



SmartUrbanity: From Accessibility to Digital Planning in the 15-Minute City

State of the Art, Measurement Frameworks and Tool
Requirements for Passenger Mobility and Urban Logistics

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Contents

Document Control	1
Executive Summary	5
List of figures	6
List of tables	7
List of abbreviations	8
1 Introduction	9
1.1 Background	9
1.2 Objectives	10
1.3 Document Structure	10
2 Theoretical foundations of the 15-Minute City	12
2.1 Literature review methodology	13
2.2 Core principles and city examples	15
2.3 Spatial and transport implementation	16
2.4 Social and societal dimension	18
2.5 Consideration in freight transport	21
3 Methodology	25
3.1 Interview-Based Perspectives on Accessibility	25
3.1.1 Perspectives from individuals with everyday mobility constraints	25
3.1.2 Perspectives from experts	26
3.2 Assessment and measurability	28
3.2.1 Indicators and measurement approaches for accessibility	28
3.2.2 Objective and subjective dimensions of 15-minute accessibility	32
3.3 Comparison of existing evaluation and modeling approaches	35
3.3.1 Accessibility analysis tools	35
3.3.2 Accessibility in agent-based models	40
4 Concrete implementation in the project	43
4.1 Conceptual framework of tool development	43
4.2 Requirements for tool development	46
4.2.1 User experience research	46
4.2.2 Stakeholders' requirements	49

5	Theoretical guidelines for methodological implementation	54
5.1	Key barriers to adoption	55
5.2	Driving user engagement	56
5.3	Building trust and motivation	58
5.4	Data and functional requirements	59
6	Summary	61
	References	65

Executive Summary

This report as Deliverable 2.1 of the SmartUrbanity project provides the conceptual, methodological, and practical foundation for the SmartUrbanity project, which develops citizen-centric digital tools to assess and improve urban accessibility in five European pilot cities: Rome, Karlsruhe, İzmir, the Lyon Metropolitan Area, and the Greater Zurich Area. The 15-Minute City (15mC), structured around the principles of proximity, diversity, density, and digitalisation, serves as the guiding framework. The report reviews its theoretical foundations, real-world implementations, and key limitations—particularly the risk of reinforcing spatial inequalities and the tendency to overlook freight transport as an integral component of urban mobility planning. A central methodological contribution is the distinction between objective and perceived accessibility. While objective measures capture spatial and network-based proximity to everyday services, perceived accessibility is shaped by qualitative factors such as safety, comfort, and service reliability—and frequently diverges from calculated indicators. This distinction is grounded not only in the literature but also in interviews conducted with individuals facing everyday mobility constraints and with experts from academia, planning, and transit operations, which revealed recurring barriers such as last-mile gaps, inconsistent physical infrastructure, and safety perceptions that diverge from formally calculated accessibility. Both dimensions must be considered to reliably assess urban proximity and its real-life implications. A comparative review of existing accessibility tools and agent-based models identifies key methodological gaps, most notably the systematic underrepresentation of subjective accessibility, which the SmartUrbanity toolkit is designed to address. The project’s digital tools—Access Together (mobile data collection) and Access Lab (GIS-based analysis and participatory web platform), including the Access Atlas, the Atlas Hub, and the Decision Support System (DSS)—form an integrated ecosystem linking citizen-generated data to evidence-based planning. Stakeholder workshops across all pilot cities and a structured user experience research process identified ease of use, transparent feedback mechanisms, inclusive design, and data quality as the critical requirements for tool adoption. These findings are consolidated into a set of methodological guidelines to guide the further development and implementation of the toolkit.

List of figures

1	Concept of the 15-Minute City	12
2	The courtyard of the Maryse Hilsz school before and after the renovation in 2020	18
3	Via Procaccini (Bologna, Italy) after the redesign in 2022	19
4	Curb extensions improve safety by shortening crossings, increasing visibility, and slowing traffic.	20
5	Worldwide E-Commerce revenue development based on [26] (left) and growth of the number of parcels in Germany based on [27] (right)	22
6	Framework of the tool development of the SmartUrbanity project	44
7	Stakeholder workshop in Karlsruhe	50
8	Workshop during the consortium meeting in Lyon	54
9	Examples of workshop results	57

List of tables

1	Indicators for the 15-Minute City	29
2	Overview of accessibility tools for the 15-Minute City	38

List of abbreviations

15mC 15-Minute City

MaaS Mobility as a Service

DRT demand-responsive transport

POI point of interest

DSS Decision Support System

ABM Agent-based models

1 Introduction

1.1 Background

Urban areas are facing increasing challenges related to sustainability, accessibility, and social inclusion. In this context, the concept of the 15-Minute City (15mC) has gained prominence as a guiding framework for rethinking urban development and mobility systems. By promoting proximity-based access to essential services, the 15mC aims to reduce reliance on motorised individual vehicles (such as cars and motorbikes) while enhancing quality of life and environmental sustainability.

At the same time, translating this conceptual vision into measurable indicators and operational assessment approaches remains a key challenge. Accessibility is not only determined by spatial proximity but also by subjective perceptions, infrastructure quality, and individual capabilities. Therefore, an integrated approach is required that integrates both objective and subjective dimensions of accessibility, as well as diverse user needs and behavioural patterns.

SmartUrbanity addresses these challenges by linking conceptual approaches with practical methodologies and implementing them through digital tools that support the assessment and improvement of urban accessibility. It aims to enhance accessibility, inclusivity, security, and navigability through a citizen-centric digital framework, thereby supporting the transition towards proximity-based urban living. A central objective is to actively integrate citizens into the planning process, enabling a more inclusive and data-driven understanding of urban mobility and accessibility. Building on and advancing existing approaches, the project leverages granular data as well as advanced methodologies such as machine learning algorithms and agent-based simulations to generate more refined insights and support decision-making.

To achieve these objectives, SmartUrbanity will develop three main digital tools. Access Together will enable citizens to actively contribute to urban development by reporting issues related to accessibility, safety, and infrastructure, as well as by tracking and reflecting on their daily mobility experiences. This will facilitate the collection of both objective and subjective data on urban accessibility. The Access Lab will provide a WebGIS-based interface to visualise and analyse aggregated data through interactive maps, heatmaps, and customizable indicators. It will support both community engagement and planning processes by allowing users to explore accessibility patterns across different population groups and urban contexts. The Decision Support System (DSS) will build on this by offering advanced analytical and simulation capabilities for policymakers. It will enable the evaluation of potential interventions, support evidence-based decision-making, and facilitate collaborative planning processes through integrated feedback mechanisms.

Through pilot implementations in several European metropolitan areas—namely Rome,

Karlsruhe, İzmir, the Lyon Metropolitan Area, and the Greater Zurich Area—the project aims to refine further indicators for accessibility, inclusivity, emissions reduction, and user satisfaction. By fostering collaboration between citizens, policymakers, researchers, and transport authorities, SmartUrbanity seeks to contribute to more sustainable, inclusive, and user-oriented urban development.

In this context, in the project, Task 2.1 follows an interdisciplinary approach that combines perspectives from mobility research, urban planning, data science, and the social sciences to capture the diverse dimensions of urban mobility concepts. It draws on literature analyses, expert input, and the evaluation of existing practices, complemented by interactive formats such as stakeholder workshops to foster exchange and co-creation. The findings of this task are synthesised in this report and deliverable, which consolidates key insights and provides a structured knowledge base to inform the design and development of the project's digital tools.

1.2 Objectives

The main objectives of this report are:

- Objective 1: To establish a conceptual and theoretical foundation for the 15-Minute City, including its spatial, social, and mobility-related dimensions.
- Objective 2: To identify and evaluate suitable methodological approaches for measuring and analysing accessibility, including both objective indicators and subjective perceptions.
- Objective 3: To build a framework for the set of digital tools—namely Access Together and Access Lab—that support data collection, analysis, and evidence-based urban planning.
- Objective 4: To derive practical requirements and guidelines for tool development based on stakeholder engagement and user experience research.

1.3 Document Structure

The document is organised into several sections that collectively develop the conceptual, methodological, and practical foundations of the project. Section 2 introduces the theoretical background of the 15-Minute City, outlining its spatial, social, and mobility-related dimensions. Building on this, Section 3 presents the methodological framework, including qualitative interviews with affected individuals and experts, key approaches to accessibility measurement, relevant indicators, and modelling techniques. Section 4 translates these foundations into practice

by describing the implementation within the SmartUrbanity project, including the development of the digital tools, stakeholder engagement, and user experience research. Section 5 then consolidates these insights into a set of methodological guidelines that address user engagement, data requirements, inclusiveness, and system design. Finally, Section 6 provides a concluding synthesis of the main findings and their implications for future development and application.

2 Theoretical foundations of the 15-Minute City

The 15mC has become a prominent paradigm for sustainable, inclusive, and resilient urban futures. First introduced by Carlos Moreno in 2016, the conceptual foundation is grounded in the ambition to restructure urban life around four core principles: proximity, diversity, density, and digitalisation [1]. The main idea behind the 15-minute concept is that all significant areas of life can be reached within 15 minutes on foot or by bicycle. These areas correspond to the six most essential functions of cities for ensuring quality of life, as identified by Moreno: living, working, commerce, healthcare, education, and entertainment [2]. Currently, the concept is also known as *X-minute city* or *15- or 20-minute neighborhood* [3]. Rooted in the context of Paris during the COVID-19 pandemic, the model was catalysed by a need for resilient, adaptable, and liveable urban environments that allow residents to reach essential services within a short walking or cycling distance from their homes, thus minimising dependence on long commutes and motorised transport [2]. Centred on the idea of "chrono-urbanism", the 15mC emphasises time as a key dimension of urban planning, promoting equitable access to essential services and supporting the development of resilient local economies [2].



Figure 1: Concept of the 15-Minute City

Image credits: City of Fort Collins, CO

2.1 Literature review methodology

The literature underlying this chapter was compiled through searches conducted between November and December 2025. Searches were carried out using Google Scholar, complemented by the AI-assisted research tools Elicit and Perplexity to support literature discovery, initial screening, and the identification of relevant grey literature and case study documentation. In addition, Dimensions and ResearchRabbit were used to explore the citation network surrounding key publications, with particular attention paid to both the references cited by relevant papers and subsequent publications citing them, in order to identify further relevant literature that keyword-based searches alone might not surface.

Search terms combined core concept keywords with terms addressing the specific dimensions covered in this chapter. For the core concept, terms included variations in the designated time threshold, given that the concept appears under different names depending on the city and source:

- "10-minute cit*" OR "15-minute cit*" OR "20-minute cit*" OR "30-minute cit*" OR "15 min cit*" OR "X-minute cit*" OR "20-minute neighbourhood*" OR "chrono-urbanism"
- "proximity-based urban planning" OR "proximity urban*"
- "15-minute cit*" AND "best practice*"
- "15-minute cit*" AND "Paris" OR "Barcelona" OR "Vienna" OR "Utrecht" OR "Bologna" OR "Milan"

For the spatial and transport dimension (Section 2.3), search terms additionally included:

- "active mobilit*" AND "urban design"
- "shared mobilit*" OR "ride-pooling" OR "demand-responsive transport"
- "Mobility as a Service" OR "MaaS"
- "mixed land use" AND "walkab*"
- "school street*" OR "car-free zone*"

For the social and societal dimension (Section 2.4), search terms also included:

- "urban equity" AND "accessibilit*"
- "gender*" AND "safety" AND "urban mobilit*"
- "child-friendly" AND "street design"

- "Superblock*" AND "Barcelona"
- "age-friendly" AND "proximity planning"
- "gentrification" AND "15-minute cit*"

For the freight transport dimension (Section 2.5), search terms further included:

- "urban freight" OR "last-mile logistic*"
- "cargo bike*" OR "e-cargo bike*"
- "low-emission zone*" OR "zero-emission zone*" AND "freight"
- "micro-hub*" AND "urban logistic*"
- "proximity logistic*" AND "best practice*"

Records were included if they were published in English, German or French, addressed at least one of the four core dimensions of the 15mC (proximity, diversity, density, digitalisation) or its social, spatial, or freight-related implications, and were either peer-reviewed academic publications or credible grey literature providing empirical or case-study evidence. Records were excluded if they were not accessible in full text, did not relate specifically to urban proximity or mobility planning, or consisted of purely journalistic or promotional content without underlying data or analysis. Titles and abstracts were screened first for topical relevance, followed by full-text screening of the remaining records to confirm their contribution to the specific sections of this chapter.

Given the mixed nature of the evidence base, an informal, manual plausibility assessment was applied to each record, judged against its relevance and fit for the specific purpose of the respective subject matter under investigation, rather than a formalised system. Peer-reviewed sources were prioritised as the primary basis for conceptual and empirical claims, while grey literature was used primarily to illustrate real-world implementation examples (e.g., city-specific case studies). This approach is subject to certain constraints, including a reliance on mostly English-language and readily accessible sources, a geographical bias toward high-income Western contexts, and the use of AI-assisted discovery tools, whose outputs were manually verified but may not capture the full breadth of relevant literature.

Drawing on this literature base, the remainder of this chapter examines the 15mC's core principles—proximity, diversity, density, and digitalisation—in detail, before turning to their spatial, social, and freight-related implications.

2.2 Core principles and city examples

The four key dimensions of the 15mC model each articulate a specific condition for achieving equitable and sustainable urban life [2]. *Proximity* emphasises reducing the physical and temporal distances to daily necessities, ensuring these can be reached within 15 minutes. *Diversity* refers to both mixed land uses within neighbourhoods, integrating housing, commerce, culture, and services, as well as social heterogeneity. That encourages inclusive urban environments and various economic opportunities. *Density*, understood as an optimal—not maximal—concentration of people and activities, supports the efficient use of infrastructure, vibrant public spaces, and the viability of local businesses. Finally, *digitalisation* increases accessibility through the use of smart technologies and digital platforms. This includes, for example, remote work, access to information, and online municipal services, thereby expanding opportunities beyond spatial limitations.

The 15mC concept addresses central urban challenges, including climate change, rapid urbanisation, and the ongoing mobility transition, by making all key services accessible within a short walk or bicycle ride. Hence, it aims to substantially reduce car dependency, traffic congestion, CO₂ emissions, and urban air pollution in general [4]. At the same time, it actively counteracts the adverse effects of urban growth, such as increased land scarcity and housing costs, through decentralisation and mixed-use strategies [5]. Key sustainability objectives include resource efficiency through the multifunctional use of buildings and an adaptable urban structure that enhances public space and quality of life. Moreover, the concept strengthens local communities and promotes social inclusion and health by enhancing everyday interactions and ensuring equitable access to services [6, 7]. Additionally, it safeguards against the development of monofunctional or exclusive urban neighbourhoods.

