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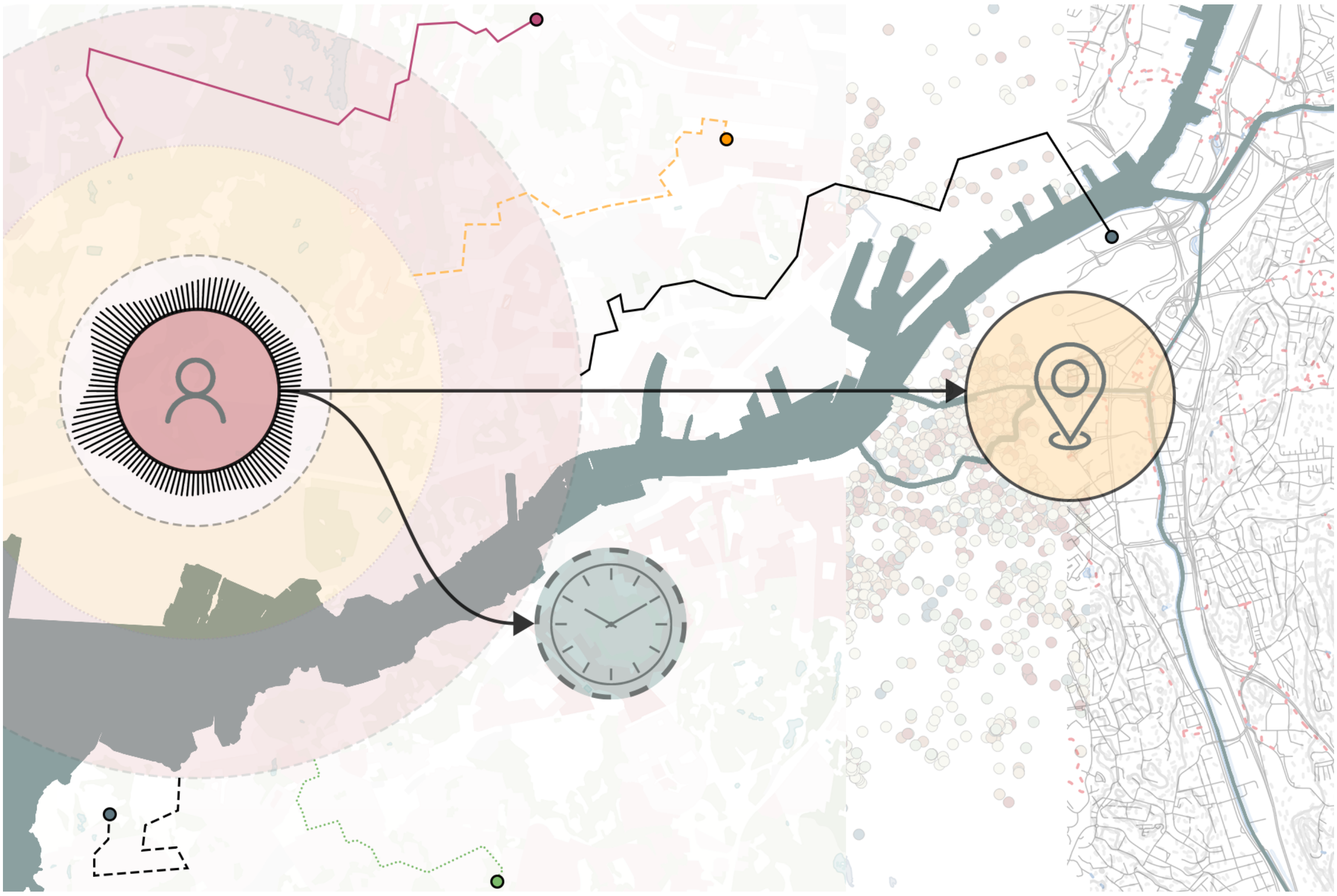

Instruments of Inquiry for Urban Social Sustainability

Activity-based urban accessibility modelling of neighbourhoods

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CHALMERS UNIVERSITY OF TECHNOLOGY
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THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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to my family

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Abstract

The primary goal of the built environment is to create the infrastructure that facilitates the needs of the people who use it and elevates their quality of life. Sustainable development has encouraged architects, urban designers, and urban planners (practitioners) to be more sensitive to the built environment's economic, environmental, and social dimensions.

Using a capabilities-based approach, practitioners can improve a neighbourhood's social equity by enhancing residents' spatial accessibility. However, the tools and methods available to practitioners cannot evaluate the distributional effects of neighbourhood planning in a disaggregated way. In comparison, methods developed in adjacent fields of mobility analysis and transportation planning have been successfully employed in such disaggregated simulations for many years.

This thesis aims to bridge the gap between theory and practice using a mixed-methods approach to develop a computational model assessing distributional access to neighbourhood amenities. The overarching research question is - "How can digital tools support practitioners in evaluating the social consequences of their designs?". The theoretical perspectives on conceptualising Urban Social Sustainability (USS) are first explored using an inductive approach. Then, using a deductive approach, a study on practitioners' conceptualisation and operationalisation of USS through interviews is conducted. Next, an indicator of distributed accessibility and an Activity-Based Model (AcBM) of Gothenburg are developed. Finally, using a neighbourhood in Gothenburg, Sweden, this thesis demonstrates how practitioners may apply AcBMs to evaluate individual accessibility early in the design and planning process.

The studies show that practitioners' conceptualisation focused on the individual perspective of neighbourhood residents, specifically by improving social capital through social equity. Therefore, urban accessibility is a tangible point of departure towards digitalising USS in the neighbourhood planning process. The validation studies of the AcBM developed in this thesis show promising results in imputing national-level mobility patterns at the neighbourhood level. The results of the demonstration case show that practitioners can use AcBMs as instruments of designerly inquiry to test neighbourhood planning scenarios and evaluate planning policies regarding their social sustainability impacts.

Theoretically, this thesis contributes to USS discourse through a conceptual framework of USS and practitioners' perspectives on USS. Methodologically, it contributes to neighbourhood planning by developing an indicator of the distributional effects of neighbourhood plans and an AcBM of neighbourhood accessibility. In conclusion, this thesis underscores the importance of mobilising existing research from adjacent fields, such as transport planning and mobility, while incorporating theoretical and practical perspectives to operationalise USS in neighbourhood planning.

Keywords: Urban Social Sustainability, neighbourhood, accessibility, digital tools, Activity-Based Modelling, synthetic population.

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Sammanfattning

Det primära målet med den byggda miljön är att skapa en infrastruktur som underlättar människors dagliga behov och höjer deras livskvalitet. Hållbar utveckling har stimulerat arkitekter, stadsplanerare och stadsbyggnadsplanerare (praktiker) att bli mer känsliga för den byggda miljöns ekonomiska, miljömässiga och sociala dimensioner.

Genom att använda ett kapacitetsbaserat tillvägagångssätt kan praktiker förbättra en stadsdels sociala rättvisa genom att förbättra invånarnas rumsliga tillgänglighet. Verktygen och metoderna som finns tillgängliga för praktiker kan dock inte utvärdera stadsdelsplaneringens fördelningsmässiga effekter på ett disaggregerat sätt. Jämförelsevis har metoder som utvecklats inom närliggande områden, exempelvis inom mobilitetsanalys och transportplanering, använts framgångsrikt under många år för sådana disaggregerade simuleringar.

Avhandlingen syftar till att överbrygga klyftan mellan teori och praktik genom att använda blandade metoder för att utveckla en beräkningsmodell som bedömer fördelningsmässig tillgång till faciliteter i stadsdelar. Den övergripande forskningsfrågan är - Hur kan digitala verktyg stödja praktiker i att utvärdera de sociala konsekvenserna av deras design?". De teoretiska perspektiven på att konceptualisera Urban Social Sustainability (USS) utforskas först med en induktiv metod. Därefter genomförs en studie om praktikers konceptualisering och operationalisering av USS genom intervjuer med en deduktiv metod. Utifrån det utvecklas en indikator för distribuerad tillgänglighet och en aktivitetsbaserad modell (AcBM) för staden Göteborg. Slutligen, baserad på fördjupningsstudie för en stadsdel i Göteborg visar avhandlingen hur praktiker kan använda AcBM för att utvärdera individuell tillgänglighet tidigt i design- och planeringsprocessen.

Studierna visar att praktikers konceptualisering fokuserade framför allt på stadsdelsinvånarnas individuella perspektiv och särskilt på att förbättra socialt kapital genom social rättvisa. Därför är tillgängligheten i stadsdelen en lämplig utgångspunkt för att digitalisera USS i stadsdelsplaneringsprocessen. Valideringsstudierna av AcBM som utvecklats i denna avhandling visar lovande resultat för att tillämpa nationella mobilitetsmönster på stadsdelsnivå. Resultaten från demonstrationsfallet visar att praktiker kan använda AcBM som ett verktyg för designmässiga undersökningar för att testa stadsdelsplaneringsscenarier och utvärdera planeringspolicys med avseende på social hållbarhet.

Teoretiskt bidrar denna avhandling till USS-diskursen genom att utveckla ett konceptuellt ramverk för USS och förståelse av praktikers perspektiv på USS. Metodologiskt bidrar den till stadsdelsplanering genom att utveckla en indikator på de fördelningsmässiga effekterna av stadsdelsplaner och AcBM för stadsdelstillgänglighet. Sammanfattningsvis understryker avhandlingen vikten av att utnyttja befintlig forskning från närliggande områden såsom transportplanering och mobilitetsforskning samtidigt som den inkorporerar teoretiska och praktiska perspektiv för att operationalisera USS i stadsdelsplanering.

Nyckelord: Urban Social Sustainability, stadsdel, tillgänglighet, digitala verktyg, aktivitetsbaserad modellering, syntetisk population.

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Sanjay Somanath
Göteborg, October 2024

List of Publications

This thesis is based on the following appended papers:

Paper 1. (Published) S. Somanath, A. Hollberg, and L. Thuvander.
Toward digitalisation of socially sustainable neighbourhood design.
Published in Local Environment, 2021.
doi: 10.1080/13549839.2021.1923002
Contribution: Sanjay Somanath was responsible for the conceptualisation, data curation, investigation, and methodology of the study and preparing the original draft, writing, reviewing and editing the manuscript, and creating visualisations.

Paper 2. (In review) S. Somanath, L. Thuvander, M. Adelfio, and A. Hollberg.
From Concept to Operation: Planning Practices of Urban Social Sustainability
Submitted to Buildings and Cities, 2024.
Contribution: Sanjay Somanath was responsible for the conceptualisation, methodology, interviewing, data curation, investigation and preparing the original draft, writing, reviewing and editing the manuscript, and creating visualisations.

Paper 3. (Published) S. Somanath, A. Hollberg, and L. Thuvander.
Effects of Sustainability Policy – Evaluating Social Consequences of Carbon Targets using Trip Completion Rates.
Published in IOP Conference Series, 2022.
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Contribution: Sanjay Somanath was responsible for the conceptualisation, methodology, data curation, investigation, preparing the original draft, writing, reviewing and editing the manuscript, and creating visualisations.

Paper 4. (Published) S. Somanath, A. Hollberg, and L. Thuvander.
An activity-based synthetic population of Gothenburg, Sweden: Dataset of residents in neighbourhoods.
Submitted to Data in Brief, 2024.
Contribution: Sanjay Somanath was responsible for the conceptualisation, methodology, software development, and validation, preparing the original draft, writing, reviewing and editing the manuscript, and creating visualisations.

Paper 5. (In review) S. Somanath,L. Thuvander, J. Gil and A. Hollberg.
Activity-based simulations for neighbourhood planning using Gothenburg as a case.
Submitted to Computers, Environments and Urban Systems, 2024.
Contribution: Sanjay Somanath was responsible for the conceptualisation, methodology, software development, investigation and original draft, writing, reviewing and editing the manuscript, and creating visualisations.

Other Publications

The following publications were produced during my PhD but are not included in this thesis, as their content does not directly contribute to its main objectives. They are listed here for further reading and to provide an overview of my broader research interests:

a. **S. Somanath**, V. Naserentin, O. Eleftheriou, D. Sjölie, B. Stahre Wästberg and A. Logg.
Towards Urban Digital Twins: A Workflow for Procedural Visualization Using Geospatial Data.
Published in Remote Sensing, Volume 16, Issue 11, Pages 1939, 2024.

b. E. Ho, M. Schneider,**S. Somanath**, Y. Yu and L. Thuvander.
Sentiment and semantic analysis: Urban quality inference using machine learning algorithms.
Published in iScience, Volume 27, Issue 7, 2024.

c. L. Thuvander, **S. Somanath**, and A. Hollberg.
Procedural Digital Twin Generation for Co-Creating in VR Focusing on Vegetation.
Published in The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume 48, Pages 189–196, 2022.

d. **S. Somanath**, A. Hollberg, S. Beemsterboer, and H. Wallbaum.
The relation between social life cycle assessment and green building certification systems.
Published in Proceedings of the 7th Social LCA Conference, Gothenburg, Sweden, Pages 14–17, 2020.

e. A. Gonzalez-Caceres, F. Hunger, J. Forssén, **S. Somanath**, A. Mark, V. Naserentin, J. Bohlin, A. Logg, B. Wästberg, D. Komisarczyk, et al.
Towards digital twinning for multi-domain simulation workflows in urban design: a case study in Gothenburg.
Published in Journal of Building Performance Simulation, Pages 1–22, 2024.

Acronyms

AcBM Activity Based Models.

BE Built Environment.

BN Bayesian Network.

CAD Computer Aided Design.

GIS Geographic Information System.

GR Generalised Raking.

HD Hellinger Distance.

IPF Iterative proportional fitting.

IPU Iterative proportional updating.

MATSim Multi-Agent Transport Simulation.

ML Machine Learning.

NGO Non Governmental Organisation.

NHTS National Household Travel Survey.

OD Origing-Destination.

OMOD open-source activity-based mobility demand.

OSM OpenStreetMap.

PPGIS Public Participation Geographic Information Systems.

PUMS Public Use Microdata Sample.

QoL Quality of Life.

RMSE Root Mean Squared Error.

RQ Research Question.

SD Sustainable Development.

SDN StadsDelsNämn - Urban Areas.

SUMO Simulation of Urban MObility.

TCR Trip Completion Rate.

USS Urban Social Sustainability.

VAE Variational Auto-encoder.

Glossary

Accessibility The ability to access.

Activity In the context of mobility, an activity is a task or an event that an individual engages in. It is also related to the National Household Travel Survey, wherein the purpose of a trip is categorised into explicit activity categories such as travel home, travel to work, shopping or picking/dropping children.

Boundary-Spanning A role within an organisation where the boundary-spanner promotes strategic decision-making by linking various sources of information, by creating and coordinating the flow of information across organisational boundaries (Saldert, 2021).

Built Environment Human-made structures and spaces that provide the setting for human activity.

Capabilities Approach An approach to understanding human well-being and development that focuses on enhancing the capabilities of the individual (Sen, 2005).

Geoinformatics The science and technology which develops and uses techniques to address problems of earth sciences such as geography, cartography, photogrammetry, GIS and related branches of science and engineering, including urban planning (Filchev et al., 2020).

Gravity Model A model that predicts the flow of people, goods or information between two locations based on the distance between them and the size of the locations (Wilson, 1971).

Hellinger Distance A statistical metric used to quantify the similarity of two probabilistic distributions. 1 indicates that the two distributions are entirely dissimilar and 0 indicates an exact similarity (Kitsos and Toulias, 2017).

How-actually Explainations that aim to identify the mechanisms that produce a phenomenon and require empirical evidence to support their claim (Bokulich, 2014).

How-possibly Speculative explanations that aim to explore potential explanations of a phenomenon whose explanatory premise does not contradict known facts (Bokulich, 2014).

Macro-accessibility The structural issues of planning, such as the spatial distribution of people, activities, transportation infrastructure and the ability of people to access these opportunities (Pereira and Herszenhut, 2023).

Micro-accessibility Micro-accessibility is related to the idea of *universal design* (Evcil, 2009). The design standards, regulations, construction and planning practices aimed at the inclusion of people with different degrees of motor and cognitive challenges (Joseph and Phillips, 1984).

Mobility People's daily travel and behaviour patterns (Pereira and Herszenhut, 2023) often quantified into number of trips taken, modes of transport used and average trip time or distance.

Mobility Pattern Patterns of human movement and behaviour that can be observed in the built environment. These patterns can be related to the number of trips taken, the mode of transport used, the average trip time or distance, and the purpose of the trips.

Mode Choice The mechanism of choosing a transport mode (like a car, bike or bus).

National Household Travel Survey An annual survey that collects data on people's daily travel patterns across the country. In the context of Sweden, the survey covers Sweden's population between ages 6 and 84 years and includes approximately 12,200 participants (RVU, 2017).

Neighbourhood A socio-spatial construct of the BE. According to Jenks and Dempsey (2007), the neighbourhood is both a community (the social component) - the collection of the neighbours (the individual component) that make up the neighbourhood and a district - the spatial construct describing the area in which people live along with its functions, infrastructure and spaces shared by its residents.

Practitioner The professionals who actively play a role in shaping the built environment through design and planning - architects, urban planners and urban designers. The term aims to represent the diverse and boundary-spanning nature of these roles.

Routing The mechanism of identifying a logical path (the route) between an origin and a destination.

Spatial Relating to the position, area, and size of things. Spatial has a broader meaning, encompassing the term *geographic*.

Spatial Accessibility The ability of people, regardless of who they are and where they live, to have equal access to resources such as primary health care, job opportunities, healthy food options and recreational opportunities.

Spatial Analysis Spatial analysis is the set of methods used when the data being analysed are spatial with the objective of solving a scientific or decision-making problem (Goodchild and Longley, 1999).

Strategic Planning A socio-spatial process that creates plans for future development based on the understanding of current societal trends (Saldert, 2021).

Synthetic Population A distribution of synthetic agents that replicates the demographic distribution of a real-world population based on census records..

Theoretical Model Theoretical models of urban spaces that aim to explain the underlying mechanisms of urban phenomena conceptually.

Tour-based A modelling approach that groups trips into tours based on the purpose of the trips.

Trip-based A modelling approach focusing on individual trips.

Urban Accessibility The structural issues of planning, such as the spatial distribution of people, activities, transportation infrastructure and the ability of people to access these opportunities (Pereira and Herszenhut, 2023).

Urban-Analytical Model Analytical models that aim to create simplified representations of urban spaces. These models are often algorithmically derived and are used to understand the underlying mechanisms of urban phenomena.

Wicked Problem Or ill-structured problem (Buchanan, 1992), is a problem or a field of problems concerned with finding novel and useful ways of approaching and transforming an uncertain situation without straightforward answers (Rittel and Webber, 1974).

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Part I

1

Introduction

The primary goal of the Built Environment (BE) is to create places that facilitate the needs of the people that use them and elevate their quality of life; to shape the physical and spatial surroundings for human purposes (Hillier, 2008). As such, the practice of shaping these spaces is inherently a social endeavour. Social and cultural studies of human interaction with the BE have shown that it is influenced by the individuals that occupy these spaces just as much as the spaces influence individuals (Lawrence and Low, 1990). These studies show how the BE may both enable and constrain certain types of behaviours. In addition to serving human needs, buildings, especially dwellings, can become focal points of personal and social identities of the cultures in which they are built (Lawrence and Low, 1990).

In light of increased human consumption of natural resources beyond Earth's planetary boundaries, in the 1980s, the Brundtland Report (WCED, 1987) put forward a new path for urban development (Kohon, 2018). *Sustainable Development* (SD) was introduced as a political vision for human development in the 21st century (Chiras, 1995). Originally conceived as *"development that meets the needs of the present without compromising the ability of the future generations to meet their own needs"* (WCED, 1987). SD has since emerged as a key concept in contemporary urban planning and is described as the *"meeting point of three major dimensions: ecology, economy and society"* (Shirazi and Keivani, 2017). However, among the three dimensions of the triple-bottom-line SD model, the social dimension has received the least attention (Vallance et al., 2011).

Popularised by the American urban planner Clarence Perry (1929) in the early 1900s, the idea of the *neighbourhood* began to emerge as an important setting for social activity (Jenks and Dempsey, 2007). As a socio-spatial construct of the BE, the neighbourhood is both familiar and complex (Choguill, 2008). It is deeply integrated into the urban fabric of cities and the social interactions that take place in them. Neighbourhoods are not only homes to diverse populations but are central to residents' daily lives and public policy. Research on neighbourhood planning shows that the BE significantly impacts its residents' Quality of Life (QoL) (Kyttä et al., 2016) and is widely used as the scale at which local planning policy can be applied (Mouratidis, 2018). But a neighbourhood is more than its geographical area; neighbourhoods also include the people (neighbours) who live within the area (Choguill, 2008). Jenks and Dempsey (2007) define a neighbourhood as both a *physical* construct, describing the area in which people live and a *social* construct, describing the people who live there.

The lack of attention to the social dimension in urban planning and development is evident in increasing concerns of social stability (Janssen et al., 2021) and growing gaps between the wealthy and poor (Saldert, 2024). These social issues presenting themselves in urban neighbourhoods have brought considerable criticism to the triple-bottom-line conceptualisation of SD and its fixation on growth (Poli, 2011; Adelfio, 2016). Over the past decades, researchers have questioned the SD paradigm, suggesting that alternative frameworks of economic growth (or degrowth), social welfare and environmental protection must be sought out (Asara et al., 2015).

Through strategic planning, contemporary urban planning policy continues to set goals formulated around Urban Social Sustainability (USS). USS is used by governments, public agencies, policymakers, Non-Governmental Organisations (NGO) and corporations in decisions affecting the sustainability and resilience of cities (Woodcraft et al., 2012). USS has entered politics and policy in the past decade, and today, it has become a central concept for strategic planning in urban development projects (Saldert, 2021). In this process, the role of architects, urban planners and urban designers as practitioners in the BE becomes important. Practitioners play a boundary-spanning role (Van Meerkerk and Edelenbos, 2014), mediating between the various stakeholders through participatory approaches, performing spatial analysis and iterating through design and planning solutions.

Like all design processes, the urban design and planning process is an iterative exploration. The practitioner evaluates each iteration to identify how the design performs based on evaluation criteria (like cost, energy, accessibility) or how it can be improved. Traditionally, this evaluation process depends on the practitioners' knowledge and competence to a large extent (Hillier, 2008). However, evidence-based design has gained attention for facilitating a well-informed debate of potential solutions (Head, 2008; Loyola, 2018). As various sub-fields related to the design of the BE have emerged and progressed (such as improved energy performance, transport modelling, and life cycle assessment), there are opportunities to evaluate potential solutions in an evidence-based manner. Practitioners use digital tools in the BE (like Computer-Aided Design (CAD) software) to expedite the feedback loop in the process of design enquiry. Digital tools are a part of the practitioners *instruments of inquiry* (Dalsgaard, 2017). Using evidence-based design and digital tools, practitioners can answer complex questions such as *how much energy will this neighbourhood consume?* or *how wide should this street be to avoid congestion?* but the social component remains under-explored.

The transition to an evidence-based computational approach to design and planning has only recently been made possible. Today, most, if not all, practitioners in the BE use digital tools to expedite the design and planning process. Digital tools for performance assessment of the BE are commonly used to test proposals for buildings, neighbourhoods, and cities quickly. The relatively recent access to computational resources has democratised the use of performance assessment tools for evaluating urban mobility (Axhausen et al., 2016) and energy consumption (Mackey and Roudsari, 2017), for example. However, present digital tools for social sustainability cover different aspects of the design and planning process. They primarily facilitate digital collaboration and participation (Maiullari et al., 2022) or gather insights from the residents. Public Participation Geographic Information Systems (PPGIS) is one such application to gather resident insights (Kyttä et al., 2016). Digital tools have been leveraged here to include the various stakeholders in the design process and foster collaboration and social inclusion, e.g. (Maiullari et al., 2023), but do not address performance-based evaluations of the social dimension.

Returning to the practitioner's role in shaping the BE, enabling residents to achieve their daily needs is a critical aspect of neighbourhood planning (Kolodinsky et al., 2013) and contributes to maintaining good health and well-being (Luiu et al., 2013; Reis et al., 2000). Studies have shown that people who demonstrate higher levels of autonomy and competence in their daily activities tend to report greater well-being (Reis et al., 2000). In addition to individual well-being, notions of equitable access to amenities and services contribute to developing resilient and socially sustainable communities (Widborg, 2017). Compact urban environments, through the density of amenities and homes, allow residents to reach more amenities, thereby increasing the ability to achieve their daily needs.

In analysing urban environments, the challenge of using analytical models begins with which type of analysis should be used (Karimi, 2012). In neighbourhood planning, accessibility studies are performed primarily through static analysis of the land-use and transport components: the neighbourhood's street network (Boeing, 2017), the morphological arrangements of the built-up regions (Palaiologou et al., 2021), and the location of amenities (Dogan et al., 2018; Thériault and Des Rosiers, 2004). Over the past 50 years, sophisticated models have been developed to represent and understand urban spaces (Cottineau et al., 2024). These models create simplified representations of urban spaces through *urban-analytical models*. Compared to theoretical-models of neighbourhood planning, analytical models aim to understand and explain the processes behind certain urban features using spatial analysis rather than create a vision of the ideal city based on a normative principle (Cottineau et al., 2024). Urban analytical models have been fundamental in improving the understanding of urban spaces and influencing the everyday interactions of residents with their BE but remain underutilised in practice (Gil, 2020).

