studies by Mehta et al. give detailed information on activities, grouped durations, the Liveliness Index and their relationship to street characteristics, other studies focus on the number of place activities in different time periods as well as differentiated by person-related information (see e.g., Gehl et al. 2004; Gehl 2018).

Daily profiles of place activities are investigated in the cities of Vancouver (Gehl 2018), Berlin and London (Shirazi 2019; Curtis et al. 2022a), and two case study cities in Vietnam (Miura et al. 2024). The distribution of the number of place activities during working days seems to follow the same patterns in Vancouver, London and Berlin. The intensity of activities increases over the day, reaches its peak in the afternoon and drops rapidly in later time periods. During the peak times, eating and drinking activities are dominant. In the evening, people are more engaged in passive recreation activities, such as watching other people and activities in the street or reading (Gehl 2018). In Vietnam, however, during daytime the activity level drops, which may be explained by the high temperature (Miura et al. 2024). Sharifi and Boland (2017) confirm situations with nearly zero activity in public spaces in relationship with temperatures higher than 30°C for Australian cities. In this respect, green infrastructure spending shade and shelter from heat are found to be important to promote place activities.

On weekends, the average volume of place activities nearly doubles compared to working days in Vancouver. Activities are more diverse than during working days (eating and drinking, commercial and cultural activities, passive recreation), increase steadily from the morning hours until 2 pm, peak in the evening between 4 pm and 6 pm and decrease afterwards. Counts of place activities in summer and winter by Gehl (2018) show a reduction of 70 percent in winter compared to summer counts.

In all case studies, the high number of place activities is associated with the land use. Especially in streets with commercial land uses, the number of place activities is high (Gehl 2018; Shirazi 2019), even higher than in family-oriented neighborhoods (Shirazi 2019). The surrounding of schools also increases place activities (Shirazi 2019; Miura et al. 2024).

No clear tendencies regarding gender distribution of place activities can be found in the literature (see e.g., Gehl 2018; Shirazi 2019). While in Vancouver, more male persons tend to stay in the public realm (Gehl 2018), Shirazi (2019) records during working days more activities of females and on weekends more male activities.

Regarding age, mostly adults are observed (around 70 % on working days, around 60 % on weekends) in summer (Gehl 2018). Shirazi (2019) shows similar findings. Adults are present with over 80 percent of all activities. Elderly people are less engaged in place activities. It is assumed, that public spaces do not fit the specific needs of elderly people, such as safety and barrier free spaces, or opportunities to have a rest. The season seems to have no effect on the distribution of ages (Gehl 2018). In winter, younger people and adults ≥ 65 years are as well represented in limited quantity in the public realm.

In the respect of the duration of place activities, there is limited knowledge in the literature. Mehta (2006) classifies data on activity duration in five categories (15 seconds to < 1minute, 1 minute to < 5 minutes, 5 minutes to < 10 minutes, 10 minutes to < 15 minutes, and ≥ 15 minutes). Especially places with physical (e.g., commercial and or public seating) and land-use qualities (e.g., variety of goods and businesses/services) attract people for longer stays (≥ 15 minutes). Ridings and Chitrakar (2021) also use classified activity durations for Brisbane (Australia), they confirm that vibrant spaces increase both, the number and the duration of place activities. The specification of the exact duration of place activities seems to be missing in literature.

3 Data and Methods

3.1 Overview of the case study areas

This study is based on the EU-project Multimodal Optimisation of Roadspace in Europe (MORE; for more information see MORE 2021) which had the primary objective to develop a comprehensive and replicable methodology to planning, designing, managing and operating urban streets in the TEN-T road network in a sustainable way that balances the needs of all (potential) user groups and is in line with the EU's sustainability goals as formulated for example for the Sustainable Urban Mobility Plans (Gerike et al. 2024). In five European cities, the optimization of limited street spaces and the development of new concepts and scenarios, tools and processes were tested. The City of Malmö was one of the case study areas in the MORE-project, it is with about 360 thousand residents the third largest city in Sweden and has a balanced modal split. In 2018, 34 percent of Malmö residents were made by car, 26 percent by bike, 25 percent by public transport and 14 percent by foot (City of Malmö 2018).

Three future scenarios were defined in the MORE project for the City of Malmö as the basis for the new development area of "Nyhamnen" (Curtis et al. 2022b):

- The car-oriented city which promotes the extension of the road network and of space for car parking as well as urban sprawl.
- The sustainable mobility city which promotes public transport, cycle networks and the reallocation of street space towards the environmentally friendly modes.
- The city of places which promotes the public realm, street activities, livability, traffic restraints and mixed-use developments.

For the evaluation of the three scenarios, the comparison with the current situation was necessary, because scenarios for a future and not yet existing area should be created. The City of Malmö selected the following five existing street sections from other parts of the city which should serve as representatives for the three scenarios in the MORE project and are also the case study areas for this study:

- Mariedalsvägen and Sallerupsvägen as representatives for the car-oriented city
- Södra Förstadsgatan and Stora Varvsgatan as representatives for the sustainable city
- Regementsgatan as the representative for the city of places

Figure 1 shows the location of the five street sections and gives a first impression of their relevance in the street network and of the neighborhoods they are located in. The five street sections are not located directly in the touristic city center but in dense and diverse neighborhoods which are well-served by public transport so that the D-variables at the neighborhood level are at similar levels for all five case study areas (Curtis et al. 2022a). Mariedalsvägen and Regementsgatan are spatially close to each other, but differ clearly in their street space characteristics (car-oriented city vs. city of places). Figure 2 shows pictures of the five streets to give a visual impression of their characteristics.

Figure 1: Case study areas in Malmö (Background map: © OpenStreetMap-contributors)

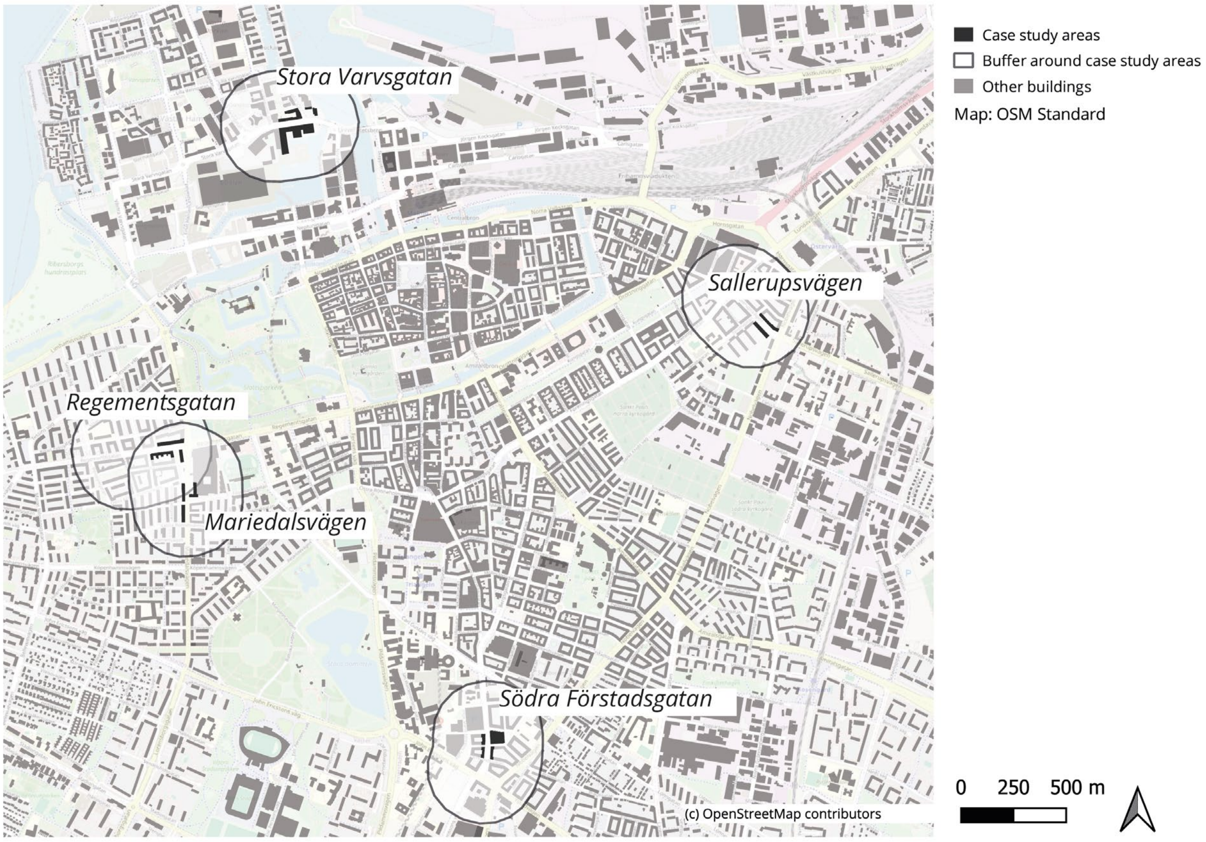


Figure 2: Images of the case study areas in Malmö (Own pictures)

Mariedalsvägen *representative for the car-oriented city*	**Sallerupsvägen** *representative for the car-oriented city*
	
Södra Förstadsgatan *representative for the sustainable city*	**Regementsgatan** *representative for the city of places*
	
Stora Varvsgatan *representative for the sustainable city*	
	

3.2 Key characteristics of land use and the built environment

The five street sections were divided into blocks and blocks into units as appropriate entities for data collection and analysis in terms of place activities and street characteristics. Data on land use, buildings and street characteristics were collected in on-site visits and complemented by data provided by the City of Malmö. Figure 3 visualizes relevant characteristics of each street section and Table 2 provides key figures on the characteristics and uses of the adjacent buildings. The urban form in all street sections is predominantly shaped by compact building construction which form densely built-up areas between grid-shaped streets. In Mariedalsvägen and Sallerupsvägen, some rowed apartment buildings exist. The density measure FAR was computed as the total building floor area for all parcels adjacent to the street divided by the total area of tax lots adjacent to the street. It can be characterized for most street sections as moderately with 40 to 50 percent. Only in Mariedalsvägen and Södra Förstadsgatan, large-scaled buildings (a Lidl supermarket and parts of a shopping mall) increase the density to higher levels (60 % and 76 %).

Land use at ground-floor level for each unit in the five case study areas was identified in on-site observations as shown in Figure 3. Diversity of land use per case study area is described with the variable "block face entropy" based on the following formula (following Ewing et al. 2016; Bordoloi et al. 2013):

$$Entropy = \sum_{i} (p_i * \ln(p_i))/\ln(i)$$

p_i = proportion of land use type i within the case study area
i= total number of six land use types (residential, gastronomy, business, daily needs, leisure, social)

The application of the natural logarithm normalizes the entropy to values from 0 and 1. The value of 0 indicates a homogenous distribution of land use types in the case study area, the value of 1 represents an equal distribution of land use types (Bordoloi et al. 2013).

Block face entropy is with 0.78 highest for Södra Förstadsgatan, followed by Mariedalsvägen and Sallerupsvägen which is consistent with the balanced proportions of the different land use types in Table 2. Block face entropy is lowest for Regementsgatan with 0.52 and Stora Varvsgatan with 0.21. The reason for the low value in Regementsgatan are the high shares of businesses and gastronomy which are supportive for place activities but, in combination with zero values for daily needs, leisure and social institutions, unbalanced in their overall entropy. Stora Varvsgatan is dominated by businesses, there is one supermarket in addition, which also offers snacks and refreshments to go, but no further land use type in this street section. The share of businesses is generally high in all five case study areas, major differences exist for the land use types residential (high in Mariedalsvägen and Sallerupsvägen) and gastronomy (high in Regementsgatan, Södra Förstadsgatan and Mariedalsvägen). The number of facilities for daily needs is generally low but the Lidl supermarket in Södra Förstadsgatan (Block 03-3) and the supermarket in Stora Varvsgatan (Block 05-2) are still of high relevance for the place activities in these case study areas (see Figure 3). The social service institution in Sallerupsvägen (Block 02-1) generates a high number of place activities with very short durations and a special character. People who rely on social services come here because they need to come and not because they voluntarily choose this destination based on their individual preferences. Overall, there is a good variety in the five street sections in terms of land use which is an appropriate basis for investigating place activities in the different contexts.

Table 2: Characteristics of land use and the built environment in the case study areas

	Mariedalsvägen *representative for the car-oriented city*	**Sallerupsvägen** *representative for the car-oriented city*	**Södra Förstadsgatan** *representative for the sustainable city*	**Regements-gatan** *representative for the city of places*	**Stora Varvsgatan** *representative for the sustainable city*
Number of surveyed blocks	3	2	4	3	4
Floor area ratio (FAR) of the block	60 %	46 %	76 %	44 %	43 %
Length of the block front [m] (Average)	38.0–104.3 m (77.7 m)	95.0– 123.6 m (109.3 m)	52.0–63.2 m (57.0 m)	15.4–126.7 m (83.5 m)	38.9–162 m (97.2 m)
Number of residential units*(residential share)	5 (38 %)	4 (40 %)	2 (12 %)	2 (10 %)	0 (0 %)
Number of gastronomy units* (gastronomy share)	3 (23 %)	1 (10 %)	5 (29 %)	7 (35 %)	0 (0 %)
Number of business units (e.g. offices, stores, beauty facilities)* (business share)	4 (31 %)	4 (40 %)	7 (41 %)	11 (55 %)	97 (88 %)
Number of facilities of daily needs counted as units*(facility of daily needs share)	0 (0 %)	0 (0 %)	2 (12 %)	0 (0 %)	1 (12 %)
Number of units for leisure purpose (e.g., fitness, wellness)* (leisure facility share)	1 (8 %)	0 (0 %)	1 (6 %)	0 (0 %)	0 (0 %)
Number of social institutions counted as units*(social institution share)	0 (0 %)	1 (10 %)	0 (0 %)	0 (0 %)	0 (0 %)
Number of all units	13**	10**	17	20	8
Number of different land uses	4	4	5	3	2
Block face entropy	0.71**	0.67**	0.78	0.52	0.21

* Counted at ground floor level across all surveyed blocks per case study area
** In Mariedalsvägen and in Sallerupsvägen units without current usage at ground floor or construction side were observed. The calculations (share and entropy) do not include these categories.