Several cities worldwide have adopted the principles of the 15mC across diverse urban contexts, implementing tailored strategies to create accessible, vibrant neighbourhoods. Paris, with a population of 2.1 million people, has been a prominent pioneer in transforming urban life since 2020, rapidly expanding cycling infrastructure, converting parking spaces into green areas, and pedestrianising major streets [2]. In addition, they invest in public transport and foster mixed-use neighbourhoods that prioritise local services and amenities—all while aiming for climate neutrality by 2050. Barcelona, with a population of 1.7 million people, has advanced the concept through its *Superblocks*, which are clusters of city blocks where car traffic is restricted [8]. This concept prioritises pedestrians, cyclists, and public activities, resulting in quieter, greener public spaces with improved air quality. Melbourne's *20-minute neighbourhoods* initiative, incorporating 5.2 million citizens in the respective area, promotes dense, walkable communities by integrating essential services, parks, schools, and active mobility networks within a 20-minute walk [6]. The purpose of this is to advance health and social inclusion. Much smaller

than the other cities, Utrecht, with a population of roughly 0.3 million citizens, exemplifies the model through its ongoing investments in cycling infrastructure and shared mobility services, with the aim of becoming a 10-minute city by 2040 [9]. Furthermore, the city emphasises multifunctional spaces and inclusive public amenities that enable residents to meet most daily needs within walking distance.

Together, these examples illustrate how different cities adapt the 15-minute principles to their own contexts while pursuing more accessible, sustainable, and people-centred urban environments. They should be understood as illustrative cases rather than as directly comparable best practices, since their design and observed impacts are shaped by factors such as city size, urban form, topography, planning paradigms, transport networks, and the spatial distribution of services. For example, the different cities show that the designated maximum threshold of travel time depends not only on infrastructure investment and certain measures but also on city size. However, this threshold does not increase or decrease proportionally with city size; rather, larger cities tend to have more neighbourhood-scale catchment areas that individually satisfy the 15-minute criterion.

Overall, this suggests that the 15mC concept must be tailored to each city's specific characteristics. In addition to urban size, relevant factors include the density of the public transport network and the existing spatial distribution of activities. For instance, in some countries and regions, healthcare facilities, schools, and public amenities may be located close to railway stations. In contrast, this pattern may not apply in the same way in other national or cultural contexts. Consequently, these approaches cannot be transferred directly to the SmartUrbanity pilots but must be assessed against local conditions, institutional capacities, and data availability during pilot-specific implementation.

2.3 Spatial and transport implementation

Designing for active mobility within the 15mC framework requires a fundamental shift in urban space allocation, prioritising walking and cycling over motorised private transport. This transformation is achieved by redefining former car lanes and parking areas as wide, continuous sidewalks, safe and protected cycleways, pedestrian plazas, and interconnected green corridors [5]. Core design interventions feature traffic calming through speed-reduction zones and protected intersections. Additionally, installing street lighting and landscaping enhances street safety and makes streets more attractive for people of all ages and mobility levels [6]. Streetscapes function as social environments with benches, water features, and greenery, while high-quality public spaces—including parks, squares, and community gardens—serve as hubs for physical activity, interaction, and local identity. This reallocation of space away from private cars enhances urban safety, air quality, and inclusivity. It thereby ensures that active mobility is

not only feasible but also the most logical, convenient, and appealing option for short everyday trips [6]. As a result, these interventions reduce barriers for all groups of a society, making active transport a realistic choice for both non-disabled individuals and those with mobility impairments, including children, older adults, and people with disabilities [7, 10].

The integration of intermodal and digital mobility supply is essential in a 15mC, beginning with *shared mobility*. Shared mobility can include various forms of collectively used mobility services, such as vehicle sharing, ride pooling, and *demand-responsive transport (DRT)*. While carpooling usually involves privately owned vehicles, ridepooling and DRT refer to services in which trips are shared among users without individual vehicle ownership being central to the concept. Shared mobility increases flexibility and allows residents to select the most efficient travel option for each trip, thereby reducing congestion and emissions. Moreover, shared and intermodal mobility services can complement public transport by improving access to transit stops and by supporting first- and last-mile connections. Though this is typically outside the scope of the 15mC, using public transport also reduces motorised transport and, in turn, emissions within urban areas. These shared options become most effective when seamlessly interconnected, facilitating transitions between modes of transport. This idea is closely related to *Mobility as a Service (MaaS)*, a user-oriented mobility concept that aims to integrate various mobility services into a coherent system [11]. Digital applications can support this concept by bringing several services together on a single platform. MaaS fosters the integration of public transport, bike and car sharing, and other modes of travel, allowing users to plan, book, and pay for diverse journeys in a single digital environment. Therefore, it eliminates the need for multiple applications or tickets and presents all available options in real time. In this sense, DRT can also be part of MaaS platforms, where it functions as one of several integrated mobility options. It describes services that adapt routes and departure times in real time based on user needs and digital bookings [12]. As a result, it bridges gaps in conventional public transport and makes door-to-door or neighbourhood-to-neighbourhood travel more accessible.

Urban design and mixed land use in the 15mC context focus on creating neighbourhoods that function as largely self-sufficient *micro-cities*, where decentralised amenities support daily life in proximity. Instead of concentrating urban functions solely in central locations, the 15mC disperses workplaces, educational institutions, healthcare facilities, retail, and recreational spaces across all districts, providing all residents with equitable access to day-to-day services [2]. Strategic land-use policies facilitate a diverse mix of housing types, commercial uses, cultural venues, and green infrastructure within compact urban layouts. They not only reduce functional distances, but also enable vibrant, multi-use spaces that foster spontaneous social encounters and civic participation [7]. In Paris, the *Cours Oasis* initiative exemplifies a multifunctional use of urban infrastructure [13]. School buildings and playgrounds are opened to the public outside school hours, transforming educational spaces into shared community assets that provide green,



(a) before

Image credits: CAUE of Paris



(b) after

Image credits: Joséphine Brueder/Ville de Paris

Figure 2: The courtyard of the Maryse Hilsz school before and after the renovation in 2020

cool, and recreational areas within neighbourhoods. As part of this initiative, the schoolyard at School Maryse Hilsz was also redesigned. A before-and-after comparison can be seen in Figure 2. Similarly, Milan promotes decentralised and mixed-use development by prioritising local shops over large malls, expanding neighbourhood healthcare services, and implementing the *Milan School Oasis* program, which also opens school grounds to the public as green spaces and venues for supplementary educational activities [3]. Such integration counters the risks of monofunctional districts, actively avoids segregation, and supports social inclusion and environmental sustainability by distributing opportunities and burdens fairly across the urban fabric [7].

2.4 Social and societal dimension

Ensuring that the 15mC advances social justice is pivotal for its legitimacy and long-term success. Urban environments should be intentionally designed to benefit all residents, especially those who may face additional barriers to access—such as children, older people, people with disabilities, and households with low incomes [6]. Equitable access must encompass affordable housing, healthcare, educational facilities, safe mobility infrastructure, and opportunities for meaningful participation in urban life [6]. Attention to health-related disparities is significant, as local environmental conditions shape well-being and quality of life. As a consequence, health equity constitutes a central pillar of this vision. Studies suggest that neighbourhood-scale interventions, such as those realised in the *Superblock* model, could significantly reduce premature mortality through lower NO₂ exposure, improved air quality, reduced noise exposure, mitigation of urban heat, and increased availability of green space [8]. Such environmental changes are linked to extended life expectancy and yield measurable economic benefits from reduced healthcare costs and productivity gains [8].

Health benefits also arise from promoting active mobility and local recreation. Proximity to parks and green areas encourages physical activity, while an urban environment that favours walking and cycling contributes to improved cardiovascular health and overall well-being [7]. However, social justice considerations demand that such interventions should be distributed equitably across all districts. Concentrating improvements only in central or affluent neighbourhoods risks reinforcing existing spatial and social inequalities [7]. Many deprived urban areas continue to lack basic pedestrian infrastructure while experiencing heavy traffic volumes, which exacerbate environmental and health burdens [7]. The principle of proximity is likewise relevant for access to healthcare. Hence, many scholars and practitioners consider the availability of basic health services within walking distance a core objective of the 15mC framework [5].

Furthermore, children's specific needs illustrate the social dimension of proximity particularly well. Enhancing walkability, improving street safety, expanding green and public spaces, and optimising the spatial layout of essential services can substantially improve children's social interactions and mental health outcomes [10]. Several European cities have begun implementing these principles through targeted interventions. In Paris, the *Rues aux écoles* (School Streets) program bans motorised traffic around schools during operating hours [14]. Thus, it transforms adjacent streets into safe, green, and pedestrian-friendly areas that promote active travel and outdoor social interaction. Bologna similarly redesigns school surroundings as car-free zones to prioritise children's safety and well-being in daily mobility, as, for example, in Via Procaccini, as shown in Figure 3 [3]. In Vienna, improved road safety is achieved through



Figure 3: Via Procaccini (Bologna, Italy) after the redesign in 2022

Image credits: Margherita Caprilli

infrastructure measures such as curb extensions and raised crossings, complemented by regulatory tools such as a general 30 km/h speed limit and car-free zones around schools [3]. These

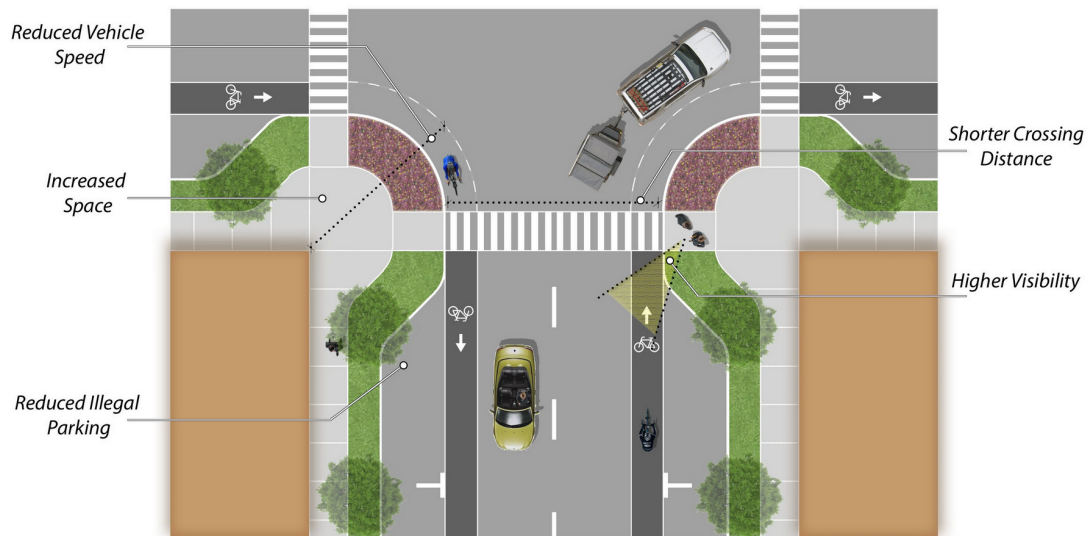


Figure 4: Curb extensions improve safety by shortening crossings, increasing visibility, and slowing traffic.

Image credits: Crafton Tull

examples demonstrate how child-centred planning can operationalise the principles of equity, health, and accessibility central to the 15mC framework.

Moreover, perceived safety and social cohesion are fundamental to the effectiveness of the 15mC, as they shape how residents interact with their neighbourhoods and adopt sustainable mobility behaviours. When individuals feel secure, they are more likely to walk or cycle [15, 16, 17]. Conversely, environments perceived as unsafe—due to crime, poor lighting, or hazardous traffic conditions—can discourage active mobility and hinder the goals of proximity-based urban planning [16, 18, 17]. Additionally, perceptions of safety differ substantially by gender and other vulnerabilities. Research indicates that women are far more likely than men to report feeling unsafe walking alone in urban areas, often citing poorly lit streets and sparsely populated spaces as primary concerns [19]. Men, in contrast, frequently fear traffic-related accidents and report that wider sidewalks improve their sense of safety [19]. As a result, women tend to adopt precautionary behaviours more regularly, such as changing walking routes, travelling with companions, or adjusting travel times, whereas men report such adaptations only rarely [19]. To address these disparities, cities should introduce measures such as well-lit streets, active pedestrian zones, accessible 24-hour transportation, and concentrated service centres [20, 19]. These centres, designed according to mixed land-use principles, combine essential functions in a single location—for example, office buildings, medical services, grocery stores, and other daily necessities—reducing travel distances while creating shared, secure public spaces.

In addition, while earlier discussions focused primarily on men and women, programs such as *The Utrecht Rainbow Agenda* aim to improve societal acknowledgement, equitable treatment, and personal safety for LGBTQI+ populations and all gender-diverse and marginalised groups [19]. Overall, gender-sensitive planning in the 15mC concept fosters independent mobility, social interaction, and a sense of community cohesion for all people [20].

Despite its equity-oriented ambitions, the 15mC carries risks that may lead to new forms of exclusion. Crucially, proximity is not equivalent to accessibility [7]. Services may be located nearby yet remain difficult to use due to limited capacity, inadequate quality, or socio-cultural and linguistic barriers [7]. Definitions of *short distance* may also be exclusive: what many residents perceive as walkable may be challenging or inaccessible for people relying on wheelchairs or other mobility aids [7]. Moreover, perceptions of distance are highly subjective and differ among people. Additionally, research on age-friendly proximity planning emphasises that proximity models must be better tailored to diverse demographic groups to avoid replicating inequitable outcomes [21]. These challenges demonstrate that a uniform, one-size-fits-all approach does not adequately address diverse needs [22, 7].

Finally, even in well-designed 15mCs, residents do not necessarily restrict their activities to nearby options. People often choose destinations based on perceived quality rather than proximity, which means some longer trips continue to occur [23]. Furthermore, bringing workplaces within walking distance remains highly challenging, as employment centres have long been separated from residential areas and continue to cluster in industrial zones or central business districts [23]. Overall, these findings show that simply living close to amenities does not ensure everyone is included. In consequence, this emphasises the importance of policies and planning that actively support community participation and equity within the 15mC.

2.5 Consideration in freight transport

Freight transport plays a crucial role in shaping urban development. Nevertheless, it remains largely unnoticed in the literature on the 15mC. As cities work toward more sustainable, liveable, and zero-emission futures, the movement of goods must be treated as an integral part of urban spatial and mobility planning. It is worth noting that urban freight systems are shaped by a diverse mix of economic, demographic, technological, and spatial dynamics. Growing populations, denser urban areas, interconnected global supply chains, and the rapid expansion of e-commerce are all fueling a steady increase in freight movement worldwide [24]. In fact, e-commerce revenues are expected to double in 2029 compared to 2020. Consequently, the number of parcels, for example, is increasing as well. Figure 5 gives an overview of these developments. In fact, a more exhaustive literature review finds that e-commerce can be more sustainable than traditional shopping, with most emissions concentrated in the last mile [25].

However, the demand for rapid delivery and the prevalence of small parcels often increase vehicle numbers and vehicle-kilometre use, thereby limiting overall sustainability gains [25]. This intensification places pressure on congested road networks, increases emissions, and necessitates new approaches to first- and last-mile logistics.