The application of urban analytical models is more commonplace within transportation research. In such models, mobility-patterns are modelled as a supply and demand problem (Rodrigue et al., 2016). Residents' demographic composition and travel behaviour contribute to the travel demand. Dimensions of the BE, such as transport infrastructure and spatial distribution of origin and destinations (ODs), constitute the supply (Talen and Anselin, 1998). To capture the distributional effects of accessibility, analytical models must account for both the temporal and individual components of spatial accessibility. The concept of *dynamic accessibility* shows promise to address the gap in analytical neighbourhood assessment tools that focus on the individual. Järv et al. (2018) developed a framework of dynamic accessibility comprising three core components: *people, transport and activities*. In this framework, ”dynamic” represents the variability of the three core components across dimensions like space, time and socio-economic variables.

Classical models for evaluating mobility demand simulate trips carried out by commuters in a region. This trip-based approach (so-called because the primary unit of analysis is a trip, i.e. an OD pair) is known as the four-step model. It consists of four main steps: trip generation, trip distribution, modal split or choice, and traffic assignment (Mcnally, 2007). In recent years, Activity-Based Models (AcBM) that capture spatially and temporally disaggregated mobility demand by implementing a *tour-based* approach have come in favour over the classic trip-based four-step model as it realistically captures the entire journey of a commuter (Miller, 2023). AcBMs are now extensively used in research and for evaluating policy decisions at the city scale, but neighbourhood planning has yet to see widespread adoption of them. This oversight results in a critical gap in the neighbourhood planner’s toolbox, where the distributional effects of neighbourhood plans on different demographic groups remain unknown (Järv et al., 2018).

Existing accessibility models used in neighbourhood planning often fall short of incorporating the dynamic interplay between the demographics of neighbourhood residents and their daily routines. Network-based approaches like space syntax (Hillier and Hanson, 1984) or econometric models like the gravity-models (Santana Palacios and El-Geneidy, 2022) can only capture glimpses of the city in a fixed frame of reference (Järv et al., 2018). Applying a dynamic approach to accessibility changes the assessment focus from just the BE to include individual perspectives, capturing the distributional effects of accessibility. Bridging this methodological gap is essential for enhancing the theoretical framework of socially sustainable neighbourhood planning and for practical applications in creating more equitable and responsive urban environments (Järv et al., 2018). As cities grow, density, and diversify, the ability to shape neighbourhoods to their residents’ changing needs and behaviours becomes increasingly important. New methods for analysing the distributional effects of spatial accessibility can help practitioners create more inclusive and equitable places, ultimately improving the QoL for all residents.

1.1 Problem definition

If planning is to become an instrument for implementing social sustainability goals, efforts must be focused on making better connections between planning procedures and policy goals (Stepanova and Romanov, 2021). For architects, urban designers, and urban planners to answer questions of *who* is affected or disadvantaged by their designs and *in what way*, new evaluation methods are required that include the distributional impacts of planning decisions and provide practitioners with digital tools to evaluate the social consequences of their designs.

Returning to USS, there is little empirical research on how practitioners conceptualise and operationalise the concept. Inconsistent conceptualisations of USS might risk implementations that do not correspond to the intended goals or even oppose them (Janssen et al., 2021; Saldert, 2021). Understanding the intricate relationship between conceptualising and operationalising USS from a practitioner lens is crucial to implementing its intended goal of *improving the life conditions for people who live now and in the future* (Chiu, 2003). Research on the social dimension of SD considers the concept vague and conceptually underdeveloped compared to the economic and environmental dimensions (Vallance et al., 2011). However, in practice, within the scope of neighbourhood planning, USS is central to several European planning policies, and practitioners are increasingly encountering the concept (Saldert, 2021). This points to a gap between theory and practice, specifically in the operationalisation and implementation of USS.

With an increasing number of social indicators, databases, and analytical methods such as exploratory spatial data analysis (Anselin et al., 2007), gaining insight into the social performance of neighbourhoods has never been more accessible. Design and planning tools guide how problems are perceived and aid in constraining the space of potential solutions. An essential aspect of using such tools in the design and planning process is that the practitioner understands how a tool operates. This enables them to recognise how these tools guide them towards specific design solutions (Peters et al., 2021). Considering the *intertwined and co-evolving* nature of design tools and the design process (Dalsgaard, 2017), digital tools have the potential to increase the knowledge gained about the design problem and expedite the process of iterating and testing against the design criteria.

Recently, decision-makers in the BE have increasingly favoured evidence-based designs to solve design and planning problems (Hillier, 2008). The nature of these problems has, in turn, shaped the design and planning process (see section 2.3); in the absence of sufficient information about the design and planning problem and a time-sensitive task, digital tools have the potential to bridge the scientists' analysis-based approach with the designers' synthesis based approach (Cross, 1982). Practitioners require appropriate *instruments of inquiry* to further the agency in improving the social qualities of the BE. There is a need to develop novel tools and methods in emergent fields of design, in some fields more so than others (Dalsgaard, 2017).

To address the social equity issues in the BE, an approach that focuses on individual residents' ability to achieve their daily needs is essential. To this end, implementing existing research and methods from transportation planning and accessibility offers a promising way forward. Not to forget that the design of the BE is fundamentally a social endeavour. By giving practitioners agency to explore the social consequences of their solutions through appropriate tools, one can improve the community's social sustainability and provide a better QoL for the present and future generations.

1.2 Research scope and central concepts

This thesis's theoretical contribution is positioned within the fields of architecture, urban design, and urban planning. The methodological contributions are positioned within computational methods to analyse neighbourhood accessibility and are exemplified through implementation for the city of Gothenburg, Sweden. There are subtle but significant differences between architecture, urban design, and urban planning. They both involve shaping the built environment and mediating between it and its stakeholders, but they differ in the scale and nature of intervention.

- Architecture deals with the design and planning of the BE at the building scale.
- Urban design involves interventions on the neighbourhood, city or regional scale.
- Urban planning is concerned with the systematic development and organisation of land use and public services and infrastructure.

The research scope of this thesis is defined by the following: The **social consequences** of architecture, design and planning in **neighbourhoods**, the role of **designers and planners**, and finally, **computational methods** to implement such inquiry for planning practitioners in the early stages of a project with a focus on **accessibility** (see Figure 1.1).

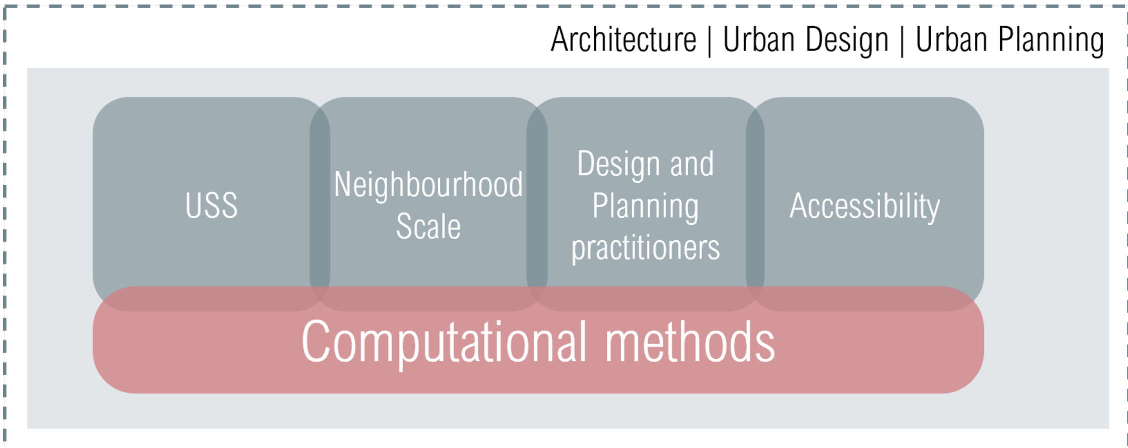


Figure 1.1: Positioning the research and the scope of the thesis.

1. **Urban Social Sustainability (USS)** This thesis recognises a relationship between the BE and the social dimension of SD, commonly referred to as urban social sustainability or USS. USS is understood as being ontologically related to SD as one of the crucial dimensions within the triple-bottom-line conceptualisation of environment, economy, and society. (Further elaborated in Section 2.1.)

2. **The neighbourhood scale** The neighbourhood is selected as the spatial scale of interest. It is a favourable scale for intervention as it provides an interface between individual residents, the local community, local authorities and policymakers. It is a pragmatic scale to address social problems and challenges as key aspects of QoL, social cohesion, and community dynamics are most evident at the neighbourhood level. (Further elaborated in Section 2.2.)

3. **Design and planning practitioners** Design and planning in the BE is understood as an exploration and transformation process. Here, a designer or planner draws upon their repertoire of knowledge, competence and resources to create something novel and appropriate that improves the existing situation. Hereafter, this thesis refers to the architect or urban designer-/planner as a *practitioner* to represent the diverse and boundary-spanning nature of these roles. (Further elaborated in Section 2.3.)

4. **Accessibility** Urban accessibility is related to notions of distributional justice and equity. Urban accessibility focuses on the relationship between people and their BE by assessing the ease of reaching destinations. In this thesis, urban accessibility is identified as a tangible dimension of social equity in neighbourhoods within a practitioner's scope of influence that can be used to influence USS. Further elaborated in Section 2.4.)

5. **Computational methods for decision support** Central to this thesis's investigations (and eventual methodological contributions) are topics related to shaping the BE through computational analysis techniques. The model developed in this thesis aims to provide decision support to practitioners at the early stages of the design process. The transport and mobility field offers insights into using analytical tools. These tools evaluate complex and interconnected relationships between the BE, the residents that use it and the policy that shapes it. Planning-adjacent fields such as *spatial analysis* and *transportation modelling* offer a means to model the movement of residents using *mobility demand modelling* and *activity-based models*.

1.3 Aim and research questions

This thesis aims to develop an analytical model to assess distributional access to neighbourhood amenities. Furthermore, it contributes to USS research in general and bridges the gap between theory and practice through inductive and deductive approaches. The main focus of this thesis is the theoretical development of USS and methodological developments in its implementation through computational methods and digital tools. It investigates USS in general and explores how it can be conceptualised and made operational to support practitioners in their design and planning process through computational methods and their implementation (see Figure 1.2).

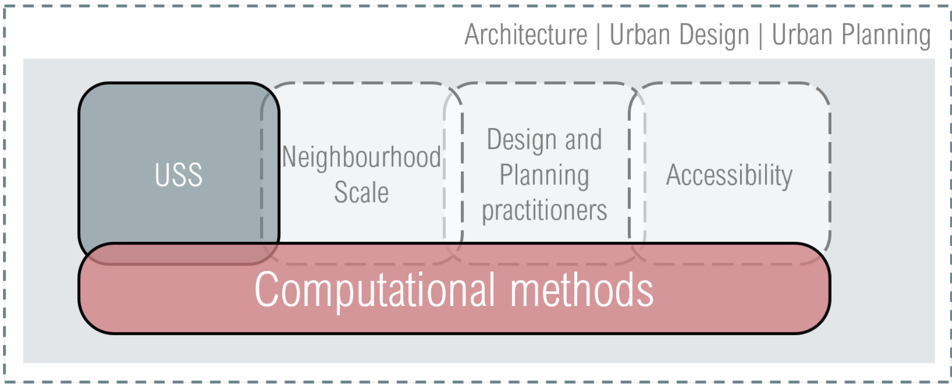


Figure 1.2: The main focus of this thesis is on theoretical and methodological development.

The overarching research question (RQ) formulated to enable the digitalisation of USS is:

RQ. **How can digital tools support practitioners in evaluating the social consequences of their designs?**

Three specific research questions are formulated to address the aim outlined above. These specific research questions focus on (1) the conceptualisation of USS in theory, (2) The conceptualisation and operationalisation of USS in practice and (3) how activity-based models of spatial accessibility can be implemented to operationalise USS in the planning process (see Figure 1.3).

Figure 1.3: The variable operationalisation process, adapted from Allen (2017)

RQ1. How is USS **conceptualised** in theory?

RQ2. How do practitioners **conceptualise** and **operationalise** USS?

RQ3. How can activity-based models of spatial accessibility be **implemented** to help practitioners operationalise USS?

1.4 Research methodology and design

Given the conceptual inconsistencies of USS, this thesis uses a mixed methods research approach in its exploration, leveraging quantitative, qualitative and abductive approaches (see Figure 1.4). Every concept has components and is defined by them (Jabareen, 2009). Therefore, it is necessary to understand how USS is conceptualised before moving towards its operationalisation through computational methods. First, by scholars in the academic literature and then by practitioners in the field. Doing so is vital to ensure that the methods developed in this thesis are indeed relevant to the research field and the end user—the practitioner. The research employs inductive theory discovering methods like conceptual framework analysis and literature reviews (Jabareen, 2009) to discover knowledge through systematically obtained data using techniques from grounded theory (Glaser, 2003) - through Study I. The grounded theory perspective to theory building is perhaps the most widely used framework in qualitative research to imbue inductive studies with qualitative rigour (Gioia et al., 2013).

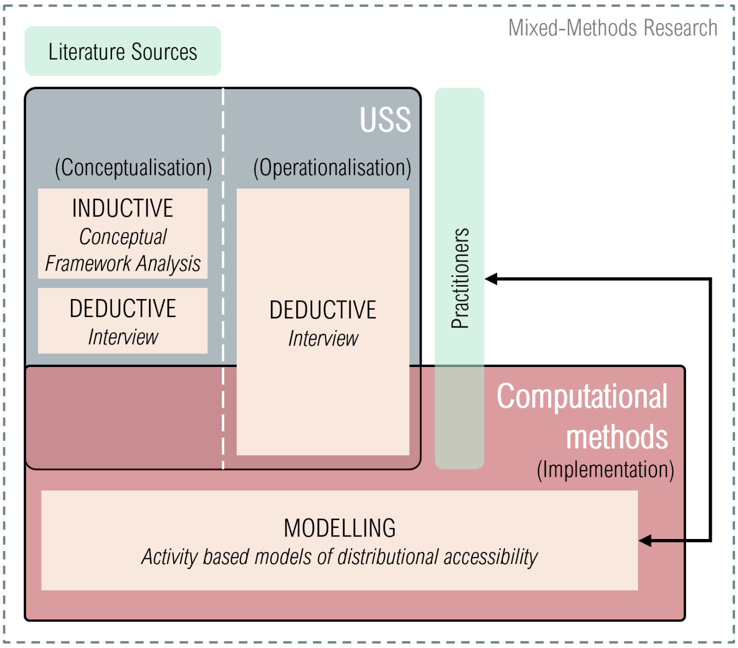


Figure 1.4: A mixed methods approach is used in this thesis

Like most professional fields, the design and planning in the BE have tensions between theory and practice (Krizek et al., 2009). To overcome these tensions, researchers have turned towards qualitative research to ground their findings in real environments (Krizek et al., 2009). Therefore, a deductive approach is adopted to gather insights from practitioners regarding how they conceptualise and operationalise USS through interviews - in Study II. For operationalisation, pragmatism as a research philosophy is better suited to USS in achieving this aim. In doing so, this thesis employs inductive and deductive approaches to build a theoretical foundation from multiple data sources. This becomes part of a larger abductive methodology towards the digitalising USS through implementing solutions based on previous findings. Abductive reasoning is described as an approach that addresses the weaknesses associated with deductive and inductive approaches and follows a pragmatic perspective that takes messy observations to lead to a “best prediction of the truth” (Mitchell and Education, 2018).

A theoretical foundation is built using these research approaches. This foundation is implemented using computational methods in two studies. First, to develop an indicator for distributional effects of neighbourhood planning - in Study III. Then, an urban analytical model for practitioners working with USS using an AcBM approach - through Studies IV and V. Each of the five studies corresponds to a paper appended at the end of Part II of this thesis, resulting in five papers.

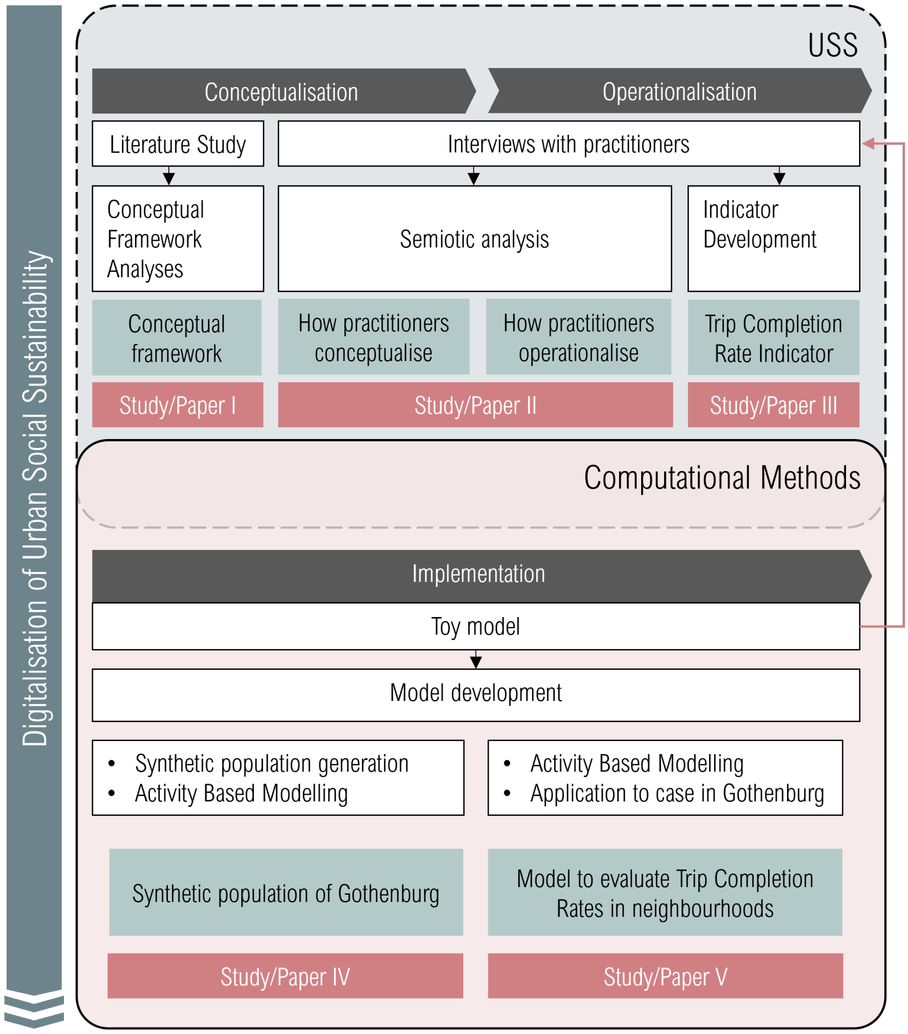


Figure 1.5: The research design and methods used and the papers produced within each study.

Based on this thesis's aim, research scope, gap, and research design, a combination of inductive, deductive, abductive and modelling-based methods are chosen for the exploration of USS (see Figure 1.5).

- To answer RQ1 - Using conceptual framework analysis, a literature review of USS is conducted to understand the reasons for inconsistent definitions and "fuzziness" in the literature and derive a conceptual framework for USS.
- To answer RQ2 - Practitioners are consulted early on through semi-structured interviews to gain insights into conceptualising and operationalising USS using interview coding and semiotic analysis.
- To answer RQ3 - An indicator and a toy AcBM of accessibility are developed and presented to the practitioner. The toy model is redeveloped based on practitioners' feedback, and its application through a case in Gothenburg is exemplified.

1.5 Outline of the thesis

This thesis consists of two parts:

Part I introduces the theoretical background, the research methods, findings discussion and conclusion:

- **Chapter 1** presents an **introduction** to the previous research related to USS and its gaps. Subsequently, the aim, overarching research question, methodology, and design are outlined.
- **Chapter 2** describes the knowledge areas that form the theoretical **background** of this thesis, along with the different computational methods used in research and practice to analyse neighbourhoods.
- **Chapter 3** presents the **research methods** used in this thesis.
- **Chapter 4** synthesises the **findings** of the studies conducted. They follow the structure presented in Figure 1.3: conceptualisation, operationalisation, implementation.
- **Chapter 5** presents a **discussion** and contextualises the findings with previous research, including limitations of the conducted research and reflection on the research methodology.
- **Chapter 6** presents the **conclusion** including the contribution to theory and practice and future research directions.

Part II contains five appended papers.

2
Background

This thesis spans the fields of USS, neighbourhood planning, the role of practitioners, and accessibility, with computational methods in focus. This chapter provides a theoretical foundation of the topics mentioned above on which this thesis's contribution is made. First, an overview of the research field of social sustainability is presented. Next, the significance of neighbourhoods is presented, followed by an overview of practitioners' ways of approaching design problems and their scope of influence. Finally, the field of spatial accessibility is introduced, along with computational methods of analysing the BE relevant to the scope of this thesis.

2.1 Urban Social Sustainability

Social sustainability is a broad topic that is entwined among several disciplines, such as philosophy, sociology, anthropology, architecture, and urban planning, to name a few. A discipline can be described as the ensemble of assumptions, concepts, theories, methods and tools employed by a particular group of scientists or scholars (Walker and Attfield, 1989, p. 1). As social sustainability gains interest and relevance and moves from a concept to a discipline, such conceptualisations are particularly useful. As a discipline matures and attains *self-awareness* (Walker and Attfield, 1989), the assumptions that constitute its conceptual formulations become more explicit. Over the past two decades, social sustainability as a concept has become increasingly self-aware; this is evident by the number of indexed documents available on the subject, but its conceptualisations are not yet explicit.

2.1.1 USS in relation to the built environment

Like SD, social sustainability has been a concept with many understandings and definitions (Chiu, 2003), and the path towards creating sustainable communities is often paved with many challenges and contesting conceptualisations (Kohon, 2018). Dempsey et al. (2011) has advocated for social sustainability to be considered a dynamic concept that changes over time. This conceptualisation is reflected in the works of Shirazi and Keivani (2019b), who identify a socially sustainable environment as: "a place with dialectic character, one where hard infrastructure, like the physical qualities of the BE and soft infrastructure, like the social capital of a community are both highly sought out".

In the context of the BE, the term *Urban social sustainability* is commonly used (Dempsey et al., 2011; Kyttä et al., 2016; Shirazi and Keivani, 2019b), indicating a relationship to the BE. Shirazi and Keivani (2019b) defines socially sustainable neighbourhoods as "localities where social qualities are exercised and practised within the neighbourhood space at an acceptable and satisfactory standard" (Shirazi and Keivani, 2019b, p. 2).

The research literature on USS suggests a strong connection between improving social qualities and aspects of the BE. Jenks and Jones (2010); Kain et al. (2022) discuss the role of densities and land use typologies of the urban form and their relationship to social qualities. The authors provide numerous research examples suggesting that higher densities and mixed-use urban forms lead to a higher QoL due to increased social interaction and community spirit.

Stren and Polèse (2000) state that cities must reflect on the social and spatial fragmentation that led to the exclusion of marginal and/or disadvantaged groups to achieve social sustainability. On the other hand, over-densification or drastic compaction can negatively impact social qualities, such as lower access to green spaces, deteriorating health, a reduction in living space and less affordable housing. Shirazi and Keivani (2021) discuss specifically the social implications of urban form and density. Through the case study of neighbourhoods in Berlin, the authors discuss the role of compact densities in offering a higher QoL for residents. Density as a measure of the concentration of physical structures is shown to have both promises and pitfalls, wherein the built form affects notions of safety, home satisfaction, interaction and networking (Stren and Polèse, 2000). However, the authors note that density is a relative concept; what is considered high to some may not be the same as another. This relative perception of density implies that the relationship between urban form and the composition of its inhabitants is relative, too. Though highly dependent on the context, the BE has strong correlations to the ability of a space to achieve USS.

2.1.2 USS in research and practice

Over the past two decades, there has been a steady increase of focus on social sustainability both in research and practice (Janssen et al., 2021). This focus on social sustainability has led to increased efforts to theorise and conceptualise it. Though still in its early stages, USS is widely recognised as an important dimension of SD that warrants further research and discussion to operationalise it. In the last decade, most works on USS (Bramley et al., 2009; Boström, 2012; Dempsey et al., 2011; Vallance et al., 2011) often discussed how social sustainability was left out of the SD discourse. They describe social sustainability as *the missing pillar* (Boström, 2012), *a concept in chaos* (Vallance et al., 2011) and *the forgotten pillar* (Opp, 2017) among other things. The research discourse has now moved towards discussions on the meanings and conceptualisation of the topic.

Urban designers and planners are increasingly obliged to deal with the dimension of USS. Existing studies on USS often focus on defining and conceptualising the concept, while little attention is given to empirically understanding how the concept is understood and actually implemented in practice. Understanding the practitioners' perspective is important since they interpret policy and translate it into the BE. These interpretations affect how people's lives will be shaped. Consequently, understanding how urban practitioners operationalise their interpretations of social sustainability in specific contexts needs to be examined to help communicate and implement social sustainability goals efficiently in urban planning through analytical methods.