Figure 3: Overview of the case study areas (Background map: © OpenStreetMap-contributors; City of Malmö: Shapefiles for streetscape elements)

3.3 Street characteristics and urban design quality factors

Street characteristics and urban design quality factors were computed based on the protocols developed in Ewing and Clemente (2013) and Mehta (2013) as shown in Table 1. Due to the high range of the block lengths in this study, a standardization per 100 meters of block length was applied for the variables by Mehta (2013). In addition to the detailed variables and the composite urban quality factors imageability, enclosure, human scale, transparency and complexity from Ewing and Clemente (2013), the Urban Design Quality Index (UDQI) was calculated as the sum of the five urban quality factors.

For the street characteristics from Mehta (2013), Regementsgatan stands out with high values for most variables (see Table 3). For example, the number of commercial seats per 100 m block length is here twice as high as in Stora Varvsgatan with the second highest value for this variable. Södra Förstadsgatan has high values for the land use qualities but lower values for the physical qualities of the street space. The other three street sections show a mixed performance across the different variables. Mariedalsvägen has a high degree of permeability of the street front, Sallerupsvägen and Regementsgatan have trees resulting in high values for shade and shelter. Mariedalsvägen and Stora Varvsgatan have a high number of street furniture per 100 m block length.

The urban quality design factors from Ewing et al. (2013) have less variation across the five case study areas. Outdoor dining is an important reason for high imageability values in Regementsgatan. The long building in Stora Varvsgatan (Block 05-4) with the brick façade design, and the articulated and decorated façades of the buildings in Regementsgatan contribute to the historic design of the buildings. Thus, the high proportions of historic buildings lead to higher imageability values in these two case study areas. Furthermore, the brick design building in Stora Varvsgatan (Block 05-4) offers a high number of gates to courtyards that contribute to imageability. In Regementsgatan, the number of buildings with non-rectangular shapes and the presence of outdoor-dining makes the streetscape recognizable and increases imageability. Differences in the proportion of sky ahead are the main reasons for variation in the enclosure variable. Stora Varvsgatan reaches the highest value for human scale, mainly because of the high number of street furniture such as bike racks and lower building heights. Transparency is in a similar magnitude for all street sections except Stora Varvsgatan with a very low proportion of active uses and a high proportion of street wall. Complexity is in the same range for all street sections, the slightly higher value for Regementsgatan is caused by the high number of outdoor dining facilities and the higher number of buildings (units) in the block.

Table 3: Street characteristics per case study area

	Mariedalsvägen *representative for the car-oriented city*	**Sallerupsvägen** *representative for the car-oriented city*	**Södra Förstadsgatan** *representative for the sustainable city*	**Regements-gatan** *representative for the city of places*	**Stora Varvsgatan** *representative for the sustainable city*
General street characteristics					
Public transport stop (yes/no)	no	yes	yes	yes	yes
Number of car lanes	2	4	3 (incl. bus lane)	2	4 (incl. bus lane)
Bike lane (yes/no)	no	yes (on sidewalk)	yes (on sidewalk)	yes (on sidewalk)	yes (on sidewalk)
Middle lane (yes/no)	no	no	no	yes (partly)	yes
Parking	on both sides	on one side	on one side	on both sides	on one side
Annual average daily traffic (AADT)*	15,000	12,000	13,000	8,000	15,000
Street characteristics according to Mehta (2013) (minimum **… unweighted average** … maximum)					
Land use qualities:					
Business variety per 100 m block length	2.4 … **3.9** … 5.8	1.6 … **2.4** …3.2	1.6 … **5.5** … 9.6	4.6 … **5.5** … 6.5	0.6 … **2.2** … 5.1
Degree of personalization of store front on the block	2.7 … **3.9** … 6.0	2.7 … **3.5** … 4.3	4.5 … **5.9** … 7.5	1.0 … **4.1** … 6.6	1.0 … **1.3** … 2.0
Degree of permeability of street front on the block	2.7 … **4.2** … 6.0	1.0 … **1.3** … 1.7	3.0 … **4.2** … 6.0	1.0 … **3.1** … 4.3	1.0 … **1.0** … 1.0
Number of independent businesses per 100m block length	2.4 … **3.9** … 5.8	2.4 … **2.8** … 3.2	1.6 … **6.4** … 11.5	6.4 … **6.9** … 7.9	0.6 … **2.2** … 5.1
Physical qualities:					
Number of public (noncommercial) seats per 100 m block length	0.0 … **0.3** … 1.0	0.0 … **0.0** … 0.0	0.0 … **0.0** … 0.0	0.0 … **0.3** … 0.8	0.0 … **0.0** … 0.0
Width on the sidewalk per block	3.6 … **5.6** … 8.8	6.0 … **8.6** … 11.2	5.3 … **6.6** … 8.3	4.5 … **7.5** … 10.1	5.9 … **8.0** … 12.1
Percentage shade and shelter from trees and canopies	1.0 … **1.0** … 1.0	1.0 … **2.5** … 4.0	1.0 … **1.8** … 2.0	1.0 … **3.0** … 5.0	1.0 … **1.3** … 2.0
Percentage articulation of street front on the block	1.0 … **1.0** … 1.0	3.0 … **3.0** … 3.0	1.0 … **2.3** … 3.0	1.0 … **3.7** … 6.0	1.0 … **2.0** … 3.0
Number of other street furniture and physical artifacts per 100 m block length	2.4 … **25.7** … 69.0	4.0 … **8.3** … 12.6	11.9 … **14.2** … 9.2	6.5 … **22.5** … 35.0	3.5 … **24.9** … 46.3
Number of commercial seating (chairs) per 100m block length	0.0 … **5.2** … 8.5	0.0 … **0.0** … 0.0	0.0 … **11.6** … 23.1	0.0 … **62.2** … 140	0.0 … **27.0** … 108
Social qualities:					
Number of community gathering places per 100 m block length	0.0 … **0.3** … 1.0	0.0 … **0.0** … 0.0	0.0 … **0.5** … 1.8	0.0 … **0.8** … 1.6	0.0 … **0.8** … 2.6
Urban design quality factors according to Ewing and Clemente (2013) (minimum … **unweighted average** … maximum)					
Imageability	2.3 … **2.5** … 2.6	1.8 … **2.3** … 2.7	1.9 … **2.5** … 2.9	1.8 … **3.8** … 4.9	2.2 … **4.1** … 6.4
Enclosure	2.0 … **2.5** … 3.4	2.4 … **2.7** … 3.0	3.3 … **3.5** … 3.6	1.0 … **1.7** … 3.1	0.5 … **1.6** … 3.0
Human scale	1.0 … **3.0** … 6.5	2.5 … **2.6** … 2.7	2.4 … **2.8** … 3.2	2.1 … **2.8** … 3.6	3.1 … **3.9** … 6.1
Transparency	3.0 … **3.4** … 3.6	2.9 … **3.4** … 3.9	3.4 … **3.7** … 4.0	3.3 … **3.5** … 3.8	2.1 … **3.0** … 3.5
Complexity	3.5 … **3.7** … 4.0	3.1 … **3.4** … 3.7	3.1 … **3.7** … 4.5	2.9 … **3.9** … 4.6	3.0 … **3.4** … 4.0
Urban design quality index (UDQI)**	12.9 … **15.1** … 19.5	14.3 … **14.4** … 14.5	14.7 … **16.3** … 17.3	11.2 … **15.7** … 19.5	14.1 … **16.1** … 20.9
* Values from Curtis et al. (2022b) | ** UDQI was calculated as the sum of the five urban quality factors					

3.4 Place activities

Static observations of place activities were conducted in the five case study areas on working days in September 2022. From a fixed point (see Figure 3), place activities along the selected blocks were mapped by two people from 7am to 7pm, allowing continuous and complete mapping of all place activities in the streets. Mapping was carried out with paper and pencil, following the protocols of previous studies (Ewing and Clemente 2013; Mehta 2013; Gehl 2010). Afterwards all mapped place activities were transferred to the Geo-Information System (GIS) QGIS. Based on this fieldwork, the following information is available for the analysis:

- Apparent gender (male, female) and age group (0–17, 18–64, 65+)
- Posture (standing, formal sitting, informal sitting, lying, multiple movement)
- Activity type (chatting, taking care of somebody, walking the dog, interaction with a bike or scooter, commercial activity such as window shopping, consuming as a representative for drinking and eating, smoking, interaction with the mobile phone, waiting)

If a person was engaged in more than one activity, all activities were mapped. In contrast to the field manual by Mehta (2013) but in line with the field manual by Ewing and Clemente (2013), the waiting activity at public transport stops was recorded, as this activity mostly takes place on the sidewalk, is often combined with other types of activity such as chatting or consuming, and might also be a starting point for further place activities. Outdoor dining was also considered as a place activity, in line with Mehta (2013) but different from Ewing and Clemente (2013). All persons of a group were marked if they jointly engaged in an activity including also the information on the membership in a group.

The observation period of 12 hours was divided into 48 observation intervals with each 15-minutes duration to facilitate data collection and to ensure a clear overview. The 15-minute intervals also correspond to Mehta (2013). Start and end time of each place activity was noted with minute and second so that the duration for each activity can be exactly computed in seconds. The mean Liveliness Index per 15-minute interval over the 12-hour observation period was calculated for each block based on Mehta (2013) as follows:

$$Liveliness\ Index_{Block} = \frac{(\sum Duration_{all\ persons\ per\ block} + \sum Duration_{persons\ in\ groups\ per\ block}) * 100}{Length_{Block} * 12 * 4}$$

This means that the Liveliness Index per block is calculated as the total of (1) the sum of the activity duration [min] of all persons engaged in place activities (alone and in groups) and (2) the sum of the activity duration [min] of all persons in groups engaged in place activities, standardized per 100 m block length and per 15-minute intervals within the survey period of twelve hours (12*4= 48 15-minute intervals) per day. The duration of activities carried out in groups is counted twice in this formula which is in line with Mehta (2013) and plausible. Group activities are more likely to be social rather than necessary activities and therefore contribute more to the liveliness of a street than activities by single persons.

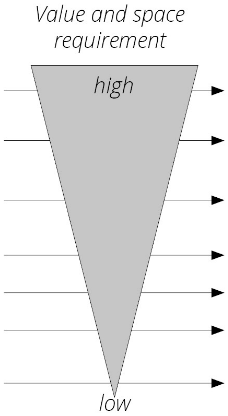
The weather conditions were good on four out of the five survey days and case study areas (sunny, 15–20°C), while the survey day for Mariedalsvägen was less favorable (rainy, around 10–15°C). Although the weather conditions were good during the survey in Sallerupsvägen, data collection had to be canceled at 4pm due to social insecurities, so that data for this street section is only available for nine instead of 12 hours.

Data processing included checks of plausibility and completeness, data records are used for the analysis if they completely include the following variables with plausible values: gender, age group, type of posture, at least one activity type, and a valid start and end time of the activity.

A priority ranking of activity types was developed based on space requirements and an assumed social value of an activity, in order to assign main activity types where several activity types were carried out in parallel. Figure 4 shows the priority ranking of the detailed activity types and their assignment to main activities. Following Gehl (2010), the activities chatting and taking care of somebody as social activities of possibly longer duration than others get the highest priority. They are the most desirable activity types, which in addition, involve at least two persons and therefore require more space. Walking the dog and interactions with bikes or e-scooters are ranked second or third, mainly because of their increased space requirements compared to single-person activities. Commercial activities, such as window shopping, and consuming are ranked fourth and fifth. The lowest priority is given to the more likely solo activities smoking, interactions with the mobile phone and waiting, which correspond to the necessary activities according to Gehl (2010). Finally, every person is assigned to one main activity based on the priority ranking as shown in Figure 4.

Figure 4: Priority ranking and assignment of main activities

	Activities
1	Chatting
2	Taking care of somebody
3	Walking the dog
4	Interaction with bike
5	Interaction with e-scooter
6	Commercial activities
7	Consuming
8	Smoking
9	Interaction with phone
10	Waiting



Priority	**Main activities**
1	Chatting or taking care of somebody
2	Walking the dog
3	Interaction with bike/e-scooter
4	Commercial activities
5	Consuming
6	Smoking
7	Interaction with phone or waiting

3.5 Analysis methods

The methodological approach for this study is a mixture of descriptive statistics of key indicators in terms of street characteristics and place activities, correlations between these two sets of variables and a detailed spatial mapping of the activities in the five case study areas. We first compute the number and duration of place activities by posture, type, duration, time and combinations of those variables in sections 4.1 to 4.3. The comparison of these characteristics of place activities for each case study area with the street characteristics as listed in Table 2 and Table 3 gives first insights on the relationship between street characteristics and place activities.