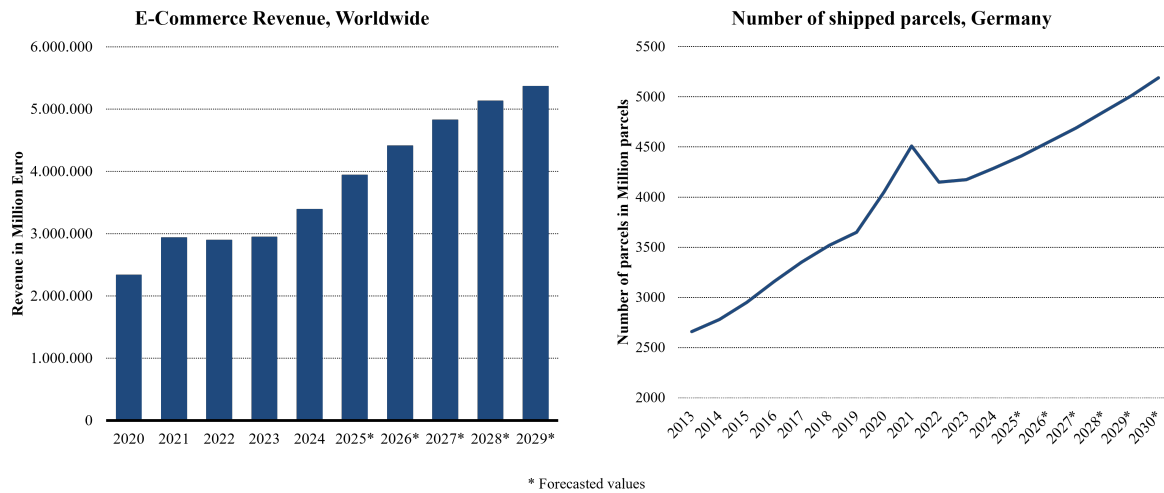


Figure 5: Worldwide E-Commerce revenue development based on [26] (left) and growth of the number of parcels in Germany based on [27] (right)

The paradigms related to the 15mC directly affect urban logistics. Avoiding motorised transport and fostering active modes for individuals' mobility behaviour also includes reducing motorised logistics transport, though it is crucial for a city's supply. Creating a *15-minute logistics* system—where essential deliveries can be carried out efficiently within short distances and non-motorised vehicles—requires a combination of spatial reorganisation, new delivery modes, and redesigned operational models. Cargo trams offer a useful example of the adaptations required for such a system, combining an alternative transport mode with the need for dedicated transshipment points and a reorganization of last-mile delivery processes. For details on that concept and its transport-related potential we refer to Barthelmes et al. [28, 29]. Beyond such operational and spatial adaptations, regulatory measures can play an important role in creating the conditions for a suitable urban logistics system within the 15mC. Regulatory instruments such as low- and zero-emission zones, however, generate complex trade-offs. On the one hand, low-emission zones have been shown to encourage fleet renewal [30, 31]. On the other hand, such measures often impose financial burdens on companies [30] and can reduce the number of logistics firms operating in urban areas [31]. Moreover, they may increase vehicle kilometres travelled due to rerouting or the addition of legs required to access consolidation centres [32, 33]. Additionally, there is disagreement about the extent to which zero-emission zones contribute to reducing emissions. Some studies indicate that zero-emission zones can drastically reduce emissions within targeted areas [32, 33]. Meanwhile, research shows that they do in fact

improve air quality but may have only limited impacts on CO₂ emissions [34]. Nevertheless, the emission reduction is primarily measurable locally and has little effect on the broader area [32]. Furthermore, the spatial configuration of such zones, rather than the strictness of environmental standards, appears to be more decisive in determining overall efficiency and economic outcomes [34]. In conclusion, zoning strategies that restrict vehicle access—for example, car-free city centres—can improve pedestrian environments. Nevertheless, they may also cause additional traffic unless supported by micro-hubs and cargo bike networks within the restricted zones [35].

A parallel trend is toward “proximity logistics”: the development of small-scale logistics facilities embedded within dense, mixed-use urban areas to shorten delivery distances and reduce transport impacts [36]. Case studies from New York, Paris, Seoul, Shanghai, and Tokyo indicate a shift toward hierarchical logistics systems linking regional hubs with local micro-facilities, including fulfilment centres, delivery stations, and multi-use buildings [36]. It has to be noted that economic factors often drive these developments more strongly than regulations or resource availability [36].

For instance, a central concept is the deployment of micro-hubs, strategically distributed facilities that enable transshipment from larger vehicles to smaller, low-impact modes. Studies in Barcelona show that optimised micro-hub placement can reduce delivery times and CO₂ emissions across different scenarios [37]. Additionally, when combined with cargo bikes, they have the potential to reduce operator costs [38] and help avoid motorised delivery vehicles, at least on the very first- and last-mile.

Cargo bikes and e-cargo bikes are among the most promising tools for achieving short-distance, low-emission logistics. Multiple simulation studies across European cities show consistent benefits. Cargo bikes can markedly lower external costs, for example, by reducing CO₂ emissions [39, 40, 41]. Nevertheless, cargo bike deliveries are usually slower than those made by traditional vans [40]. In addition, a simulation study in Antwerp indicates that using cargo bikes increases logistics companies’ operational costs [39]. But economic evaluations also show that cargo bikes can be more cost-effective than delivery trucks or electric vans for short distances, small parcel volumes, and high-density neighbourhoods [42]. As a result, studies suggest combining conventional fleets with electric vans and cargo bikes in order to lower external costs and shorten overall delivery times [43].

Pick-up points offer another decoupling approach, though their benefits depend strongly on customer behaviour. They are designated collection locations—such as parcel lockers, retail shops, or service counters—where customers retrieve shipments themselves rather than receive doorstep delivery. While they can reduce operational costs, they sometimes increase external costs due to additional customer trips [39]. Nevertheless, combining pick-up points with cargo bike delivery can improve both citizens’ quality of life and service providers’ attractiveness

[39]. In summary, logistics decoupling concepts can yield system-level improvements in environmental performance, but at the company level, these positive effects remain comparatively marginal to date [44].

As a result, effective governance is essential to ensure that urban freight systems can evolve into a spatially compatible component of 15mC logistics, aligning infrastructure use and regulatory steering. Surveys conducted in six European cities emphasise that technological innovation, changing consumer expectations, and economic and demographic shifts are the most influential factors shaping future freight operations [45]. However, public and private stakeholders often prioritise different objectives: while public authorities focus on reducing external costs, private companies emphasise efficiency, profitability, and regulatory clarity [45]. Consequently, achieving a sustainable and spatially efficient freight system requires a governance framework that bridges the gap between logistics operations and urban planning. Studies consistently indicate that early integration of freight considerations into planning processes, as well as close collaboration between public and private actors, are crucial for developing workable, future-proof logistics systems [46, 47]. In addition, research emphasises that regulation alone—typically through low-emission zones or restricted delivery time windows—cannot achieve a well-functioning or low-impact urban logistics system [48]. Meanwhile, providing sufficient loading and unloading zones remains a critical but often overlooked governance tool. Research from Rome shows that increasing the number and availability of loading bays, or enabling time-differentiated use of parking spaces, can significantly improve delivery efficiency [49]. At the same time, entrance fees in restricted zones tend to decrease operator utility. Therefore, clear and harmonised regulations, along with coordinated space management, are widely demanded by practitioners, particularly in light of the increasing pressure on limited urban space [45]. In conclusion, governing "15-minute logistics" is less about eliminating freight from urban space and more about coordinating it transparently and collaboratively to sustain mobility, environmental goals, and reliable service across all urban districts, hand in hand with the general 15mC guidance for people's travel behaviour.

3 Methodology

Building on the conceptual foundations of the 15mC outlined in the previous chapter, this section focuses on its methodological operationalisation. While the concept is intuitively appealing, its empirical assessment and implementation require clearly defined indicators, measurement approaches, and modelling frameworks.

A key challenge lies in translating the normative idea of proximity and accessibility into quantifiable metrics that capture both spatial and experiential dimensions. In particular, it is necessary to distinguish between objective measures of accessibility, such as travel times and service availability, and subjective perceptions of accessibility, which may vary across population groups.

To complement this literature-based perspective with first-hand accounts, Section 3.1 presents qualitative insights from a series of interviews with affected individuals and experts, focusing on how accessibility and the 15mC are perceived in practice. Against this background, Section 3.2.1 discusses approaches to assessing and measuring 15-minute accessibility, including relevant indicators and their limitations. Section 3.2.2 then reviews existing evaluation and modelling approaches, ranging from accessibility analysis tools to agent-based models, and reflects on their suitability for analysing and simulating 15mC dynamics.

3.1 Interview-Based Perspectives on Accessibility

In addition to the literature review, the conceptual and methodological groundwork of this report was informed by interviews conducted in January and February 2026. Ten interviews of approximately one hour each were carried out with three individuals directly affected by mobility restrictions in their everyday lives and seven experts from academia, urban and transport planning, and public transit operations. The interviews aimed to collect first-hand accounts of how people perceive accessibility in their daily environments, which barriers they encounter on the way toward a 15mC, and how the concept is assessed from different professional perspectives. The following two sections summarise the resulting statements, focusing specifically on accessibility and the perception of the 15mC.

3.1.1 Perspectives from individuals with everyday mobility constraints

The three affected individuals interviewed live in Berlin but differ in the nature of their mobility restriction: one is an older woman experiencing age-related mobility decline and no longer driving herself, one is a mother whose mobility needs are shaped by young children and a stroller, and one is temporarily reliant on crutches following an injury. Despite these differing circumstances, the interviews revealed a shared distinction between the accessibility of the

immediate neighbourhood and the accessibility of destinations beyond it. Two of the three interviewees described their immediate surroundings as well connected to transit. Cultural and leisure venues located further out, however, were consistently associated with the car or, when unavailable, considerable additional time and effort. At the same time, all three pointed to a pronounced "last-mile" problem — the stretch between a transit stop and the actual destination consistently emerged as the most limiting factor, more so than overall travel time. One interviewee, temporarily reliant on crutches, described a personal accessibility radius of no more than 400–500 metres, beyond which any errand became disproportionately effortful. Accessibility of everyday destinations within the immediate neighbourhood was generally described as good, whereas cultural and leisure venues located further out were consistently associated with the car or, when unavailable, considerable additional time and effort.

Physical infrastructure was repeatedly named as a source of exclusion, independent of a person's specific impairment. Non-level tram and bus stops, insufficiently lowered kerbs, unreliable lifts at local train/tram stations, and underpasses without ramps were described as barriers not only for wheelchair users but equally for parents with strollers or people using rollators. One interviewee noted that certain stations were deliberately avoided altogether because they were known to lack functioning lifts. This leads to a mental map of "usable" and "unusable" stops that shaped everyday route choices independent of the fastest connection. Cycling infrastructure was perceived as inconsistent: well-built, protected cycle paths were welcomed, but narrow, obstructed, or abruptly ending paths were seen as unsafe, particularly when children were involved.

Digital and ticketing accessibility was raised as a further, less obvious barrier: one interviewee noted that online tickets are cheaper than those purchased in person — a discrepancy she found hard to navigate as an older, less digitally confident traveller. A wish expressed by one interviewee was for a single, unified application covering trip planning, ticketing, and real-time disruption information across all modes, rather than several separate tools.

Finally, subjective perception of accessibility diverged from the objectively available transit network in several instances. Reliability, rather than frequency or proximity, was frequently cited as decisive: interviewees reported choosing the car over public transit not because transit was unavailable, but because its unpredictability made planning difficult. Perceived safety, particularly after dark, further reduced the practical accessibility of otherwise adequately served routes, especially when travelling alone.

3.1.2 Perspectives from experts

Across academic, planning, and transit-operator perspectives, the 15mC concept was consistently regarded as a valuable and largely welcome guiding principle. It was credited in par-

ticular with successfully bridging academic accessibility research and practical urban planning — a transfer described by one interviewee as unusually rare and therefore noteworthy in itself. At the same time, several experts cautioned against applying the concept too rigidly. It was emphasised that a hard 15-minute threshold is somewhat arbitrary and should be differentiated by frequency of need: daily necessities warrant a strict standard, while less frequently used destinations were considered acceptable at greater distances. Another expert cautioned that the concept should not be applied too narrowly, since people's destinations and needs within that radius vary considerably from person to person. Additionally, one expert added that even the choice of which destinations should count within the 15-minute radius is itself value-laden and dependent on local and cultural context.

It was stressed that the concept must be understood as a link between land-use and transport planning rather than a transport measure in isolation. It only functions if everyday destinations are genuinely relocated closer to residents, for example, by discouraging out-of-town supermarkets that remain unreachable by active modes despite being nominally accessible by car. One interviewee from the planning practice described applying the concept in project work by defining a standard set of destinations reachable on foot or by bike from a neighbourhood centre — a transit stop, a supermarket, a health facility, and a school or childcare centre. They stressed, however, that this is applied flexibly rather than as a strict percentage-of-population target.

Two experts stated the gap between real and perceived accessibility, echoing observations from the affected individuals. One person argued that isochrone-based accessibility measures should account for subjective quality-of-route factors — safety, shade, surface quality — since an objectively short route may be avoided in practice if it feels unsafe or unpleasant, effectively reducing real-world accessibility even where formal travel-time calculations suggest otherwise. This was additionally illustrated with the example of trams whose boarding ramps frequently malfunction. This means that formally accessible services are, for wheelchair users, considerably less reliably accessible. Another highlighted that fear of using an unlit underpass at night can effectively add ten minutes or more to an otherwise 15-minute route. This illustrates how safety perception directly reduces measured accessibility, especially between men and women.

From the transit-operator perspective, the 15mC was seen as reinforcing the case for denser service. This was mentioned particularly for destinations that fall just outside the range achievable by walking or cycling within 15 minutes but could still be reached via well-timed public transit. One expert emphasised that the concept should not be understood as sufficient on its own. For destinations that inherently lie beyond a 15-minute radius, reliable, well-connected, and clearly communicated transit remains essential. Moreover, one interviewee cautioned against treating the concept as a rigid spatial template to be replicated identically in rural areas. They suggested instead that the underlying goal — equitable access to basic needs such as food, health, education, and leisure — should guide implementation, with the specific

means of reaching these adapted to local density and infrastructure.

3.2 Assessment and measurability

3.2.1 Indicators and measurement approaches for accessibility

While the 15mC has attracted attention in both research and policy discussions, the concept is missing an agreed-upon definition. Moreno himself presents it as a normative, flexible framework rather than a formalised model with clearly defined benchmarks or indicators [2]. As a result, there is no standardised set of indicators that unequivocally determines whether an urban area qualifies as a 15mC. Nevertheless, as elaborated in the previous chapter, Moreno focuses on four core components that compose the 15mC concept: proximity, density, diversity, and digitalisation [2]. Although fixed metrics do not define them, each pillar can be translated into measurable indicators.

Proximity is the foundational pillar of the 15mC, referring to the spatial and temporal closeness between residents and essential urban functions. The Federal Institute for Research on Building, Urban Affairs and Spatial Development in Germany classified proximity-related indicators for the 15mC into three main categories [50]. The first category is expressed by the *X-Minute City* indicator. This indicator measures the average time required to reach a predefined weighted set of amenities within a city. It provides a straightforward, time-based representation of accessibility. Another proposed indicator is the *15-Minute City Fulfilment Rate*. This indicator measures the degree to which a defined set of opportunity types is accessible within 15 minutes. Other authors also refer to this indicator as the X-minute city score [51], the *15-Minute Index* [52], or *Accessibility Score* [21]. Finally, the third proposed indicator, the *15-Minute City Index*, builds on the fulfilment rate framework but provides a more nuanced measure of accessibility. It aggregates access to multiple weighted amenities and accounts for population characteristics, for example, by distinguishing age groups with different walking or cycling speeds and different amenity weights, resulting in a composite indicator of neighbourhood-level proximity. Similarly, the *Walking Index* incorporates weights for various destinations, derived from questionnaire responses [10]. Furthermore, they implemented a time-attenuation rate, representing the declining likelihood of walking to amenities as the time required increases. Besides, simpler indices can be used to measure the 15mC, for instance, the total number of service categories reachable within a defined time threshold [52].