2.1.3 USS in planning policy

In the context of planning policies, notions of social justice, social equality and social cohesion are widely used to describe USS at different levels of scale (Stepanova and Romanov, 2021). Social sustainability as a policy tool can help authorities assess the social sustainability qualities of a neighbourhood or a region - or any scale for that matter, by deeply understanding the object of interest and identifying the challenges and concerns (Shirazi and Keivani, 2019b). In the context of planning policy, however, researchers have pointed out a lack of understanding of the relationship between planning and social sustainability goals, often criticised for being normative and visionary (Stepanova and Romanov, 2021). Such fuzziness in the discourse has equally critical implications for implementation of policy in practice.

More recently, research has focused on advancing the topic by including empirical evidence (Shirazi and Keivani, 2021). There is a long-standing discourse on urban form and its relationship to sustainable cities and communities (Bramley et al., 2006; Shirazi and Keivani, 2021; Janssen et al., 2021), and recently this discourse has intersected with USS. USS literature suggests that the BE, in the present and the future, is crucial for achieving social sustainability and improving human well-being while mitigating environmental risk (Eizenberg and Jabareen, 2017; Hedayati Marzbali et al., 2021). To achieve a sustainable BE, a design process that ensures a sustainable relationship between human beings and the BE must be followed (Lami and Mecca, 2021). While scholars focus their efforts on theorising the social aspects of sustainability (Vallance et al., 2011), urban policies have continued to discuss theoretical notions of what constitutes a socially sustainable community (Hedayati Marzbali et al., 2021; Davidson, 2009).

2.1.4 Beyond sustainability

Social SD is just one of many possible solutions to the way forward in human development. The lack of attention to the social dimension is evident in increasing concerns of social segregation, social stability in European member states (Janssen et al., 2021) and growing gaps between the wealthy and poor (Saldert, 2024). These social issues have brought considerable criticism to the triple-bottom-line conceptualisation of SD and its fixation on growth (Adelfio, 2016; Poli, 2011; Raworth, 2017). Over the past decades, researchers have questioned the SD paradigm, suggesting that alternative frameworks of economic growth, social welfare and environmental protection must be sought out (Asara et al., 2015).

Still, through strategic planning, contemporary urban planning policy continues to set goals formulated around USS. Recently, other approaches have been presented as complementary to SD or as alternatives.

Regardless of the conceptual differences in these approaches, their motivation is closely aligned with facilitating human development to ensure that present and future generations of humans have a satisfactory QoL. One such approach is the *capabilities approach* (Sen, 2005). Sen (2013) argues that while SD is an improvement from earlier approaches to development, it is incomplete. Rather than limiting the focus of development to fulfilling *felt needs*, one must look further towards sustaining *human freedoms*. The central theme of the capabilities approach is first to sustain the freedom to choose, asking the question - which needs must be fulfilled?.

Another approach is that of *urban resilience*. Urban resilience is defined as *the ability of an urban system to maintain or rapidly return to desired functions in the face of a disturbance* (Meerow et al., 2016). It is often referenced alongside concepts linked to *sustainability, adaptation,* and *vulnerability*. Amirzadeh et al. (2022) suggest that the ultimate goal of resilience is *achieve sustainability*; in that resilience is contingent on sustainability. Resilience is sometimes viewed as conceptually in conflict with the idea of sustainability (Meerow et al., 2019). While sustainability seeks to find an optimal balance between current and future needs, resilience stresses uncertainty and building *adaptive capacity* in present systems in preparation for unexpected future changes.

2.2 Neighbourhoods

As mentioned previously, this thesis focuses on the neighbourhood scale. The neighbourhood concept is both familiar yet complex (Choguill, 2008). The term *neighbourhood* is used widely in different contexts like urban planning, healthcare, sociology and urban policy. It has been the focus of attention of practitioners for a long time (Kallus and Law-Yone, 2000). In the planning context, the term was most notably popularised in the 1900s by the American urban planner Clarence Arthur Perry as the *Neighbourhood Unit* in the context of America's rapid sub-urbanisation (Silver, 1985).

In the context of the BE, it is the *geographical area that lies between the micro level of a dwelling and the macro level of a city or region* (Mouratidis, 2018) (see Figure 2.1). Researchers have argued that the importance given to the neighbourhood concept in these fields arguably exceeds the understanding of its definition and meaning (Jenks and Dempsey, 2007). Perry conceptualised the neighbourhood as an idyllic urban spatial unit which incorporated the standard ingredients of the American suburban vision consisting of residential space for 1000 families, recreation space, provision of neighbourhood amenities such as local shops, a school, a gymnasium and separate pedestrian and vehicular separation (Silver, 1985).

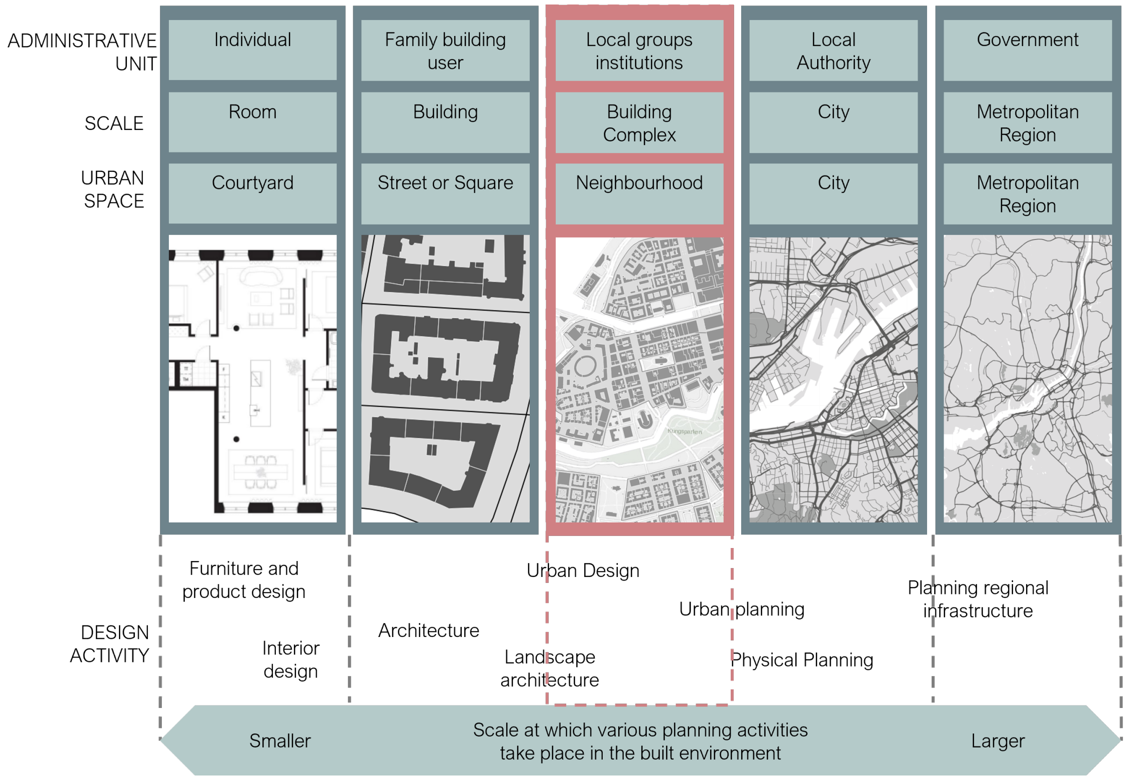


Figure 2.1: Scales of design and planning activity in the BE. Moving from a spectrum of smaller to larger, each activity is carried out in what can be viewed in terms of an administrative unit, scale or urban space, adapted from Erickson and Lloyd-Jones (2001)

2.2.1 Neighbourhoods - A socio-spatial construct

In this thesis, the term neighbourhood is understood as a socio-spatial construct of the BE. According to Jenks and Dempsey (2007), the neighbourhood is both a community (the social component) - the collection of the neighbours (the individual component) that make up the neighbourhood and a district - the spatial construct describing the area in which people live along with its functions, infrastructure and spaces shared by its residents. Research on neighbourhood planning shows that the BE significantly impacts its residents' QoL (Kyttä et al., 2016) and is widely used as the scale at which planning policy can be applied (Mouratidis, 2018) as it provides an interface between individual residents, local authorities, policymakers and the community as a collective. It is a pragmatic scale to address social problems and challenges as several neighbourhood-oriented sustainability assessment tools work directly at this scale already (Shirazi and Keivani, 2019a). Additionally, the neighbourhood scale serves as a pragmatic design device (Kallus and Law-Yone, 2000). It provides the practitioner with an opportunity to meaningfully express their ideas in an urban context as a flexible device which is both practical and theoretically founded (Kallus and Law-Yone, 2000).

2.2.2 Defining neighbourhood boundaries

Given the social and spatial conceptualisation of a neighbourhood, defining the exact boundary of a neighbourhood for analytical assessment can be extremely challenging since its definition (in concept and boundary) should achieve two main goals. First, it should be recognisable to researchers, practitioners and residents. Second, this definition should identify a physical setting or a definable boundary (Jenks and Dempsey, 2007). For the following discussion, a distinction must be drawn between the words *space* and *place* (as in place-making). Tuan (1979); Relph (2009) describe space as a location which is devoid of any social connection. It is simply a geographic entity. A place, on the contrary, is more than a location; in addition to being a geographic entity, there is an element of human experiences associated with it. Drawing a geographical boundary to define a neighbourhood is an exercise to extract the space from the place considered a neighbourhood. In the literature, researchers have outlined several ways through which a geographic boundary can be drawn to define a neighbourhood.

2.3 Role of practitioners

As mentioned in section 1.2, this thesis uses the term *practitioners* to refer to professionals who actively play a role in shaping the BE through design and planning - architects, urban designers and urban planners. This grouping of professions refers to the collective boundary-spanning roles related to the BE due to their overlapping skills and responsibilities. Researchers studying the interrelated and overlapping roles of the practitioner have often used collective terminology like *urban agent* (Hernberg and Maze, 2017) or *urban curator* Petrescu (2013) to characterise the professional roles involved in shaping the BE through design and planning.

2.3.1 Practitioners as boundary spanners

While these roles are more clearly defined at the ends of the spatial scale (like the building and regional scale), at the neighbourhood scale (the scale of interest for this thesis), the term "practitioner" encompasses multiple roles. Petrescu (2013) on participatory approaches says, "An architect who acts as curator defines his/her professional location in the middle, in between institutions, clients, and users. Rather than a master, (s)he is a mediator". Petrescu (2013) discusses the role of the architect mediating in the participation of a mainstream planning process. Practitioners play interchangeable, interactive Alexander (2005) and boundary-spanning roles (Van Meerkerk and Edelenbos, 2014).

The practice of urban design and planning follows some of the same fundamental principles of creation. For example, the design process of Erickson and Lloyd-Jones (2001) and the planning process described by Yeh (1999) share the same fundamental steps of goal formation, analysis of the existing situation, evaluating options and iterating between them. Both these processes will be discussed in the following sections of this thesis.

Given the importance of the BE in shaping USS, the practitioners in the BE play a vital role in this process. Professional planners and designers - practitioners in the BE, play a role not just as makers of urban forms but more so as *cultural intermediaries* (Kimbell, 2011). In the design and planning process, several stakeholders have varied interests, and practitioners can often find themselves as or employed by any one of them. However, they must frequently address the interests of those who are not necessarily their employers - the end user (Erickson and Lloyd-Jones, 2001). Often, the practitioner intermediates between the intent of the decision-makers and those most affected by these decisions. According to Kimbell (2011), the designer serves the role of the *glue* in the multidisciplinary teams that are involved in the shaping of the BE; they are the *interpreters and facilitators of changes in the culture who then synthesise new kinds of cultural forms*.

2.3.2 Designerly ways of knowing

Design can be viewed as *a field concerned with finding novel and useful ways of approaching and transforming an uncertain situation in which there are no straightforward answers* (Dalsgaard, 2017, p. 24). Such problems are often referred to as wicked-problems (Rittel and Webber, 1974) or ill-structured problems (Buchanan, 1992; Cross, 1982). Rittel and Webber (1974) state that there can be no objective definitions of equity in a pluralistic society. The information necessary to sufficiently understand wicked problems depends on one's approach to solving them, requiring an exhaustive inventory of all potential solutions ahead of time.

Wicked problems fundamentally differ from the objective and well-defined problems from classical engineering. Although the latter may be complex, they have set goals and unambiguous boundary conditions (Rittel and Webber, 1974). Wicked problems are *problems for which all the necessary information is not or ever can be available to the problem solver* (Cross, 1982, p. 227) as opposed to the puzzles of scientists and mathematicians who can suspend decision-making until more information about the problem is known.

There is a *designerly* nature to exploring design solutions that separate designers and scientists (Cross, 1982). To investigate this claim, Lawson (1979) set up a block-stacking experiment involving architecture and science students. Lawson discovered that the two groups approached the problems differently. The scientists systematically investigated the possible combinations of the blocks to discover the underlying rules. The architects proposed a series of solutions until they discovered an acceptable solution. The essential difference between these two approaches was that the scientists focused on discovering the rule. In contrast, the architects focused on discovering the solution (Cross, 1982), learning something about the underlying rules by exploring the solutions.

The research on cognitive design describes the methods of designers (and planners) to solve design tasks as design thinking, *designerly ways of knowing* (Cross, 1982) or *designerly inquiry*. It is broadly defined as:

> *...an exploratory and transformative process through which designers draw upon their repertoire of knowledge and competencies as well as resources in the situation, including instruments, to create something novel and appropriate that changes an undesirable situation for the better.* - (Dalsgaard, 2017).

The exploratory nature of the design process may tell us about the nature of design problems and that they warrant exploration. However, there are some drawbacks to such an approach. Designers may rely on hunches or presuppositions, not just facts (Kimbell, 2011). The materials contributing to these hunches need not always stem from accumulated experience. Instead, they can be instinctual or from theories, trends and widespread beliefs, ultimately influencing the design and planning of spaces. Hillier (2008) points to the example of planning theories from the 20th century; it was thought that lower densities would lessen crime, that open-plan schools would support children's learning, or that enclosed outdoor public spaces would be successful. In hindsight, solutions presented as materials to support solving the problem may have been a part of the problem rather than the solution.

2.3.3 The design process

Erickson and Lloyd-Jones (2001) describes the design process as being open-ended rather than linear, consisting of three phases: the brief, the solution and the implementation (see Figure 2.2). The design process in the BE is similar in its requirement to interact with and iterate over the design solution till a satisfactory design solution is obtained.

The first task in the design process is to evaluate the existing condition and ask questions that help define the goals of the design task: *where are we and where we want to be?* (Erickson and Lloyd-Jones, 2001). In this analysis, designers may employ various instruments of inquiry that aid in better understanding the existing condition. This exploration results in a design criteria or the goal of the design task. The second task is to try new scenarios. Similar to the observations made by Lawson (1979), a solution-focused approach is applied to evaluate new scenarios and see if they fit (Erickson and Lloyd-Jones, 2001), similar to the concept of ideation by Jonson (2005). The ideation process occurs at the early stages of the design (Peters et al., 2021). Each proposed solution is then evaluated against the previously determined design criteria. As this iterative process progresses, solutions to this design problem emerge.

Practitioners can test their proposals through appropriate instruments of inquiry. These instruments can provide "how-possibly" explanations to learn from prototypes, spark new ideas, and reveal insights that may address the problem. Along the continuum of explanations for a phenomenon that spans from its general or specific instances, "how-possibly" explanations are potential explanations whose

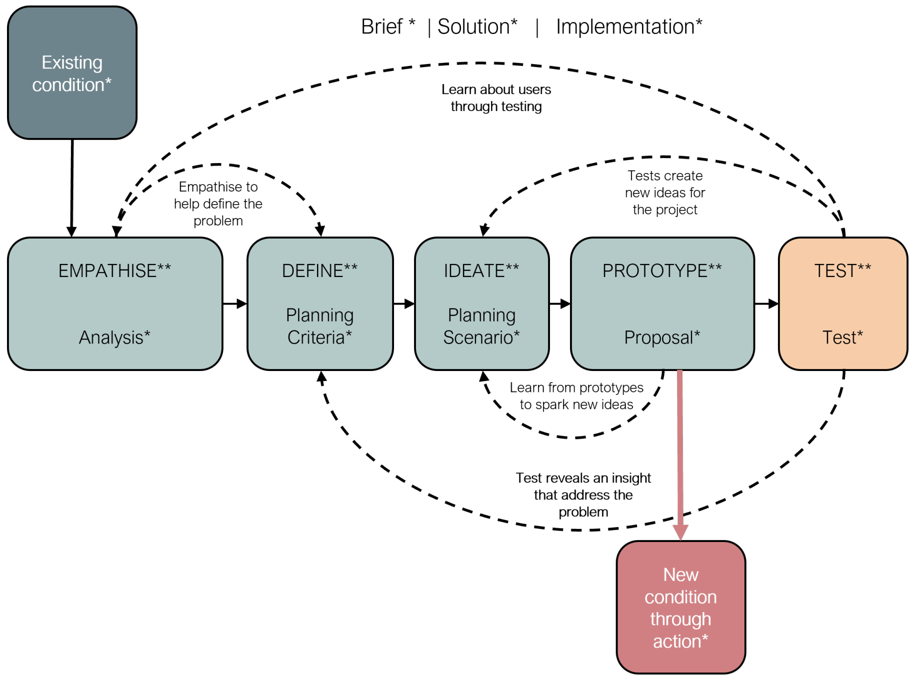


Figure 2.2: Design process in the BE, adapted from Erickson and Lloyd-Jones (2001)* and the Interaction Design Foundation (2021)**

explanatory premise does not contradict known facts (Bokulich, 2014). Reasoning using idealised computational models (or toy models) can, therefore, be used as such instruments of inquiry to support practitioners with decision-making in the early stages of projects where many unknown variables may influence the final design/planning proposal.

Dalsgaard (2017) refers to such design tools as *instruments of inquiry* and proposes a framework that underscores the explorative nature of design and the role that these instruments play. The framework comprises five qualities - perception, conception, externalisation, knowing through action and mediation (Dalsgaard, 2017).

One such tool used for exploration and inquiry is through analytical toy models. Toy models are highly idealised and extremely simple representations of a phenomenon that occurs in the real world. There is no sharp boundary between toy models and other models (Reutlinger et al., 2018). Rather, they lie on a continuum of models varying in their degree of simplicity and idealisation. As such, the use of toy models with non-specific representations of their targets is on firm epistemic ground Nguyen (2020), provided they are interpreted appropriately. However, the process of exploration in design first starts by empathising with the end-users and their existing condition to help define the problem. (For an in-depth discussion on the nature of design problems, this thesis refers readers to (Cross, 1982)).

2.3.4 Evidence-based decision making

In the context of SD, evidence-based decision-making has proven to be a *potent vehicle* to help practitioners achieve the SDGs (Bell and Morse, 2010). This is reflected in the BE, evident from the proliferation of performance indicators in the design and planning process (Hiremath et al., 2013; Huang et al., 2015). But in practice, practitioners still need to ask - *"is this solution better than that in this context?"* or *"will this work for these people?"* (Hillier, 2008). Compared to social sustainability, indicators and tools relating to environmental sustainability are more developed (Bouzguenda et al., 2019). Sustainability evaluation frameworks such as Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), Comprehensive Assessment System for BE Efficiency (CASBEE) and German Green Building Council (DGNB) are reflective of the environmental underpinnings of SD (Olakitan Atanda, 2019; Ali and Al Nsairat, 2009).

The scope of such evaluation frameworks primarily focuses on the environmental and sometimes the economic dimensions of SD (Sharifi and Murayama, 2013). The social aspects included in such tools are often limited to occupant well-being and comfort. They do not extend to the broader social sustainability themes like social equity and justice.

2.4 Urban Accessibility

Accessibility, quite simply, is the ability to access. The term accessibility is used in many different contexts, such as conceptual accessibility to a topic, accessible buildings, accessibility of websites, or accessible cities. In Spatial terms, accessibility refers to the ability of people, inclusive of varying degrees of their motor and cognitive challenges and where they live, to have equal access to resources such as primary health care, job opportunities, healthy food options and recreational opportunities at both a micro and macro level. This form of accessibility is also called spatial accessibility.

To further clarify the concept of accessibility, it can be understood on two levels, micro-accessibility and macro-accessibility. Micro-accessibility is related to the idea of universal design Evcil (2009); the design standards, regulations, construction and planning practices aimed at including people with different degrees of motor and cognitive challenges Pereira and Herszenhut (2023). Macro-accessibility, commonly referred to as urban-accessibility, deals with a broader understanding of access. It refers to the structural issues of planning, such as the spatial distribution of people, activities, transportation infrastructure and the ability of people to access these opportunities Pereira and Herszenhut (2023). Van Wee and Geurs (2011) define urban accessibility in the context of urban planning and transport as *"the extent to which land-use and transport systems enable individuals to reach activities or destination by means of a combination of transport modes"*.

Accessibility, as used in this thesis, refers specifically to *urban accessibility*. Urban accessibility is related to notions of distributional justice and equity, which focus on the relationship between people and their BE by assessing the ease of reaching destinations. Urban accessibility depends on the spatial distribution of destinations, land use, and transportation (Boisjoly and El-Geneidy, 2017). Accessibility indicators are sensitive to the scale at which a region is studied. Often, trade-offs are made between local and regional scales that cause shifts in the distribution of accessibility. In operationalising accessibility measures and indicators for neighbourhood planning, *cumulative-opportunity* measures such as distance and travel-time thresholds are better suited as they are easy to communicate and interpret (Boisjoly and El-Geneidy, 2017). Urban accessibility studies have a long tradition of being mathematically modelled (Koenig, 1980) and have evolved into independent research domains focusing on the different components of accessibility such as *unmet travel needs*, *latent demand*, and *barrier effects* (Clifton, 2017; Eldijk, 2019; Luiu et al., 2018), subsequently developing various methods for calculating and evaluating urban accessibility.

2.4.1 Components of urban accessibility

Urban accessibility has four broad components - land-use, transport, temporal and individual (Geurs and Van Wee, 2004) (see Figure 2.3. *Land-use* is the locations and characteristics of where demand is generated and the opportunities to satisfy this demand. The *transport* component is the infrastructure through which individuals can move between the OD to satisfy their needs. The *temporal* component is the times at which demand is generated and the window within which they may be satisfied, and finally, the *individual* component is the demographic characteristics that contribute to the type of demand generated along with the subjective preferences of the individual. Ideally, accessibility measures should consider a combination of all four components; however, in practice, applied accessibility measures focus only on one or a selection of components (Van Wee and Geurs, 2011).

2.4.2 Distributional accessibility

Urban accessibility is related to notions of distributional justice and equity. On the central role of urban accessibility in enabling people to satisfy their basic needs, Pereira et al. (2017) highlights the utility of viewing urban accessibility as a basic capability. Urban accessibility through the lens of Amartya Sen's Capabilities Approach to Development (Sen, 2005) (introduced in section 2.1) brings a new perspective to the traditional conceptualisation of accessibility - as exclusively an attribute of locations. Rather, it views accessibility as an attribute of individuals. It considers how personal characteristics such as age, gender and household compositions shape interpersonal differences in accessibility levels Pereira et al. (2017). *Achieving daily needs* is a key component of USS; it contributes to maintaining good health, and wellbeing (Kolodinsky et al., 2013; Luiu et al., 2013; Reis et al., 2000). Studies have shown that people who demonstrate higher levels of autonomy and competence in their daily activities tend to report greater levels

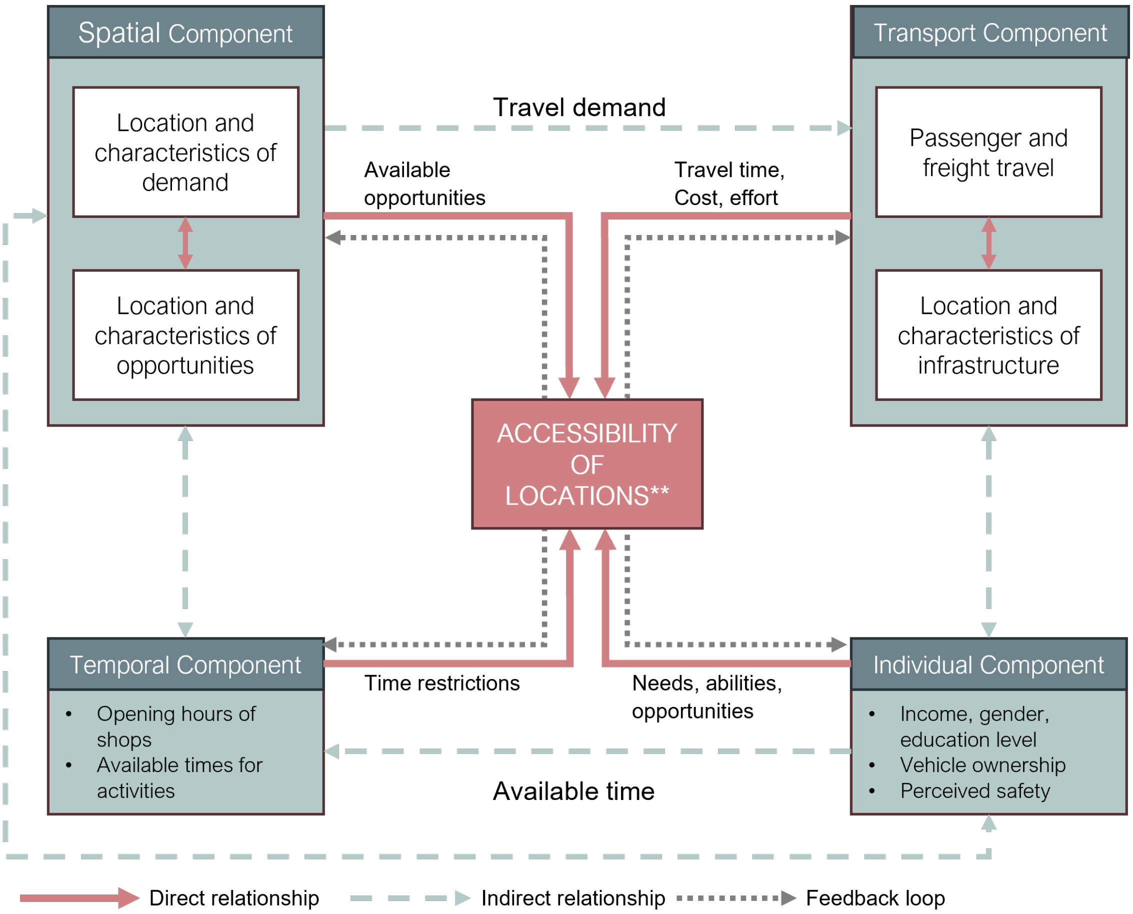


Figure 2.3: Components of accessibility, adapted from Geurs and Van Wee (2004)

of well-being in general (Reis et al., 2000). In addition to individual well-being, notions of equitable access to amenities and services contribute to developing resilient and socially sustainable communities (Widborg, 2017).