In the next step, we compute correlations between the street characteristics proposed by Ewing and Clemente (2013) and Mehta (2013) (as listed in Table 3) and place activities. With this approach, we extend the study done by Mehta (2013). The correlations in this study are computed per block to account for differences between the blocks within a case study area. Mariedalsvägen is excluded from the analysis because of the specific patterns of a rainy day. The number of 13 blocks to be considered for computing the correlations is similar to Mehta (2013), who investigates three street sections and 15 blocks. In addition to Mehta (2013), who only shows correlations, we also present the scatter plots to visualize the patterns behind each single correlation value. We do not compute regression models as Ewing and Clemente (2013) do for their 588 street segments. Instead, we compute the Urban Design Quality Index (UDQI) proposed in Ewing and Clemente (2013) as the weighted sum of the five urban design quality factors imageability, enclosure, human scale, transparency and complexity (see Table 3) and correlate this index with indicators of place activities, including the Liveliness Index, the number and the duration of all place activities. In addition to these correlations with the UDQI, we check all possible correlations between single street characteristics used by Ewing and Clemente (2013) to compute their five urban design quality factors and different indicators for place activities.

These descriptive statistics, correlations and the detailed spatial mapping of all place activities in section 4.5 together provide a holistic picture of the place activities and their determinants in the five case study areas in a typical medium-sized European city. This is the first European application of the methods developed in the US context, which allows for a direct comparison with previous studies on place activities (Mehta 2013) and on the overall pedestrian activities including movement and place (Ewing and Clemente 2013). In addition, this study also generates hypotheses about drivers and barriers to place activities that can be further explored in future studies with larger sample sizes.

4 Results

4.1 Key characteristics of place activities

Table 4 shows the number and duration of all place activities per case study area. The number of place activities per hour is lowest in Mariedalsvägen and in addition, the share of very short activities < 15 seconds is with 38 percent highest in this street section. The rainy weather can be assumed to be the main reason for this. For the other four case study areas, the number of place activities per hour including activities of any duration is between 47 in Regementsgatan and 39 in Södra Förstadsgatan and thus in a similar range. The complete sample of activities shows with values between 15 percent in Sallerupsvägen and 26 percent in Södra Förstadsgatan a substantial share of very short activities < 15 seconds which are found to be systematically different from activities with longer durations. These very short activities are mainly short stops within a movement activity, e.g. for orientation or for lighting a cigarette, they are inherent parts of movement activities, which are interrupted but then continued. The activities < 15 seconds are therefore taken out for further analysis, following Mehta (2013) who used a similar approach.

Differences in the hourly activity numbers get bigger when looking only at the number of activities ≥ 15 seconds, values range now between 40 in Regementsgatan and 29 in Södra Förstadsgatan. The mean duration of all activities ≥ 15 seconds range between 4 minutes in Regementsgatan and 2.2 minutes in Sallerupsvägen but median values are very similar with a range only between 1.2 minutes in Södra Förstadsgatan and 1.5 minutes in Regementsgatan. The reason for these different patterns of mean and median values is that the standard deviations and maximum values are very different, ranging from 16 minutes in Sallerupsvägen to 59 minutes in Södra Förstadsgatan. Mariedalsvägen stands out also for activity duration with a very low standard deviation and median value.

Table 4: Number and duration of place activities per case study area

	Mariedalsvägen *representative for the car-oriented city*	**Sallerupsvägen** *representative for the car-oriented city*	**Södra Förstadsgatan** *representative for the sustainable city*	**Regements-gatan** *representative for the city of places*	**Stora Varvsgatan** *representative for the sustainable city*	**Total**
Number of all place activities – inclusive place activities < 15 sec.						
Total number of all place activities per 12 h	136	393*	472	563	524	2088
Number of all place activities per hour	11.3	43.7	39.3	46.9	43.7	174.0
Share of place activities< 15 sec in all place activities	38 %	15 %*	26 %	16 %	22 %	21 %
Number of place activities ≥ 15 sec.						
Total number of place activities ≥15 sec. per 12 h	85	333*	351	475	410	1,654
Number of place activities ≥15 sec per hour	7	37	29	40	34	138
Duration in Minutes of place activities ≥ 15 sec.						
Average	2.0 min.	2.2 min.	3.6 min.	4.5 min.	2.6 min.	3.2 min.
Median	0.8 min.	1.3 min.	1.2 min.	1.5 min.	1.4 min.	1.3 min.
Std.-Deviation	2.5 min.	2.3 min.	7.3 min.	7.7 min.	3.3 min.	5.8 min.
Minimum	0.25 min.	0.25 min.	0.25 min.	0.25 min.	0.25 min.	0.25 min.
Maximum	10.8 min.	16.2 min.	58.6 min.	54.3 min.	30.1 min.	58.6 min.
* Nine hours counted in Sallerupsvägen only.						

Further results for activity duration are presented in Figure 5 and Figure 6. The cumulative distribution in Figure 5 visualizes all place activities (incl. place activities < 15 seconds) and confirms the tendencies identified with the key descriptive statistics in Table 4. Mariedalsvägen and Regementsgatan stand out, while similar patterns are found for the other three case study areas. The share of short activities is generally high, 70 percent of the activities have a duration of less than 2 minutes, 41 percent less than 5 minutes and 90 percent less than six minutes.

Looking at the percentage shares of the grouped activity durations in Figure 6 (only place activities ≥ 15 seconds), differences are found mainly for higher durations. The share of activities ≥ 5 minutes is with 25 percent highest in Regementsgatan, one out of five activities belong here to this group. This share is with 11 percent lowest in Sallerupsvägen, 11 percent are also found for Mariedalsvägen on the rainy day. Sallerupsvägen and Stora Varvsgatan have with almost 50 percent the highest values for activities in the middle group with durations of 1 minute and < 5 minutes. The share of activities < 1 minute is quite similar for all case study areas except Mariedalsvägen. Combining the results on the number and duration of activities, both criteria do not necessarily show the same patterns. Regementsgatan with the highest number of activities has also the longest durations but Sallerupsvägen, which is in the second position in terms of activity numbers, has a very low share of activities ≥ 5 minutes.

Figure 5: Cumulative distribution of the duration of all place activities [min], inclusive place activities < 15 sec (n = 2,088)

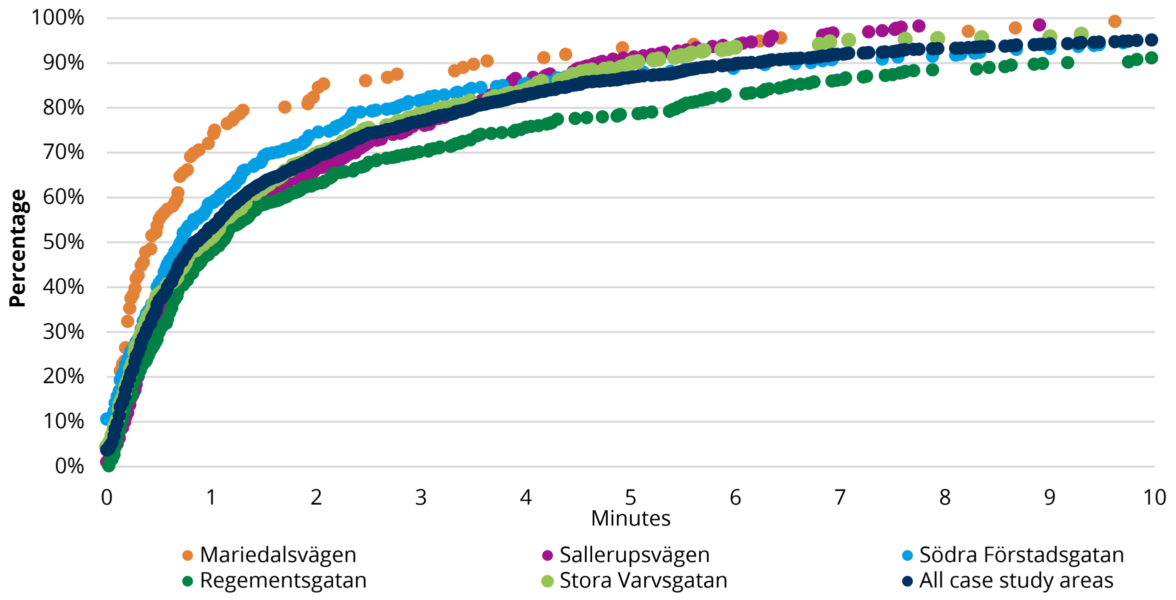
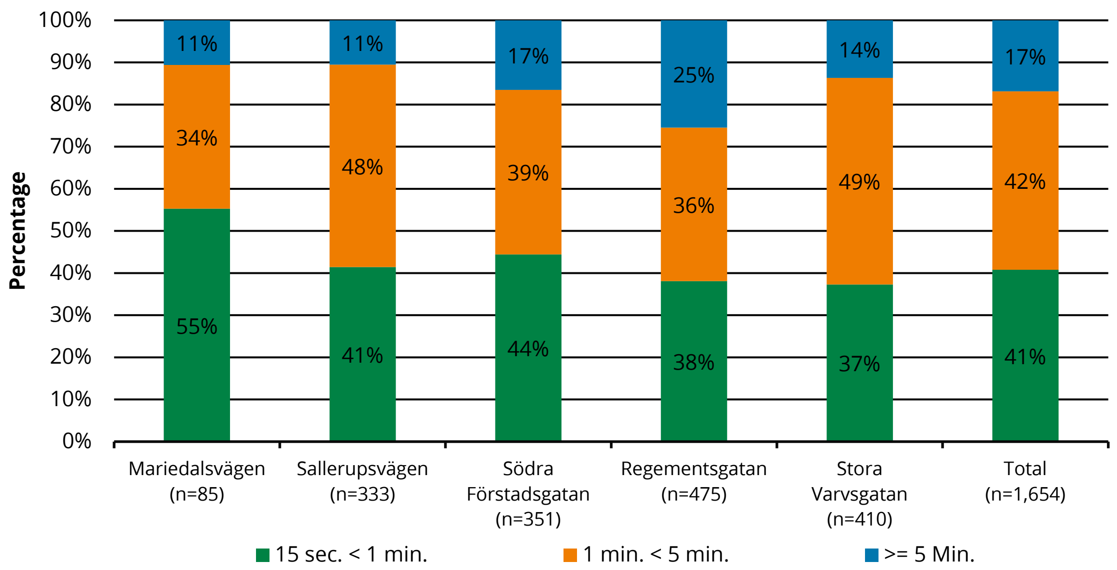


Figure 6: Place activities by duration and case study area (place activities ≥ 15 sec; n = 1,654)



The predominant posture in all case study areas is standing with 87 percent of all activities as shown in Figure 7. Commercial seating is mainly provided in Regementsgatan and Stora Varvsgatan, to a lesser extent in Södra Förstadsgatan and Mariedalsvägen but not in Sallerupsvägen. The number of noncommercial seating options is generally very low or non-existing in all case study areas. The share of formal seating activities is with 10 percent highest in Regementsgatan, followed by Stora Varvsgatan with eight percent and Södra Förstadsgatan with six percent, which is an indication of typical shares that can be reached with the provision of seating facilities and related services, which are here mainly gastronomy. There is not one single seating facility in Sallerupsvägen, this is one possible reason of the low share of two percent of seating activities and also for the low share of activities with a duration of ≥ 5 minutes. Few people have been observed in lying positions, they rather did not seem to be in a good shape, particularly in Sallerupsvägen. Activities in the "multiple movement" category are defined as a sequence of place activities with very short movements in between, e.g. when someone stops to answer the phone, walks a few steps and stops again to continue a phone call.