It follows that proximity indicators are operationalised through a set of measurable variables. This involves selecting urban amenities within 15 minutes that serve as destinations for everyday activities. Despite differing classifications, most studies consistently include opportunity types related to basic provisioning, healthcare, education, and recreation, such as grocery

stores, medical services, pharmacies, primary schools, and public parks [53, 4, 21, 54, 52, 55, 56, 51, 57, 58, 50]. Some of these approaches expand this core set by adding workplaces, cultural and religious facilities, entertainment venues, or sports facilities. In addition, restaurants, community services, finance, and mobility-related amenities such as public transport stops or shared mobility stations may also be considered. Variations across studies mainly reflect differences in detail rather than fundamentally different understandings of essential services.

Table 1: Indicators for the 15-Minute City

Cat.	Name / short description	Concept / idea	Source
Proximity	X-Minute City	Average travel time required to reach a predefined weighted set of amenities	[50, 57]
	15-Minute City Fulfilment Rate / X-Minute City Score / 15-Minute Index / Accessibility Score	Share of amenities reachable within a defined time threshold (typically 15 minutes)	[21, 50, 51, 52]
	15-Minute City Index	Builds on the 15-Minute City Fulfilment Rate but uses time classes (e.g., 0–5, 5–10, 10–15, 15–20, >20 min) and aggregates weighted amenity access across a neighbourhood	[52, 58]
	Number of reachable amenities	Count of amenities accessible within a defined time threshold (e.g., 15 minutes)	[52]
	Walking Index	Accessibility weighted by likelihood of walking, decreasing with travel time	[10]
	Walk Score®	Gravity-based walkability index based on weighted accessibility to amenities within a defined radius	[59]
Density	Population density	Number of inhabitants per unit area; structural precondition for proximity, as sufficient concentration of people and activities is needed to sustain local services	[50, 51, 57, 58, 60]
Diversity	Number of distinct amenity categories	Number of different amenity categories accessible within the defined time threshold; captures functional diversity of places	[50, 52, 61, 60]
	Shannon Entropy	Diversity index accounting for both the number and distribution of points of interest (POIs) across amenity categories accessible to inhabitants	[56]
	Simpson's Diversity Index	Reflects the number and heterogeneity of reachable key amenities	[62, 63]
	Sociodemographic variables	Operationalised via gender, age groups, household type, income, education level, race, and employment to capture social and demographic composition	[21, 50, 51, 59, 55, 54, 64]

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Cat.	Name / Short Description	Concept / Idea	Source
	Inequality-sensitive measures	Kolm-Pollak Equally Distributed Equivalent (derived from the Atkinson Index) penalises income inequality; gentrification is measured via income distributions	[57, 54]
Digitalization	Digital Economy and Society Index	Composite EU index across 4 dimensions and 32 indicators covering e.g., human capital, connectivity, digital technology integration, and digital public services	[65, 66]
	Urban Digitalisation Index	Composite index covering, including e.g., technology infrastructure, adoption, human capital, governance, smart city applications, innovation environment, and digital market	[67]
	Digital Cities Index	Combines quantitative indicators (e.g. internet speed, e-payment value), qualitative indicators (e.g. digital technology adoption), and survey data (e.g. digital banking uptake)	[68]
	Smart City Index	Assesses digitalisation in five domains: administration, IT and communication, energy and environment, mobility, and society and education	[69, 70]

The assessment of proximity-based accessibility relies on combining geospatial data that capture where people live and work, as well as the spatial distribution of everyday services and facilities. Such information is typically derived from a combination of national and regional open data portals, administrative records, digital mapping services, and volunteered geographic data. In several cases, multiple databases are combined for the same category to improve spatial coverage and consistency, for example, by integrating official geodata with OpenStreetMap or other point-of-interest datasets [52, 55, 56, 57, 50]. Overall, the data foundation reflects a multi-source approach that varies by country and case study, drawing on both public and proprietary spatial data.

Transport modes considered in proximity analyses are predominantly walking. Although cycling is part of Moreno's definition of 15mC accessibility [2], it is often overlooked. However, some studies do investigate additional modes of transport, such as cycling, public transport, or car accessibility [59, 55, 51, 50]. Distances within the 15mC are measured primarily using network-based assessments [59, 4, 62, 21, 52, 55, 56, 64, 57, 50, 10]. Routes are calculated within an existing road network, thereby determining accessible destinations within a specified time frame. For this reason, assumptions about travel speed are necessary to convert time thresholds into accessible areas. Walking speeds typically range between about 3.25 and 5 km/h [53, 4, 62, 21, 52, 55, 64, 50], and cycling speeds between 11 and 15 km/h [51, 50]. Additionally, some studies adjust travel speeds by age, mobility constraints, or infrastructure quality [21, 50]. In contrast to time-based measures, few studies apply simple Euclidean distance thresh-

olds, such as 500-meter or 600-meter operating radii [61, 54]. Overall, current proximity-based studies vary widely in their methodological approaches, frequently focusing on walking and relying on simplified assumptions about travel speeds or distance thresholds.

Density represents the structural precondition for proximity, as a sufficient concentration of people and activities is required to sustain local services. Density indicators in the 15mC context typically measure population density [51, 57, 58, 50, 60]. Other density-related indicators are typically not used in the context of the 15mC.

Furthermore, diversity captures the degree to which urban neighbourhoods support a broad range of functions, activities, and social groups within close spatial proximity. According to the framework proposed by Moreno et al. [2], diversity can be measured along two complementary indicator dimensions: mixed-use neighbourhoods and cultural and demographic diversity. The first indicator captures the functional diversity of places within a defined accessibility threshold. It is commonly measured by the number of distinct amenities or amenity categories accessible within 15 minutes [61, 52, 50, 60]. Another option is diversity indices, such as the *Shannon Entropy*, which also account for the number of POIs within given categories [56]. Similarly, *Simpson's Diversity Index* reflects the number and heterogeneity of key amenities [63, 62].

The second indicator addresses social and demographic diversity. It is operationalised using variables such as gender, age groups, household types, income levels, race, education, and employment [59, 55, 64, 51, 50]. It is complemented by inequality-sensitive measures, such as the *Kolm-Pollak Equally Distributed Equivalent*, which focuses on income disparities [57]. Likewise, gentrification can be quantified using income distributions [54]. Together, these two indicators reflect the dual role of diversity in the 15mC as both a functional and a social dimension of local accessibility.

Within the 15mC concept, Moreno frames digitalisation as an extension of the smart city approach, in which digital tools supplement physical proximity by providing alternatives to travel and supporting optimised urban systems [2]. This pillar is primarily associated with the following practices: e-commerce, cashless payment systems, teleworking, digitally enabled mobility services, and the use of sensors for traffic control [2]. In empirical research, the level of digitalisation is usually evaluated using composite indicators that capture infrastructure, usage, and governance. One example is the *Digital Economy and Society Index* in the European Commission's State of the Digital Decade 2025 report [65, 66]. It assesses digital competences, the availability and quality of digital connectivity, the degree of digital business transformation, and the provision of public services through digital channels. It thereby provides an overview of public digital readiness. Similarly, the *Urban Digitalisation Index* focuses on the availability and uptake of digital infrastructure, institutional and governance capabilities, broader contextual conditions for innovation, and the deployment of smart city solutions [67]. Correspondingly, the *Digital Cities Index* integrates quantitative assessments of digital infrastructure

performance, qualitative evaluations of technology adoption, and surveys of user behaviour and perceptions [68]. Hence, it provides a neutral view of digitalisation in everyday urban settings. A more general approach is the *Smart City Index*, which evaluates digitalisation in Germany across thematic domains, including public administration, information and communication systems, transport, and energy-related services, as well as social and educational dimensions [69, 70]. Consequently, this index captures the cross-sectoral dimension of digital tools in cities. Together, these indicators operationalise digitalisation as a multidimensional factor that supports accessibility in the 15mC beyond spatial proximity. Nevertheless, measuring urban digitalisation is often overlooked in the 15mC context.

In short, existing measurement approaches indicate that accessibility within the 15mC is primarily determined by measures of spatial proximity, alongside indicators of travel times, the availability of everyday services, and the proportion of the population they serve. Although density and diversity create the conditions for local access, digitalisation increases accessibility by providing non-physical ways of accessing activities and services. Together, these indicators give a multidimensional measurement framework that reflects current research and supports evidence-based urban planning.

3.2.2 Objective and subjective dimensions of 15-minute accessibility

When evaluating the 15mC, it is important to distinguish between objective and perceived accessibility. Objective or measured accessibility captures the actual opportunities to reach destinations based on spatial and transport system characteristics. It considers elements such as the built environment, travel times, distances, and costs, as well as transportation mode attributes, typically quantified through spatial data and network analysis [71, 72, 73]. In contrast, perceived or subjective accessibility reflects how individuals experience their ability to access destinations and engage in preferred activities. It is inherently subjective and relates to residents' evaluations of how well local amenities meet their everyday needs [72], their sense of how close or convenient destinations feel [74, 75], and whether the transport system enables them to maintain the lifestyle they consider fulfilling [76, 77]. This subjective dimension encompasses not only the ease of using a specific mode of transport but also the ease of accessing the transport system and the extent to which it provides sufficient opportunities to carry out everyday activities. Together, objective and perceived accessibility both need to be considered to reliably assess urban proximity and its real-life implications.

A wide range of methodological approaches is used to assess perceived accessibility, most of which rely on questionnaires, surveys, or interviews that capture how individuals evaluate their ability to reach destinations and conduct daily activities. Perceived accessibility indicators can be categorised into six thematic groups [78]. They range from assessments focused on des-

tinations and activities to evaluations of travel-mode experience, service quality and safety, travel times and distances, utility, and general satisfaction with accomplishing day-to-day activities. To measure subjective accessibility, many studies use structured survey instruments that ask respondents to rate, on a scale, how easily they feel they can access different categories of amenities or activities [79, 80, 73]. Further research includes questions on network reach, weather-influenced travel behaviour, and walking conditions in their accessibility calculations [81]. Furthermore, another study asked participants to evaluate their overall perception of accessibility and to explain their dissatisfaction. [72]. Another commonly used approach is the Perceived Accessibility Scale, typically consisting of four items rated on a seven-point Likert scale [74, 76, 77, 71, 82]. The questionnaire asks participants to reflect on how easy it is to carry out everyday activities with a specific mode, whether they could continue living the way they want if it were their only mode of travel, whether it enables them to engage in their preferred activities, and how satisfying their access to these activities is when using that mode. An additional study employed mode-specific measures—for example, rating the suitability of a specific transport mode for reaching amenities on a scale [83]. Moreover, the Short Perceived Walkability Scale focuses exclusively on walking and evaluates the suitability and enjoyment of walking for daily activities, public transport access, or recreation within the neighbourhood [84]. Together, these methods provide a nuanced understanding of the subjective factors shaping how accessible a neighbourhood feels.

Objective accessibility, by contrast, is typically measured using spatial and network-based analyses to quantify actual opportunities to reach activities [72, 80]. Activity-based accessibility metrics, for example, assess how easily people can reach everyday local facilities—such as grocery stores, green spaces, or educational facilities—by measuring travel distances between start and endpoints as described in 3.2.1. An accessibility indicator is then derived from these results [72, 80].

However, research indicates ongoing debate and mixed evidence regarding the extent to which objective accessibility measures align with people’s subjective perceptions of access. On the one hand, a case study across three cities in Spain found that perceived and measured proximity yielded similar results, indicating a general alignment between subjective impressions and objective distances [80]. Nevertheless, perceptions of how far destinations are can vary depending on the type of activity being considered and the sociodemographic background of the person being asked. While people living near many destinations often feel they are nearby, locations can also feel close even when there is not a large concentration of options within a 15-minute walking distance [80, 71]. Besides, rural residence does not automatically imply low perceived accessibility unless compounded by further disadvantages [79]. On the other hand, perceived accessibility often does not align with spatially derived indicators and is not determined only by distance or travel time. [71]. Evidence further shows that measured accessibility and residents’

perceived accessibility are influenced by distinct drivers, leading to notable discrepancies even within a single neighbourhood [72]. Furthermore, it is important to emphasise that no measure is fully "objective", as all accessibility indicators are modelled representations that fail to capture residents' limited knowledge of potential destinations, personal priorities, or differences in people's awareness of their surroundings [75]. Consequently, they propose the term "calculated accessibility", which should be interpreted as a proxy rather than a factual counterpart to subjective assessments.

By contrast, multiple studies indicate that people's sense of accessibility is influenced more by qualitative factors than by the mere presence of infrastructure. Across the literature, elements such as service reliability and comfort, feelings of safety, and surrounding built environment conditions consistently shape how accessible places are perceived [84, 74, 78, 76]. Overall, operational aspects of service quality, including punctuality, trip frequency, trip duration, seamless connections, and stop proximity, outweigh cost considerations [74]. Meanwhile, clear information and a comfortable travel environment enhance passengers' sense of safety, thereby increasing their perceived accessibility of surrounding amenities [74]. This is particularly evident for older adults, for whom comfort and ease of use are decisive factors in assessing access to public transport [82]. Generally speaking, perceived accessibility varies across population groups, with observed associations with age, gender, and mobility habits [76, 79], and, in some cases, with lower perceived accessibility among frequent public transport users [74].

The link between accessibility and mode choice is similarly perception-driven. Travel behaviour appears to be guided less by formally calculated access conditions than by how well a transport option is experienced as meeting individual needs [71]. A broader literature review indicates that subjective evaluations of accessibility—particularly perceptions of walkability—are consistently associated with higher walking levels, even when objective indicators suggest limited accessibility [84]. Online survey results further show that people who perceive walking or public transport as accessible are more likely to use these modes regularly [83]. This relationship is further supported by findings showing that people's perceptions of access are linked to spatial conditions and walking activity [80]. In particular, individual judgments about the ease of reaching destinations—such as restaurants—tend to shape walking behaviour more strongly than calculated distances. In contrast, calculated accessibility indicators often fail to account for actual mode shares. Notably, many frequent walkers and public transport users reside in areas rated as poorly accessible by conventional metrics [83]. Accessibility is only one of several subjective factors influencing mode choice. Other psychological factors, such as perceived autonomy in mode use, can also play an important role in determining the use of a distinct mode, as shown for public transport use in Berlin [85]. Overall, these findings suggest that while objective measures provide useful insights, understanding residents' perceived accessibility is crucial for capturing the full experience of how people navigate and value their neighbourhoods.