The satisfaction of needs through physiological, social, and self-actualisation needs in individuals is a common characteristic of socially sustainable communities (Mehan and Soflaei, 2017). Notions of spatial equity and justice are achieved by providing residents with opportunities and resources to achieve their needs. It leads to socially cohesive and physically integrated urban units (Mehan and Soflaei, 2017). Kolodinsky et al. (2013) draw a connection between personal mobility and accessibility to notions of QoL and well-being, which is well established in transportation research (Chatterjee et al., 2020).

However, it is important to consider the differences between urban accessibility and mobility. Mobility refers to people's daily travel and behaviour patterns (Pereira and Herszenhut, 2023) often quantified into number of trips taken, modes of transport used and average trip time or distance. Traditionally, transport planning focuses on mobility, specifically, the quantitative aspect of mobility (Banister, 2011). Suppose the end goal is to enable people to have more opportunities to achieve their daily needs (their capabilities). In that case, efforts should be placed into improving their accessibility rather than their mobility (Banister, 2011).

2.5 Spatial Analysis

Spatial analysis is the set of methods used when the data being analysed are spatial to solve a scientific or decision-making problem (Goodchild and Longley, 1999). While the techniques of spatial analysis predate modern computing, with the advent of computers, the main tools for spatial analysis are built on Geographical Information Systems (GIS). GIS refers to geographically oriented computer technologies, particularly remote sensing, computer cartography, computer-aided design and database management (Maguire, 1991). Several sub-fields have since evolved that focus on particular intersections of GIS and its specific data sources and analysis tools, such as geoinformatics. Geoinformatics is the science and technology which develops and uses techniques to address problems of earth sciences such as geography, cartography, photogrammetry, GIS and related branches of science and engineering, including urban planning (Filchev et al., 2020).

2.5.1 Geographic Information Systems

Geospatial data refer to spatially explicit locations (Wegmann et al., 2020). GIS datasets are either *raster* or *vector* data types. Vector data usually refers to spatial features like administrative boundaries, roads, or locations of field measurements, while vector data often represents images or elevation data. Vector data is used to represent three types of shapes: *points*, *lines*, or *polygons*, along with their associated data tables. Raster data, on the other hand, can only hold one kind of (numeric) information within one raster cell (see Figure 2.4).

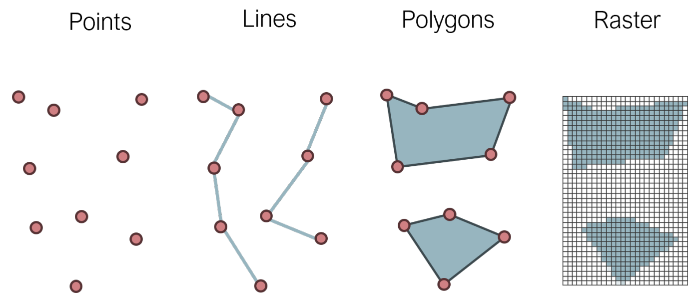


Figure 2.4: The different data types and shapes of GIS data.

Urban planning is one of the main applications of GIS. In the planning process (similar to designerly inquiry in Section 2.3.3), the practitioner starts by determining the objectives, preparing an inventory of the different resources available to them and an analysis of the existing situation. The practitioner generates models and projections of the existing solution and begins the development of planning options. Finally, a planning option is selected and implemented, and planning outcomes are evaluated. In this process, practitioners use GIS for analysis, urban modelling and as a spatial database (see Figure 2.5).

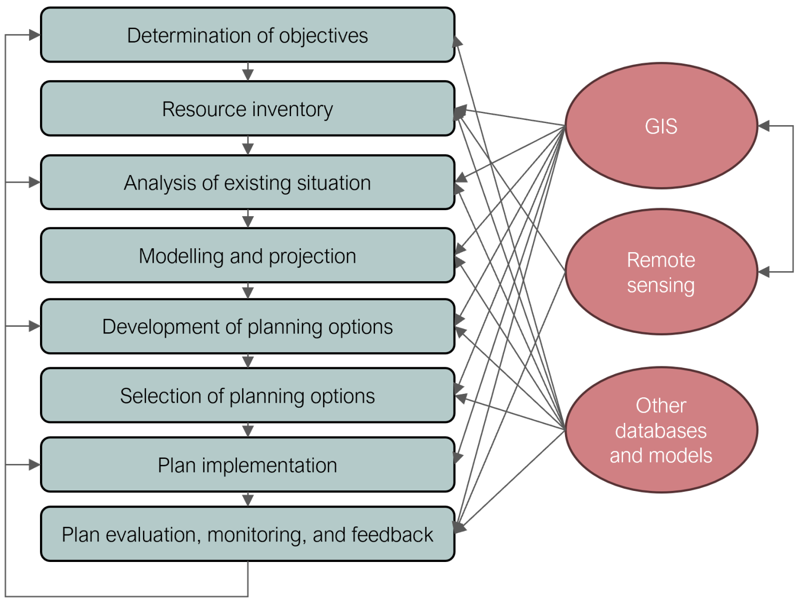


Figure 2.5: The urban planning process and the integration of GIS, remote sensing, and other databases and models. Adapted from Yeh (1999).

2.5.2 Geospatial analysis of individual accessibility

GIS has many applications depending on the scale and stages of planning. Four steps in the planning process are particularly interesting to this thesis: analysis of the existing situation, modelling and projections, development of planning options, and finally, selection of planning options (see Figure 2.5). Common spatial analysis techniques use spatial query and mapping functions of GIS to analyse the existing situation in an area (Yeh, 1999). In addition to the querying, mapping and visualisation features of GIS, practitioners can create models to analyse specific aspects of the BE, such as accessibility studies.

The analytical focus of accessibility assessment techniques is usually limited to the ability of the BE to service its residents. Extending this focus to include the resident's ability to fulfil their daily needs allows practitioners to understand the distributional effects of accessibility in neighbourhoods. The most common analytical method of assessing spatial accessibility is a catchment or service area map showing the accessible areas within the same time or distance. A service area map shows the opportunities or facilities available to a person from a fixed location (Koenig, 1980). A simplified version of this map is the smallest convex shape that encompasses all points on the network that are within a specified distance or time from a given point called an *isochrone map*.

When evaluating policy, decision-makers use residents' cumulative opportunities to quantify the impacts of the policy in monetary terms. However, such evaluations fail to capture the nuances of social equity. While monetary valuations are very valuable for a cost-benefit analysis, decision-makers might be interested in the level of accessibility as an indicator in itself (Van Wee and Geurs, 2011).

To address the individual perspectives through spatial analysis, Hillier and Hanson (1984) developed the methodological framework of *space syntax*. Metrics of space syntax use network analysis theories and indicators and adapt them for use in spatial analysis, but they, too, fail to capture the distributional effects of accessibility across the population. Geurs and Van Wee (2004) point out some significant challenges in operationalising individual accessibility and communicating the results. The first challenge is in procuring detailed individual activity-travel data. Capturing distributional effects regarding accessibility across a region requires access to detailed travel diaries. This is often not available or can be costly to procure. Second is the computational intensity of assessing individual accessibility.

2.6 Transportation Networks

To address the social equity issues in the BE, this thesis aims to implement existing research and methods in transportation planning, mobility, and accessibility. Complex systems are often represented as networks or graphs, consisting of nodes and edges embedded in space (Barthélemy, 2011). The study of networks relies primarily on the theory of graphs. The terms graph and networks are different words that refer to the same idea. A *graph* is commonly used in fields related to mathematics, and a *network* is used in more applied areas. While networks are utilised in numerous fields, this section provides an overview of transportation networks.

A transportation network is commonly represented as a planar spatial network in two dimensions (Boeing, 2017). Each street segment is represented as an edge, and the intersections at which different street segments meet are represented as nodes. The graph representation of networks allows for the analysis of several aspects of the transportation infrastructure, such as its metric measures (like street length and intersection density), centrality (the importance of nodes in a network) and topology (the configuration and robustness of the network and how these characteristics are distributed).

2.6.1 Routing

A key advantage of the graph representation of street networks is the ability to perform routing, more specifically, to identify the shortest path between two nodes. Identifying the shortest path along a street network is a fundamental problem in street network analysis with applications ranging from route guidance systems to solving spatial allocation problems (Zeng and Church, 2009). One of the most commonly used algorithms to find the shortest path between two nodes in a graph is Dijkstra (1959)'s shortest path algorithm (Figure 2.6).

The distance in the Dijkstra algorithm is essentially a weight assigned to the nodes on a weighted graph. These weights can be modified to return the shortest paths, considering different parameters like speed, time, and distance. In the case of pedestrian and bicycling networks, qualitative weights such as distance to nature or inclination of the street segment can be introduced (Nourian et al., 2015).

Like street networks, public transportation networks can be represented by graphs. This is supported by the development of the Generic Transit Feed Specification (GTFS). The GTFS is a standardised data format used by transportation agencies to represent the stops, routes and schedules of the transport system, among other useful information. Shortest path algorithms performed using GTFS data do not necessarily use a graph representation of the transport network in the same way the Dijkstra or A* algorithm but rather use a round-based approach (Fink et al., 2022).

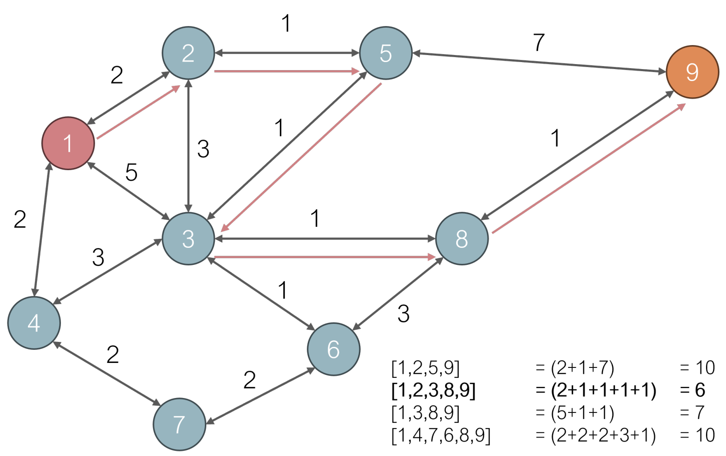


Figure 2.6: Shortest path from node 1 to node 9. The figure illustrates a graph consisting of 9 nodes and 14 edges. Each of the edges carries a distance or weight. Considering the weights of the edges, the shortest path from node 1 to node 9 traverses the sequence 1-2-3-8-9 with a total distance of (2+1+1+1+1) 6.

2.7 Mobility demand modelling

Land use and transport interaction (LUTI) models form an umbrella category of multi-disciplinary analytical urban models that integrate methodologies from different disciplines. The relationship between the ability to achieve daily needs and the BE can be seen in methods developed within transportation planning literature through travel demand forecasting using travel models. One of the most ubiquitous approaches to travel demand forecasting is the four-step model (see Section 1, page 4), where current travel behaviour is used to forecast future travel patterns (Mcnally, 2007).

Travel patterns are modelled as a supply and demand problem (Rodrigue et al., 2016). Residents' demographic composition and travel behaviour contribute to the travel demand and dimensions of the BE, such as transport infrastructure and spatial distribution of ODs, which constitute the supply (Talen and Anselin, 1998). To capture the distributional effects of accessibility, analytical models must account for both the temporal and individual components of spatial accessibility. To do this, the concept of *dynamic accessibility* formulated by Järv et al. (2018) is used. Järv et al. (2018) developed a framework of dynamic accessibility comprising three core components: people, transport and activities. In this framework, "dynamic" is expressed as the variability of the three core components across dimensions like space, time and socio-economic variables.

The ability to achieve one's daily needs can be evaluated by examining resident travel behaviour. However, the relationship to social aspects is not direct due to the complex interactions between travel demand and available amenities. For instance, research has shown that increased mobility does not necessarily directly translate to improved QoL (Curl et al., 2011). Though travel patterns can provide insights into the ability to achieve one's daily needs, a comprehensive view of the various cross-sections of the data must be evaluated.

2.8 Activity-based simulations

Conventional accessibility measures tend to be static in nature Miller (2018). Because the well-being of everyone is seen as equally important, a utilitarian approach focuses on aggregate measures of transport performance, paying no particular attention to how accessibility is distributed among individual members of society Miller (2018)

While the classic trip-based approach of the four-step model remains the standard practice to derive mobility demand in most parts of the world, there is a slow but increasing adoption of activity-based travel demand models (Miller, 2023). AcBMs explicitly model the activity participation of each individual in the model using a "tour-based" approach. These models are designed to model intuitive dynamics of how people participate in different activities in their daily lives, allowing users to evaluate the individual ability of residents to achieve their daily needs.

The main advantage of AcBM is the ability to model spatially and temporally disaggregated activity patterns that residents may engage in (Liu et al., 2021). There are different components to an AcBM depending on the purpose of the model and the data available. However, the main components of an AcBM are synthetic-population generation, activity generation and scheduling, mode choice, destination choice, and routing.

2.8.1 Synthetic population modelling

A sound synthetic population and synthetic travel demand are essential for transportation models (Hörl and Balac, 2021). A synthetic population is a virtual population of a region where the aggregated demographic distribution follows the real-world population.

Researchers have used several approaches to creating synthetic populations: generative statistical approaches such as Beysian Networks (BN) and fitting approaches like Generalised Raking (GR) (Zhou et al., 2022). BN models are a part of generative statistical models used in population synthesis that use data from a microdata sample to learn the weights or train a statistical model to sample from the joint distribution. In synthesising the ’living’ population, Zhou et al. (2022) included synthesising the ’non-living’ population to connect the synthetic agent population to a synthetic building stock. In Sweden, Nägeli et al. (2018) developed a model to generate synthetic building stocks to assess the energy demands and greenhouse gas emissions of national building stocks using methods like Iterative Proportional Fitting (IPF) and Iterative Proportional Updating (IPU). Tozluoğlu et al. (2023) developed an approach to generate synthetic populations of over 10 million residents in Sweden using a combination of stochastic approaches combined with Neural networks. This approach produces synthetic populations that are representative of the actual population and include their mobility behaviour that can be used to generate activity schedules for each agent.

Aemmer and MacKenzie (2022) developed a generative model for synthetic population modelling to address the shortcomings of traditional models like IPF and IPU through sub-region modelling and simultaneously modelling individuals and households. Generative models use all the variables in a microdata set and then model a joint distribution to sample the synthetic population. Then, the authors use a neural network like a Variational Autoencoder (VAE) to learn from micro datasets such as public use microdata samples (PUMS).

Generative models are promising in synthesising accurate data at a sub-regional level and modelling individuals and households simultaneously. Still, not all regions have access to high-quality micro-sample data like the PUMS, as in Gothenburg. In such cases, Monte-Carlo sampling can generate any number of features using more readily available one or two-dimensional attributes from a population register. Using Monte-Carlo sampling, households and persons can sample features in the order they influence each other, resulting in a more realistic population (Moeckel et al., 2003).

2.8.2 Integrated pipelines for activity-based modelling

For practitioners to adopt AcBMs, an integrated pipeline approach can reduce technical barriers, allowing users to focus on the planning process rather than the technical challenges in linking the different model components. Thanks to the increased data availability, developments in open-source programming libraries and access to increased computation have resulted in several case studies demonstrating fully open-source and replicable synthetic travel demand pipelines (Zhou et al., 2022).

Below are examples of integrated pipelines applied in different regions and an overview of their approach to the different modelling steps:

- Barthelemy and Toint (2015) in Belgium developed a stochastic AcBM that scales to country-sized populations. The *VirtualBelgium* project consists of synthetic populations and activity patterns for approximately 10,000,000 individuals and 4,350,000 households across municipalities in Belgium. One of the model's drawbacks is that it does not rely on geo-referenced data for different activities or work locations and lacks a mode-choice mechanism.

- Researchers in Germany developed an open-source activity-based mobility demand (OMOD) (Strobel and Pruckner, 2023) generation tool based on OpenStreetMap (OSM) (OpenStreetMap contributors, 2017) data to determine what a person would like to do on a given day or week if they had the necessary means of transportation. The OMOD model limits its scope to activity generation and leaves mode and route choice undetermined for other software like MATSim (Axhausen et al., 2016) or SUMO (Krajzewicz, 2010).

- Hörl and Balac (2021) developed a generalised synthetic population, and AcBM applied to a region in Paris using publicly available and open data. The researchers used statistical matching to sample activity schedules from NHTS data; the minimum observations are set to 20 compared to the 30 in OMOD by Strobel and Pruckner (2023), and a similar hierarchical approach is employed in the matched attributes. While household units are defined, there are no explicit investigations into validating ontological relationships between households.

- Liu et al. (2021) in Beijing, China and Delhoum et al. (2020) in Paris, France, explored applications of synthetic populations for neighbourhood planning. The authors used an AcBM and a synthetic population pipeline to simulate a proposal for a new development and present a validation of the representativeness of their model. Though the authors do not evaluate disaggregated trip results, they show that it is possible to synthesise realistic mobility demand from a proposed scenario.

2.9 Research Gap

The key research gaps identified in this research are twofold: theoretical and methodological. First, the theoretical gap concerns the conceptual and operational understanding of USS through empirical data. Next, the methodological gap concerns using AcBMs for neighbourhood planning, which can ultimately help improve neighbourhoods' USS.

Theoretical gap: First, a fundamental theoretical gap in the research on USS must be addressed to cover the methodological gap. USS is increasingly used by governments, public agencies, policymakers, NGOs, and corporations to make decisions affecting cities' sustainability and resilience. In the past decade, USS has entered politics and policy, and today, it has become a central concept for strategic planning in urban development projects. However, there is little empirical research on how practitioners conceptualise and operationalise USS.

Methodological gap: While some researchers have explored using AcBMs for neighbourhood planning, these investigations were limited to aggregated mobility patterns. These models evaluated the application of AcBMs in neighbourhood planning, but their focus was limited to mobility and not on the accessibility of individual residents. Research exploring the distributional effects of accessibility on residents across demographics using AcBMs and exploring residents' ability to fulfil their daily needs at a neighbourhood level is lacking.

3
Research methods

The selection of the research methods is based on the research design (see Section 1.4). The following sections provide a brief overview of the different methods applied in this thesis to answer the research questions in the different studies.

3.1 Conceptual framework analysis

USS has been extensively studied since the early 2000s, resulting in a vast body of academic literature. Researchers have previously defined USS as a process, a condition, or an end goal (among other things). But above all, it is a concept. Researchers either used an existing conceptual framework of USS or formulated a new conceptual framework. While these conceptual frameworks overlap, they are not necessarily aligned in their constituent sub-concepts. To systematically map the different sub-concepts of USS, the conceptual framework analysis method by Jabareen (2009) is used. A concept studied by different authors over a long period inevitably has conceptual differences. A systematised literature review of the academic literature was included in the conceptual framework analysis to gain an overall understanding of the concept.

The conceptual framework analysis method comprises six steps, which are grouped to align with this study's aims. They consist of the mapping, reading and categorising of data sources, identifying and naming concepts, deconstructing and categorising concepts, integrating concepts and finally, the synthesis and resynthesis of the results (see Paper 2).

3.2 Semi-structured interviews

To identify the diverse ways practitioners conceptualise USS and understand how these concepts translate into tangible applications in real-world planning scenarios, semi-structured interviews were conducted with 15 practitioners from private planning offices in Sweden, Denmark and the Netherlands. The logic of using the semi-structured interview process is to generate data interactively through a ”flexible and fluid structure” (Lewis-Beck et al., 2024).

To ensure the trustworthiness and objectivity of the study, a rigorous interview guide was developed based on recommendations by Kallio et al. (2016). The interview's main focus was on the experiences and issues faced by practitioners in encountering and operationalising the concept of USS. Details regarding the selection criteria and the interview guide can be found in Paper 2. Table 3.1

shows an overview of the practitioners interviewed in this study along with their professional experience, role and the size of their current company.

Table 3.1: List of Respondents

COUNTRY	RESPONDENT	PROFESSIONAL EXPERIENCE	COMPANY SIZE
Sweden	UP1	5-10 years	200+
Sweden	UP2	5-10 years	200+
Sweden	UP3	5-10 years	200+
Sweden	UP4	0-5 years	200+
Sweden	UP5	10-15 years	200+
Sweden	AT1	0-5 years	10-50
Sweden	UP6	0-5 years	10-50
Sweden	UP7	5-10 years	200+
Netherlands	UP8	10-15 years	10-50
Netherlands	MC1	0-5 years	Under 10
Netherlands	UP9	0-5 years	10-50
Denmark	CD1	0-5 years	200+
Denmark	UP10	10-15 years	200+
Denmark	AT2	15+	50-100
Denmark	UP11	10-15 years	200+

AT: Architect, UP: Urban Planner, CD: Computational Designer, MC: Mobility Consultant.

3.3 Coding and semiotic analysis

The transcripts from the semi-structured interviews were categorised through open coding (Holton, 2007) to identify relevant concepts and ideas related to the conceptualisation and operationalisation of USS. After coding, the codes were grouped into first-order concepts and further into five second-order concepts relevant to our research questions. Next, semiotic analysis was used to analyse the transcripts from the interviews.

Semiotic analysis or semiotics is the study of signs in communication. A sign is anything that can be used to stand for something else (Berger, 2014). Semiotics seeks to understand how meaning is created and conveyed through different modes of expression through assumptions and concepts that allow for a systematic analysis of symbolic systems. This thesis relies on the interpretation of semiotic analysis by Berger and Cullum-Swan (see Paper 2).

3.4 Trip Completion Rate indicator

To capture the distributional effects of accessibility across various demographic groups in a neighbourhood, the Trip Completion Rate (TCR) indicator is developed. TCR is a *person-based* measure of access that represents residents' ability to meet daily needs against evaluation criteria (like distance or time). A detailed description on the construction of the TCR indicator is available in Paper 3 and

Paper 4. The TCR indicator allows practitioners and decision-makers to incorporate their normative values of equity by defining a threshold variable such as travel time, trip distance or emissions (for example, all trips under fifteen minutes) and evaluate the distributional effects of neighbourhood planning across the three core components of dynamic accessibility, i.e. people, transport modes and activities, aggregated on the individual or the household level (Järv et al., 2018).

During interviews with the practitioners, the TCR indicator was presented and the following questions were asked (see Table 3.2):

Table 3.2: Interview questions related to the TCR indicator.

Interview Questions
What are your impressions on the indicator (TCR)?
Is the indicator clear?
What can you say about the results you see in the figure?
Would you use it?
What use cases can you think of for TCR?

The interview transcripts were then analysed to form first and second-order groupings of the practitioner's feedback into interpretability, utility and application, and potential improvements.

To exemplify the TCR indicator's application in evaluating the distributional effects of planning policy on diverse populations, two examples are presented in Paper 3. The first example is a case of distributional accessibility across the Västra Götaland region based on NHTS data, and the second example is an evaluation of the distributional impacts of a hypothetical personal carbon allowance in the Västra Götaland region. While the results from this study are relevant to this thesis and are included in the findings section, the specific examples are not discussed in this thesis.

3.5 Activity-based modelling

Activity-based models have been used to model how people participate in different activities in their daily lives, allowing modellers to evaluate the individual ability of residents to achieve their daily needs.