Figure 7: Place activities by posture and case study area (place activities ≥ 15 sec; n = 1,654)

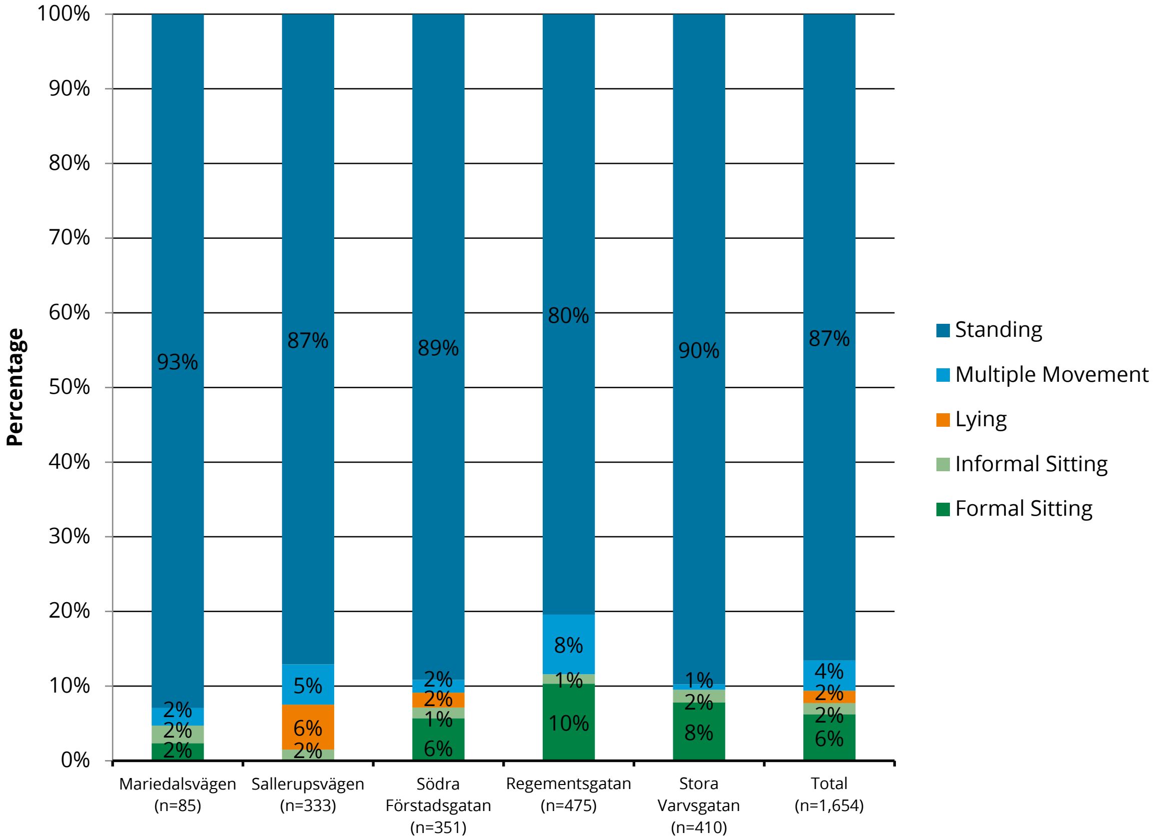
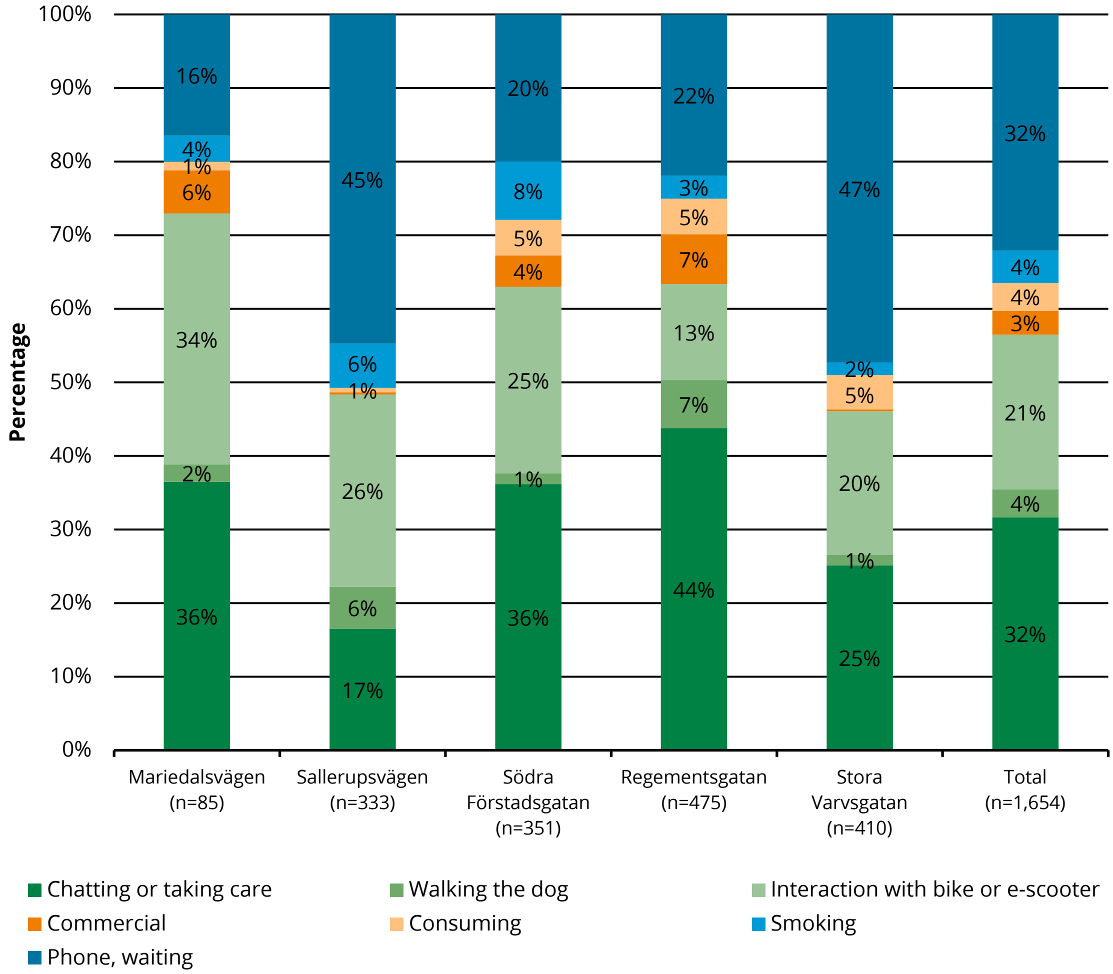


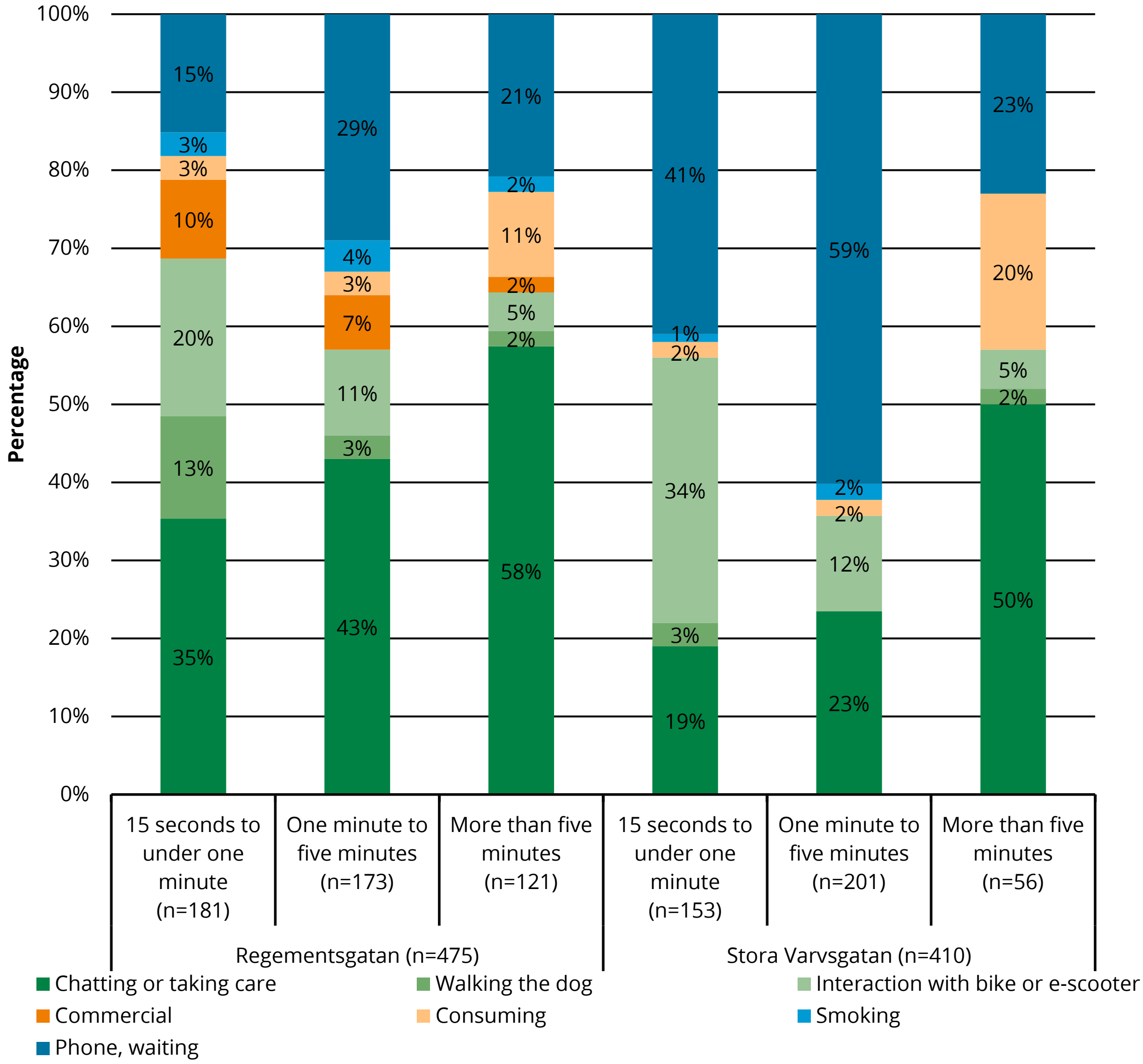
Figure 8 presents the distribution of the place activities across the main activity types for each case study area. The shares of "chatting or taking care" is with 44 percent highest in Regementsgatan, followed by Södra Förstadsgatan with 36 percent. This means that almost half of all activities belong to the social activities as defined by Gehl (2010), which is the most desirable activity type in terms of duration and of its contribution to street life and vibrancy. In Sallerupsvägen and Stora Varvsgatan, "phone, waiting" has the highest share with almost half of all activities, these are rather short activities of single persons. "Commercial" and "consuming" have significant shares with around 10 percent only in Regementsgatan and Södra Förstadsgatan, they are included as secondary activities also in "chatting or taking care". The share of "interaction with bike or e-scooter" is highest in Mariedalsvägen, one third of all activities belong here to this category. Sallerupsvägen and Södra Förstadsgatan follow with around 25 percent which are related to the high cycling share in the residents' modal split and also to the bike racks that are installed in the case study areas. The other activity types have lower shares but still are visible and different in the five case study areas.

Figure 8: Main activities by case study area (place activities ≥ 15 sec; n = 1,654)



Main activity types by activity duration are shown in Figure 9 for Regementsgatan and Stora Varvsgatan. These two case study areas are chosen for the following three reasons: They are more active than Mariedalsvägen and Södra Förstadsgatan, they are very different from each other in their characteristics of the street, its surroundings and in the place activities, and they do not have the socially specific user groups coming for social services as this is the case in Sallerupsvägen. Distinct patterns can be identified for the two case study areas and for the three time periods. Place activities in Stora Varvsgatan are dominated by employees from the companies located at this case study area, there are only offices except one supermarket (see Table 2). Land use in Regementsgatan is a combination of gastronomy, service-oriented businesses (e.g., jewelry, beauty) and two residential block units (see Table 2). For both case study areas, the share of "interaction with bike or e-scooter" is highest for the short activities < 1 minute while the share of "chatting or taking case" is increasing with increasing activity duration. "Phone, waiting" has the highest shares in the middle group of 1 to 5 minutes, 59 percent of all activities in this group belong to this category in Stora Varvsgatan, these are mainly people waiting for the bus. "Commercial" and "consuming" have the highest shares for activities ≥ 5 minutes, they are also included as secondary activities in "chatting or taking care".

Figure 9: Main activities by duration in Regementsgatan and Stora Varvsgatan (place activities ≥ 15 sec; n = 1,654)

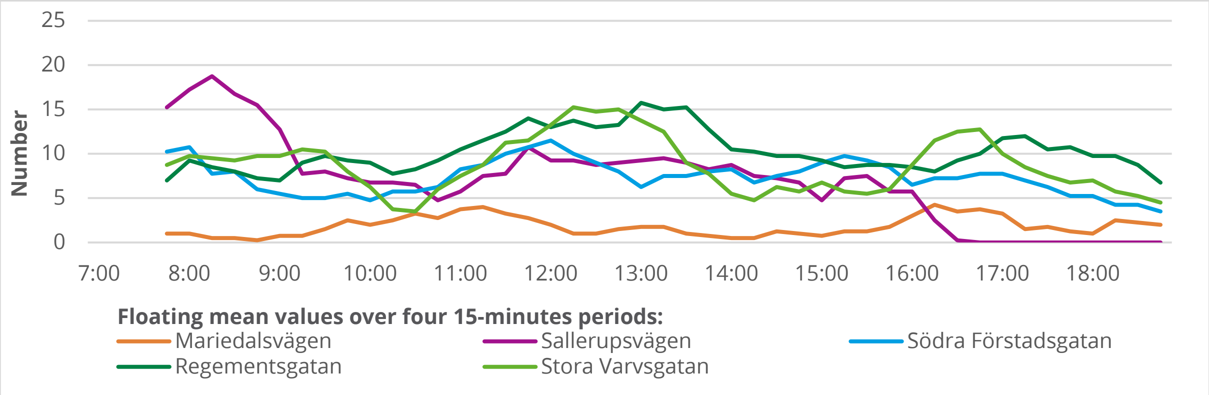


4.2 Daily profiles of place activities

Figure 10, Figure 11 and Figure 12 show the daily profiles of place activities in number and duration for each case study area and as floating mean values over four 15-minutes periods for all five case study areas. The typical profiles with one peak during lunch time and one in the afternoon, as identified also in previous studies, is found in Regementsgatan and Stora Varvsgatan. The peaks are similar in their magnitudes but interestingly, they are somewhat earlier in Regementsgatan than in Stora Varvsgatan. Very slight lunch time and afternoon peaks are also found in Södra Förstadsgatan but these are less distinct. The more mixed land use in Södra Förstadsgatan than in Regementsgatan and Stora Varvsgatan can be assumed to be the reason for this, all land use types except social institutions are represented in this case study area. Sallerupsvägen shows a very specific profile with a distinct morning peak when social services open (Block 02-1), followed by a lunch time peak that lasts until the afternoon when field work was stopped for security reasons. The restaurant and beauty shops in this street seem to be less impactful for the overall daily profile but can be assumed to be the reason for the slight lunch time peak. The share of the peak hours is apparently with around 23 percent highest in