3.3 Comparison of existing evaluation and modeling approaches

3.3.1 Accessibility analysis tools

A growing number of digital tools are available to assess, map, and compare accessibility within the 15mC framework. While they vary in geographic coverage, methodological focus, and target audiences, they all aim to operationalise the concept of proximity through quantifiable measures. However, they typically focus on objective measures, while perceived accessibility is still disregarded in existing tools. Several tools provide detailed, interactive representations of accessibility throughout specific cities or regions. For instance, the *X Minute City platform* (Urban Intelligence, University of Canterbury) features a reliable model for 42 New Zealand cities by mapping access to six key facilities within supermarkets, educational facilities, healthcare, pharmacies, and parks across walking, cycling, and driving [86, 57]. Heatmaps and summary statistics illustrate the proportion of residents within 5–20+ minutes of each service, enabling city-level and intra-urban comparisons. Additionally, for each city, detailed information on the average time to reach facilities is provided, along with the number of people living within 10 minutes of all amenities by travel mode. Finally, an overview of the least accessible destination type is given.

Further, *Close* is a platform developed by Henry Spatial Analysis, LLC for the USA [87]. It provides multimodal (walking, biking, public transport) travel times for a wide range of services, including special facilities such as farmer markets and community centres. It offers a detailed block-level heatmap with adjustable filters for amenities and travel modes. Besides, the considered destinations are shown on the map, along with their names and addresses.

The *HERE app*, developed by HERE Technologies, similarly shows nearby points of interest for locations in the United States [88]. It maps services across multiple categories such as grocery stores, healthcare, education, public transport, and leisure. In addition, the tool assesses whether a specific address meets the requirements of a 15-minute city for walking or driving. It also supplies detailed information on points of interest, including their names, addresses, and distance from the selected location.

The *15min City Score Gallery* (Transform Transport) evaluates walkability access to 112 cities participating in the EU mission for Climate-Neutral and Smart Cities by 2030 [89, 90]. It supplies a standardised “15-minute city score” for each neighbourhood, covering standard categories such as healthcare, education, shops, services, cultural facilities, and mobility. The heatmap allows differentiation between routes of up to 70 minutes. Additionally, for each area, the number of reachable amenity categories is given.

Furthermore, the Baden-Württemberg Institut für nachhaltige Mobilität developed *Mobi.mapr*, a tool for accessibility analysis in Germany [91]. It provides maps for different combinations

of travel modes, including walking, cycling, driving, and public transport. The tool offers heatmaps of a mobility index by land type and a mobility score that includes subjective factors. For example, they considered the *ADFC Cycling Climate Test*, a non-representative survey-based assessment that rates the bike-friendliness of cities. Moreover, bar charts provide an overview of the different amenity weights and accessibility scores for every category. In addition, accessibility scores for various individuals, including vehicle availability, age, and employment, are provided for comparison. Lastly, the tool offers rankings comparing the accessibility of federal states, districts, and municipalities.

Map4Citizens, developed by Plan4Better, the Technical University of Munich, and Humankind, concentrates on Munich [92]. It integrates diverse layers, such as noise levels, public transport quality, population density, and a "15-minute score" for each district and building, into its heatmap. Furthermore, the "flower-of-proximity" option allows users to specify their preferred distances to amenities in categories such as food, health, education, leisure, services, and mobility. For each opportunity type, users can set a time limit of 0 to 20 minutes to calculate current or desired accessibility levels.

The tool *BXLGIS - The City at 10 minutes* offers an integrative view of service accessibility and neighbourhood dynamics in Brussels [93]. The map provides an overview of the number of services available from a chosen location. Moreover, each amenity is shown on the map. It maps four major categories—environment, community life, services, and mobility—and lists accessible services along with demographic context. Each category has a dedicated information page that describes, for example, nearby urban projects, educational facilities, recycling stations, cultural spaces, and mobility infrastructure. Additionally, measurements inside the map are possible.

Furthermore, some tools provide accessibility indicators worldwide, as exemplified by the *City-AccessMap* developed by the TU Delft and the Centre of Urban Science and Policy [94, 95]. It quantifies walking accessibility for a set of services, including food, education, healthcare, leisure, and public transport. For this purpose, it uses global open data sources, namely OpenStreetMap and the European Commission's Global Human Settlement Layer. For each city, the tool supports customizable walking thresholds and weights different service categories. Heatmaps are used to display average walking times and to show the proportion of the population that can reach amenities within a 15-minute walk. This goes along with city rankings of major metropolitan areas.

15 min City platform by Sony CSL similarly covers a wide range of cities globally [96]. It produces heatmaps of walking and cycling proximity, calculated from the 20 nearest points of interest (POIs). For each area, a bar chart shows the time required to access different services by mode of transport. Furthermore, scenario modelling in selected cities (e.g., Paris) shows how redistributing services can equalise accessibility across neighbourhoods.

In addition, *Wheelmap.org* (Sozialhelden e.V.) contributes a strongly user-centred perspective on accessibility by focusing specifically on wheelchair access worldwide [97]. The platform applies a simple traffic-light classification system to indicate the accessibility of locations: green for step-free access, orange for partial accessibility, and red for non-accessible places. Users can also evaluate accessible toilets, upload photos, and contribute updates, making it a crowd-sourced and continuously evolving dataset. Filters allow users to search by accessibility status and place categories, and the tool is available both as a mobile app and a web platform, facilitating everyday usability and awareness of physical barriers in urban space.

The presented platforms are typically high-resolution, citizen-facing, and designed to reveal local and global accessibility strengths and deficits in fine spatial detail. By contrast, the *Walk Score*® originates from a consumer-facing application, available for cities in the United States and Canada [98]. It provides heatmaps for a walk and bike score. It is supplemented by maps of public transport networks and associated travel times, as well as maps showing cycling paths, topography, and bike commuters. In addition, information about the neighbourhood and surrounding districts, as well as city and neighbourhood rankings, is included.

Another approach is represented by the *Comfort-based accessibility tool*, developed by InclusiveSpaces and applied in contexts such as Hamburg (Germany) and Penteli (Greece) [99]. Unlike conventional travel-time-based tools, the tool introduces comfort-weighted routing, in which accessibility is determined not only by distance or time but also by the perceived quality of the travel environment. Users can customise the weighting of comfort factors—such as safety, infrastructure quality, or environmental conditions—according to their preferences, or select predefined user profiles. The tool visualises how accessibility areas change depending on these preferences, thereby highlighting inequalities that are not captured by purely measured metrics. By combining calculated travel data with survey-based perception data, this tool provides a more nuanced and inclusive understanding of accessibility within the 15-minute city framework.

Pedestrians First (Institute for Transportation & Development Policy) evaluates walkability for vulnerable users, namely babies, young children, and people caring for them, within the tool *View city measurements* [100]. For many cities worldwide, it provides maps and detailed information on five indicators: education and healthcare, public transport, block density, population density, and access to places without motorised traffic. In addition to the spatial data, the platform also provides policy recommendations for each indicator, thereby advancing the equity dimension of the 15-minute city. These tools are explicitly decision-support systems that help planners identify gaps in service provision, target interventions, and communicate accessibility concepts to citizens.

Table 2: Overview of accessibility tools for the 15-Minute City

Name	Origin / publisher	Location	Short description	functional Details
The X Minute City	University of Canterbury & Urban Intelligence	New Zealand (42 cities)	Interactive spatial platform mapping access to key service categories	6 amenity categories (supermarket, school, pharmacy, GP, park); 3 modes (walking, cycling, driving); heatmaps; city stats on avg. travel time, population within 10 min, and least accessible amenity
Close	Henry Spatial Analysis, LLC	USA	Travel-time mapping tool for accessibility to a wide range of services	Multi-modal routing (walk, bike, public transport); block-level heatmaps; many categories incl. farmers' markets and community centres; destinations shown with name and address
HERE app	HERE Technologies	USA	Tool showing proximity to points of interest and 15-minute city compliance	6 POI categories (groceries, medical, culture, education, public transport, leisure); 2 modes (Walking, driving), shows nearby POIs with name, address and distance; binary 15-min city indicator per location; distance and travel-time calculation
15min City Score Gallery	Transform Transport	Global (112 cities)	Standardized 15-minute city walkability score for 112 cities in the EU Mission for Climate-Neutral and Smart Cities by 2030	Single walkability score per neighborhood; heatmaps; shows number of reachable service categories; 8 service categories (neighborhood services, healthcare, neighborhood shops, education, sports, cultural entertainment, open leisure, mobility)
Mobi.mapr	Baden-Württemberg Institut für Nachhaltige Mobilität	Germany	Platform for multimodal accessibility and mobility analysis including subjective comfort factors and persona-based analysis	4 modes (walking, cycling, driving, public transport, multimodality); 200 m hexagon resolution; score includes subjective factors; persona-based analysis by age, vehicle access and employment; rankings at state/district/municipality level
Map4Citizens	Plan4Better, TU München & Humankind	Munich (Germany)	Web-based application for exploring urban mobility and local accessibility with a personalised flower-of-proximity	15-min Score per district/building; heatmaps with thematic layers (noise, density, land use, public transport); Flower-of-proximity lets users set personal 0–20 min thresholds across 8 amenity groups

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Name	Origin / Publisher	Location	Short Description	Functional Details
BXLGIS – 10-Minute City	Eurocities & City of Brussels	Brussels (Belgium)	Integrative neighbourhood service map identifying service gaps and supporting strategic planning (FR/NL only)	4 categories (living environment, living together, economy, mobility); shows reachable services, neighbourhood demographics, ongoing urban projects, and per-category detail pages; map-based measurements
CityAccessMap	TU Delft & Centre of Urban Science and Policy (CUSP)	Global	Quantifies and visualises walking accessibility to a variety of services for cities worldwide	7 service categories; customizable weights and thresholds; block-level heatmaps; per-area line charts and a global ranking for cities over 500k
15min-City Platform	Sony CSL Rome & Sapienza University of Rome	Global	Worldwide platform measuring walking and cycling proximity based on the 20 nearest POIs	9 amenity categories; heatmaps for walk and bike proximity; per-area travel time bar charts by mode; ideal-scenario modelling for redistribution of services available for selected cities (e.g. Paris)
Wheelmap.org	Sozialhelden e.V.	Global	Crowdsourced platform mapping wheelchair accessibility of public places worldwide using a traffic-light classification.	Green/orange/red classification for step-free, partial and no access; user-generated ratings and photo uploads; accessibility of toilets; filterable by status and category
Walk Score®	Walk Score (Redfin Corporation)	USA & Canada	Consumer-facing platform providing walk, public transport, and bike scores, aimed primarily at home-seekers.	Walk, bike and public transport score heatmaps with route maps; neighbourhood info; topography; bike commuter density and city/neighborhood rankings
Comfort-based Accessibility Tool	InclusiveSpaces	Hamburg (Germany) & Penteli (Greece)	Tool assessing accessibility based on comfort and perceived travel quality	Comfort-weighted routing; customizable weighting of factors (safety, infrastructure, environment); predefined user profiles; visualisation of accessibility changes; integration of objective travel data with survey-based perception data
Pedestrians First	Institute for Transportation & Development Policy (ITDP)	Global	Walkability measurement focused on vulnerable users (babies, toddlers, caregivers) with policy recommendations.	5 indicators (access to services, public transport proximity, block density, population density, car-free places); city maps with percentages and policy recommendations per indicator; global city comparisons

The current range of accessibility tools for the 15-minute city shows a wide variety of analysis platforms. While some tools offer a detailed, citizen-oriented analysis of travel times to services, others allow for global comparability, the presentation of policy measures, or inclusive metrics for walkability. The recurring methodological approach includes the use of open geodata, mode-dependent travel time calculations, weighted services, and heat maps. Despite their differences, all of these instruments focus on the main idea of the 15-minute city by evaluating residents' proximity to key services.

3.3.2 Accessibility in agent-based models

Agent-based models (ABMs) provide a complementary perspective to accessibility analysis tools by explicitly incorporating the demand side of urban mobility. While traditional accessibility measures typically assess the spatial distribution of opportunities and the travel times required to reach them, they remain largely static and supply-oriented. In contrast, ABMs conceptualize accessibility as the outcome of individual decision-making processes, thereby introducing a dynamic and behaviorally grounded perspective.

In the context of urban and transport modelling, ABMs simulate the travel behaviour of individual agents representing the population of a defined planning area [101]. These agents are often embedded within a household context, allowing for a more detailed representation of interdependencies—such as shared mobility resources or car availability—among household members. This agent-based structure enables the analysis of travel behaviour at the individual level. Accordingly, ABMs model agents' decisions regarding their daily activities, including where, when, and how these activities are performed. Rather than treating trips as isolated events, these models typically follow an activity-based approach in which travel demand emerges from the need to participate in activities distributed across space and time. As a result, mobility patterns are not predefined but arise endogenously from the interaction between individual preferences, temporal constraints, and the spatial structure of the city. Most established ABMs, such as MAT-Sim [102], POLARIS [103], or SimMobility [104], simulate mobility behaviour over the course of a single day, often iterated over multiple days, whereas models such as mobiTopp [105] explicitly simulate a full week, thereby capturing differences between weekdays and weekends. Although often overlooked in the accessibility literature, this demand-oriented perspective is highly relevant for understanding accessibility. From an agent-based viewpoint, accessibility is not solely determined by the physical proximity of opportunities, but by the extent to which these opportunities align with the heterogeneous needs, activities and routines of the population. Differences in socio-demographic characteristics, time constraints, and available mobility resources lead to diverse activity patterns, which in turn shape individual accessibility levels. Moreover, accessibility becomes inherently linked to complete activity chains rather than single

trips, highlighting the importance of sequencing and timing in everyday life.

Within the 15mC framework, these aspects are particularly important. Accessibility analysis tools can indicate whether essential services are theoretically reachable within a given time threshold; however, they do not capture whether these services are effectively integrated into individuals' daily routines. ABMs address this limitation by enabling the simulation of complete daily or weekly activity patterns grounded in behavioural foundations, thereby allowing the assessment of whether typical activity chains can be realised within local neighbourhoods. This makes it possible to evaluate whether the core objective of the 15-minute city, meeting daily needs within short distances, is achieved in practice, rather than merely being feasible from an infrastructural perspective.

Furthermore, ABMs enable the analysis of behavioural adaptation processes in response to changes in the urban environment. The introduction or relocation of local services may influence destination choices, mode preferences, and travel frequencies. Such dynamic responses are essential for assessing whether proximity-based planning strategies lead to an actual reduction in travel distances and car dependency, or whether travel demand is simply redistributed. In addition, the explicit representation of heterogeneous agents allows for the identification of distributional effects, revealing which population groups benefit from improved local accessibility and which remain disadvantaged.