The main advantage of AcBM is the ability to model spatially and temporally disaggregated activity patterns that residents may engage in (Liu et al., 2021). There are different components to an AcBM depending on the purpose of the model and the data available. The main components of the AcBM proposed in this thesis are synthetic population generation, activity generation and scheduling, mode assignment, destination assignment, and multi-modal routing (see Section 2.8). This thesis adopts a multi-step approach to exploring the feasibility of using AcBMs as a decision-support tool for practitioners. First, based on the conceptual framework of USS and AcBM literature, a toy model with minimal AcBM components is developed. Then, the toy model is presented to practitioners for feedback on input data, modelling requirements, and visualisation of the results.

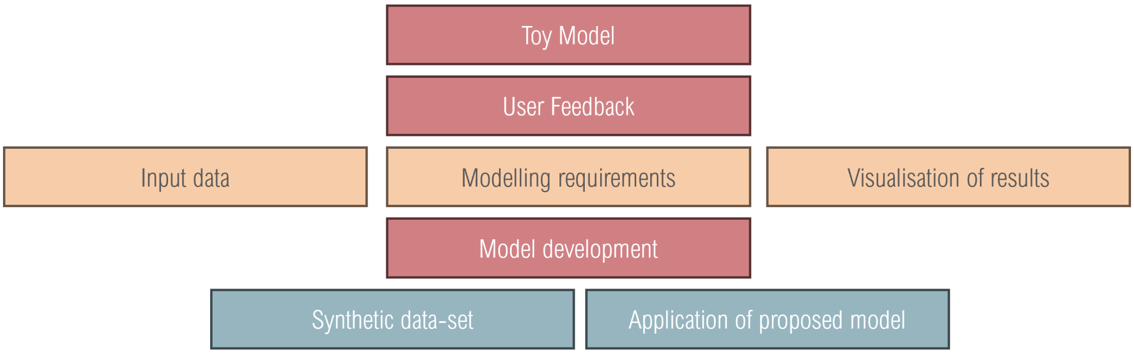


Figure 3.1: The multi-step approach to exploring the feasibility of using AcBMs as a decision-support tool for practitioners.

3.5.1 Iterative development of the toy model

A highly simplified and idealised AcBM for the Gothenburg region was initially developed to be presented to practitioners to gather insight as to whether such models are applicable in practice and could add to the practitioner's instruments of designerly inquiry, (Dalsgaard, 2017) (see Section 2.3).

To gather this insight, the toy model first needed to capture the ability of neighbourhood residents to access everyday amenities. The toy model was not intended to provide a *how-actually* Bokulich (2014) understanding of what residents do in their daily lives nor to predict what residents would do in the future. Instead, it aims to provide a *how-possibly* Bokulich (2014) understanding of the practitioner's decisions on the distributed accessibility of the residents in the neighbourhood.

The toy model was implemented using the Python programming language, and free and open-source libraries were used to achieve its functions. With Gothenburg selected as the location for the modelling exercise, practitioners could choose a neighbourhood in the city to situate the simulation. A minimal synthetic population was created, with each resident having three demographic attributes (sex, age, and household type). The synthetic residents were then allocated to existing residential buildings and an activity schedule based on the Swedish National Household Travel Survey (NHTS). The residents' routes were calculated using a simple shortest-path routing algorithm based on their activity. The results from the model were tabulated as a TCR matrix where the threshold variable could be selected and varied to illustrate which demographic groups satisfied their daily needs under the selected criteria and presented to the practitioners [1].

Based on insights from previous literature and feedback from practitioners through interviews, additional details are added to the toy model (see Figure 3.2). For an overview of the data requirements for developing the AcBM, see Paper 5.

[1] https://snjsomnath.github.io/GAPSIM_data/

1. **Population synthesis**: Additional demographic variables like car ownership, work/study status and number of children are included using probabilistic assignment based on Tozluoğlu et al. (2023) and Machine Learning (ML) models to predict demographic variables as described by Hubert and Toint (2003); Avery (2011); Cornelis et al. (2012).

2. **Assigning activity chains**: Activity sequences from the NHTS are first validated to be realistic and coherent. Then, probabilistic matching is used to include the additional demographic variables and assign activity sequences based on Strobel and Pruckner (2023); D'Orazio et al. (2006); Namazi-Rad et al. (2017).

3. **Destination assignment**: For the OD assignment, a three-step approach is used: home assignment, primary location (work or study) assignment and secondary location (shopping, grocery, leisure) assignment based on actual work locations and amenity locations in the city.

4. **Routing**: A multi-modal routing mechanism is developed by storing the pedestrian, cycling and driving network as an undirected iGraph (Csardi and Nepusz, 2006) graph. For the pedestrian and cycling network, the graph edges are weighted using street inclination and proximity to green spaces. For the driving network, the network edges are weighted using the travel time.

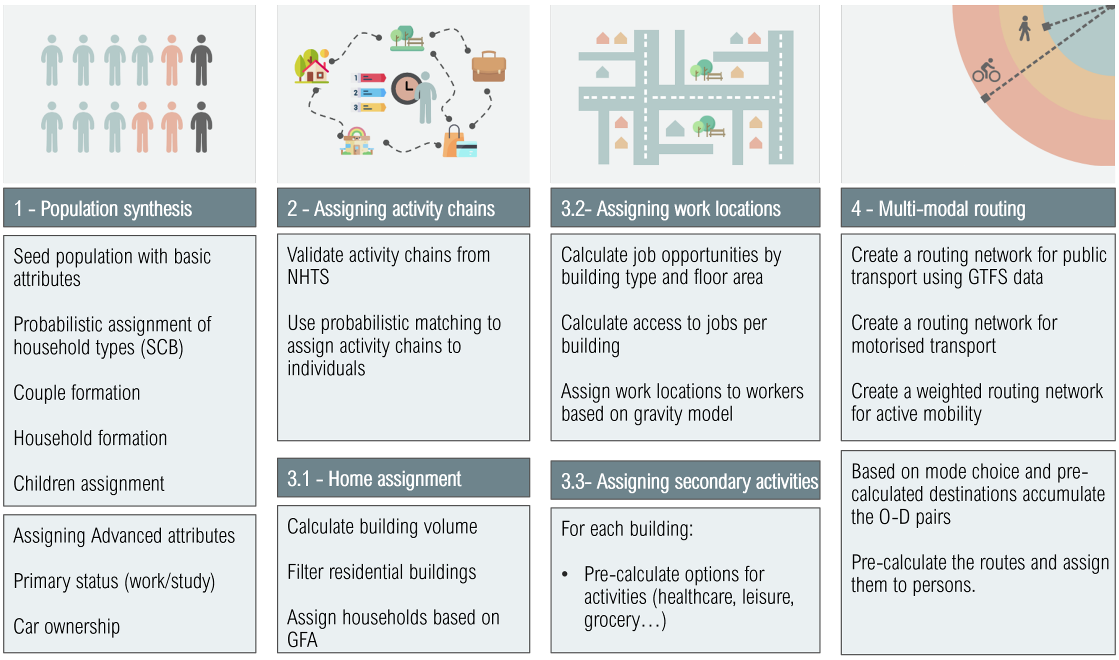


Figure 3.2: Detailed steps in the proposed AcBM based on previous literature and feedback from practitioners.

3.5.2 Model validation

In the AcBM field, the process of determining whether a model is an accurate representation of the studied system is called validation Drchal et al. (2016). Traditionally, model validation is carried out at each phase of the model. The proposed model consists of a synthetic population, assigning ODs and routing. Therefore, the model validation is carried out in four steps. The first is the representativeness of disjointed variables of the synthetic population, the second is the joint variables, the third is validating the ML models used to predict additional demographic variables, and the fourth is the OD assignment and routing using travel patterns. However, it must be noted that, unlike traditional models, the proposed model is not aimed at accurately predicting mobility patterns. Rather, it aims to provide users with insights into how their proposed designs and plans affect residents' spatial equity. Therefore, further application studies are required to establish the model's validity.

- **Disjointed variables**: The model was designed to sample from a three-dimensional distribution of demographic characteristics at the neighbourhood level. However, additional constraints in the model's design, such as couple matching and assignment of children to households, introduce discrepancies in these attributes. To assess the model's performance, two disjointed variables—the age group and sex—are individually assessed and quantified as percentage errors for each of the 95 neighbourhoods in the study region.

- **Joint variables**: The accuracy of the joint distributions of demographic variables is evaluated to examine the relationship between variables simultaneously. The normalised Root Mean Squared Error (RMSE) at the intersection of the age group and the sex variable is calculated for each neighbourhood.

- **Machine learning models**: ML models are used to predict car ownership, the primary status of the resident (whether working, studying or inactive), and to classify the residents' mode choice. The performance of the ML models is evaluated based on accuracy, precision, recall and the F1-score of the predictions. The classification data contained high imbalances between classification targets in all three cases. For example, work is the most common primary status, and positive car ownership and car as a preferred mode of travel are both the majority of the classes in the training data. Techniques like synthetic over-sampling and hyperparameter tuning were used to improve the classification accuracy. The car ownership numbers were again evaluated using neighbourhood-level statistics to evaluate the accuracy of locally imputing national-level attributes. This error is quantified using percentage error in car ownership compared to the actual population for each neighbourhood.

- **Routing and destination assignment**: Proportional differences as normalised percentage errors are used to compare the modal split and purpose split in the synthetic and survey data sets. The model is designed to attribute activity demand and mobility behaviour from national data and adapt it to the neighbourhood scale. To achieve this, median travel times and durations are calculated for each neighbourhood across different modes of transport and for different activity purposes. These median values are then compared to the median travel times and durations at the larger urban area division (SDN) by calculating the normalised percentage error between the values. Next, we compare the similarity of the distributions using a metric called Hellinger Distance (HD). An HD of 0 indicates that the two distributions are identical, while 1 indicates dissimilar distributions.

3.5.3 Application to a case in Gothenburg

Gothenburg is Sweden's second-largest city after Stockholm, with a population of over 600,000. The city is divided into four hierarchical, administrative divisions: urban areas (*stadsområden*), intermediate areas (*mellanområden*), primary areas (*primäromraden*) and base areas (*basområden*) from the largest to smallest. There are 96 primary areas in Gothenburg, ranging between 0.23 square kilometres in the central high-density areas and 57 square kilometres on the outskirts.

A series of hypothetical scenarios demonstrate the model's application to provide decision support in practice. The model is applied to these hypothetical scenarios, and their results are evaluated using the TCR indicator. The neighbourhood of Länsmansgården is selected in the city of Gothenburg. Länsmansgården is one of the vulnerable neighbourhoods identified in Gothenburg. It has a population of around 6,000 residents and an above-average level of unemployment (12.3% compared to 6.6% in the municipality) (see Figure 3.3).

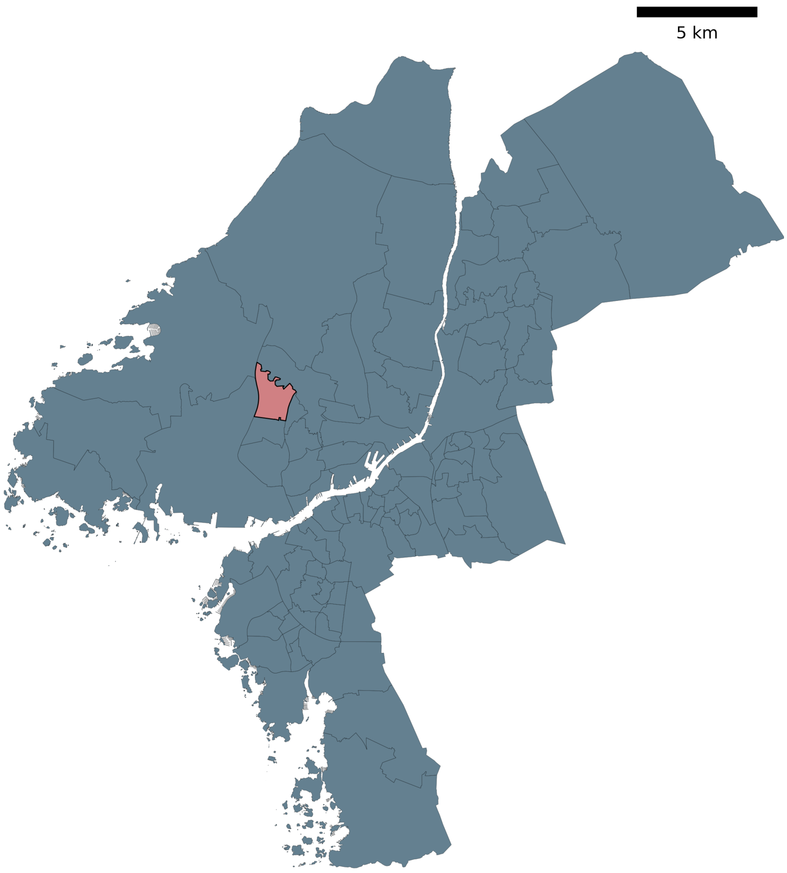


Figure 3.3: The selected neighbourhood of Länsmansgården in Gothenburg.

Länsmansgårdern is well connected to the public transportation system and is near nature, recreational areas and pre-schools. However, it lacks an adult education facility and access to jobs closer to homes and healthcare facilities (see Figure 3.4). The city aims to implement the 15-minute city concept for the new neighbourhood to reduce overall car usage.

Using publicly available planning and public consultation documents, Four scenarios are generated and evaluated using the AcBM. The **baseline scenario** includes new residential buildings and the new residents moving into the neighbourhood but no new amenities. **Scenario A** adds new amenities; **Scenario B** adds healthcare and educational amenities as found in the public consultation documents. **Scenario C** evaluates public and active modes of transport to simulate a car-free scenario in scenario B. Finally, a cumulative TCR is plotted for all scenarios to evaluate the application of the 15-minute city concept for this neighbourhood.

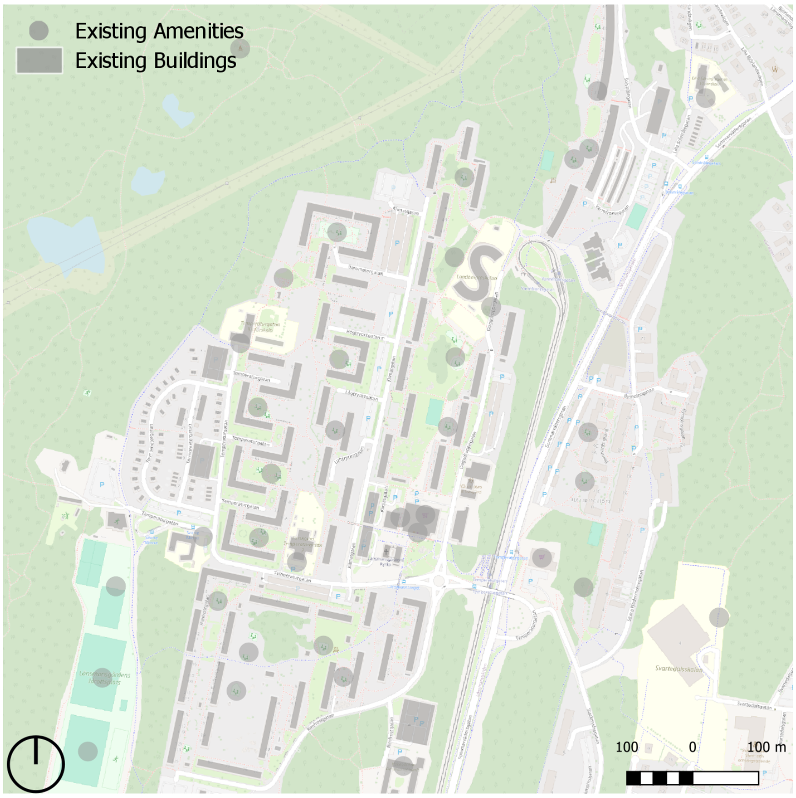


Figure 3.4: Existing buildings and amenities in Länsmansgården. Existing buildings are shown as grey building footprints, and existing amenities are shown as circles

4
Findings

This chapter presents the findings of the various studies conducted in this research. The following sections explore the conceptualisation of USS, its operationalisation, and the implementation of an AcBM for neighbourhood planning. Each section synthesises the key findings and how they relate to one another. The detailed findings for each study can be found in the corresponding papers.

4.1 Conceptual Framework of USS (Paper I)

The literature study provides insights on USS from a theoretical perspective. The findings help better understand the *fuzzy* nature of USS by understanding its historical context, the problems associated with it and finally, a common conceptual framework that will be used in future studies to identify tangible ways towards operationalising the concept.

Six factors are identified that indicate why the USS discourse has been fragmented. These factors shed light on why there is a lack of consensus. They are divided into two categories: intrinsic and extrinsic factors. Intrinsic factors arise due to the inherent nature of USS. The complexities are are due to the multiple stakeholders involved, the overlapping discipline studying it, the difficulty in quantifying social interactions and the tangibility of social consequences. In addition to the inherent factors, two extrinsic factors are identified. These factors arise due to USS's political backdrop, rooted in an environmental basis and stakeholder perceptions of SD that prefer clear causal relationships between an action and a consequence, which can be complicated in USS (see Paper 1).

Next, the study showed that researchers often used specific terms to describe what social sustainability meant to them. These terms are referred to as identifiers. The literature review resulted in USS identifiers within the following three categories: *an ability, a conditional state*, and *a process*. Sometimes, a weak identifier or a loose definition is used; such instances are grouped as *a vague concept*. Davidson (2009) refers to the vague nature of USS as playing an important organisational role in the conceptualisation process, as an empty signifier. Empty signifiers hold a nominal status, accommodating conflicting value systems without impairing normative decision-making. Hence, their utility in conceptualising USS (see Table 4.1).

Table 4.1: Definitions of Identifiers found in USS Definitions. (Adapted from Paper 1)

Identifier	Definition
Ability	An ability of a society to satisfy a given condition implies that it must possess the resources to facilitate positive interaction between various actors in society. An "ability" emphasizes the exhaustive nature of these resources. "Ability" has the inherent implication of a limitation to the ability.
Conditional state	USS as a conditional state implies that USS is achieved due to successfully satisfying a set of conditions proposed in the definition. Here, USS is often described as an end state of the social system; it results in positive interactions between stakeholders when achieved.
Process	USS as a process implies that it is a series of decisions, actions, or steps taken to achieve an expected outcome of positive interactions between stakeholders.
Vague Concept	USS is often defined using terms such as "a quality" or by describing it through a relationship to certain necessary but not satisfactory conditions. Hence, the meaning is vague and often left open to interpretation.

Finally, the study formulates a common conceptual framework of USS consisting of two overarching categories: social equity and social capital (see Table 4.2).

Table 4.2: Conceptual framework for neighbourhood USS. (Adapted from Paper 1)

Conceptual framework for neighbourhood USS		
	Themes	**Sub-Themes (Indefinite)**
SOCIAL EQUITY	**Amenities**	Health Food Facilities and Services
	Community infrastructure	Education/Child Care/Health Aesthetic/Maintenance
	Recreation and Open spaces	Availability of open spaces, recreation, public realm Pedestrian Comfort/Microclimate
	Connectivity	Transport, Location and Connectivity, Accessibility Walkability
	Jobs	Distribution of wealth, Economic Welfare, Employment
	Housing	Housing / Living Conditions
SOCIAL CAPITAL	**Interaction**	Social Interaction in Society Social Networks
	Participation	Public Participation
	Stability of the community	Stability of the community/Tolerance
	Sense of Attachment	Sense of belonging, community responsibility Culture
	Safety and Security	Safety, Security, Crime, Peace and Justice

Social themes under social equity arise from opportunities for interactions between members of society and their physical environment. Social equity concerns the availability of and access to services, facilities, and amenities (the distributive notions of social justice). The social themes of social equity are amenities, community infrastructure, recreation and open spaces, connectivity, jobs, and housing. The social theme of amenity is the most referenced in the literature and has the most data and indicators available. This indicates that while social capital can be challenging to quantify analytically, social equity presents an opportunity to address USS through data and analytical methods.

Social themes under social capital are the emergent properties that arise from social interactions between members of society through interpersonal relationships. Social capital is closely linked to the notion of community cohesion. In the literature, social capital and community cohesion are often used interchangeably. Social capital can be seen as analogous to Colantonio (2010)'s soft or emerging themes of Social Sustainability. The social themes of social capital are interaction, participation, the stability of the community, a sense of attachment, and safety and security.

Themes of social equity reflect the physical aspects, while themes of social capital reflect the non-physical aspects of USS. The distribution of social themes under social equity and social capital is once again supported by the view that socially SD needs to address both physical and non-physical aspects of USS.

Implications for model development

The results of the literature review and the conceptual framework analysis highlight the thematic areas important for addressing the social sustainability of neighbourhoods.

- The categorisation of the different themes points to tangible areas that a decision-support tool can address.
- While social capital can be difficult to quantify and understand analytically, social equity presents an opportunity to address USS through analytical methods.
- Conceptually, it is useful to view USS as an empty signifier. This container concept is made up of interrelated themes that are determined by the stakeholders depending on their context.

4.2 Practitioners perspectives on conceptualisation (Paper II)

After establishing a common conceptual framework for USS and providing an overview of conceptual inconsistencies in the literature, this thesis explores practitioners' perspectives on USS. Interviews with practitioners provided insights into their mental models of USS and how these mental models are translated into practice. The findings from this interview study are a categorisation of different conceptual strategies of USS that practitioners used and the different methods employed to operationalise USS through reconceptualisation. In addition to the classification, the interviews provided insights into how practitioners view the planning process (see Paper 2).

Practitioners illustrated six different strategies for conceptualising USS: through ambiguity, intuition, stakeholder perspectives, hypothetical and rhetorical questions, placeholder concepts, and hierarchy of needs. Of particular interest to this thesis is the conceptualisation through *propositions using hypothetical and rhetorical questions* (see Figure 4.1).

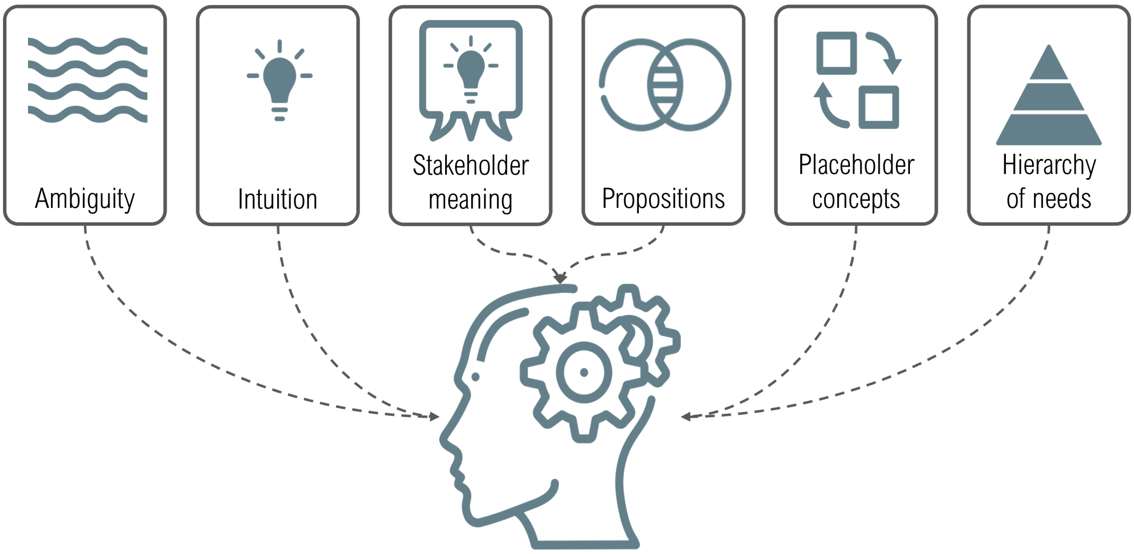


Figure 4.1: Ways of conceptualising USS found among the interview participants. (Adapted from Paper 2)

Practitioners often used propositions to express their mental models of USS and what they aimed to achieve in their projects. They exemplified what USS meant to them by narrating the experiences of individual residents and how they would experience the proposed design. This way of conceptualising USS highlights the natural way in which practitioners reasoned with their proposals, focusing on the individual while considering the impact of their decisions on the broader community.

The results emphasise the contextual and normative nature of USS. USS is a normative endeavour (Eizenberg and Jabareen, 2017; Hofstad, 2023; Janssen et al., 2021), and it is essential to recognise any biases affecting value-laden planning decisions. In the interviews, participants (N=4) discuss the certainty that there are trade-offs between stakeholder needs in the planning process. This is not unusual; planning is a multi-stakeholder endeavour, and often conflicting needs must be resolved. Central to the practice of any design discipline is the role of normative theories, and normativity is at the very core of planning (Lynch, 1984). Of the many factors that influence how these conflicts are resolved, power dynamics between the stakeholders play a significant role in shaping the normative decisions made by practitioners. In a socially sustainable planning process, the focus is on identifying and sustaining existing social qualities for future generations while making normative decisions on which social qualities to sustain and whom to benefit.

Implications for model development

The findings from the two studies related to the conceptualisation of USS show that from a theoretical perspective, USS as a concept seems to be stuck in an epistemological gridlock. From a practical perspective, practitioners are unable to find a consistent conceptualisation or an operational form of how they apply USS. However, a deeper look into the empirical data highlights a misalignment between how practitioners approach the social issues in neighbourhood planning and the available tools.
The results from the interview study provide valuable insights into developing decision-support tools for USS.