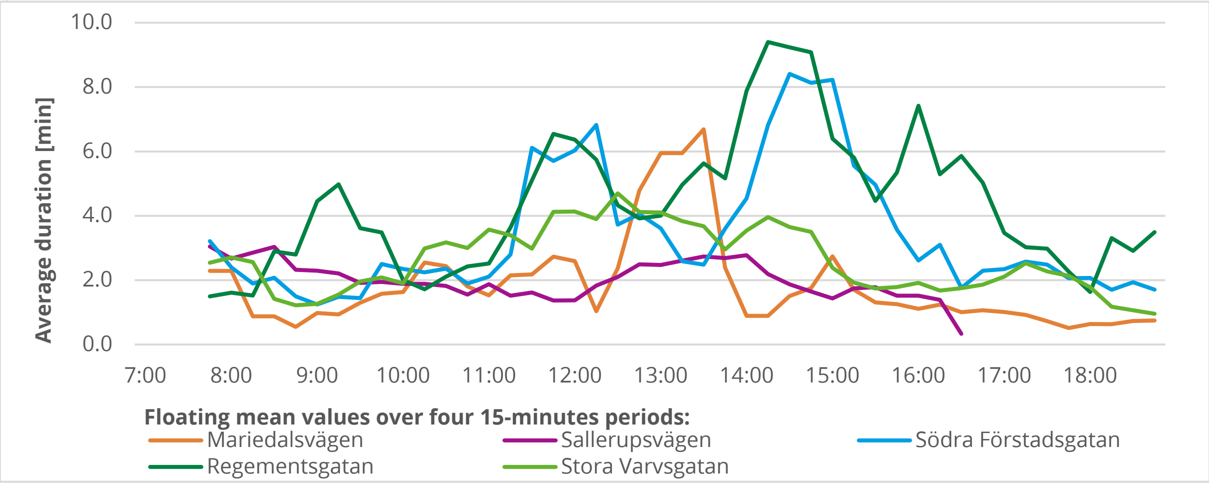
Sallerupsvägen. This value results from the nine hour counting period and is thus not directly comparable with the other case study areas. Considering similar conditions (i.e., 12h-count, good weather) Stora Varvsgatan shows the highest share of peal hours with 15 percent followed by Regementsgatan and Södra Förstadsgatan which are in with around13 percent in a similar range. The number of place activities in Mariedalsvägen is low throughout the day due to the rainy weather.

Figure 10: Daily profile of the number of place activities per 15 minutes by case study area (place activities ≥ 15 sec; n = 1,654)



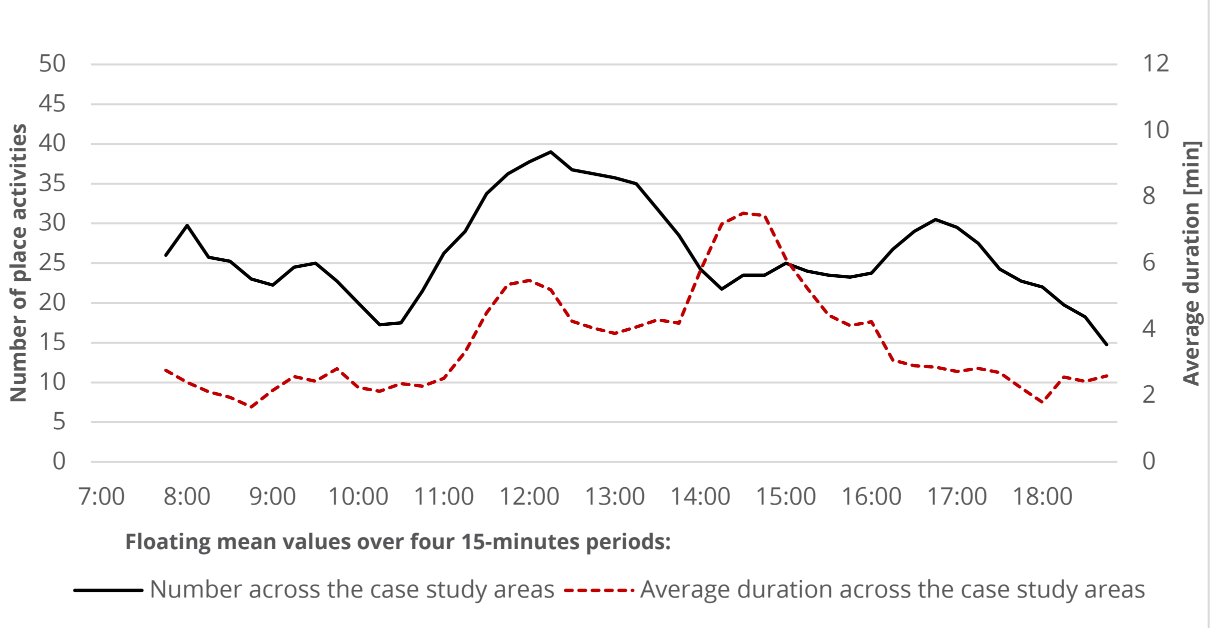
Regarding the daily profile of the average duration of place activities as shown in Figure 11, interestingly Regementsgatan shows four peaks in activity duration, which is with around nine minutes highest between 1pm and 3pm. Södra Förstadsgatan follows the patterns of Regementsgatan in the two peaks at lunch time and in the afternoon with a maximum average duration of about eight minutes in the early afternoon. In Stora Varvsgatan as a business district the average duration of place activities is at a lower level than in Regementsgatan and Södra Förstadsgatan with a slight peak around lunch time. Despite the rainy weather conditions, the average durations of place activities in Mariedalsvägen reach a peak of around seven minutes during lunch time. Sallerupsvägen shows short activity durations between one and two minutes throughout the day. Average activity duration drops in all case study areas in the evening.

Figure 11: Daily profile of the average duration of place activities per 15 minutes by case study area (place activities ≥ 15 sec; n = 1,654)



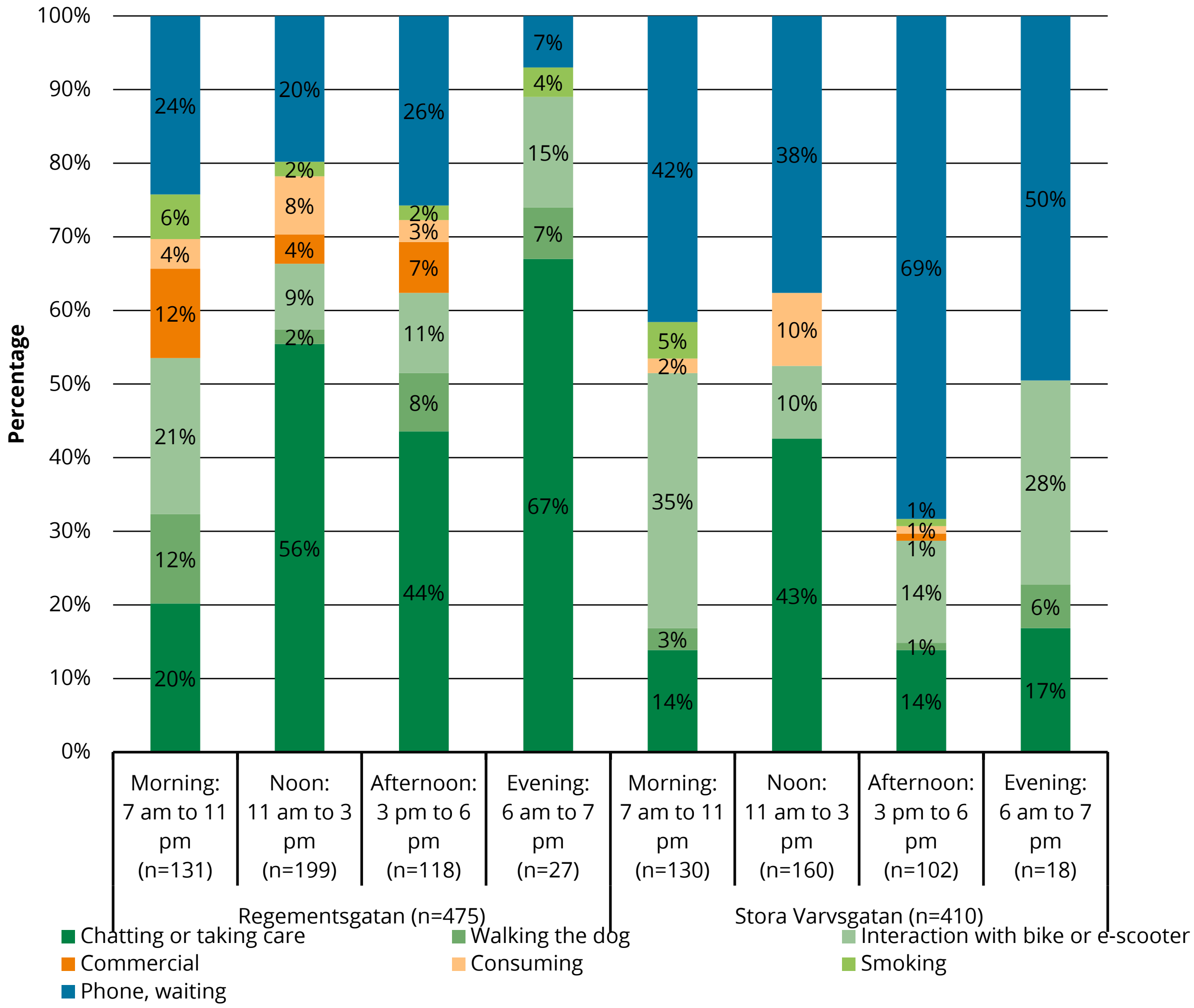
Across all case study areas except Mariedalsvägen, which was taken out because of its specific profile of a rainy day, two clear peaks in activity numbers get visible, one during lunch time and the other in the afternoon. The lunch-time peak is broader because of the slightly different positions of the peak hours in the case study areas. Activity duration peaks during lunch time and again in the early afternoon. The afternoon peak in activity duration is particularly shaped by Regementsgatan and Södra Förstadsgatan, which is interesting. It seems like the high share of gastronomy and service-oriented businesses in these two case study areas generates different patterns than the offices in Stora Varvsgatan with their high activity numbers combined with low durations in the later afternoon when office workers can be assumed to return to their home. The share of the peak hour across all five case study areas is 13 percent of the overall daily activity number.

Figure 12: Daily profile of the number of place activities and durations per 15 minutes across all case study areas (without Mariedalsvägen and Sallerupsvägen; n = 1,236)



Main activity types by time of the day are shown in Figure 13 for Regementsgatan and Stora Varvsgatan. The share of "chatting or taking care" in Regementsgatan is highest during lunch time and in the evening which is interesting, seeing that activity duration peaks in the afternoon. "Commercial" and "consumption" have in Regementsgatan the highest shares in the morning, at lunch time and in the afternoon but still happen as secondary activities in the evening, when people meet to socialize – and consume mainly food in parallel. Similar to Regementsgatan, "chatting or taking care" have the highest shares during lunch time and in the evening also in Stora Varvsgatan but at a far lower level, especially in the evening. Place activities seem to be dominated here by employees who arrive in the morning by bus (activity type "phone, waiting") or the bike ("interaction with bike or e-scooter") at their offices, come back to the street for having their lunch break and possibly in the afternoon again for getting some fresh air, and finally leave their office in the evening resulting again in the two main activity types "phone, waiting" and "interaction with bike or e-scooter".

Figure 13: Main activities by daytime in Regementsgatan and Stora Varvsgatan (place activities ≥ 15 sec)



4.3 Place activities by gender and age

Place activities by gender in Table 5 are well balanced between men and women in Mariedalsvägen and Stora Varvsgatan. The share of women is higher in Sallerupsvägen and Regementsgatan but lower in Södra Förstadsgatan. The share of the middle age group of 18 to 64 years as shown in Table 6 is high in all five case study areas, the share of seniors aged 65+ is highest in Mariedalsvägen and Regementsgatan. The share of people aged zero to 17 years is generally low and lowest in Regementsgatan and Stora Varvsgatan, which is plausible seeing that no school is located in the direct vicinity of any of the five case study areas. Besides the assumed dominance of office workers in Stora Varvsgatan, no further obvious reasons can be identified for the observed differences in gender and age.