Beyond passenger transport, agent-based modelling can also be applied to urban logistics and freight transport. Freight-oriented models frequently exist as extensions of, or closely coupled counterparts to, established passenger transport ABMs, enabling a holistic analysis of urban mobility patterns. Examples include MATSim Freight [106, 107] as an extension of MATSim, CRISTAL [108] as an agent-based freight model developed within the POLARIS modelling environment, SimMobility Freight [109] as the freight component of SimMobility, and logiTopp [110, 111, 112] as an extension of mobiTopp for modelling private and commercial parcel demand as well as first- and last-mile shipment processes with advanced modelling features such as contract models between carriers and customers [113]. These models represent the decisions and interactions of relevant actors, including consumers, establishments, carriers, logistics service providers, and delivery vehicle operators, and thus enable the analysis of how changes in urban structures affect both passenger travel and the movement of goods. This is particularly relevant in the context of the 15mC, as the relocation, decentralisation, or restructuring of retail and service facilities may not only change residents' destination choices and travel patterns but also affect shipment volumes, delivery frequencies, vehicle tours, and the spatial distribution of logistics traffic. Consequently, ABMs are not limited to examining accessibility from the demand side of passenger mobility. By jointly considering how people access urban opportunities and how these opportunities are supplied, passenger and freight models can provide a more comprehensive picture of the mobility impacts of proximity-based urban planning and reveal

potential trade-offs between improved local accessibility and the logistics activities required to sustain it.

Despite these advantages, agent-based models also face several challenges. They require detailed input data on individual behaviour and preferences, involve complex calibration procedures, and are computationally intensive. Moreover, their results can be more difficult to communicate than aggregated accessibility indicators. For this reason, ABMs should not be seen as a replacement for traditional accessibility analysis tools, but rather as a complementary approach that enhances and validates their explanatory power by linking spatial structures with behavioural responses.

In summary, while accessibility analysis tools provide valuable insights into what is potentially reachable within a given urban structure, ABMs offer a deeper understanding of how accessibility is actually experienced and utilised. By incorporating the demand side, they enable a more comprehensive assessment of whether the principles of the 15mC translate into realistic and equitable mobility patterns. At the same time, it remains an open question to what extent the results derived from ABMs differ systematically from those obtained through traditional accessibility measures, and how both perspectives can be meaningfully integrated. While accessibility indicators capture structural potentials, ABMs reflect behavioural realisations of these potentials. Bridging these approaches and understanding their respective explanatory power, therefore, represents an important direction for ongoing research, which will be addressed within SmartUrbanity. However, D2.1 does not prescribe a common approach for integrating accessibility indicators into agent-based models. As model structures, data requirements and pilot objectives differ, the selection and use of indicators, calibration parameters, validation procedures and potential transfer of model outputs to the project's toolkit must be defined separately for each relevant application in WP4. Agent-based modelling will therefore only be applied in those pilots for which it is methodologically appropriate and supported by the required data.

4 Concrete implementation in the project

Building on the methodological foundations developed in Chapter 3, this chapter marks the transition from theoretical conceptualisation to practical implementation. The review shows that a range of tools and approaches for analysing and modelling accessibility already exists. However, their practical application often provides limited opportunities for meaningful stakeholder participation and does not sufficiently account for the needs and experiences of vulnerable groups. Moreover, people-centred approaches are not yet consistently integrated into the development and implementation of accessibility solutions. Rather than addressing a distinct research gap, the SmartUrbanity project responds to this implementation and participation gap by combining existing analytical approaches with inclusive, participatory, and people-centred processes aiming at an innovation-oriented approach.

For that purpose, while the previous sections focused on operationalising accessibility—particularly the distinction between objective and perceived dimensions—and reviewing existing analytical and modelling approaches, Chapter 4 shifts the focus to their application within the SmartUrbanity project. Hereby, the indicators and methodological approaches reviewed in Chapter 3 should be understood as a project-independent overview of available options rather than as a predefined methodological baseline for SmartUrbanity. Accordingly, D2.1 does not classify indicators as mandatory, optional, experimental or deferred. Their final selection and operationalisation—including specific data requirements, partner responsibilities, pilot relevance and validation procedures—will be determined through the modelling activities in WP3 and the pilot- and data-specific activities in WP4. These decisions will depend on the requirements of the respective models and pilots, as well as on the availability, quality and suitability of the required data.

Against this background, Chapter 4 shows how the identified concepts, indicators, and methods inform the development of concrete tools, participatory processes, and empirical research activities within SmartUrbanity. In doing so, the chapter not only addresses the technical implementation of the digital toolkit but also emphasises the integration of user experience research and stakeholder workshops to ensure that the developed solutions are closely aligned with real-world needs and use contexts. Further details on the underlying data platforms and data management protocols are provided in the project’s Deliverable D2.3.

4.1 Conceptual framework of tool development

The SmartUrbanity conceptual framework for tool development builds on previous literature. It establishes an integrated ecosystem where data-driven analysis and participatory planning converge to improve urban mobility while addressing the gaps identified earlier. As illustrated

in Figure 6, this system creates a continuous feedback loop between Citizens, who provide real-world data through the Access Together mobile app and the Access Hub web app, and Decision Makers, who use the Access Lab suite to evaluate interventions. By combining objective technical metrics from the Access Atlas with subjective citizen perceptions integrated into the DSS, the framework ensures that urban planning decisions are evidence-based, inclusive, and responsive to the lived experiences of all community members. The following paragraphs briefly introduce each tool and its role within the framework.

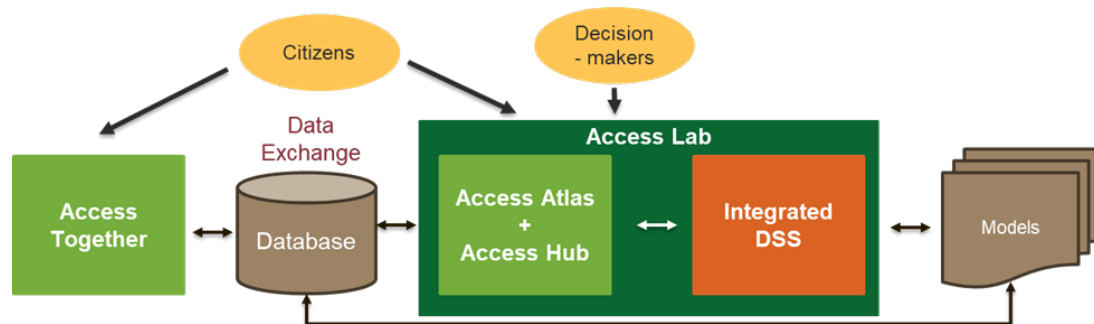


Figure 6: Framework of the tool development of the SmartUrbanity project

Mobile App: Access Together

Access Together serves as the primary data-collection interface, designed to capture user-contributed mobility and, especially, perception data through structured, repeated interactions to include the ability to measure objective and perceived accessibility differentiated by distinct sociodemographic groups. The app integrates passive data collection (e.g., GPS traces and trip attributes) with active user inputs such as short questionnaires, contextual reports, and perception-based evaluations. This dual approach enables the construction of an experiential data layer that links observed behaviour with subjective perceptions. The tool supports longitudinal data collection, allowing the estimation of user-specific and scenario-dependent parameters, such as perceived effort and sensitivity to accessibility conditions. Overall, it plays a central role in calibrating behavioural models and validating accessibility indicators across diverse user profiles.

Web Platform: Access Lab

The Access Hub complements the mobile application by enabling map-based, deliberative, and collective user contributions. It allows users to report spatial perceptions, identify accessibility barriers, and contribute to mapping and validating points of interest and interventions. The platform supports participatory processes such as commenting, verification, and voting, which

enhance the reliability and traceability of user-generated data. By aggregating validation signals, Access Lab contributes to quality assurance mechanisms within the modelling framework. It thus serves as a bridge between individual experiences and collective knowledge, supporting governance workflows and participatory planning.

The Access Atlas platform is an accessibility analysis tool that assesses how easily people can reach essential urban services, such as healthcare, education, mobility, leisure, and daily needs. Along with other models, it mainly relies on Open Data and combines geographic data, transport networks, service locations, and urban zones to provide a realistic picture of accessibility across the city. The platform allows users to analyse accessibility not only by location but also by mobility conditions and user characteristics, making the results more socially inclusive, individualised, and relevant. Through interactive maps and visual dashboards, it shows how services are distributed and which areas have better or worse access. This helps identify underserved neighbourhoods and supports better planning decisions for more equitable and efficient cities. Overall, the platform serves as a practical tool for understanding and improving urban accessibility within the framework of the 15mC and inclusive planning strategies.

The DSS is an advanced platform designed to assist policymakers in evaluating and comparing urban mobility interventions. It serves as a tool for decision-makers to monitor infrastructure, analyse mobility patterns, and assess potential interventions based on factors such as costs, urgency, projected outcomes, and their specific impacts on disadvantaged groups. To enhance its effectiveness, the DSS is designed to integrate both objective quantitative data and subjective qualitative feedback from citizens, such as spatial reports and perceived travel experiences, into a single analytical framework. Furthermore, the system aims to promote transparency by providing detailed statistics and visualising the potential impacts of possible interventions on accessibility, as well as climate and environmental factors. This allows decision-makers to select the most appropriate measures based on the data provided and their own strategic priorities.

Surveys and Engagement Activities (Community Connectors)

Surveys and engagement activities are designed to capture behavioural, perceptual, and contextual variables that cannot be reliably obtained through passive sensing. These activities are implemented through modular questionnaires and targeted campaigns, often in collaboration with Community Connectors such as NGOs and local associations. This approach ensures inclusivity by reaching underrepresented groups and adapting data collection to local contexts. In addition, engagement formats such as workshops and guided activities enhance the interpretability of collected data by grounding it in lived experiences. These tools play a key role in enriching the dataset and supporting robust behavioural analysis.

Workshops and Focus Groups

Workshops and focus groups provide a structured environment for collecting qualitative insights and validating user needs and system requirements. These in-person interactions enable direct dialogue with participants, facilitating a deeper understanding of mobility behaviours, perceptions, and constraints. Data collected through these sessions, including demographic, behavioural, and experiential information, support user segmentation, persona development, and model validation. Furthermore, these activities contribute to refining tool functionalities and may support recruitment for further data collection phases. They are essential for ensuring that the modelling framework reflects real-world user experiences and stakeholder perspectives.

4.2 Requirements for tool development

In the following chapter, the further development of the SmartUrbanity toolkit builds upon the theoretical and conceptual foundations outlined in the preceding sections and is complemented by empirical insights. To inform this process, additional data collection and evaluation activities were conducted, yielding key insights into the needs, expectations, and usage contexts of relevant stakeholder groups. Based on these findings, the existing toolkit concept is iteratively refined and adapted, ensuring that both the principles identified in the literature and the practical insights gained from these complementary research components are systematically integrated into the tool development process.

4.2.1 User experience research

The project follows a user-centred research approach that places the needs and lived experiences of citizens – in particular those from vulnerable population groups – at its core. Recommendations are grounded in these user-based insights, ensuring that digital solutions reflect genuine everyday realities. The following provides only a brief overview of the user experience research conducted to date within the project. A detailed account of all activities, methods, and findings is available in the project's Deliverable D2.4.

The research process was structured around four consecutive phases. In the first phase, a structured literature review was conducted to identify key factors shaping mobility preferences and the design of digital tools. This was followed by five regional workshops in which citizens and policymakers actively participated in shaping the project's digital solutions. A third phase of structured usability testing with defined participant groups is currently being prepared. Finally, qualitative and quantitative findings will be synthesised into concrete recommendations and communicated directly to the development teams.

The methodology integrated both quantitative and qualitative techniques in a mixed-methods

design. Quantitative approaches proved well-suited to measuring adoption rates and usage patterns, while qualitative methods provided the depth needed to understand subjective perceptions and behavioural drivers. A detailed account of the workshop methodology, locations, and analytical approach is provided in Section 4.2.2. Additional data sources included outputs from earlier stakeholder engagement activities and feedback gathered during presentations of the tools.

User needs and mobility preferences The findings presented in this paragraph are derived from the literature review conducted in the first phase of the research process. In public transport, reliability consistently emerged as the most significant driver of passenger satisfaction, while overcrowding was identified as the leading source of dissatisfaction. Extended waiting times were found to reduce satisfaction, though this effect could be partially offset by providing accurate real-time information. Physical comfort factors – including seat availability, personal space, and the ability to work during travel – also significantly influenced how passengers perceived their overall journey.

The review additionally showed that different population groups varied considerably in how they engaged with mobility services. Safety was a particularly high priority for women, especially when using public transport at night. Younger users placed strong emphasis on digital tools and punctuality, whereas older users tended to prefer face-to-face assistance and rarely required navigation support for routine journeys. Sociodemographic characteristics, such as education level and income, were also found to be statistically associated with the likelihood of using certain services, such as ride-sourcing.

External circumstances were found to override a person's usual mode preferences strongly. Adverse weather conditions frequently caused cyclists and pedestrians to switch to public transport or car-sharing. Trip-specific constraints – such as carrying luggage, travelling with children, or facing tight time schedules – reduced the appeal of active or public modes. The quality of urban infrastructure, including dedicated cycling lanes, street lighting, and accessible footpaths, was directly associated with higher usage rates and improved safety perceptions among active transport users. The presence of green infrastructure, such as tree cover and proximity to parks, further enhanced comfort, particularly for vulnerable groups.

Personas for usability testing Drawing on local population data and mobility surveys, five representative user profiles were developed to serve as the basis for the planned usability testing. Each persona captures demographic characteristics, mobility behaviour, digital literacy, and typical usage scenarios.

- Public transport-dependent commuter (42 years): Commutes daily by bus, has moderate

digital skills, and a low tolerance for delays. Avoids public transport at night and relies on punctuality for managing a busy schedule.

- Active local traveller (68 years): Uses a bicycle for short local errands, has limited digital confidence, and depends on safe cycling infrastructure. Avoids crowded public transport hubs and does not cycle at night or in bad weather conditions.
- Cost-conscious active cyclist (23 years): Cycles daily and holds high digital skills. Makes use of affordable bike-sharing plans and switches to public transport in adverse weather conditions.
- Car-oriented long-distance traveller (35 years): Prioritises the private car for safety and flexibility, particularly during early morning and late-night work shifts. Rarely uses public transport.
- Car-dependent long-distance commuter (51 years): Has moderate digital skills and relies heavily on the car for both family and professional trips. Increasingly affected by parking regulations and low-emission zone restrictions.

The personas represent the main sociodemographic groups within the target population. The personas developed for the current usability testing do not represent all potentially vulnerable user groups. In particular, children and people with different types of disabilities are not included as separate personas in the present testing framework. This does not imply that their needs are irrelevant to SmartUrbanity's inclusion objectives. Rather, their appropriate involvement and representation would require additional legal and ethical safeguards, specialised expertise, targeted recruitment, and dedicated testing resources that could not be fully incorporated into the current activities.

Usability testing plan Building on insights from the literature review, workshops, and persona development, tailored usability testing procedures have been designed for each of the three digital tools. All tests will follow a task-based approach in which participants complete predefined assignments under structured observation.

Testing of the Access Together mobile application will involve a total of 11 participants, including older adults, students, working-age adults, and non-native speakers. Features to be evaluated include user registration, trip tracking, barrier reporting, and reward functions. The assessment will focus on ease of use, clarity of information, intuitive navigation, and privacy comfort. All sessions will be conducted online in small groups of up to four participants, each accompanied by a dedicated coordinator.