1. It illustrates the normative nature of the planning process and the need to provide the practitioner with adequate disaggregated and aggregated data on the neighbourhood residents. It would allow the practitioner to place a value judgment on what is considered socially sustainable for the neighbourhood.
2. It illustrated how practitioners reasoned with ideas related to conceptualising USS by formulating hypothetical and rhetorical questions about individual residents' abilities to fulfil their daily needs in the conceptualisation stage.

4.3 Practitioners' ways of operationalising USS (Paper II)

Moving to practitioners' perspectives on operationalising USS, they discussed three methods of operationalising USS: through municipalities and municipal policies, stakeholder participation, and tools they adopt or develop internally. Additionally, practitioners highlighted other factors that play a role in operationalising USS: the limitations of their scope of influence in the planning process and secondary functions of stakeholder participation. However, most notably, the practitioners 'reconceptualised' USS as an intermediate translation stage between conceptualisation and operationalisation. This conceptualisation stage is influenced by several factors, from the role of the municipality to that of the planning office.

The operationalisation of USS through tools is particularly interesting to this thesis. Practitioners highlighted that in recent years they prioritise evidence based design through the use of tools over intuition. In some cases practitioners developed internal tools to support their design process, particularly in building performance assessments. In addition to the ways of operationalising USS, practitioners highlighted prerequisite conditions to achieving it. One prerequisite is recognising their scope of influence.

The practitioners acknowledge their limitations and recognise what they can and cannot affect. For example, they pointed out that the residents often define the scope of USS by specifying what intervention is required in the neighbourhood and where. Here, practitioners emphasise that recognising and being transparent about what they have no influence over plays an essential role in avoiding conflicts with residents and building trust. At a broader level, practitioners acknowledge that the BE cannot address certain issues alone. Sometimes complex social issues require synergies from multiple stakeholders and depend on external factors to be solved.

In addition to the direct outcomes of a participation process, practitioners highlighted three secondary functions of early-stage stakeholder engagement: *community building, informing, and creating a sense of ownership.* While these secondary functions do not directly impact the conceptualisation of USS, they provide a key insight into the role of computational methods early in the design/planning process (see Table 4.3).

Table 4.3: Secondary functions of early-stage stakeholder engagement in the design/planning process. (Adapted from Paper 2)

Secondary Function	Description
Community Building	Early stakeholder involvement as a community-building activity is crucial in the design process. Although not the explicit goal, this process helps develop the community's social capital by raising awareness of their agency in influencing the BE. Communal activities create shared memories that may catalyse residents to become more involved in their neighbourhoods.
A Way to Inform	Practitioners can use community initiatives to inform or raise awareness and bring the BE into the residents' daily conversation. For example, creating city models in the computer game Minecraft was mentioned: "These initiatives, over time, bring the BE and social aspects of that into (...) people's everyday conversations." (UP7).
Creating a Sense of Ownership	Involving the community early in the design process can create a sense of ownership in the project. When residents play an active role in the early stages (and their concerns are heard and influence the design), it re-positions the planner's role. Rather than defending their design, the planner actively empowers the residents through their design.

Implications for model development

- The results show that practitioners are increasingly looking towards evidence-based tools to supplement their reconceptualisation of USS early in their projects.
- The results show that tools for USS must be applicable within the scope of influence of the practitioner to contribute towards reconceptualising USS.
- Finally, the role of stakeholder participation through public consultation shows that analytical tools cannot replace other qualitative methods in the design and planning process. Rather, they must complement the design process by allowing the practitioner to use the rich data gathered in this process.

4.4 An indicator of distributional accessibility (Paper III)

Based on Study I, social equity is identified as a tangle way to operationalise USS. Operationalising USS requires effective ways to measure and represent the social impacts quantitatively. To do this, an indicator development framework is used to develop Trip Completion Rate (TCR). TCR is an indicator of the distributional effects across populations. This section summarises the findings of Study III (see Paper 3).

The feedback from the practitioners was grouped into three categories: interpretability, utility and application and potential improvements. The interpretability of an indicator is described as *the ease with which the user may understand and properly use and analyse the data*. In the analysis of the interview transcripts, instances of practitioners interacting with the TCR matrix to generate insights were treated as a measure of the interpretability of the indicator (N=8). They described what they understood about the analysed area from the TCR matrix. In some instances, practitioners combined the insights from the indicator with potential design decisions. For example, the practitioners propose building a new healthcare facility rather than a bike lane because of the low number of residents who use bicycles to visit healthcare facilities.

Next, practitioners proposed further applications for the TCR indicator (N=18). These are grouped under *utility* to illustrate how practitioners could utilise the indicator. Examples of potential applications include the extension of TCR as an indicator to analyse the impact of climate change or transportation, compare how different residents experience the cities, and inform the planning process in general.

Finally, potential improvement. TCR was initially represented as a matrix and coloured as a heat map. In discussions with the practitioners on the feasibility of using the TCR indicator, first, they reported that they understood the indicator representation but requested a map visualisation (see Figure 4.2). While practitioners could generate insights from the TCR results, they reported that TCR is better suited for technical users than non-technical users, indicating that further improvements could be made in communicating the TCR results.

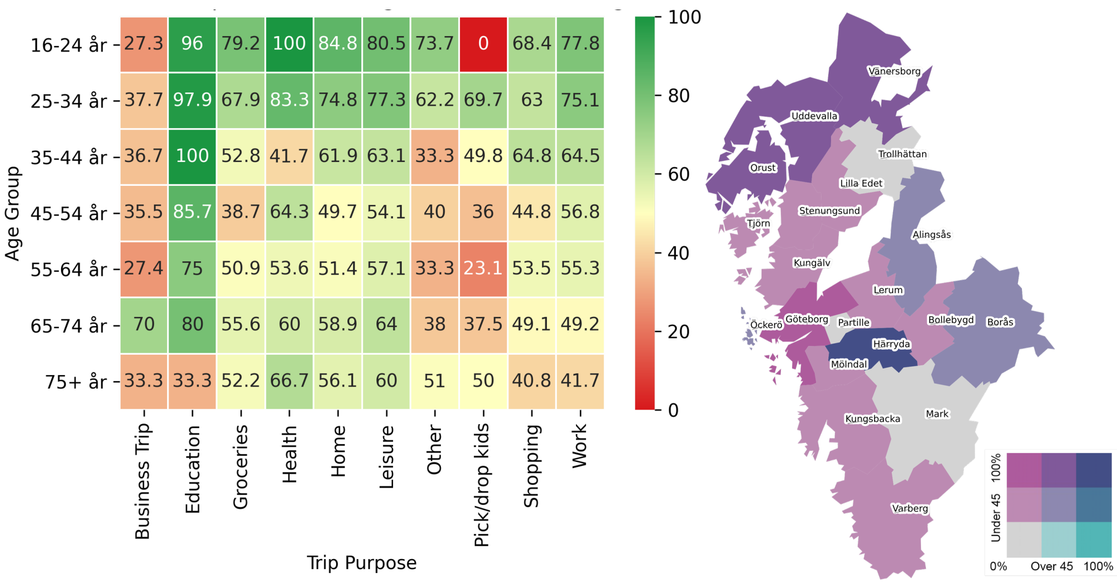


Figure 4.2: (left) The TCR represents the distributional effects of a personal carbon allowance for trips under 0.68kg CO2e across age groups and trip purposes. (right) The map visualisation of the TCR shows the distributional effects of the personal carbon allowance on residents of different age groups. (Originally developed for Paper 3)

Implications for model development

- The results show that TCR is a feasible indicator to represent the distributional effects of neighbourhood planning scenarios.
- Practitioners can reason about the causality of the results by interpreting the indicator.
- Practitioners prefer map-based visualisations over matrix visualisation.
- TCR may be better suited for technical users.

4.5 Implementing activity-based models of spatial accessibility (Paper IV)

Following the development of the TCR indicator, a toy model of distributional accessibility was developed in consultation with practitioners. Practitioners provided feedback on the model's different modelling assumptions and features. The final proposed model is evaluated to gauge its validity. This section presents the results of the validation studies; for a detailed discussion on the validation study, see Paper 4.

- **Disjointed variables**: The evaluation of the disjointed variables shows that despite the constraints on household sizes and the couple matching heuristic used, there is a low percentage of error in the distribution of individual variables. The evaluation shows that of the 95 residential neighbourhoods in Gothenburg, 94 are below a 2% error percentage; effectively, less than 2% of the synthetic population is incorrectly classified in the disjointed attributes.
- **Joint distribution**: The RMSE is evaluated across all neighbourhoods on the joint distribution of two demographic variables (for instance, age and sex). The results show an average RMSE between 2 and 3 per neighbourhood. The results also show that older residents are being underrepresented in the synthetic population. One possible explanation for this is in the step of household formation. Residents are sorted by increasing order of age. Finally, when the number of required households per neighbourhood is achieved, the members at the end of the list are moved to other household types to be re-allocated.
- **Predicted variables**: The ML model used in the proposed model was trained to have high accuracy in predicting national-level data. The evaluation of the predicted variables shows that in 93 of the 95 neighbourhoods, the error in total cars assigned is less than 2%
- **Routing and mobility**: Comparing average travel time across each neighbourhood to the average travel times in the NHTS, the results show that, on average, more centrally located neighbourhoods with higher concentration of amenities report lower travel time than the national average. In contrast, neighbourhoods towards the suburbs of Gothenburg, with a lower density of amenities, report higher travel time than the national average.

4.6 Application to a case in Gothenburg (Paper V)

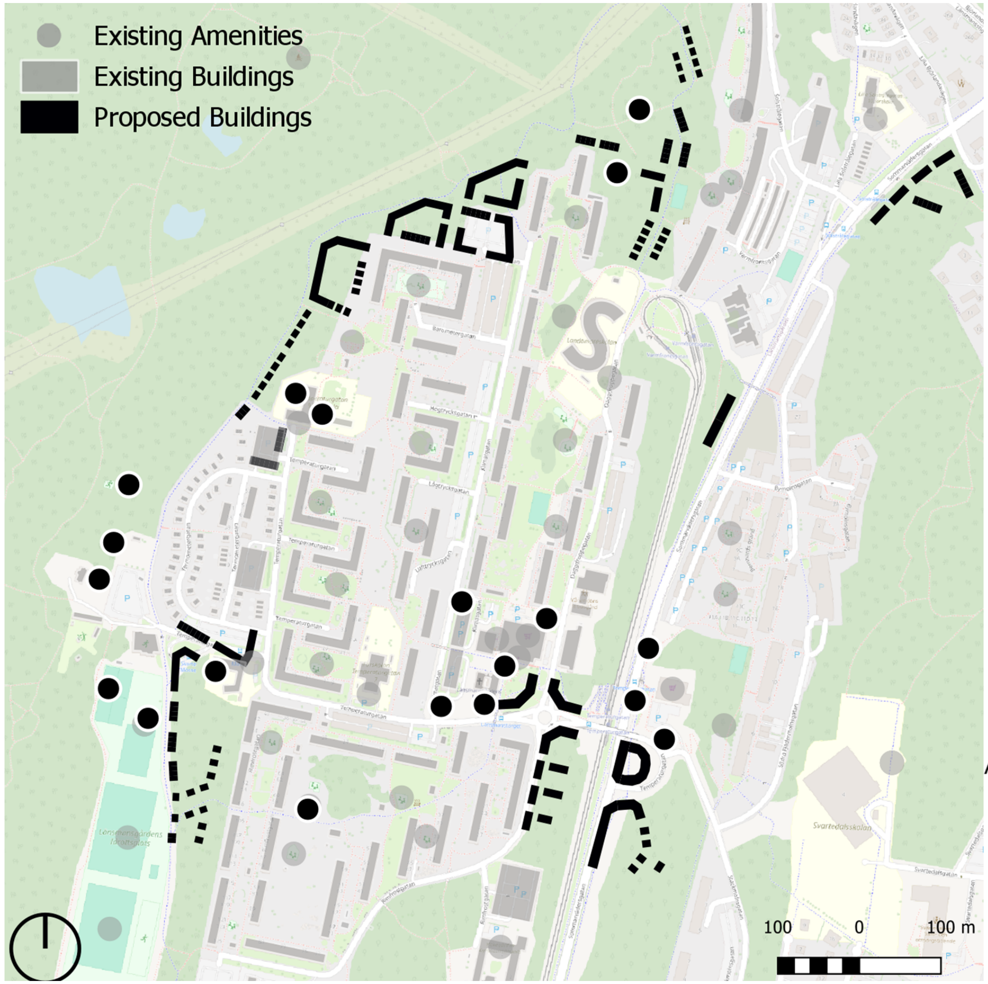
The following section describes how practitioners can apply the proposed model in their practice. In an exemplary case, a neighbourhood redevelopment plan for Gothenburg was selected to explore how activity patterns change as new residents move into the neighbourhood and how practitioners can evaluate the distributional effects of accessibility using the model developed in this thesis.

While this model evaluates four scenarios, only the first and fourth are summarised below. A detailed analysis and discussion of the evaluated scenarios can be found in Paper 5.

Figure 4.3 shows that *leisure* activities have the highest completion rate (84%) followed by *grocery shopping* (80%), *home* (76%) and *picking up and dropping off children* from schools (72%). The neighbourhood's existing recreational spaces, supermarkets and preschools explain the high TCR in these categories. The lowest TCR are for adult *education* (8%), *work* (26%), followed by *healthcare* (48%) trips. For *education* and *work*, residents travel to the city centre and other high-density areas for job opportunities. The randomness induced in the sampling results in some amenity categories not receiving any trips from certain age groups; these are marked with *Not a Number - 'NaN'* in the TCR matrix.

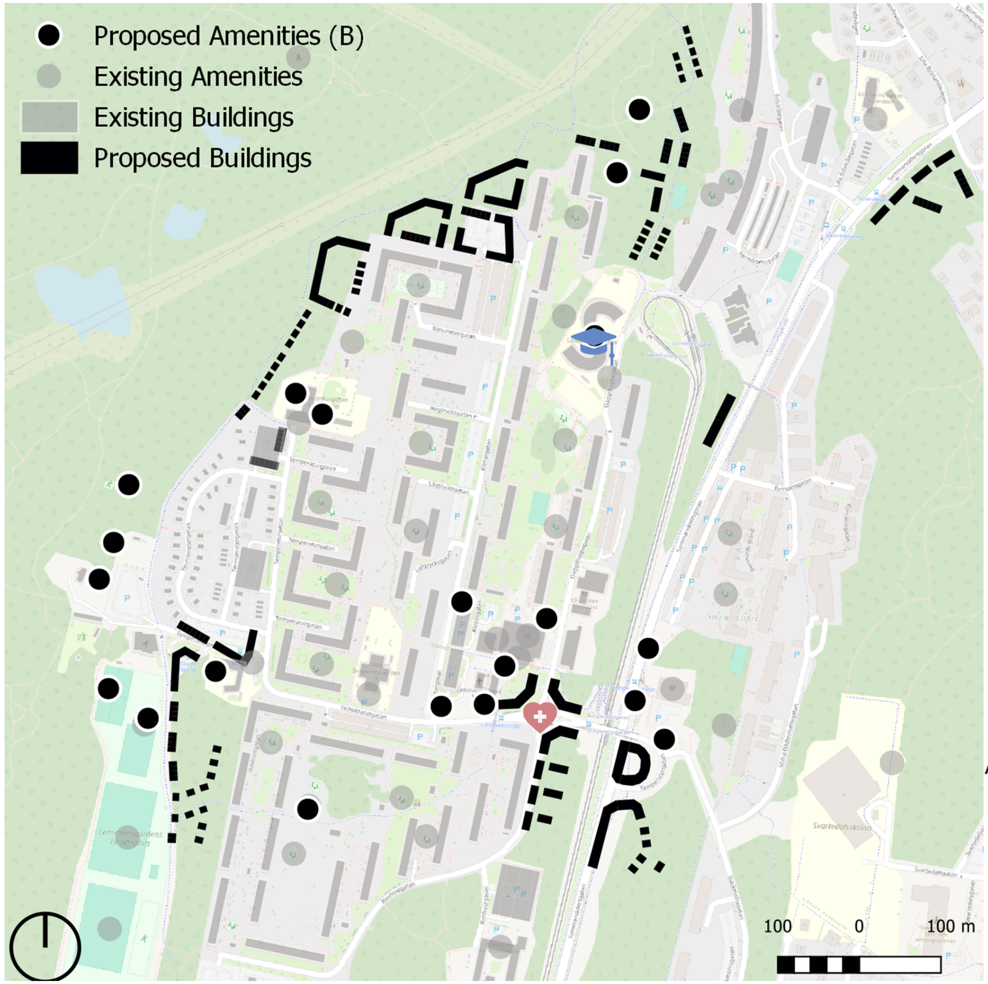
However, the new neighbourhood plan aimed to promote a car-free neighbourhood. One where residents could access all amenities in 15 minutes, scenario C. By filtering the results to residents who do not use cars (see Figure 4.4), the results show that education, shopping and healthcare had the most significant improvement across age groups in reaching their destinations in under 15 minutes. At the same time, work destinations experienced adverse effects. In this scenario, the planner can use such feedback to propose alternative planning scenarios or social infrastructure to compensate for the reduced TCR using complementary bus routes or at-home services for specific demographic groups.

Given sufficient time, residents will eventually reach their destinations. Figure 4.5 shows the TCR over increasing travel time thresholds. Notably, all proposals converge to around 95% TCR after one hour in two distinct phases: an initial rapid increase and a gradual rise. The first represents the activities that can be fulfilled within the neighbourhood, while the second corresponds to activities outside the neighbourhood. Using this method, practitioners can investigate whether 15 minutes is a reasonable ask from the neighbourhood. As Figure 4.5 shows, there is indeed a potential for many residents to complete their trips between 15 and 20 minutes, suggesting that a 15-minute city concept may be feasible.



Age Group	Education	Grocery	Healthcare	Home	Leisure	Pickup/Dropoff child	Shopping	Work	Avg.↑
16-18	5	86	NaN	83	91	NaN	NaN	NaN	66
19-24	9	79	48	79	87	18	65	28	52
25-34	5	75	54	69	78	82	51	27	55
35-44	6	71	47	65	76	79	49	24	52
45-54	17	63	37	50	74	82	26	28	47
55-64	NaN	57	36	56	65	79	50	27	53
65-74	NaN	95	57	93	97	93	57	23	74
75-84	NaN	97	58	96	98	NaN	70	NaN	84
85+	NaN	96	48	94	94	NaN	52	NaN	77
Avg.→	8	80	48	76	84	72	52	26	

Figure 4.3: Baseline scenario: with added residential buildings and no additional amenities (left). Neighbourhood TCR for all trips under 15 minutes with existing amenities (right). TCR is the proportion of all trips that are completed under 15 minutes. (Originally developed for Paper 5)



Age Group	Education	Grocery	Healthcare	Home	Leisure	Pickup/Dropoff child	Shopping	Work	Avg.↑
16-18	93	13	NaN	17	6	NaN	NaN	NaN	32
19-24	88	20	-8	10	5	2	18	-23	14
25-34	95	9	33	1	4	-4	26	-23	18
35-44	85	0	36	-2	-3	3	22	-20	15
45-54	13	-10	15	-7	-6	1	1	-23	-2
55-64	NaN	-3	18	-8	-6	-7	14	-23	-2
65-74	NaN	-0	38	-5	-2	-1	36	-17	7
75-84	NaN	-1	40	-5	-2	NaN	29	NaN	12
85+	NaN	-1	42	-4	0	NaN	18	NaN	11
Avg.→	75	3	27	-0	-0	-1	21	-22	

Figure 4.4: Scenario C (left). Relative change in TCR for non-car trips under 15 minutes compared to the baseline scenario (right). (Originally developed for Paper 5)

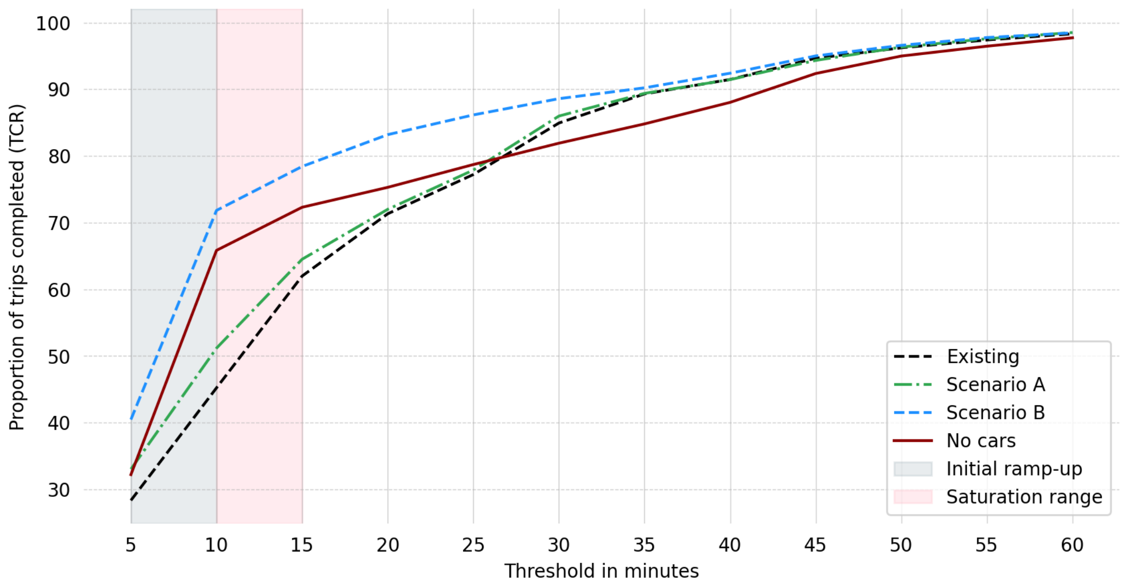


Figure 4.5: Cumulative TCR (y-axis) over time (x-axis) for different scenarios. (Originally developed for Paper 5)

Summary of findings

The examples demonstrating the model's application show that practitioners can use comparative scenarios to formulate solutions that do not necessarily require the creation of new amenities. Instead, they can introduce social equity initiatives and explore strategies like flexible land-use allocation and supplementary transit routes. The findings from the implementation of modelling approaches are summarised below:

- The proposed model can represent real-world population distributions concerning demographic characteristics, mode choice, and travel patterns.
- The results show that the model can impute mobility patterns from NHTS data and adapt them to the neighbourhood scale
- The model supports multiple visualisation outputs for aggregated and disaggregated data.
- The results demonstrate how practitioners can use the proposed model to generate new planning solutions and reason the applicability of planning policies.

4.7 Visualisation of results

The results of Study III emphasise the importance of visualisations. Based on the practitioners' recommendations, the proposed model supports a series of disaggregated and aggregated visualisations, including both spatial and non-spatial data. Six visualisation types are built into the model and automatically generated after each simulation. The visualisation considers the normalisation of values and colour scales used and includes the raw data if the users wish to explore it.

Individual space-time cube: Originally developed by Swedish geographer Hägerstrand (1970), the space-time cube is a three-dimensional visualisation of people's movements in space and time. The cube's horizontal plane represents space, and the vertical axis represents time. In the proposed model, a space-time cube can be generated for each resident to visualise their travel patterns throughout 24 hours. Colours represent the mode of transport used for each activity. Green and red triangles represent the home location at the trip's start and end, and text annotations mark the activity's purpose (see Figure 4.6.)

TCR: As explained in previous sections, the TCR matrix is a visualisation that represents the distributional effects of neighbourhood planning scenarios on different demographic groups. Two variables can be visualised at a time: one demographic variable (such as age group) and one trip variable (such as trip purpose). Each cell in the matrix represents the total proportion of residents in that demographic category that can satisfy selected evaluation criteria (such as trip duration or distance). Additionally, aggregate marginals are presented as normalised percentages on the right and the bottom. Two colour schemes are used: one to visualise the TCR numbers and another for the marginals (see Figure 4.7).

Household activity schedule: At the household level, each member's activity sequence is visualised as a timeline. The horizontal axis represents the time of the day with hourly markers. Colours are used to represent the activity each resident is engaged in and the mode of transport used (see Figure 4.8).

Aggregated activity engagement profile: An aggregated measure of the neighbourhood's activity engagement profile is provided as an area chart. This visualisation shows the number of residents engaged in different activities simultaneously at every hourly interval. The visualisation is inspired by the amenity demand pattern visualisation by Dogan et al. (2018) (see Figure 4.9).

Aggregated amenity demand profile: A second aggregate measure of the neighbourhood's activity demand profile is also visualised. The visualisation elaborates the "transit" activity from the aggregated activity engagement profile (Figure 4.9). The visualisation shows a breakdown of each transit activity divided by the activity type at the destination. (see Figure 4.10).

Interactive time-series route map: The visualisation is an interactive-animated web map[1] that overlays visualisations of residents' homes (with annotations on the number of households and residents within the building), amenity locations (with annotations on the amenity type and the name of the actual amenity if available), and an animated line that visualised the mode of transport and the speed at which each resident is travelling. While the visualisation does not necessarily facilitate actionable insights into the neighbourhood planning scenario, the practitioners reported that the visualisation gives an intuitive understanding of how the model functions. It is helpful to communicate to non-technical users the mechanism of the underlying model used to inform decision-making (see Figure 4.11).