Table 5: Place activities by gender and case study area (place activities ≥ 15 sec; n = 1,654)

	Mariedalsvägen *representative for the car-oriented city*	**Sallerupsvägen** *representative for the car-oriented city*	**Södra Förstadsgatan** *representative for the sustainable city*	**Regementsgatan** *representative for the city of places*	**Stora Varvsgatan** *representative for the sustainable city*	**Total**
	Percent of column					
Male	49 %	44 %	58 %	45 %	51 %	49 %
Female	51 %	56 %	42 %	55 %	49 %	51 %
	100 %	100 %	100 %	100 %	100 %	100 %
n	85	333	351	475	410	1,654

Table 6: Place activities by age group and case study area (place activities ≥ 15 sec; n = 1,654)

	Mariedalsvägen *representative for the car-oriented city*	**Sallerupsvägen** *representative for the car-oriented city*	**Södra Förstadsgatan** *representative for the sustainable city*	**Regementsgatan** *representative for the city of places*	**Stora Varvsgatan** *representative for the sustainable city*	**Total**
	Percent of column					
0–17 years	7 %	6 %	5 %	2 %	1 %	4 %
18–64 years	75 %	87 %	87 %	81 %	91 %	86 %
65+ years	18 %	7 %	7 %	17 %	7 %	11 %
	100%	100 %	100 %	100 %	100 %	100 %
n	85	333	351	475	410	1,654

Table 7 and Table 8 show the shares of activities by posture and main activity type across all case study areas except Mariedalsvägen for the different groups in gender and age. In terms of activity numbers, the higher share of the two older age groups compared to people aged zero to 17 years for formal sitting and the low share of the middle age group for informal sitting is interesting. A higher share of females engages in "chatting or taking care" and "phone, waiting", while a higher share of men is active in "consuming" and "smoking". Seniors aged 65+ have high shares of "walking the dog" and "commercial" and a particularly low share of "chatting or taking care" and "interaction with bike or e-scooter", the latter might result from lower bike use in this age group. The share of "smoking" is particularly high in the middle age group and of "phone, waiting" in the youngest age group.

Activity duration as shown in Table 7 is longest for formal and informal sitting which is plausible. Interestingly, activity duration for these two postures but also across all postures is substantially higher for men than for women. Similar patterns can be identified when looking at the main activity types in Table 8. Activity duration is higher for men than for women for all activity types except "commercial". Men seem to either need more time or take more time than women for similar activities in terms of posture and type. Looking at the age groups, activity duration for seniors aged 65+ tends to be longest for all postures and particularly for sitting. Patterns for main activity types are more specific for the different age groups. Activity duration for seniors aged 65+ is particularly high for "chatting or taking care" and "walking the dog" and low for "commercial". Activity duration for the youngest age group is particularly short for "interaction with bike or e-scooter", they seem to be more efficient with this than the other age groups. Activity duration for "smoking" is longest for the middle age group and for "phone, waiting" for the youngest age group.

Table 7: Share and duration of place activities by posture, gender and age (place activities ≥ 15 sec; n = 1,569; sample without Mariedalsvägen)

	Standing	Formal Sitting	Informal Sitting	Lying	Multiple Movement	Total
	Share of place activities (Percent of row)					
Male	84 %	8 %	2 %	2 %	4 %	100 % (n = 773)
Female	88 %	5 %	1 %	2 %	4 %	100 % (n = 769)
Total	86 %	6 %	1 %	2 %	4 %	100 % (n = 1,569)
0–17 years	88 %	2 %	4 %	4 %	4 %	100 % (n = 56)
18–64 years	87 %	7 %	1 %	2 %	4 %	100 % (n = 1,354)
65+ years	82 %	7 %	3 %	1 %	6 %	100 % (n = 159)
Total	86 %	6 %	1 %	2 %	4 %	100 % (n = 1,569)
	Average Duration [min]					
Male	2.6 min	14.9 min	6.4 min	2.0 min	4.1 min	3.7 min
Female	2.3 min	13.5 min	3.9 min	1.7 min	3.4 min	2.9 min
Total	2.5 min	14.4 min	5.3 min	1.8 min	3.7 min	3.3 min
0–17 years	2.1 min	12.8 min	2.1 min	3.9 min	2.9 min	2.4 min
18–64 years	2.5 min	13.5 min	5.3 min	1.6 min	4.0 min	3.3 min
65+ years	2.6 min	21.5 min	6.6 min	2.6 min	2.7 min.	4.0 min.
Total	2.5 min.	14.4 min.	5.3 min.	1.8 min.	3.7 min.	3.3 min.

Table 8: Share and duration of place activities by main activity type, gender and age (place activities ≥15 sec; n = 1,569; sample without Mariedalsvägen)

	Chatting or taking care	Walking the dog	Interaction with bike or e-scooter	Commercial	Consuming	Smoking	Phone, waiting	Total
	Share of place activities (Percent of row)							
Male	29 %	3 %	22 %	3 %	6 %	7 %	30 %	100 % (n = 773)
Female	34 %	5 %	19 %	4 %	2 %	2 %	35 %	100 % (n = 769)
Total	31 %	4 %	20 %	3 %	4 %	4 %	33 %	100 % (n = 1,569)
0–17 years	32 %	2 %	18 %	2 %	0 %	2 %	45 %	100 % (n = 56)
18–64 years	32 %	4 %	22 %	2 %	4 %	5 %	32 %	100 % (n = 1,354)
65+ years	26 %	7 %	9 %	13 %	5 %	2 %	37 %	100 % (n = 159)
Total	31 %	4 %	20 %	3 %	4 %	4 %	33 %	100 % (n = 1,569)
	Average Duration [min]							
Male	5.0 min	1.6 min	2.0 min	1.6 min	10.2 min	3.4 min	2.9 min	3.7 min
Female	4.3 min	0.9 min	1.3 min	2.2 min	5.7 min	3.1 min	2.6 min	2.9 min
Total	4.6 min	1.2 min	1.7 min	2.0 min	9.1 min	3.4 min	2.8 min	3.3 min
0–17 years	2.4 min	0.6 min	0.5 min	2.4 min	–	0.5 min	3.3 min	2.4 min
18–64 years	4.4 min	0.9 min	1.7 min	2.6 min	9.2 min	3.5 min	2.7 min	3.3 min
65+ years	7.7 min	2.3 min	1.6 min	1.1 min	8.9 min	1.1 min	2.8 min	4.0 min
Total	4.6 min	1.2 min	1.7 min	2.0 min	9.1 min	3.4 min	2.8 min	3.3 min

4.4 Relationship between street characteristics and place activities

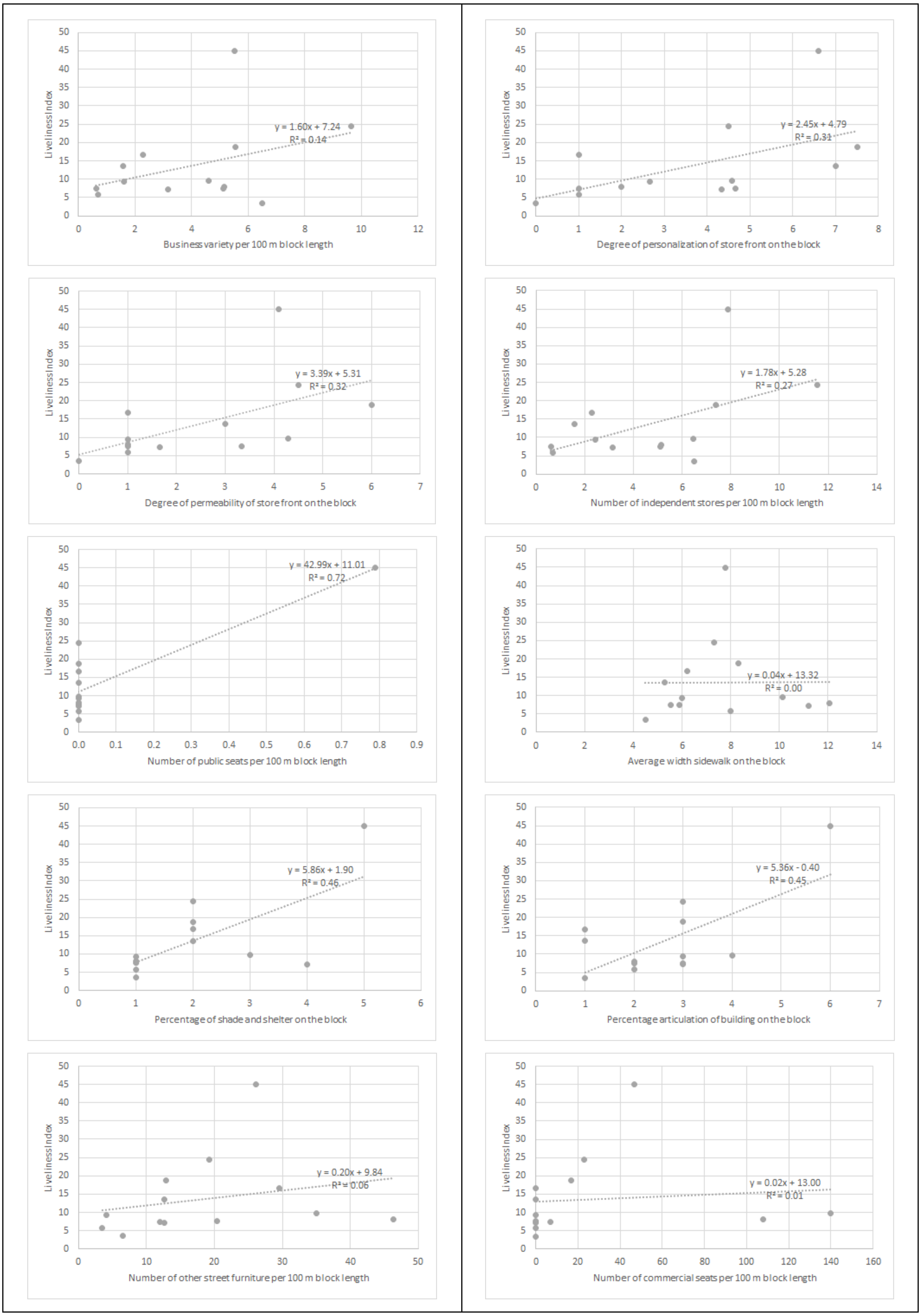
Correlations between the individual street characteristics proposed by Mehta (2013) (see Table 3) and the Liveliness Index are presented for all blocks except the ones in Mariedalsvägen in Figure 14. Scatter plots are provided in addition to the correlation values to show the patterns behind the single values. Correlations get significant for several street characteristics but are often shaped by single values, e.g. for the number of public seats or the percentage of shade and shelter. At the same time, tendencies can be identified for the relationship between street characteristics and place activities for the following three variables.

- Degree of personalization of the store front on the block segment (R^2=0.31)
- Degree of permeability of the street front on the block segment (R^2=0.32)
- Percentage articulation of the street front on the block segment (R^2=0.45)

The personalization of building façades of businesses according to Mehta (2013) describes how they are embellished with personal touches such as displays or decorations, it corresponds to the number of buildings with identifiers according to Ewing and Clemente (2013) and is significant in all studies carried out by the group around Mehta et al. The articulation of a façade according to Mehta (2013) measures how much it is articulated and punctuated with nooks, corners, alcoves, small setbacks etc. at street level, no direct corresponding factor in Ewing and Clemente (2013) could be identified but from their description, both variables, the personalization and the articulation, seem to belong to the urban design quality factor imageability according to Ewing and Clemente (2013), which often gets significant in the studies carried out by the group around Ewing et al. Permeability according to Mehta (2013) measures how well activities inside the buildings are visible and could be sensed by smell or sound from the street. This variable corresponds to the variable proportion of windows in Ewing and Clemente (2013) and can clearly be assigned to the urban design quality factor transparency, which gets significant in all studies done by Ewing et al.

Figure 15 presents the correlations between the Urban Design Quality Index (UDQI) from Ewing and Clemente (2013) (see Table 3) and three indicators of place activities. Tendencies for a positive relationship between the UDQI and activity numbers as well as the Liveliness Index can be identified but not for activity duration. Correlations between each of the five urban design quality factors from Ewing and Clemente (2013) and place activities are also checked, tendencies for a positive relationship with activity numbers are only identified for imageability which are also presented in Figure 15.

Figure 14: Correlations between street characteristics and the Liveliness Index per block



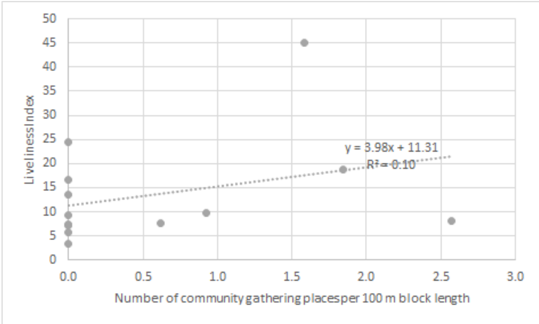
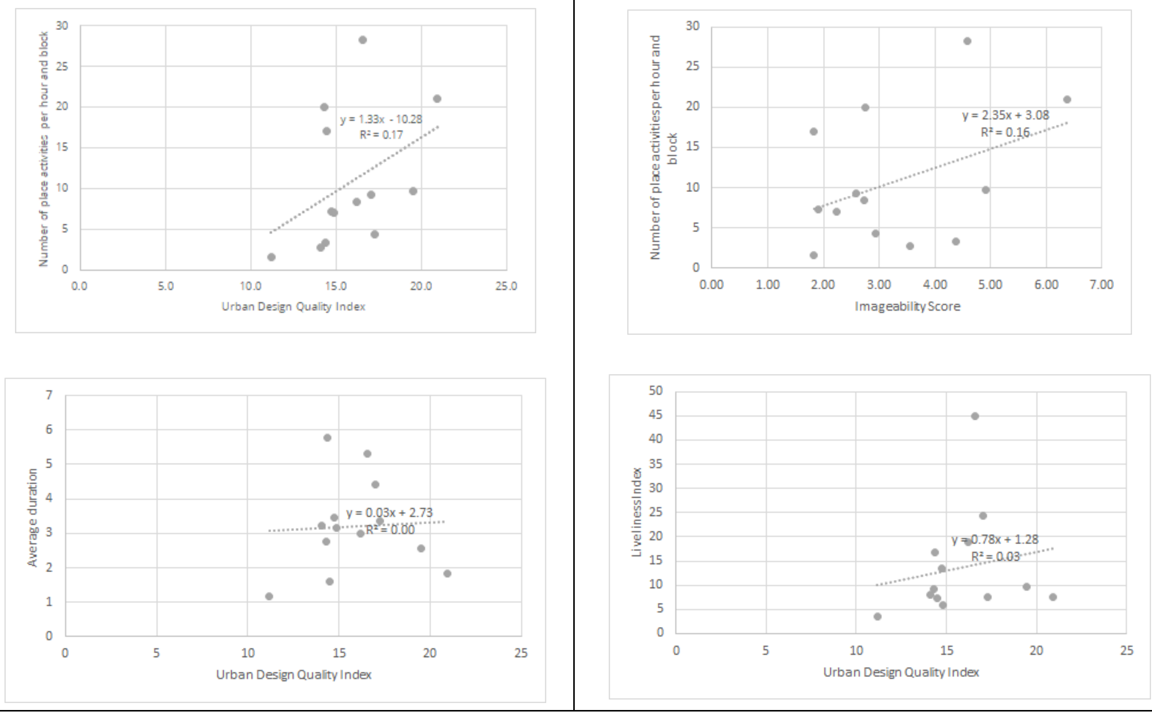