The web-based analytical tool Access Hub will be tested with ten participants drawn from across the consortium countries, all of whom have prior experience with accessibility tools and urban data management. Spread across two testing phases, tasks will cover data import, model configuration, data filtering, spatial analysis, and questionnaire functions. Evaluation metrics will include task completion rate, error rate, time on task, ease of use, and clarity of information. As the DSS is still in an early stage of development, testing will be limited to pilot leaders from the partner countries. The sessions will centre on modelling and comparing mobility interventions, evaluating the comprehensibility of system-generated recommendations, and assessing the projected impact on the accessibility of different population groups. Testing will take place in a single phase, following a methodology comparable to that applied for the Access Hub.

4.2.2 Stakeholders' requirements

A participatory and user-oriented approach was applied to assess and further develop the project's digital framework across all pilot locations. Workshops were conducted in each pilot using a shared agenda, with room for adaptation to local contexts and needs. The methodology was designed to enable comparable results across cities while accommodating local conditions and stakeholder environments. It combined structured stakeholder involvement, coordinated workshop delivery, and a unified approach to capturing and analysing outcomes. For a detailed description of the workshop's results, we refer to the project's Deliverable D2.2. However, for this Deliverable, we provide a concise overview of the relevant results for the development of the digital toolkit below.

The workshops brought together a diverse range of participants in order to reflect multiple perspectives on mobility and accessibility. These included representatives from local administrations and transport authorities, various community groups—including those representing marginalised populations—mobility service providers, as well as actors from academia, civil society, and the project consortium. While a general stakeholder framework was available, the identification and selection of participants were carried out by the local pilot leaders. This ensured that each workshop engaged individuals and organisations with direct relevance to local mobility systems, planning processes, and community needs.

Each pilot city held one workshop that addressed the central elements of the framework. The initial workshop in Rome served as a reference for subsequent implementations, allowing adjustments based on practical experience and feedback. Depending on local circumstances, workshops were conducted in various formats, including face-to-face, online, or hybrid. In some cases, additional sessions were organised to ensure the participation of key stakeholders. A joint preparation phase preceded the workshops, during which templates for registration, questionnaires, and reporting were developed and aligned among all partners. Following each



Figure 7: Stakeholder workshop in Karlsruhe

workshop, the local teams compiled and submitted the relevant documentation, which was later aggregated in the project's Deliverable D2.2 to support cross-city comparison and synthesis.

All workshops were structured around the main components: the Access Together application and the Access Lab platform, including the Access Hub, the Access Atlas, and the DSS. Each session combined brief introductory presentations with interactive discussion formats to facilitate exchange among participants. The design differentiated between sessions focusing on user perspectives—such as needs, expectations, and potential barriers—and sessions addressing institutional viewpoints, including planning processes, data requirements, and system integration. In addition, joint sessions brought together all stakeholder groups to enable dialogue across perspectives and to discuss overarching topics such as usability, inclusiveness, and data privacy. To support comparability across locations, a consistent set of participatory methods was used. Questionnaires provided background information on participants and their mobility behaviour, helping to contextualise qualitative insights. Interactive techniques such as mind mapping enabled participants to express ideas and challenges in a structured yet open format, while SWOT analyses facilitated systematic reflection among expert groups. In joint sessions, voting methods using visual markers allowed participants to prioritise options and highlight differences and similarities between stakeholder groups. Throughout the process, the pilot leaders guided the discussions, ensured balanced participation, and summarised key findings, maintaining a neutral and inclusive environment.

Overall, this approach ensured a consistent yet adaptable implementation of the workshops across all pilot locations, enabling structured stakeholder engagement and comparable insights

while remaining sensitive to local contexts. It provided a solid methodological foundation for the following chapter, which briefly presents the results derived from these activities.

Key findings from the pilot workshops

Findings from the workshops across all pilot locations point to broad overlap in stakeholder expectations, alongside some context-specific differences. Regarding the Access Together application, participants consistently emphasised its role as an intuitive, efficient tool for capturing mobility-related experiences, enabling structured feedback, and encouraging broad participation. Across all cities, there was a clear expectation that the application should allow users to report both immediate, short-term issues—such as delays, crowding, or disruptions—and more persistent infrastructural problems, including physical barriers, missing infrastructure, or malfunctioning accessibility features. A clear distinction between temporary incidents and long-term deficiencies was considered essential to ensure meaningful categorisation and usability of the data.

Ease of use was repeatedly emphasised as a critical success factor. Participants stressed that reporting should require minimal time and effort, ideally allowing quick input with the option to provide additional details later. Additional features, such as offline data entry and persistent login, were seen as important for everyday use. Accessibility considerations were also central, including compatibility with assistive technologies for visually impaired people, simplified interfaces, and multilingual options to reach a diverse user base. Beyond reporting functions, stakeholders expressed interest in community-oriented features that could foster local interaction and engagement.

In addition, the integration of motivational elements was widely discussed. Participants favoured incentive structures that support civic engagement rather than those that promote competition. Suggested approaches included symbolic rewards, benefits related to sustainable mobility, and feedback on personal mobility behaviour, such as environmental or health-related indicators. At the same time, competitive elements such as rankings were viewed critically, as they could distort user behaviour.

Looking at the Access Hub, ensuring the reliability of user-generated content emerged as a key concern. Stakeholders highlighted the importance of incorporating verification mechanisms, such as the ability to upload photos or videos, as well as confirmation processes involving nearby users. At the same time, there was a strong preference for structured input formats over open-ended communication channels in order to reduce noise and simplify moderation. Another central requirement was implementing transparent feedback mechanisms that allow users to track the status of their contributions across multiple stages, from submission to resolution. This included progress notifications and clear information about responsible authorities, ensuring

that user input remains visible and actionable.

Turning to the Access Atlas, stakeholders consistently described accessibility as a multifaceted and context-dependent concept. Key dimensions included reliability, safety, route continuity, and the integration of different transport modes. The platform was expected to account for diverse user needs by offering customizable filters, for example, based on age, mobility aids, or temporary constraints such as travelling with strollers. Additional considerations, such as gender-related safety aspects and weather conditions, were also highlighted as relevant factors influencing accessibility. However, the general foundation of accessibility, in terms of its multiple ways of measuring it, has not been discussed. The participants largely approached accessibility from a universal and undifferentiated perspective, without explicitly considering the differentiated methods of calculation discussed in the literature or the distinction between objective and subjective accessibility.

In terms of functionality, participants emphasised the importance of clear and informative visualisations. This included mapping accessible routes, transport stops, and vehicles, as well as highlighting critical locations such as areas with safety concerns or frequent conflicts. Features such as elevation profiles, real-time information on construction works, and advanced filtering options for heatmaps were also considered valuable. Transparency in how routes are generated was seen as essential, with users expecting clear explanations for suggested paths.

The DSS was primarily understood as a tool for structuring and interpreting available data rather than as an additional input channel. Stakeholders, mainly policy-makers, emphasised its role in aggregating user-generated information into meaningful, spatially referenced insights that can support planning and decision-making. A key requirement was integrating qualitative user input with quantitative indicators, including cost considerations, accessibility standards, and environmental impacts. Compatibility with existing municipal systems was also highlighted as essential to ensure practical usability.

Another central aspect concerned the logic used to prioritise interventions. Participants stressed the need for transparent, understandable criteria that account for safety, cost-effectiveness, and the distinction between long-term planning measures and short-term maintenance tasks. The system should also support assigning issues to the appropriate administrative units. At the same time, concerns were raised regarding the quality and representativeness of the data, including the risk of overloading the system with unverified reports or underrepresentation of certain groups.

Finally, stakeholders emphasised that the system must align closely with existing institutional processes and constraints. This includes compatibility with legal frameworks, budget limitations, and established decision-making procedures. Clear communication was seen as important for managing expectations and avoiding misunderstandings, particularly regarding how citizen input is used. Overall, structured and moderated forms of participation were preferred

over open-ended formats, ensuring that contributions can be effectively integrated into formal planning processes.

5 Theoretical guidelines for methodological implementation

The final step of the process involved an internal workshop with project partners during the consortium meeting in Lyon, held on 10 April 2026 from 10:00 to 12:00 and attended by all members of the General Assembly. This workshop aimed to synthesise and align insights from the pilot workshops and user experience research with the concept of the digital toolkit, translating them into a set of overarching methodological guidelines for the further development and implementation of the digital tools.



Figure 8: Workshop during the consortium meeting in Lyon

The workshop opened with a presentation of the results from the pilot workshops (see D2.2), which served as the empirical basis for the subsequent discussion. Building on these findings, participants worked collaboratively under the guiding question "What are the key requirements for designing and implementing the three digital tools?" to identify key categories for further elaboration. The consortium selected the following categories as most relevant:

- User engagement & participation barriers
- Incentives, trust & gamification
- Accessibility for all tools (inclusion)
- Requirements for all tools
- Challenges & barriers

- Data requirements
- Nice-to-have features (but clearly out of scope)

The workshop then proceeded through a structured sequence of activities: participants first worked individually during a silent brainstorming phase to develop ideas for each category, followed by a joint session to collect and cluster the key points that emerged, as for example in Figure 9. The discussion focused on identifying common principles, addressing cross-cutting challenges, and defining requirements that ensure usability, inclusiveness, and practical relevance across different contexts.

The workshop also aimed to critically assess the feasibility of stakeholder requirements within the scope of the project. In this context, particular attention was given to filtering out functionalities and preferences that could not be realistically addressed, whether due to technical limitations, resource constraints, or misalignment with the project's objectives. This process helped ensure a more focused, implementable set of requirements for subsequent tool development.

The workshop concluded with a discussion on the implications for the project and next steps, guided by the following questions:

- What are the key requirements for databases and indicators?
- How can social and participatory aspects be included in the implementation of the three digital tools?
- What specific recommendations can be derived for tool design and evaluation?

The results of this workshop form the basis for the requirements and recommendations presented in the following sections.

5.1 Key barriers to adoption

A range of structural and practical barriers to adoption and participation was identified across all pilot contexts. One of the most prominent challenges concerns inclusiveness, particularly for elderly users and individuals with limited digital skills or specific accessibility needs. The digital divide remains a critical issue, as not all users are equally able or willing to interact with app-based solutions. To address this, alternative approaches such as allowing submissions on behalf of others within their profiles could be considered. Another potential option discussed was the use of physical submission channels, for example, through paper-based reporting supported by volunteers who would transfer the information into the system. Alternative participation channels can be supported through SmartUrbanity's civic network of Community Connectors,

including local associations and trusted intermediaries who help less digitally engaged groups contribute.

Another key barrier concerns the fragmentation of existing digital solutions. The presence of multiple applications in the mobility ecosystem can lead to confusion and reduced adoption, highlighting the need for clear communication. While integration with existing applications could help address this issue, it was deemed infeasible within the project's scope. On the one hand, such integration would exceed the available time and resources. On the other hand, many of these tools are owned and managed by cities or private providers, making integration complex and often restrictive. In addition, the wide variation in functionalities across existing applications further complicates interoperability. However, clearly communicating to users that the app is a temporary solution intended to support the tool's fine-tuning and that its functionalities could later be integrated into existing applications, such as municipal apps, may help increase acceptance among citizens.

Lastly, ensuring sufficient and high-quality data collection was identified as a challenge, particularly when relying on voluntary user input. These barriers underline the importance of designing solutions that are not only technically robust but also accessible, clearly communicated, and supported by gamification elements to make using the application a joyful activity.

5.2 Driving user engagement

Communication was identified as a critical success factor for the adoption and effective use of the tools. Users need a clear, easily understandable explanation of each tool's purpose, how it differs from existing applications, and the specific added value it provides. It is essential to highlight how the tools complement rather than duplicate existing solutions, for example, by focusing on accessibility-related insights or by linking user input to planning processes.

Beyond explaining functionality, communication must also emphasise the tangible benefits of participation. Users are more likely to engage if they understand how their contributions can lead to visible improvements, such as safer routes, better infrastructure, or more inclusive mobility services. This includes not only communicating the intended impact but also making the outcomes of user contributions visible over time. Clear messaging, both within and outside the applications, is therefore necessary to build trust, demonstrate relevance, and encourage sustained participation.

Building on these structural challenges, the discussion emphasised the importance of fostering active and sustained user engagement. A central requirement is establishing clear and responsive feedback mechanisms. Users expect their reports to trigger visible reactions within the application, ideally within a reasonable timeframe. This includes structured feedback loops where contributions are acknowledged, processed, and updated transparently.

At the same time, important limitations related to feedback management were identified. Effective feedback systems would require consistent moderation to handle false reports, inappropriate content, and duplicate submissions. However, providing such a level of moderation is beyond the project's scope. One potential approach discussed was involving voluntary “community connectors” who could take on moderation tasks. While promising, this would require identifying, training, and coordinating such individuals, which goes beyond the project's current capacities. Similarly, more advanced features, such as automatic detection of duplicate or irrelevant reports, direct feedback from municipalities and transport providers, or allowing users to react to each other's reports directly, were considered valuable but not implementable within the given framework.

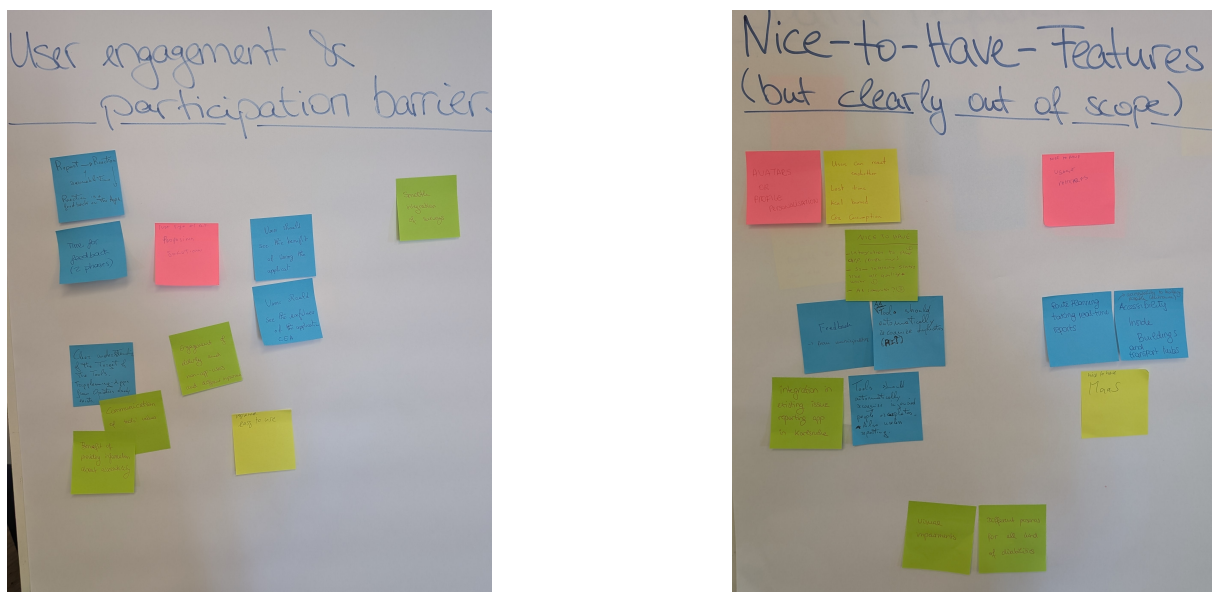


Figure 9: Examples of workshop results

As a pragmatic solution, it was proposed that each report include a clearly visible recipient, such as a municipality or public transport authority, so users understand who is responsible for handling the issue. Enabling users not only to report issues but also to propose potential solutions was seen as a valuable way to strengthen engagement and ownership. In addition, communication should make clear that submitted feedback is forwarded to the relevant actors for further processing. However, continuous status updates on individual reports cannot be guaranteed within the current system.