[1] https://snjsomnath.github.io/PhDThesisRepo/

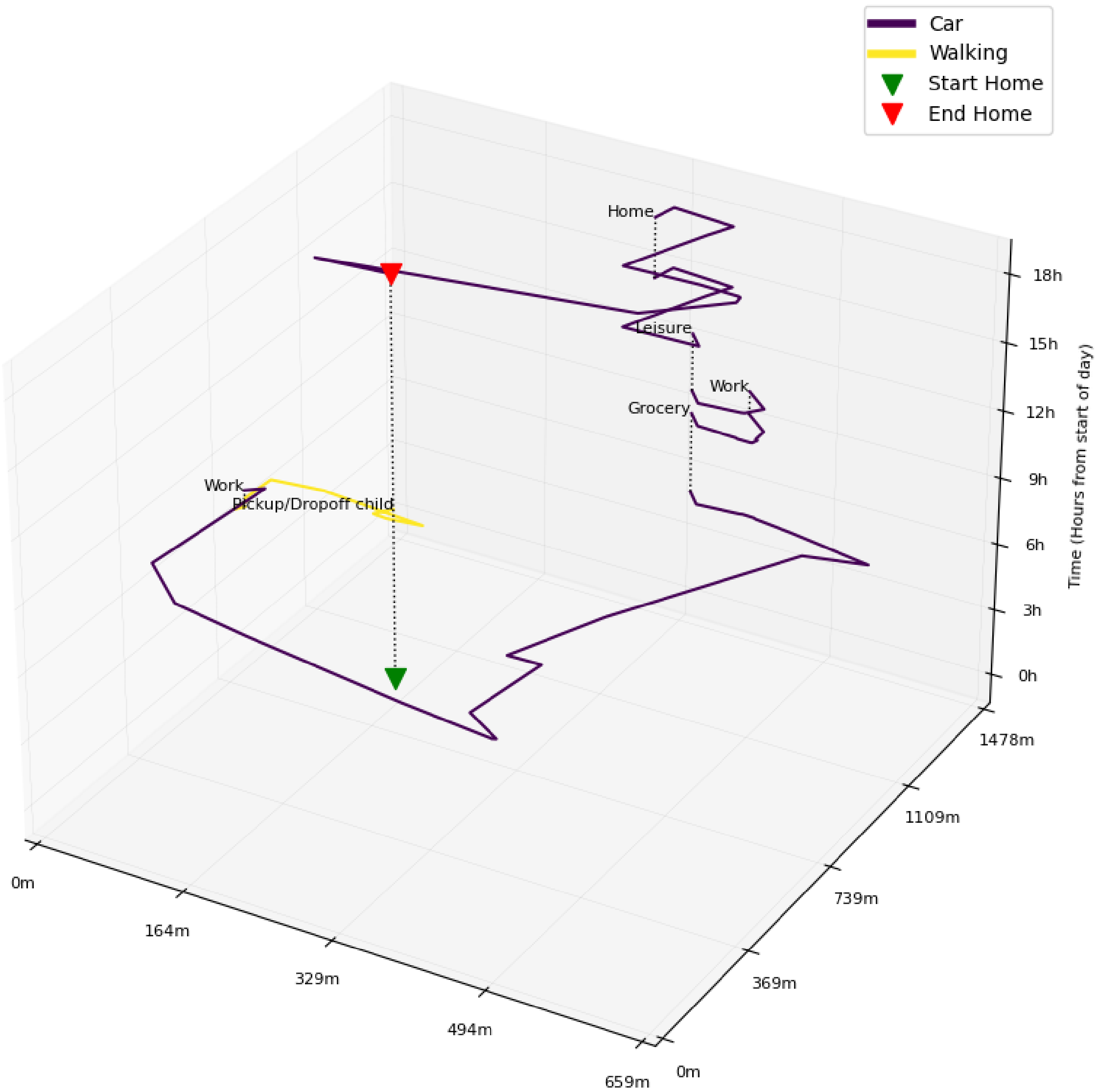


Figure 4.6: Supported model visualisation: Space-Time Cube with the horizontal plane representing the spatial dimension and the vertical axis representing time.

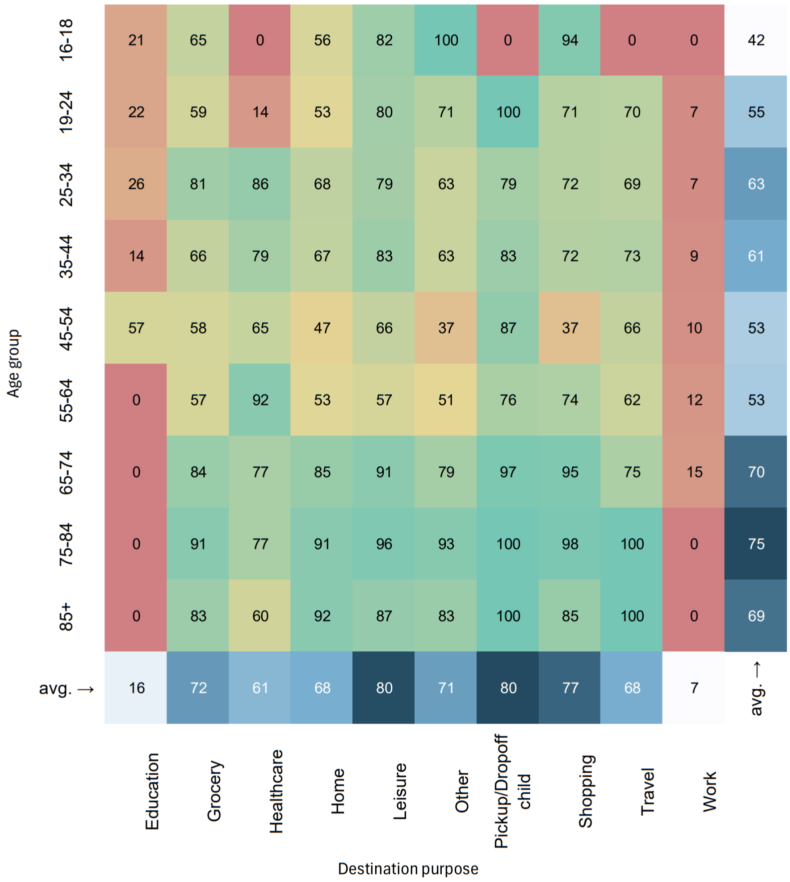


Figure 4.7: Supported model visualisation: Trip completion rate matrix visualised as a heat map. The numbers in the matrix are out of 100, with 100 indicating all residents in that demographic group can satisfy the evaluation criteria and 0 indicating that none of the individuals are able to satisfy the evaluation criteria. If there are no individuals in a particular category, the cell is shown in grey with the text ”NaN”. The marginals show the total percentage across a single dimension, originally developed for Paper 5

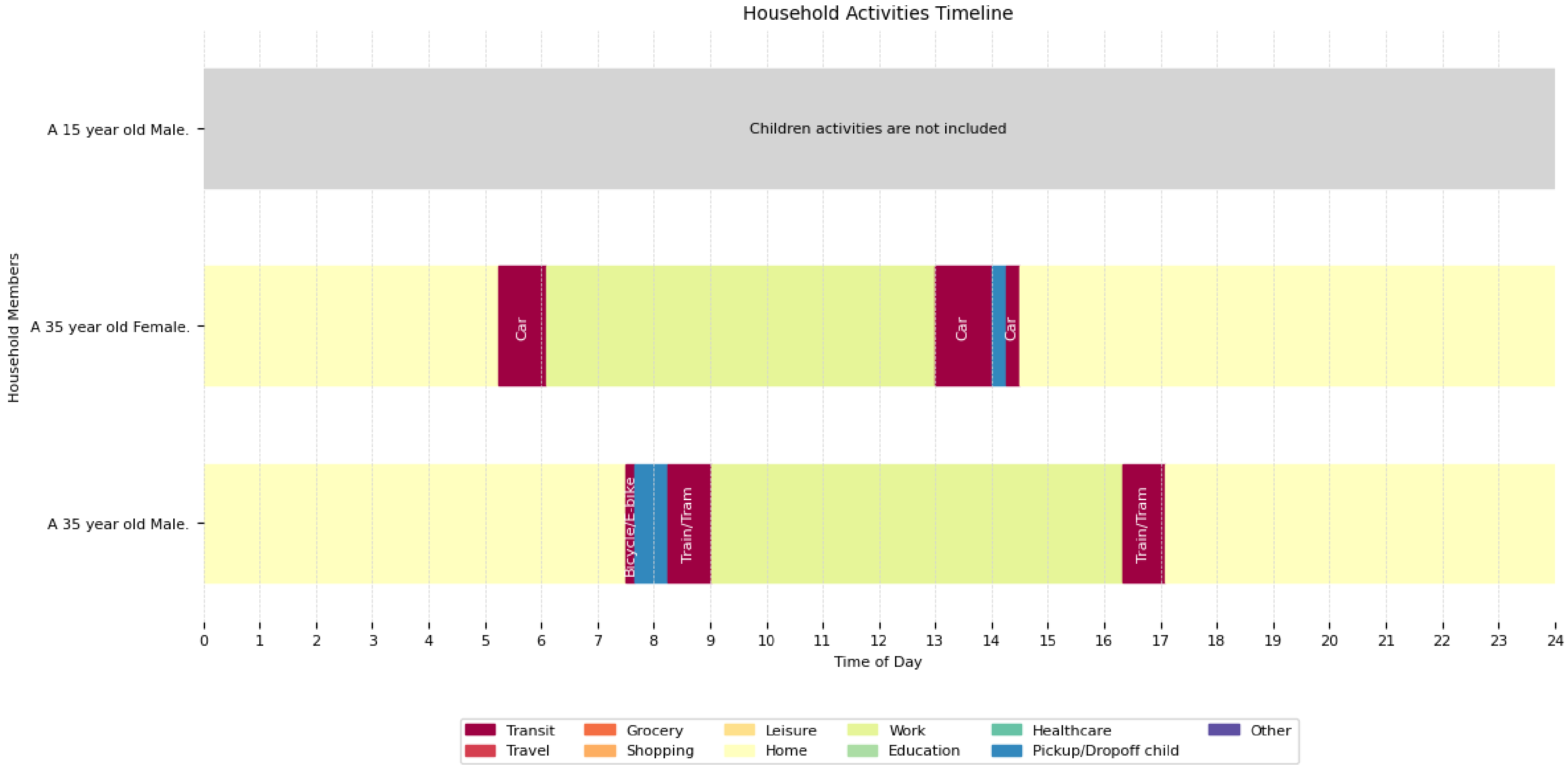


Figure 4.8: Supported model visualisation: Household activity schedule representing the activity a household member is engaged in and its duration and mode of transport. Members under the age of 18 are left blank.

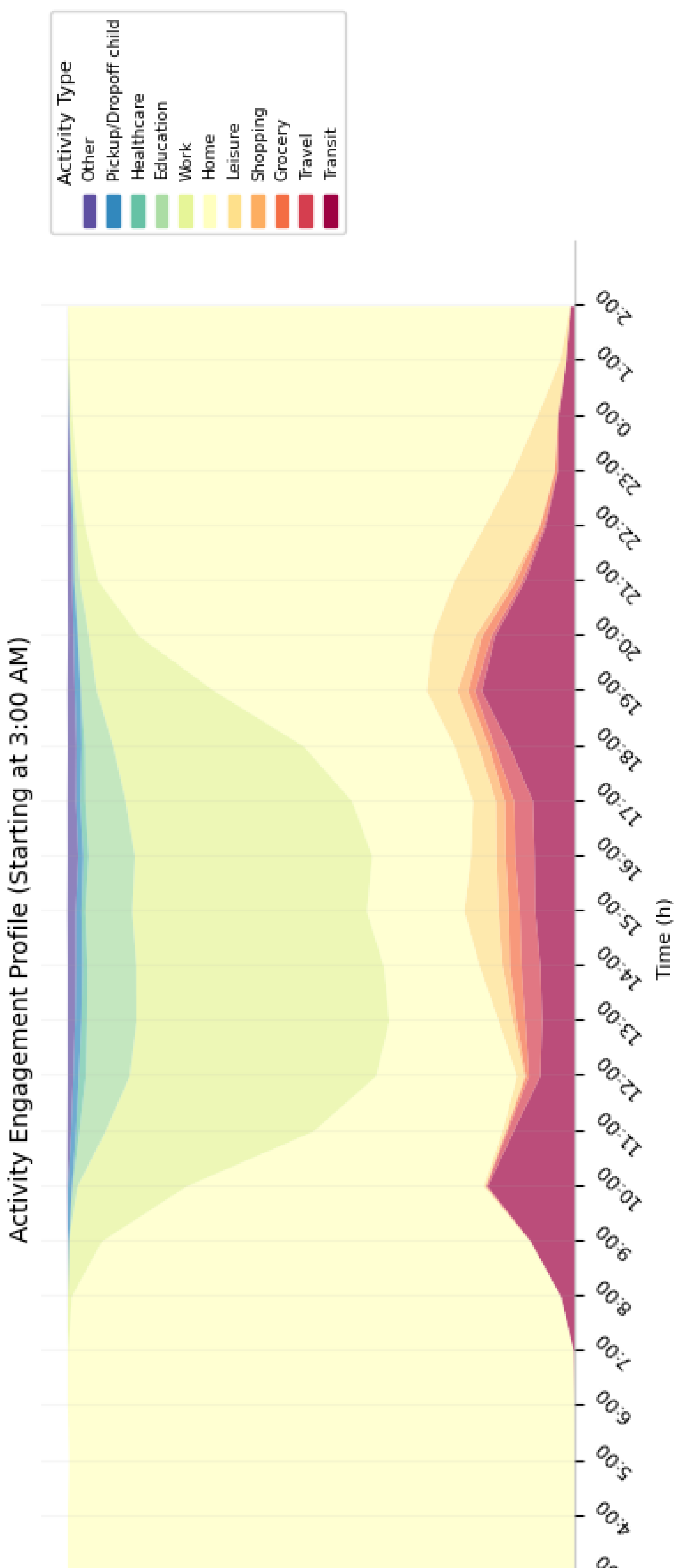


Figure 4.9: Supported model visualisation: Aggregated activity engagement profile representing the number of individuals in the neighbourhood engaged in a particular activity category. (Originally developed for Paper 4)

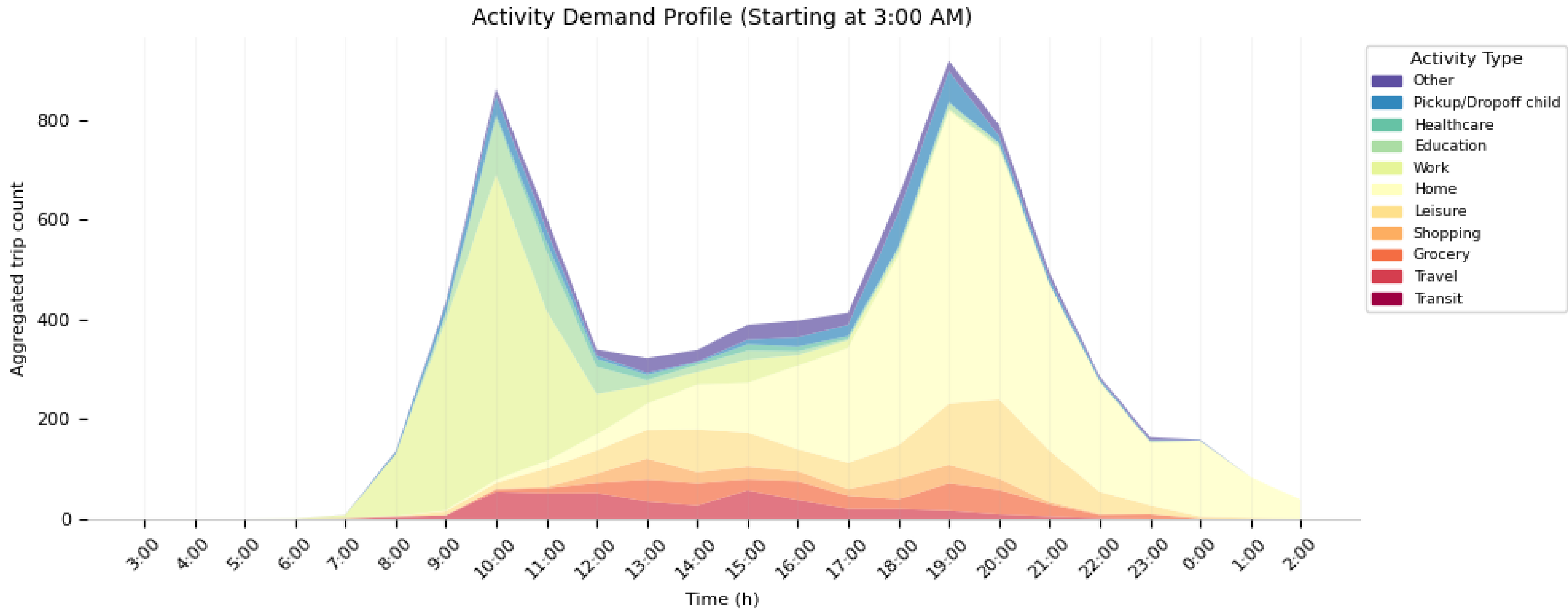


Figure 4.10: Supported model visualisation: Aggregated amenity demand profile representing the number of individuals in a neighbourhood travelling at a given hour. The colours represent the activity at the resident's destination. (Originally developed for Paper 4)

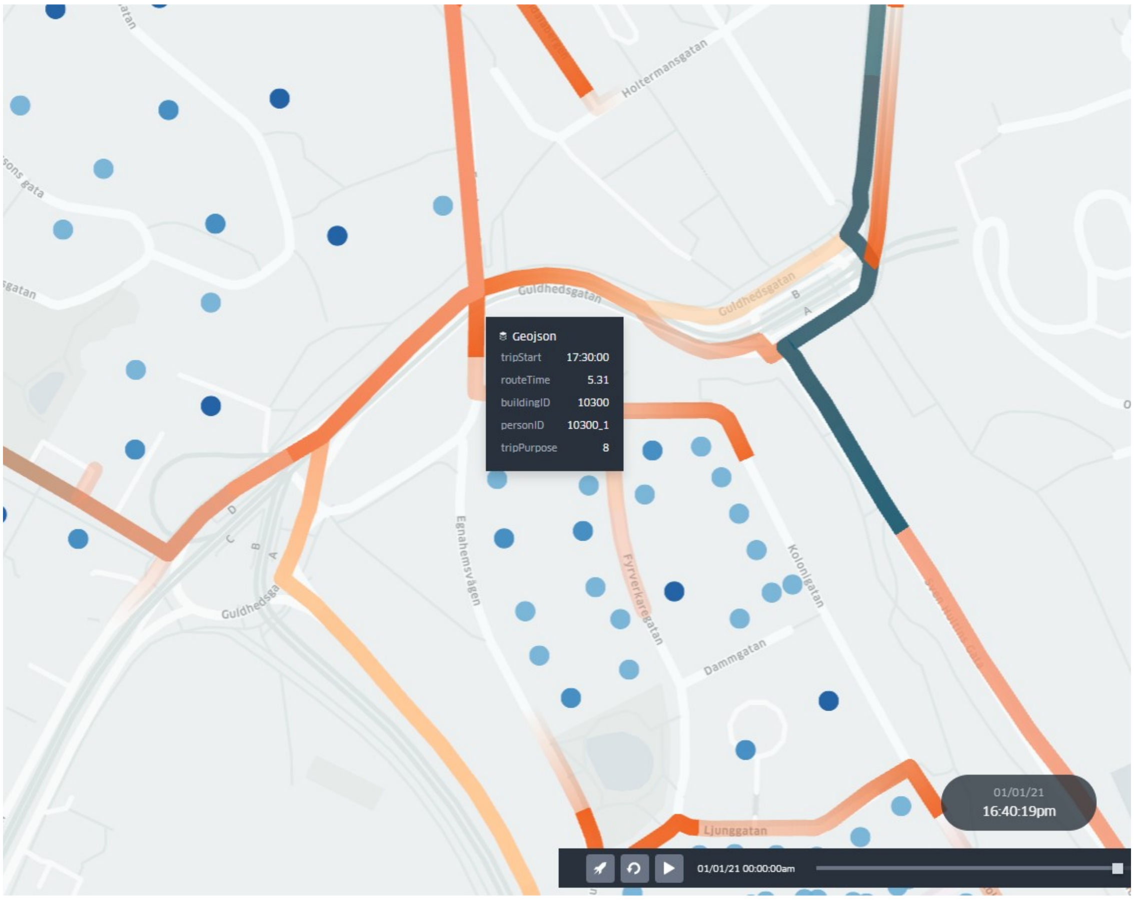


Figure 4.11: Supported model visualisation: Interactive web-based time-series route map.

5
Discussion

This thesis set out to contribute to the research on USS and bridge the gaps between theory and practice. The four studies carried out throughout this thesis contribute to the knowledge on conceptualising USS in theory and practice and finally operationalising it for practitioners through computational methods. This chapter discusses the results of the studies to answer the thesis's RQs and reflect on their significance to previous literature. Additionally, recommendations are made regarding developing AcBMs for neighbourhood planning targeted at practitioners.

5.1 Digital tools as instruments of designerly inquiry

Main RQ - How can digital tools support practitioners in evaluating the social consequences of their designs?

The studies indicate that digital tools can support the explorative and experimental nature of the design and planning process in the form of instruments of inquiry. They do this by elucidating ”how-possibly” explanations. Through highly idealised and simple representations of social phenomena like distributional accessibility, this thesis illustrates the use of AcBMs to support designerly inquiry.

Wicked or ill-structured problems are complex to solve and, in practice, are often solved by teams of individuals who use tools to help them solve such problems (Peters et al., 2021). Peters et al. (2021) define *design tools* as *something that provides materials with which a designer interacts to create a situation that talks back to the designer*. Dalsgaard (2017) refers to such tools of design as *instruments of inquiry*, consisting of five qualities - perception, conception, externalisation, knowing through action and mediation. Design tools are fundamental to the design process, and they scaffold the *process of inquiry* (Dalsgaard, 2017).

Based on Studies I and II, urban accessibility is identified as a tangible point of intervention for practitioners to operationalise USS within their scope of influence through *reconceptualisation*. This is implemented in Studies III, IV, and V through an indicator of distributional accessibility and a toy model. Study III demonstrates the potential of the indicator to operationalise the measurement and evaluation of *a resident's ability to achieve their daily needs* as a social theme of social equity. The resident's ability to achieve their daily needs or their TCR is not in itself a full characterisation of social equity. It is an indicator of one part of the whole concept that can be combined with other indicators.

Study V demonstrates that by using the AcBM to simulate neighbourhood planning scenarios and interpreting their results through the TCR, practitioners can perceive facets of the neighbourhood proposal that were otherwise hidden, such as the distributional effects of accessibility across demographic groups. This demonstrates the ability of such models to empathise with the existing condition of the users or ask, "Where are we, and where do we want to be? (Erickson and Lloyd-Jones, 2001). This illustrates the quality of the proposed model to enable and support *perception* within the design process.

After the initial phase of perceiving and framing the design problem comes a phase of forming, exploring, and potentially revising hypotheses about how the situation may be resolved Dalsgaard (2017). The exemplary case demonstrated in Study V shows how new scenarios may be evaluated using the proposed model and examine existing hypotheses used to evaluate the designs, illustrating the ability of such models to enable and support *conception and externalisation*. In Study II, the interviews with practitioners show that USS is conceived by examining hypothetical scenarios focusing on individual residents. However, this form of disaggregated evaluation is not possible with current planning tools. Models that simulate disaggregated populations can extend practitioners' capacities by offloading cognition to external tools and playing to their cognitive strengths Dalsgaard (2017).

While AcBMs have been used to predict future scenarios and provide users with "how actually" explanations (Strobel and Pruckner, 2023; Hörl and Balać, 2020; Axhausen et al., 2016), the goal of the model presented in this thesis is to give the users "why possibly" (Bokulich, 2014) explanations at the generative phases of design (Peters et al., 2021). As demonstrated in the Lawson (1979) experiments, practitioners learn the underlying mechanism of a design problem by exploring different potential solutions. The TCR indicator and the proposed AcBM developed in this thesis enable and support *knowing through action*. Practitioners can iteratively simulate different scenarios to facilitate a designerly way of knowing (Cross, 1982).

Finally, the ability of the proposed model to visualise and communicate the practitioner's design and planning solutions to other stakeholders supports *mediation*. Visualising the results as a two-dimensional matrix allows users to frame complex questions about socially relevant variables from data sets such as the synthetic population published in Paper 4 or the Swedish NHTS (Trafikanalys, 2020).

5.2 AcBM for neighbourhood planning

How can activity-based models of spatial accessibility be **implemented** to help practitioners operationalise USS?

Study IV demonstrates how the spatial, temporal, transport and individual components of urban accessibility can be implemented using AcBM in a neighbourhood planning context. By focusing the AcBM approach on residents' accessibility rather than mobility, practitioners are able to operationalise USS in their natural way of reasoning through design and planning scenarios. This is a noteworthy contribution considering that traditional transport planning approaches focus on mobility and, more specifically, the quantitative aspects of mobility rather than accessibility (Banister, 2011).