Figure 15: Correlations between place-activity variables and Urban Design Quality



4.5 Spatial patterns of place activities

Place activities are mapped for each case study area by duration in Figure 16 and by activity type in Figure 17. This spatial mapping of the activities provides background information for the analyses presented in the previous sections. Main attractors of place activities can be visually identified, these might be destinations in the buildings adjacent to the street or equipment in the street itself such as benches. The following destinations in the adjacent buildings are identified as main attractors of place activities:

- Restaurants in Mariedalsvägen (blocks 01-2, 01-3), Södra Förstadsgatan (blocks 03-1, 03-2, 03-4) and Regementsgatan (blocks 04-2, 04-3);
- Facilities of daily needs in Södra Förstadsgatan (Lidl in block 03-3, local shop in block 03-2), Stora Varvsgatan (block 05-2);
- Social service facility in Sallerupsvägen (block 02-1);
- A major shopping mall (Kronprinsen in Mariedalsvägen, block 01-1);
- Entrances of residential buildings in Sallerupsvägen (block 02-2) or office buildings in Stora Varvsgatan (blocks 05-1, 05-3, 05-4).

The following transport-related "destinations" in the street are found to be particularly relevant for place activities:

- Bus stops in Sallerupsvägen (block 02-2), Södra Förstadsgatan (block 03-1), Regementsgatan (block 04-3) and Stora Varvsgatan (blocks 05-1, 05-4);
- Bike racks in Sallerupsvägen (block 02-1), Södra Förstadsgatan (blocks 03-1, 03-2, 03-4), Regementsgatan (block 04-2, 04-3) and Stora Varvsgatan (blocks 05-3, 05-4);
- Car parking in Södra Förstadsgatan (block 03-4) and Stora Varvsgatan (block 05-3).

Bus stops and parking facilities have a special role as they attract in the first place "intermediate place activities". These transport-related place activities are part of an intermodal trip with unknown origins, destinations and types of activities at the destinations. People come or continue their trip by public transport, bike or car to get to destinations, which might be located in the street (e.g. playing table tennis if such a facility would be provided in the street), in the buildings adjacent to the street (e.g., the workplace) or at any other location outside the street. We did not observe many people who combined the parking activity or access to / egress from public transport with other on-street place activities, people rather came from or went to destinations after having finished the parking activity and we lost track which destinations these are because of our focus on the observation of the place activities themselves.

Relevant destinations in the adjacent buildings attract place activities when they offer their services directly in the street as this is the case for the restaurants that put tables in the street space. Relevant destinations in the adjacent buildings also attract place activities just because people enter or leave these buildings. For example, people met for a short chat before they entered a building or said good bye before continuing their way to their next destination separately, people came out of their office for having some fresh air, possibly combined with a cigarette or a phone call. This relationship between destinations in the adjacent buildings and place activities leads to hotspots of place activities next to relevant destinations even though sidewalks are small and not attractive, e.g. in Södra Förstadsgatan next to the entrance of the Lidl supermarket (block 03-3) and at the upper corner of block 03-2, or in Mariedalsvägen with the narrow sidewalk in block 01-2 and at the upper corner of block 01-3 (see Figure 16).

Figure 16: Exemplary impressions of the street (Own pictures)

<table>
<tr><td>Södra Förstadsgatan
block 03-2 upper corner</td><td>Mariedalsvägen
block 01-2</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Mariedalsvägen
block 01-3 upper corner</td><td></td></tr>
<tr><td>
</td><td></td></tr>
</table>

Restaurants are the most relevant destinations generating these hotspots of place activities, they put commercial (and in some places temporary) seating on the sidewalk even though space for this is hardly available. The high number of parked bikes in Södra Förstadsgatan next to the entrance of the Lidl supermarket (block 03-3) is another example of place activities without suitable facilities in the streets pace. On the other hand, we have also identified hotspots of place activities at locations without specific destinations, e.g. in Södra Förstadsgatan at the lower corner of block 03-3. People seem to come here for place activities just because the space is quieter and less crowded than the space next to their destinations such as the bus stop or the entrance of the Lidl supermarket in block 03-3.

The higher number and duration of place activities in the northern side of Regementsgatan (block 04-3) is noteworthy. We identified the sun as the main reason for this, the northern side of the street was bathed in sunshine all day long which was obviously welcomed by place users in the Swedish autumn weather. The southern part of Regementsgatan was in the shade for the entire day except the space between block 04-1 and 04-2 where again more place activities were observed. The higher number of place activities around an art & book-store and the neighboring fashion store in Regementsgatan (block 04-2) are examples for destinations that are not restaurants but still attract place activities. Different sizes of catchment areas were identified for the different destinations depending on the number of place users and also the available space. For example, the entrance to the social service facility in Sallerupsvägen, in combination with the bike racks, attracted place activities along the entire block 02-1, probably because many persons come in a short period of time (mainly in the morning, see section 4.2) and because space is available and similarly attractive along the entire street section.

Besides these hotspots, we observed place activities that were more evenly distributed along the entire street sections including mainly the types phone, smoking and walking the dog. For those activities, the movement function of the street seems to be more relevant than the place function. People walked along the street section coming from and getting to unknown destinations, stopped for these place activities and continued their trip afterwards. Based on our observation method, we could not clearly disentangle the main determinants of the street users' choices of the locations for these place activities. They may have stopped because they received a phone call just in this moment or because their dog asked for a break. They may have consciously chosen a certain location in the street for their phone call or for the dog's break because of the sun, a niche in a nice historic building, a nice view or other characteristics of the street environment.

Example indications for the influence of street design and equipment on place activities include Stora Varvsgatan (block 05-4), which has a bike path off-the carriageway so that the remaining space for pedestrians to walk, wait or to do other things is small. This results in waiting activities mainly directly next to the building to avoid the bike path. It is interesting that people wait longer and chat more at the bus station in Regementsgatan (block 04-3) than e.g. in Stora Varvsgatan (blocks 05-1, 05-4). Street design might be a possible reason for this or also different frequencies in buses serving the stops. Seating in the form of outdoor dining as another type of street equipment clearly is related to a higher number and longer duration of place activities. Possible effects of other types of seating or street furniture and equipment could not be systematically investigated because their number was too low in the case study areas.

Figure 18 and Figure 19 confirm the daily profiles of place activities as identified in section 4.2 and also the general patterns over the entire day as described above. The higher number of activities in the northern side of Regementsgatan gets even more visible and also the lunch peak in Stora Varvsgatan. Figure 20 and Figure 21 map the main activities by duration. In Regementsgatan, the café in block 04-3 is dominant for all activity durations, activities around the bus stop have here mainly a duration between one and five minutes. In Stora Varvsgatan, activity duration at the bus stops is shorter than in Regementsgatan and more dominated by "phone, waiting" than by "chatting or taking care of somebody". The place activities next to the entrances of the office buildings in Stora Varvsgatan are mainly between one and five minutes, they are often done in groups of persons who chat together and often also smoke.

Figure 17: Place activities by duration and case study area (Background map: © OpenStreetMap-contributors)

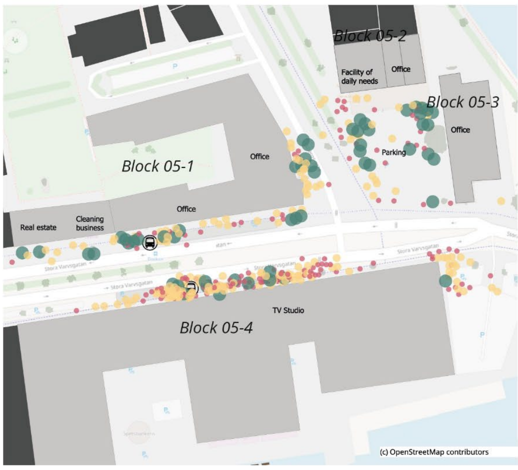
Mariedalsvägen
representative for the car-oriented city

Sallerupsvägen
representative for the car-oriented city

Södra Förstadsgatan
representative for the sustainable city

Regementsgatan
representative for the city of places

Stora Varvsgatan
representative for the sustainable city



- 15 seconds to under one minute
- one minute to under five minutes
- more than five minutes
- Land use (ground floor)*
- Other buildings

Other elements

- Tree crown coverage
- Bench
- Outdoor dining
- Bus stop

Map: OSM Standard

* refers to the situation in September 2022

0 10 20 m

Figure 18: Place activities by main activities (Background map: © OpenStreetMap-contributors)

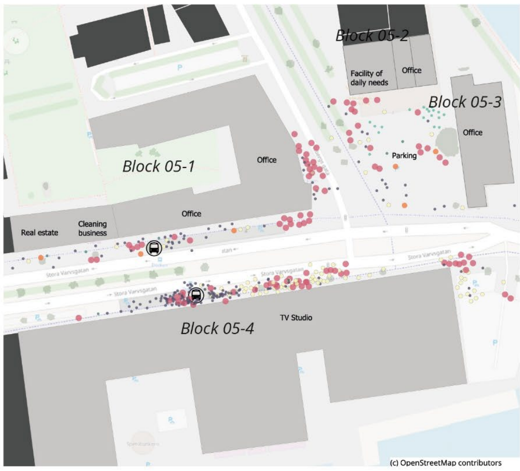
Mariedalsvägen
representative for the car-oriented city

Sallerupsvägen
representative for the car-oriented city

Södra Förstadsgatan
representative for the sustainable city

Regementsgatan
representative for the city of places

Stora Varvsgatan
representative for the sustainable city



- Chatting or taking care of somebody
- Walking the dog
- Bicycle or E-Scooter
- Commercial
- Consuming
- Smoking
- Phone, waiting, recreation, culture
- Land use (ground floor)*
- Other buildings

Other elements

- Tree crown coverage
- Bench
- Outdoor dining
- Bus stop

Map: OSM Standard

* refers to the situation in September 2022

0 10 20 m

Figure 19: Main activities by daytime in Regementsgatan (Background map: © OpenStreetMap-contributors)

Regementsgatan
representative for the city of places

Main activities in the morning (7 am to 11 am)	*Main activities in the noon (11 am to 3 pm)*
	
Main activities in the afternoon (3 pm to 6 pm)	*Main activities in the evening (6 pm to 7 pm)*
	

- Chatting or taking care of somebody
- Walking the dog
- Bicycle or E-Scooter
- Commercial
- Consuming
- Smoking
- Phone, waiting, recreation, culture
- Land use (ground floor)*
- Other buildings

Other elements

- Tree crown coverage
- Bench
- Outdoor dining
- Bus stop

Map: OSM Standard

* refers to the situation in September 2022

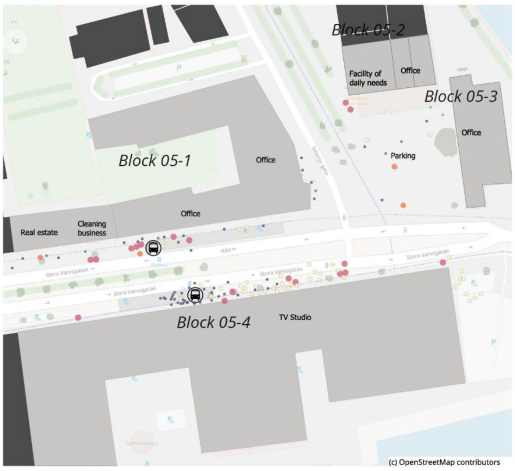
0 10 20 m

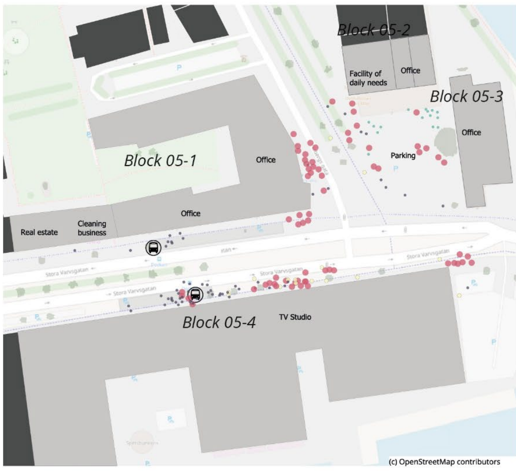
Figure 20: Main activities by daytime in Stora Varvsgatan (Background map: © OpenStreetMap-contributors)