Ensuring accessibility across all tools was considered a core design principle, closely linked to the goal of minimising user effort. This includes technical aspects, such as a unified login system—emphasising that Access Together and Access Lab should use the same login credentials—and simplified access processes. In addition, intuitive interfaces, minimal input requirements, and the seamless integration of survey elements into the application were highlighted as

essential features. Reducing the number of steps required to access and use the tools was seen as particularly important for improving overall usability and encouraging participation.

Interface-related considerations play a key role in ensuring inclusiveness, including the use of accessible colour schemes, clear and inclusive language, and multilingual support. At the same time, inclusiveness requires addressing the diverse needs of different user groups, such as individuals with disabilities, users with limited digital literacy, and those with temporary mobility constraints. A user-centred design approach that prioritises simplicity and clarity is therefore essential to make the tools usable for as many people as possible. Ensuring accessibility across the tools remains a central design objective. At the same time, the workshops demonstrated that the requirements of specific user groups can differ substantially and may require specialised expertise, dedicated testing procedures, and additional development resources. The current project can therefore address overarching principles such as clear language, accessible colour schemes, simplified workflows, multilingual support, and compatibility with established accessibility standards. Still, it cannot guarantee that all requirements associated with every form of disability will be comprehensively implemented and validated. Still, the consortium is aware of the need to implement inclusive solutions and pursues this to the highest possible degree within available capacities.

The project findings further show that vulnerable users cannot be treated as a homogeneous group. Different physical, sensory, cognitive, social, and temporary limitations entail distinct requirements for participation, data collection, interface design, and model development. Developing and validating separate personas and functionalities for each group would require targeted involvement from the beginning of the project and corresponding legal, methodological, technical, and financial resources. For example, within the Access Hub, a separate persona for each type of disability cannot be addressed, primarily because the data collected through Access Together is not expected to be sufficient to calibrate a large number of highly differentiated personas reliably. This should be considered explicitly in the planning of future projects. Within SmartUrbanity, the available resources are therefore used to pursue inclusive and people-centred solutions while transparently acknowledging the limitations of the current implementation.

5.3 Building trust and motivation

Trust was identified as a fundamental prerequisite for user participation, particularly regarding data privacy and the handling of personal information. Transparent communication about data use and protection measures is therefore essential. This should also include mechanisms for feedback and control in cases of potential privacy violations, for example when injured people, license plates, or other individuals are unintentionally captured in pictures. In addition, users need to perceive that their contributions have a tangible impact. This includes making the urban

impact of user behaviour visible.

At the same time, it was acknowledged that more advanced forms of impact visualisation—such as detailed statistics on time savings, CO₂ emissions, calories burned, air quality, weather impacts, or broader usage patterns—would be too resource-intensive to implement and would fall outside the project’s core focus. Instead of achieving behavioural change in the first place, the project’s objective is to collect data and gather information on people’s everyday mobility to calibrate the models of the digital toolkit. So, even if the resources were available, such statistics as mentioned before are not intended to be integrated, as they may affect people’s mobility behaviour. Instead, the emphasis should remain on simple, clear, and meaningful representations of impact and city statistics.

Gamification was discussed as a means to encourage long-term engagement, provided it is designed carefully. Incentives should reward meaningful participation, such as the number of contributions or the quality of information provided, rather than promoting competition. In particular, neither travel distance nor specific transport modes should be rewarded, as this could unintentionally influence user behaviour and distort the data collected as outlined before. Instead, users could accumulate points based on their level of engagement, for example, through reporting activities or providing relevant information. These points could then be exchanged for incentives such as discounts or participation in raffles for small rewards. The exact design and implementation of these mechanisms, however, should remain flexible and be adapted to the specific context of each pilot location.

The creation of avatars and highly personalised user profiles was also discussed, but is not foreseen within the scope of the project. While such features may enhance user engagement and provide a more playful and individualised experience, their implementation would require additional resources and development effort. Given that the project already focuses on gamification mechanisms to motivate participation, the introduction of advanced personalisation features was considered beyond the current scope.

5.4 Data and functional requirements

Several overarching requirements were identified across all components of the digital framework, particularly regarding functionality and data handling. Supporting multimodal mobility is a key aspect, including the ability to capture and analyse intermodal travel chains. While such intermodal tracking is technically feasible within Access Together, its representation and analysis in the Access Hub are not currently implemented, as this would significantly increase complexity. However, this feature may be considered as a potential extension in future developments of SmartUrbanity.

High-quality data collection and processing were identified as essential to the overall effec-

tiveness of the tools. Reports should be systematically structured, aggregated, and validated to ensure consistency and reliability. To achieve this, input formats need to be clearly defined, which may also require limiting the number of reporting categories in order to reduce ambiguity and improve data quality.

In addition to basic reporting, collecting contextual information—such as trip purpose—was considered important for understanding user behaviour. Pre-trip and post-trip questions can provide further insights into user expectations and experiences.

Real-time data, particularly on service reliability or dynamic conditions, was also seen as valuable, though its scope should remain clearly defined. In this context, very short-term events such as accidents should not be included in the reporting system, as they do not represent structural or recurring accessibility issues but rather temporary disruptions. In contrast, longer-lasting changes, such as construction sites, should be included in the reporting categories, as they can significantly affect accessibility over an extended period.

Additionally, the representation of accessibility within buildings and transport hubs cannot be fully covered within the Access Lab. This limitation is primarily due to the lack of reliable and sufficiently detailed data for such detailed indoor environments. While access to buildings—for example, entrances—can be considered within the analysis, more granular information on internal accessibility cannot be provided within the current scope.

Open access to the data generated within the project was identified as a key principle to support transparency and broader usability. Providing up-to-date and publicly available information can strengthen trust and enable additional applications beyond the project itself. At the same time, the use of standardised data formats is essential to ensure that the tools can be transferred and implemented in other contexts with minimal adaptation.

6 Summary

This report has been developed as Deliverable D2.1 of the SmartUrbanity project and serves as the conceptual and methodological foundation for the subsequent development of the project's digital toolkit. Structured around four interrelated objectives, it synthesises insights from literature analysis, stakeholder workshops, and user experience research to inform the design of accessible, inclusive, and evidence-based urban planning tools.

The first objective was to establish a broad theoretical foundation for the 15mC concept, encompassing its spatial, social, and mobility-related dimensions. Section 2 demonstrated that the 15mC, first introduced by Carlos Moreno in 2016, is structured around four core principles—proximity, diversity, density, and digitalisation—with the overarching aim of ensuring that all essential urban functions are reachable within 15 minutes on foot or by bicycle. Far from being a uniform prescription, the concept manifests differently across urban contexts: Paris has pursued rapid cycling infrastructure expansion and pedestrianisation, Barcelona has leveraged its Superblock model to reclaim street space, Melbourne has advanced 20-minute walkable neighbourhoods, and Utrecht is working toward a 10-minute city by 2040.

From a spatial and transport perspective, implementing the 15mC requires a fundamental reallocation of urban space away from private motorised vehicles toward pedestrians and cyclists. This is complemented by the integration of shared mobility services, MaaS platforms, and DRT, all of which extend the reach and flexibility of sustainable mobility options. The social and societal dimension of the concept underlines that proximity alone does not guarantee accessibility: services must be equitably distributed, physically usable, and culturally inclusive. Particular attention has to be given to the needs of children, older adults, people with disabilities, and women, whose safety perceptions and mobility behaviours differ substantially. Additionally, the report identifies freight transport as an underexplored dimension of the 15mC, arguing for a 15-minute logistics approach in which goods delivery is spatially reorganised through micro-hubs, cargo bikes, and coordinated governance frameworks. Together, these findings establish that the 15mC is a multidimensional urban transition framework requiring integrated action across infrastructure, land use, mobility services, and social policy.

The second objective was to identify and evaluate methodological approaches for measuring and analysing 15-minute accessibility, integrating both objective indicators and subjective perceptions. Section 3 addressed this by structuring the methodological review along two complementary dimensions. On the objective side, a broad set of indicators was identified and organised according to the four pillars of the 15mC. Proximity is primarily captured through time-based metrics such as the X-Minute City indicator, the 15-Minute City Fulfilment Rate, and composite indices that aggregate weighted accessibility to key amenities, including grocery stores, health-

care facilities, pharmacies, schools, and parks. Most studies rely on network-based assessments with fixed walking and cycling speeds. Density is operationalised through population density as a structural precondition for sustaining local services, while diversity is captured, e.g., through land-use mix indicators, Shannon Entropy, or the Simpson's Diversity Index. Digitalisation, though often overlooked in 15mC research, can be operationalised through composite indices such as the Digital Economy and Society Index, the Urban Digitalisation Index, or the Smart City Index.

On the subjective side, the report highlights that perceived accessibility—how individuals experience their ability to access destinations and conduct daily activities—diverges systematically from objective measures. Evidence from multiple studies shows that qualitative factors such as service reliability, comfort, safety perceptions, and built environment quality shape perceived accessibility more strongly than spatial distance alone. Tools such as the Perceived Accessibility Scale and the Short Perceived Walkability Scale were reviewed as established instruments for capturing these dimensions. The report further highlights that subjective assessments of walkability are consistently associated with higher walking levels, even when objective indicators suggest limited accessibility—a finding with direct implications for the design of SmartUrbanity's data collection instruments.

These methodological distinctions were further substantiated through interviews with three individuals experiencing everyday mobility constraints and seven experts from academia, planning practice, and transit operations. These interviews confirmed a recurring gap between formally calculated accessibility and lived experience. They highlighted factors such as unreliable lift infrastructure, a pronounced "last-mile" problem, digital and ticketing barriers, and gendered differences in safety perception, as well as expert caution against applying a rigid 15-minute threshold uniformly across population groups and contexts.

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The comparative review of existing accessibility analysis tools (Section 3.3) revealed a growing ecosystem of platforms that operationalise proximity using open geodata, mode-dependent travel time calculations, and weighted service categories. However, these tools predominantly focus on objective measures and largely disregard perceived accessibility. ABMs such as MAT-Sim, POLARIS, and mobiTopp were identified as complementary tools capable of simulating individual decision-making, activity chains, and behavioural adaptation, thereby offering a

demand-side perspective that static accessibility measures cannot provide.

The third objective was to develop a conceptual framework for the SmartUrbanity digital tools, specifically the Access Together mobile application and the Access Lab web platform. Section 4 presented the integrated ecosystem developed to address the gaps identified in the theoretical and methodological review. The framework establishes a continuous feedback loop between citizens, who contribute mobility and perception data, and decision-makers, who use aggregated analytical outputs to evaluate and compare urban interventions.

Within this framework, Access Together serves as the primary data collection interface, combining passive GPS-based tracking with active user inputs such as short questionnaires, barrier reports, and perception-based evaluations. This dual approach enables the construction of an experiential data layer that links observed behaviour with subjective perceptions across diverse sociodemographic profiles. The Access Lab encompasses both the Access Hub—a participatory web platform for map-based reporting, voting, and verification of accessibility issues—and the Access Atlas, a GIS-based accessibility analysis tool that combines open geographic data, transport networks, and service locations to produce socially differentiated accessibility profiles. The DSS builds on these outputs to provide policymakers with advanced simulation and scenario evaluation capabilities, integrating both quantitative indicators and qualitative citizen feedback into a single analytical framework. This architecture directly responds to the core gaps identified in existing tools: integrating subjective accessibility dimensions, differentiating accessibility by user profile, and linking citizen-generated data to evidence-based planning processes.

The fourth objective was to derive concrete requirements and methodological guidelines for tool development, grounded in stakeholder engagement and user experience research. Sections 4.2 and 5 synthesised findings from five regional workshops conducted across the pilot cities of Rome, Karlsruhe, İzmir, the Lyon Metropolitan Area, and the Greater Zurich Area, as well as from a structured literature review and persona-based usability planning.

Stakeholder workshops consistently identified ease of use, minimal reporting effort, and transparent feedback mechanisms as critical success factors for citizen-facing tools. Users emphasised the need to distinguish between temporary incidents and persistent infrastructure deficiencies, and expressed a clear preference for structured, moderated input formats over open-ended communication channels. Motivational design was seen as important but should reward civic engagement—such as reporting quality and frequency—rather than travel behaviour, to avoid distorting the collected data. For the Access Atlas and DSS, stakeholders prioritised clear and informative visualisations, transparent routing logic, and compatibility with existing institutional systems and planning processes.

The internal synthesis workshop identified inclusiveness, digital literacy, and the fragmentation of existing mobility applications as key barriers to adoption. In response, the methodologi-

cal guidelines emphasise the need for a unified login system across tools, accessible colour schemes and multilingual interfaces, and simplified input workflows. Trust was identified as a prerequisite for sustained participation, requiring transparent communication about data use and a design focus on simple, meaningful representations of urban impact rather than behavioural metrics that could influence user behaviour and compromise data integrity.

Several limitations should be considered when interpreting the findings of this report. As already outlined in section 2.1, the underlying literature analysis is subject to potential selection bias, as it prioritised readily accessible, mostly English-language academic sources and may under-represent relevant work published through other channels or in other languages. The evidence base also reflects a geographical imbalance, drawing predominantly on Western European and North American contexts, which may limit its applicability to other urban settings. In addition, the review relies in part on grey literature which has not undergone peer review and should be interpreted with corresponding caution, while evidence on tools for measuring perceived accessibility remains comparatively limited compared to objective indicators. Similarly, the qualitative interviews conducted for this Deliverable involved a small sample of three affected individuals, all based in Berlin, and seven experts. While these interviews provided valuable first-hand insights, they cannot be considered representative of the diverse mobility contexts across the five SmartUrbanity pilot cities.

Concerning the stakeholder workshops, participation across the five pilot sites was uneven across stakeholder groups, meaning the identified requirements may not fully represent all user groups. Furthermore, the transferability of findings across pilot locations is limited by context-specific factors such as local governance structures and digital infrastructure. Finally, as digital urban planning tools continue to evolve rapidly, the comparative review reflects the state of the art at the time of writing and may require future updating. These limitations do not undermine the report's overall conclusions but should be kept in mind when applying its findings to the subsequent development of the SmartUrbanity digital toolkit.

Taken together, the findings and frameworks presented in this report provide a structured knowledge base that directly informs the subsequent development and implementation of the SmartUrbanity digital toolkit. By combining theoretical grounding in the 15mC literature, methodological rigour in accessibility measurement, and empirical sensitivity to stakeholder needs, Deliverable D2.1 establishes the conceptual foundations necessary for developing tools that are not only technically sound but also inclusive, user-centred, and practically relevant across diverse urban contexts. The insights gained will be further elaborated and operationalised in the subsequent project Deliverables, particularly D2.3 (tool modelling) and D2.4 (user experience research).

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