In Study II, practitioners *conceptualised* USS not as a single coherent concept but as a collection of overlapping concepts through *reconceptualisation*. They anchored their conceptualisation around the individual residents of the neighbourhood. Practitioners imagined how residents with different social, economic and demographic backgrounds could achieve their daily needs within the proposed neighbourhood.

Regarding *operationalisation*, practitioners relied on evidence-based design supported by digital tools. They emphasised the role of proximity and accessibility while reporting their individual conceptualisation of USS and emphasising other operational requirements of the design and planning process, such as participatory planning and communicating results with other stakeholders.

The AcBM developed in this thesis consists of four main steps: population synthesis, assigning activity chains, assigning ODs, and multi-modal routing. Each step was designed with practitioners' conceptualisation of USS in mind.

Previous studies on synthetic population generation (Zhou et al., 2022; Aemmer and MacKenzie, 2022) relied on micro-sample data like PUMS, which is not readily available in all regions, including practitioners in Gothenburg. The proposed model, instead, uses a combination of stochastic approaches and population heuristics to generate its synthetic population (Tozluoğlu et al., 2023). The practitioners' hypothetical scenarios during the interviews highlighted the role of interpersonal relationships in the household. The synthetic population pipeline developed in Study IV generates ontologically related agents (like couples and children) within a household.

Previous research on AcBM has often focused on national or regional scales. Therefore, the level of detail regarding the supported activity types and the location of amenities has been limited. For example, in the model by Barthelemy and Toint (2015), no georeferenced datasets are used for different activities or work locations. The proposed model combined multiple open-data sources to form a database of amenity locations from the city of Gothenburg and OpenStreetMaps OpenStreetMap contributors (2017). For example, school location and categorisation (pre-school, primary school, primary school, etc.) were collected from the city of Gothenburg and fed into the model to make the destination assignment more realistic for other amenities such as healthcare, leisure, grocery shopping, etc. OpenStreetMap amenity tags were examined and grouped accordingly. The model uses a gravity-based approach for the work locations to determine the availability and attraction of jobs in different parts of the city based on the density of non-residential buildings.

Finally, for the multi-modal routing, practitioners expressed that they would like qualitative factors about the route chosen included, like slope and proximity to green spaces. These features are added to the toy model during the iterative development process. Many of the synthetic population pipelines mentioned previously do not explicitly model them within their own pipelines (Strobel and Pruckner, 2023); instead, this task is performed by other models like MATSIM (Axhausen et al., 2016) and SUMO (Krajzewicz, 2010), giving the practitioner less control over the design process and also increasing model complexity. To solve this, the proposed model consists of an end-to-end pipeline curated for the neighbourhoods of Gothenburg.

5.3 Practitioners perspectives on USS

How do practitioners **conceptualise** and **operationalise** USS?

The findings from II show that practitioners conceptualise USS at two levels: shallow and flexible, and the second is contextualised and concrete. The first level relies on stakeholder values and the municipal interpretation of USS. The six strategies presented in the study findings demonstrate the second and more concrete conceptualisation through its reconceptualisation.

While such conceptual fluidity can be navigated, it inevitably shapes their operational approaches (Missimer et al., 2017). The ways practitioners conceptualise USS echo the multiplicity in perspectives of USS demonstrated by Dempsey (2017); Shirazi and Keivani (2017). Hence, this reinforces the view that USS will change over time and is context-dependent. Practitioners reconceptualise USS by positioning the individual resident at the centre of their evaluations and considering the impact of their design and planning decisions on the resident's ability to fulfil their daily needs. Pragmatic considerations made by the practitioners helped shape USS to be more clearly defined in its scope. Consistent with Janssen et al. (2021) findings, reconceptualisation provides opportunities to define USS rather than seeking specificity in the conceptualisation. Given its normative nature, the plurality in conceptions of USS is understandable. However, meaning can be specified when the focus is switched to operationalisation in a specific context (Janssen et al., 2021) under reconceptualisation.

Another key finding from Study II is the role of municipalities in the design and planning process. The study showed that municipalities first identify problems related to USS. Then, through public participation, municipalities formulate what USS means to them based on the social aspirations of the community or neighbourhood. At this stage, USS is conceptualised as a goal or a broader vision and does not consider the specific trade-offs or challenges in operationalisation. Once the municipality has formulated the goals and visions, the concept is handed over to practitioners who further refine the concept and transform it into its operational form.

During the operationalisation phase, practitioners identify opportunities to improve the USS in the community through social themes within their scope of influence. These social themes constitute the more tangible components of USS (Janssen et al., 2021; Dempsey et al., 2012) such as spatial equity and access to amenities. The study also showed that municipalities offer more precise directives regarding the operationalisation of USS; through Social Impact Assessment, Child Impact assessment and mandatory participatory planning, municipalities provide practitioners with guidance on operationalising USS. However, municipalities are tasked with performing a balancing act between formulating prescriptive definitions of USS or leaving it as a vague concept to be refined during the design and planning process. Both extremes often lead to potential misalignment with the stakeholders' needs. Without appropriate municipal guidelines, practitioners are often left to extrapolate their conceptual understanding of USS from the operational measures provided.

5.4 Theoretical perspectives on USS

How is USS **conceptualised** in theory?

In the design of a research methodology, defining and conceptualising a phenomenon to establish a common meaning frame is often the first step (Maxwell, 2012). Defining and conceptualising are methods of generating meaning but have some key differences. Conceptualisation is concerned with the idea or the concept itself (Allen, 2017). It is the image created when thinking of a cluster of interrelated ideas. In comparison, a definition is meant to be more precise. It is a syntactic representation designed to draw the boundaries around a phenomenon through the use of language (Lavrakas, 2008). Through this process of generating meaning, a concept can be operationalised (Allen, 2017). Therefore, an investigation of the theoretical perspectives of USS was necessary before exploring practitioners' perspectives on conceptualising and operationalising USS.

Study I showed that social themes under social equity arise from opportunities for interactions between members of society and their (physical) systems and (social) institutions. It is concerned with the availability of and access to services, facilities, and amenities (the distributive notions of social justice). In comparison, social capital is understood as the *emergent properties that arise from social interactions between members of society through interpersonal relationships*. Social capital can be seen as analogous to Colantonio (2010)'s soft or emerging themes of Social Sustainability.

To contextualise USS as it is understood in this thesis, USS is considered a *phenomenon*; it is observed to exist or happen without sufficient clarity as to why it happens. To research or discuss the consequences of any phenomenon, there must be a clear idea of what that phenomenon is (Quarantelli, 1988). Allen (2017) suggests that to measure a phenomenon, it must first be conceptualised and defined, and finally, it can be operationalised.Study II identified a key step in the operationalisation of USS, reconceptualisation. Reconceptualisation is the translation step that takes place between USS conceptualisation and operationalisation depending on the context of the project.

The study also shows two general views on the definition: whether USS would benefit from multiple definitions or a single one. On the one hand, Dempsey et al.

(2011) reviewed concepts and associated concepts of social sustainability in the BE at a neighbourhood scale and identified two overarching dimensions of social equity and sustainable community. Shirazi and Keivani (2019a) identified three dimensions called the 'triad of social sustainability': the neighbour, neighbouring and neighbourhood. This multiple conceptualisation allows planning projects to be compared to assess which ones demonstrate higher USS qualities and why. On the other, proponents of a singular definition, like Missimer et al. (2017), argue that the vagueness of definitions allows unsustainable actions to be presented as suitable ones.

While there is no consensus on definitions for USS in the literature, there is consensus on the conceptual framework of USS. USS comprises two overarching categories - *social equity* and *social capital*. On the foundations laid out by this conceptualisation, several studies and policy documents have furthered the research on USS (Shirazi and Keivani, 2019b; Dempsey et al., 2011; Kyttä et al., 2016) without requiring a consensus on definitions. Given that there is no consensus on defining USS and efforts to operationalise it have progressed based on the conceptualisation alone, it raises the question of whether there is much utility in defining the phenomenon to begin with.

5.5 Reflection on research design

The research conducted in this thesis is multidisciplinary and exploratory. A mixed methods approach combining inductive, deductive, and modelling approaches is used to achieve this exploration. This section provides reflections on the research design of this thesis.

Regarding the approach to USS theory, while inductive methods have proven to be quite fruitful in theorising USS, it is in the conceptualisation phase of the phenomenon that an *epistemological deadlock* (Friedrichs and Kratochwil, 2009) is observed regarding the definitions of USS. Perhaps this is because consensus is a necessary pre-requisite for social scientific knowledge (Friedrichs and Kratochwil, 2009). To deal with this epistemological deadlock, this thesis adopts the position proposed by Davidson (2009) by viewing USS as an empty signifier from the functional pragmatism theory of knowledge (Davidson, 2009). Study II showed that practitioners also use a similar conceptualisation of USS. This is not to use pragmatism as a pretext for doing empirical research without the methodological and epistemological considerations of the theory. Rather, to use pragmatism as an instrument to conduct research with an appropriate level of awareness of the epistemological issues (Friedrichs and Kratochwil, 2009).

The qualitative nature of Study II played a significant role in exploring and summarising the practical approaches to USS and identifying tangible points of departure to operationalise the concept. The interview studies served three purposes: gathering insights on practitioners' perspectives on USS, gathering feedback on the TCR indicator and its applicability and finally, gathering practitioners' insights on the suitability of AcBM approaches to neighbourhood planning. However, due to the time-bound nature of a PhD project, it was not feasible to include more practitioners in these studies. Additionally, the design of the interview studies could be adapted to generate more coherent results regarding the identification of conceptualisation methods. For instance, focus group studies or observational studies could lead to richer descriptions of mental models used by practitioners.

Regarding computational modelling, due to the exploratory nature of this research, significant time was spent on determining appropriate modelling frameworks, selecting modelling tools and defining the model's scope. While this led to a deeper understanding of the challenges related to AcBM, the approach could benefit from adapting existing modelling frameworks like MATSIM (Axhausen et al., 2016). This also meant limited time was available to conduct additional application studies, which would have led to a more robust model. For example using additional micro data from GPS traces and Regarding the reproducibility of the present work, significant effort was placed into ensuring that the model code used open data sources and that the code archiving and documentation were thorough. However, the validity of such models is not entirely dependent on the statistical evaluation of the model results. Equally important is the suitability of the approach from a practitioner's perspective and the applicability of these approaches to address issues of distributional accessibility, which was possible through qualitative studies.

The modelling approach adopted in this thesis focused on the Gothenburg region. However, recent AcBM literature shows a growing interest in developing generalised end-to-end pipelines (Barthelemy and Toint, 2015; Hörl and Balac, 2021; Strobel and Pruckner, 2023) that address the different steps required of an AcBM without specificity to a geographical region. While this is extremely important to the development of the field and exemplifies the utility of AcBMs in applications outside of transport planning, there is also a need for models tailored to the data availability of specific regions. Even when statistical data is openly available, variations in the data structure can determine feasible methods. This thesis encourages researchers to explore the development of generalised models but not to ignore the value in geographically specific models that, while limited to a region, provide value to local stakeholders.

5.6 Limitations of the research

The findings of this thesis must be understood with certain limitations in mind. These limitations arise due to the nature of USS, the research setting in which the research is conducted, and the inherent complexities of computational modelling. The following section discusses these limitations.

Scope of conceptualisation and operationalisation: USS is explored in this thesis through three stages: Conceptualisation, operationalisation and implementation. As explored in RQ1, the use of inductive methods to develop theory around USS, while valuable, is constrained by the conceptual inconsistencies in the field. Adopting a pragmatist approach, which views USS as an ”empty signifier," helps navigate these conceptual inconsistencies but does not entirely resolve them. As a result, the conceptual framework developed through the literature review may lack a universally accepted theoretical foundation. Further, while this thesis aims to bridge the gaps between theory and practice, the empirical studies explored in RQ2 show that practitioners formulate their mental models of USS using various strategies depending on the planning context. The conceptual framework, therefore, is a guiding template that aims to capture the overarching themes of USS rather than a prescriptive framework for operationalisation.

Limited sample size and scope practitioners engagement: Another limitation concerns the limited sample size of the practitioners interviewed in exploring RQ2. The interview study was conducted with 15 practitioners from Sweden, Denmark and the Netherlands. While the thesis aimed to gather in-depth and nuanced perspectives from practitioners, the limited number of practitioners interviewed only represented the practitioners' context and experience. The results, therefore, cannot be generalised across all practitioners like the study of a large-scale survey could. The studies are also limited to the perspectives of urban planners, designers, architects and related professionals without considering end-user perspectives. While this aligns with the aim of this thesis to develop methods for practitioners to use, it limits the scope of the findings in terms of understanding the effects of these tools on the end-user. Finally, the feedback from the practitioners, while valuable, has a limited scope of engagement. Due to time limitations in this thesis, practitioners could not directly apply the methods developed in their practice.

Contextual constraints and data availability: This thesis is contextually specific to Sweden and, more specifically, the city of Gothenburg. The models and their findings are closely tied to the socio-cultural and data environments of the region. While the methods developed in this thesis are designed to be adaptable to different contexts, the availability of the data, such as the neighbourhood-level demographic counts and the NHTS, varies across regions. While theoretically, the proposed model can be applied elsewhere, its practical applicability may be constrained by data availability. Consequently, the findings may not generally apply to other regions with different socio-cultural settings or where such data is not readily available.

AcBM development and model simplification: Developing AcBM to support practitioners introduces another set of limitations. While the methods developed in this thesis offer several advantages in terms of extending the practitioner's capabilities by offloading cognition to external tools and handling large datasets, they also require significant simplification of complex social phenomena. For instance, in Study IV, the exclusion of economic attributes and the use of car ownership as a proxy, oversimplification of social relationship-forming mechanisms using couple formation, or the exclusion of activity sequences for minors. These simplifications are necessary to operationalise USS within computational tools but may lead to losing important nuance, particularly those related to household dynamics.

Model validation: The proposed model is intended to be used as a design support tool through simplified toy models rather than to predict future scenarios. However, it is essential to recognise the need for model validation. While the model validation steps attempt to cover different components of the model design, the divergence observed between the model output and real-world data indicates areas where the model requires further refinement. Further validation efforts are necessary to enhance the model's reliability, such as applying the VALFRAM validation approach (Drchal et al., 2016). Users of the model should be aware of these limitations and understand that while the model provides valuable insights, it must be used in parallel with existing design processes, such as stakeholder participation and interpreted with caution.

Data complexity and communication: "Model-based measures improve upon many of the failings of the simpler measures, but often generate a massive amount of data that are difficult to digest, while the methods themselves are generally incomprehensible to the non-modeller." (Miller, 2018) Study III highlights the challenge of communicating complex data to stakeholders who may not be familiar with such information or ways of representing data. While the thesis offers a range of visualisation techniques based on stakeholder recommendations, non-expert practitioners could find the data overwhelming or difficult to interpret. This limitation is particularly relevant given the focus on bridging theory and practice and operationalising USS for practitioners. The trade-off between digestible visualisations and the potential loss of important insights during the simplification must be considered when practitioners choose which visualisations to present to other stakeholders.

6
Conclusion

This thesis makes two main contributions: first, it makes a theoretical contribution to the field of USS. Second, it makes a methodological contribution to the techniques used to analyse urban accessibility in neighbourhoods. This thesis presents a conceptualisation of urban social sustainability (USS) and bridges the gap between theory and practice by addressing the challenges in operationalising it for practitioners. Additionally, it explored how new indicators could be developed to explore the social consequences of different urban and environmental policies through an indicator to evaluate a resident's Trip Completion Rate (TCR). Finally, in the implementation stage, this thesis makes a methodological contribution to how practitioners can operationalise USS by applying AcBM to neighbourhood accessibility evaluations.

6.1 Contributions

The studies on the theory of USS indicate that research on USS is stuck in an epistemological gridlock that stems from a positivist research outlook. While Study I identifies common overlapping themes among the various conceptual frameworks of USS presented in the literature, it highlights the limitations of these frameworks due to several extrinsic and intrinsic factors. USS is a complex and interdisciplinary concept that presents several challenges in conceptualising it; the chronology of its origin, its multi-disciplinary nature, and the role of stakeholder value systems have caused contention at several stages of its conceptual development. The existing body of literature shows that though the core concept is grounded in theory, USS has many interpretations. Incorporating stakeholder values and the ability to analyse social themes quantitatively play an essential role in designing socially sustainable neighbourhoods. To address these issues, viewing USS as an empty signifier is suggested. Adopting a collaborative planning process to ensure multiple stakeholder perspectives is vital for achieving USS. USS is conceptualised as consisting of social equity and social capital. Further, Study I highlighted a gap in USS research where scholars are more concerned with refining conceptual models than with exploring how these models are understood and applied in practice. To address this gap, this thesis suggests a shift towards more interpretive and context-sensitive methodologies, such as abductive reasoning through empirical data.

Through empirical studies, Study II highlighted that the practitioner's conceptualisation and operationalisation of USS are influenced by several contextual factors, such as the role of municipalities in the planning process, the importance of stakeholder involvement, the practitioner's scope of influence and the potential for digital tools to aid in the operationalisation of USS. The study showed that practitioners' conceptualisation and operationalisation are closely linked, and operationalisation manifests through an approach where practitioners focus on individual experiences and evaluate the distributional effects of their neighbourhood proposals on urban accessibility.

Studies III, IV, and V make methodological contributions to indicator development and the evaluation of urban accessibility through digital tools. In Study III, social equity and, more specifically, equitable access to amenities is selected as a practical point of entry for digital tools to be developed around operationalising USS. TCR is proposed to indicate residents' ability to fulfil their needs. TCR aims to provide practitioners with the means to evaluate the social consequences of their designs. It is developed on data sets and variables accessible to the practitioner and within their scope of influence. It has a social focus and does not require specialised knowledge to evaluate. Traditionally, these evaluations depend on best practices, recommendations from policy or input from practitioners specialising in these techniques. These practices often lead to the social dimension of sustainability being left out of performance assessments. Through interviews with practitioners, Study III identifies that the TCR indicator proposed in this paper can generate insights about the analysed area and be integrated into the design process. The interviewees could envision additional applications of the indicator beyond what was presented. The thesis highlights that while USS indicators may be used to evaluate its multiple dimensions, the visualisation and communication of the results require consideration. Alternative methods to visualise the results are provided to address this. Studies IV and V illustrate how computational methods developed in transport planning and mobility analysis can be applied to neighbourhoods using AcBMs. Practitioners can use such models as instruments of designerly inquiry to evaluate the distributional effects of urban accessibility. The development and application of such models are illustrated in the implementation stage of the research through the development of AcBM models, the publication of open synthetic data sets and the application of said models in a neighbourhood of Gothenburg.

This thesis complements the research on USS and urban accessibility by bridging the gap between theory and practice. The conceptual framework and insights into the nature of USS are presented in Paper 1, and the practitioner's perspectives on USS are presented in Paper 2. Indicators to support disaggregated evaluation of neighbourhoods' urban accessibility are presented in Paper 3. Paper 4 introduces an AcBM to model and evaluate equitable access in neighbourhoods computationally and provides an open dataset to support future research. finally, Paper 5 presents an application of such models through examples. Table 6.1 presents an overview of this thesis's different theoretical and methodological contributions.

In conclusion, this thesis advocates for practitioners to reevaluate and refine their understanding of USS continuously. USS is a politically loaded concept that does not carry inherent value. Rather, it is a container concept that needs to be filled with meaning and shaped by its context. This thesis argues for a shift in how computational methods evaluate neighbourhood accessibility. By supporting disaggregated evaluation of neighbourhood accessibility, computational methods can aid practitioners in developing deeper insights into their proposals and support designerly inquiry.

Table 6.1: Contributions of the different studies

Study	Contributions
Study 1	Identifies a common conceptual framework of USS
	Classified semantic identifiers used to define USS
	Identifies intrinsic and extrinsic factors contributing to USS' conceptual ambiguity
	Presents a User-Interaction model to develop digital tools for USS
Study 2	Identifies practitioner strategies in conceptualising and operationalising USS
	Reveals insight into the relationship between municipalities and practitioners
	Provides insights into how practitioners assess the USS of neighbourhood plans
	Highlights the role of stakeholder participation in the neighbourhood planning process
	Provides insights into how analytical results of USS can be communicated
Study 3	Develops an indicator of distributional effects on diverse populations TCR
	Exemplifies the use of TCR in two cases
Study 4	Develops an activity-based model of distributional accessibility in neighbourhoods
	Develops a dataset of synthetic populations with their activity sequences for all neighbourhoods in Gothenburg
	Validates the activity-based model
Study 5	Demonstrates how activity-based models for distributional accessibility in neighbourhoods can be developed
	Exemplifies the application of activity-based models for neighbourhood planning
	Applies the TCR indicator to evaluate results from activity-based modelling
	Exemplifies how analytical results of USS can be communicated

6.2 Implications for practice

The practitioner's role is one of this thesis's central themes. Practitioners' role as boundary spanners (Saldert, 2021) is instrumental in creating socially sustainable neighbourhoods. While the study presented in this thesis draws from the experiences of practitioners in Sweden, Denmark, and the Netherlands, the findings are relevant to practitioners worldwide who work with USS. This thesis offers insights to practitioners and municipalities on how to navigate USS. For practitioners, the findings of this thesis show that while the inherent vagueness in the conceptualisation of USS can be accommodated within the design and planning process, ambiguity in conceptualisation risks misunderstandings when translated into real-world projects. While the ambiguity in conception benefits the conceptual phase, USS must be refined with concrete meaning and clear definitions in the operational phase.

For municipalities, this thesis advocates consideration of the different meaning-making strategies while formulating their goals. For instance, differentiating between conceptual and operational definitions of USS, in which the conceptual definitions represent the overarching vision, and the operational definition helps in defining goals and selecting indicators. For practitioners, this thesis suggests exploring different meaning-making strategies and introspecting on their own meaning-making strategy to clarify what is within their scope of influence. Finally, using data-driven approaches and exploring new tools for USS to complement experience-based design can be beneficial in the implementation stage. This thesis advocates for a more cohesive, transparent, and actionable USS framework at the municipal level to ensure consistent and effective translation of USS objectives into real-world outcomes in the implementation stage.

For practitioners to operationalise USS, i.e. have a tangible grasp on making socially sustainable interventions in their practice, they require tools and indicators Payne and Payne (2004). The AcBM approach developed in this thesis focuses on the practitioner as the end user. The modelling considerations prioritise using commonly available and open data sources and programming libraries. Additionally, the modelling code is designed to be modular and easily extensible with detailed documentation, providing opportunities to be integrated into larger design and planning frameworks. The feedback gathered from the practitioner at the early stages of model development aims to align the model capabilities to the practitioner's requirements. The proposed model provides practitioners with a way to assess the social consequences of their design decisions in a systematic and data-driven manner. Incorporating AcBMs of spatial accessibility allows practitioners to evaluate how different design choices impact residents' access to amenities and, in part, social equity and overall USS.

Finally, the model offers a foundation for future development and refinement in practice. Practitioners can build on the work presented in this thesis by extending their abilities through additional data sources, modifying the assumptions within the model, and adding additional capabilities. However, practitioners must also navigate the model's limitations, using them to complement existing practices rather than replace them to achieve more socially sustainable urban environments.

6.3 Future research

Throughout this research, several research directions were investigated but not pursued. The following section presents potential research paths to explore or develop further.

1. **Validation in practice**: As mentioned above in the study's limitations, an application study with practitioners using the model in a real-world setting was not feasible. This feedback would be a valuable future research direction to improve the usability and reliability of the model. Practitioners could provide additional feedback on the visualisations to help improve the communication of results.

2. **Modelling urban co-presence**: Using the proposed model, this thesis initially explored themes of USS to operationalise and implement. One of the initial social themes explored was urban co-presence. The model could identify spaces in the neighbourhood that facilitate urban co-presence. Areas where residents with diverse backgrounds would have the opportunity to be co-present without actively interacting with one another. Literature on urban co-presence shows that it contributes positively to the residents' feeling of belonging in the neighbourhood and develops a sense of community while improving perceived safety. However, this was not pursued due to time limitations and added model complexity.
3. **Introducing service availability to amenities**: The current model views accessibility as the access to an amenity but not the availability of the amenity. The amenity locations obtained using OpenStreetMaps data and from the City of Gothenburg already contain opening and closing times of services. Using this, the amenity could be made unavailable during out-of-service hours. Additionally, the physical capacity of amenities could also be introduced where, beyond a certain number of visitors, an amenity is considered unavailable to more accurately represent neighbourhood services and the ability of residents to achieve their daily needs.
4. **Extending application to other domains**: The proposed model is limited to its application in urban accessibility. Future research could explore the application of the AcBM framework and its focus on distributional effects and equity perspectives in other areas of neighbourhood planning, such as energy consumption. The model could be used to evaluate the distributional impacts of energy policy on demographic groups to identify if certain groups are disproportionately disadvantaged.

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Part II
Appended Papers

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Sanjay Somanath, Alexander Hollberg and Liane Thuvander

Published in Local Environment 2021, VOL. 26, NO. 6, 770-789

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