Stora Varvsgatan

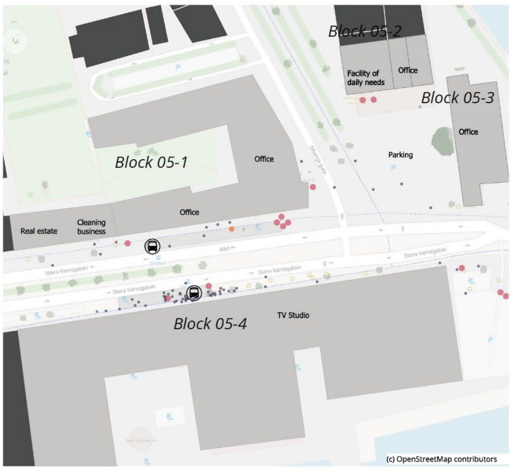
representative for the sustainable city

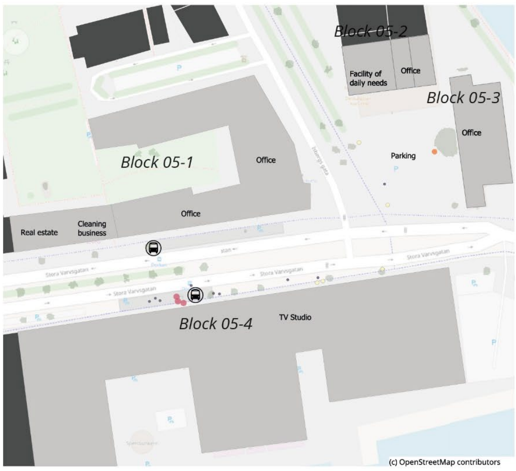
Main activities in the morning (7 am to 11 am)	*Main activities in the noon (11 am to 3 pm)*





Main activities in the afternoon (3 pm to 6 pm)	*Main activities in the evening (6 pm to 7 pm)*





- Chatting or taking care of somebody
- Walking the dog
- Bicycle or E-Scooter
- Commercial
- Consuming
- Smoking
- Phone, waiting, recreation, culture
- Land use (ground floor)*
- Other buildings

Other elements

- Tree crown coverage
- Bench
- Outdoor dining
- Bus stop

Map: OSM Standard

* refers to the situation in September 2022

0 10 20 m

Figure 21: Main activities by duration in Regementsgatan (Background map: © OpenStreetMap-contributors)

Regementsgatan

representative for the city of places

Main activities of 15 seconds to under one minute

Main activities of one minute to under five minutes

Main activities of more than five minutes

- Chatting or taking care of somebody
- Walking the dog
- Bicycle or E-Scooter
- Commercial
- Consuming
- Smoking
- Phone, waiting, recreation, culture
- Land use (ground floor)*
- Other buildings

Other elements

- Tree crown coverage
- Bench
- Outdoor dining
- Bus stop

Map: OSM Standard

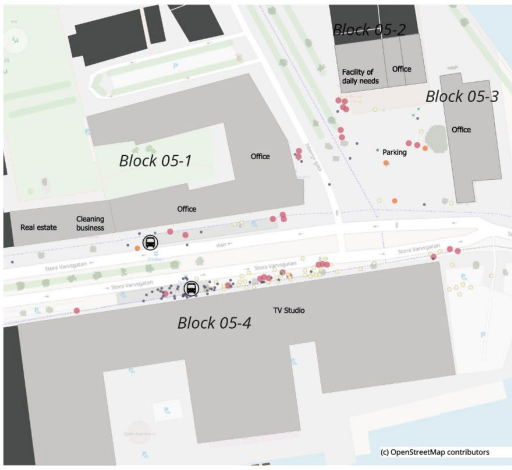
* refers to the situation in September 2022

0 10 20 m

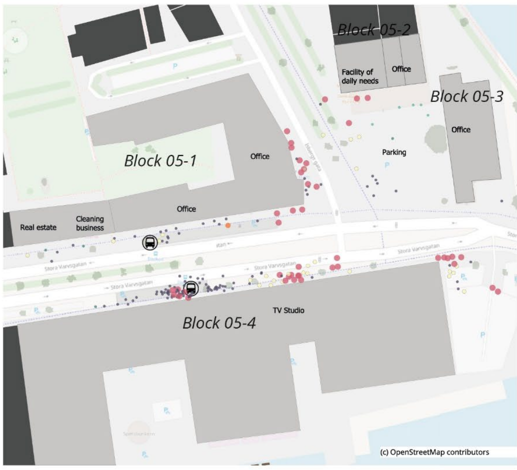
Figure 22: Main activities by duration in Stora Varvsgatan (Background map: © OpenStreetMap-contributors)

Stora Varvsgatan
representative for the sustainable city

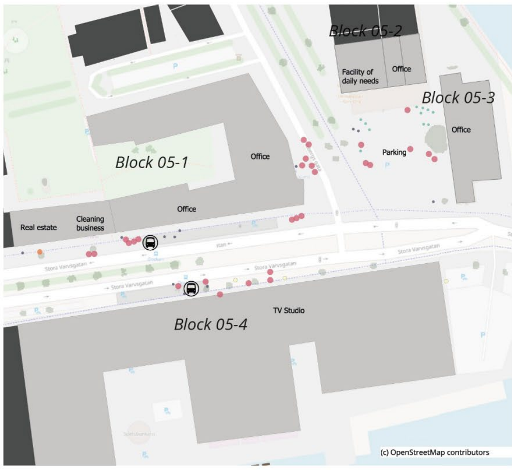
Main activities of 15 seconds to under one minute



Main activities of one minute to under five minutes



Main activities of more than five minutes



- Chatting or taking care of somebody
- Walking the dog
- Bicycle or E-Scooter
- Commercial
- Consuming
- Smoking
- Phone, waiting, recreation, culture
- Land use (ground floor)*
- Other buildings

Other elements

- Tree crown coverage
- Bench
- Outdoor dining
- Bus stop

Map: OSM Standard

* refers to the situation in September 2022

0 10 20 m

5 Discussion and conclusions

Getting back to the research questions, we find similar magnitudes of place activities in all five case study areas in terms of the overall numbers which are between 40 and 50 per hour. Differences appear when looking at the various characteristics of the activities. The share of activities longer than five minutes differs between 25 and 11 percent, maximum durations between 16 minutes and one hour. The share of sitting as a posture differs between two and ten percent. "Chatting and taking care" as the main activity type, which might include other types as secondary activities, and "phone, waiting" are most relevant with each 32 percent across all case study areas, followed by "interaction with bike or e-scooter" with 21 percent.

Place activities show distinct patterns in the five case study areas, which are explored in their relationship with the general land use types and with the specific variables describing the street layout and the characteristics of the adjacent buildings proposed by Ewing and Clemente (2013) and Mehta (2013). The general land use variables turn out to be most useful in understanding the overall activity patterns. Stora Varvsgatan, with mainly offices in the street and the neighborhood, shows the typical activity patterns and daily profiles of office workers who come in the morning, go out for lunch or short smoking breaks during the day, and leave in the evening. Activities in Sallerupsvägen are dominated by the social service institution with a distinct peak in the morning. Regementsgatan and Södra Förstadsgatan with many service-oriented businesses and gastronomy have activity peaks in the morning (only Regementsgatan), during lunch and in the afternoon. These streets have also the highest activity durations and shares of "chatting and taking care" as the most desirable and interactive activity types. Mariedalsvägen shows place activities on a rainy day with a drop in activity number and duration, hardly any peak hours could be identified here but still, the share of "chatting and taking care" is with 36 percent quite high.

These general land use variables, in combination with the D-variables at the neighborhood level as introduced in section 2.1, seem to be the basis for place activities, they "generate" a higher or lower potential for these activities in terms of number, type, duration and daily profiles. The variables proposed by Ewing and Clemente (2013) and Mehta (2013), which describe the street layout, proportions of street space and buildings as well as ground floor use and facades of adjacent buildings, seem to measure then in the next step how streets with their specific characteristics can materialize and exploit this potential, how they can translate it into the wished levels of place activities. Positive relationships are found between several variables from Ewing and Clemente (2013) and Mehta (2013) with place activities. For example, personalization and permeability proposed by Mehta (2013) and also the Urban Design Quality Index proposed by Ewing and Clemente (2013) show a positive correlation with activity numbers and the Liveliness Index.

Both sets of variables are therefore considered useful and applicable to place activities in the European context. The street characteristics proposed by Mehta (2013) with their more distinct focus on land use and physical qualities seem to cover the more fundamental and impactful determinants of place activities. They have some overlap to the variables proposed by Ewing and Clemente (2013), which add relevant indicators for the street layout in the context of the adjacent buildings and also on the specific characteristics of these buildings. The individual variables proposed by Ewing and Clemente (2013) seem to be more insightful than the aggregated Urban Design Quality Factors, which, in addition, are partly based on the same individual variables. We also need to remember that these variables were initially developed for understanding the attractiveness of a street for walking as assessed by experts and not for understanding pedestrian activities in terms of number and characteristics. On the contrary, the number of people in a street was a significant determinant of the Urban Design Quality Factor "complexity" in the earlier studies from Ewing et al. (Ewing and Clemente 2013; Ewing and Handy 2009). Mehta (2013) only works with individual variables describing street characteristics which well explain place activities and could be supplemented by selected variables from Ewing and Clemente (2013).

Relationships between the different indicators describing the place activities differ between the case study areas. For example, a higher number of place activities does not necessarily lead to longer activity durations. Our recommendation is therefore to use aggregated indices such as the Liveliness Index for a quick and easy-to-understand benchmark, but to compute and communicate in addition all the different activity characteristics separately for a more detailed understanding of the place activities.

The spatial mapping of activities in the final step of our analysis provides background information that complements the previous analyses of aggregated variables for blocks or street sections. We identified local hotspots of place activities and their main attractors in terms of adjacent buildings and street characteristics. Entrances to buildings attract place activities, particularly for outdoor dining but also for entrances to supermarkets, a social service facility and offices. Parking facilities particularly for bikes and public transport stops are also relevant, which can be assumed to be a major difference between the European and the US-American context. Based on the insights from this detailed spatial mapping, hypotheses for future studies, that analyze again aggregated variables for a higher number of case study areas, could be formulated. For example, we recommend to distinguish the type of ground floor land use types in the adjacent buildings in more detail including not only gastronomy and the number of independent stores but also facilities of daily needs (supermarkets), shopping malls and specific destinations such as fitness studios or social services. On the other hand, the spatial mapping of place activities as done in this study might be also helpful for future more detailed analyses, probably again with a low number of street sections. For example, on-site surveys of place users might help to better understand their choices in terms of destinations, when e.g., more than one restaurant is available, in terms of locations for the activity types that are not directly related to a specific destination such as "phone" or "smoking", and also in terms of the perceived importance of each singly activity type when more than one activity type is performed in parallel. The effect of street furniture and non-commercial seating on place activities could only be investigated to a limited extent in this study, simply because hardly any of such items existed in the five case study areas. In future studies, it would be interesting to investigate street sections with more street furniture such as public seating, playing equipment for children, monkey bars, sandboxes, slides, seesaws, table-tennis tables, fountains or other water facilities. We hypothesize that such facilities, put at the right locations, could have an impact on activity types, durations and also street user types in terms of gender and age.

Methodologically, this study is placed in between first the specific local perspective with its detailed analysis and mapping of each single place activity and second the generalizing perspective with the descriptive statistics and correlations of the various indicators describing street characteristics and place activities. For the specific local perspective, this study is rather in the higher range of case study areas with its five street sections and 16 blocks. For the generalizing perspective, it is in the lower range. With this approach, this study provides to the best of our knowledge first insights on place activities in a typical medium-sized European city for five case study areas which all have a good potential for place activities based on their neighborhood and street characteristics. At the same time, this study makes a methodological contribution by combining variables from two different "schools" (Ewing and Clemente 2013;

Mehta 2013), it investigates their relevance and thus provides the ground for future studies with larger sample sizes. The manual static observation method with two observers was found to be suitable. Video recordings with an automated extraction of the number and characteristics of place activities could increase the efficiency of data collection substantially but so far, the identified tools are able to count pedestrians but cannot reliably distinguish movement and place activities and extract information on gender, age, postures and activity types. While the main activity type has proved effective, future studies could also look more closely at the different combinations of individual activity types under the main type of each activity. Detailed activity durations measured by minute and second turned out to be useful as the basis for computing the cumulative distribution of activity duration where differences between the case study areas were mainly identified for activities with the longest durations.

The joint investigation of pedestrian movement and place activities would be an interesting avenue for future research including also the change between these two types of activities while walking along a street. Place activities in this study in the European context are generated both by the street as a "conduit" with its movement function, where people walk to destinations, and by the street as a place, where people come to carry out activities directly in the street or in the adjacent buildings. The in-depth understanding of place activities therefore requires the collaboration between urban and transport planning and design, and possibly also further disciplines such as environmental planning. Higher modal-split shares of walking, cycling and public transport in a city, shaped by transport planning, can potentially increase the number of place activities. High betweenness values of a street, due to its high connectivity to other parts of the network as shaped by transport and urban planning, increase the likelihood that people will simply pass by and possibly stop for place activities. Dense and mixed land use in combination with attractive street designs, as shaped mainly by urban planning, attract businesses and again also place activities. All these different mechanisms are highly interdependent, which is both a responsibility and an opportunity to design active and vibrant streets with multiple benefits for community building, public health, economic success and environmental quality.

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