

This research investigates long-distance walking routes as strategic infrastructures for sustainable mobility, territorial development, and responsible tourism, addressing a gap in scientific studies characterized by fragmentation and lack of unified methodologies. The work introduces an integrated framework combining modelling, simulation, and evaluation tools, with original contributions across four research questions. RQ1 presents a methodology for classifying trails, a novel concept of trail life cycle, a cost function treating travel time as benefit, network and demand analysis methods, and a simulation architecture based on Causal Loop Diagrams and System Dynamics. RQ2 develops a multidimensional set of indicators for Level of Service, risk assessment, equity, gender inclusivity, and sustainability. RQ3 defines “trail logistics,” proposes the PATHS Module and P.A.T.H.S. methodology for new design standards, and integrates smart trail concepts with Industry 4.0 technologies. RQ4 introduces gender and inclusion dimensions as structural criteria, analysing differentiated risk perception and usage modes. Future research perspectives, framed through the PATHS methodology (Place, Accessibility and Inclusion, Technological Integration, Harmonization, Sustainability), envisage expanded applications for pedestrian mobility, urban contexts, advanced monitoring, inclusive design, and strategic planning. Elevating pedestrian infrastructure to a strategic level enhances safety, inclusivity, environmental sustainability, public health, local economy, and territorial resilience, positioning active mobility as a central component of sustainable and equitable transport systems.

Questa ricerca indaga i percorsi pedonali a lunga distanza come infrastrutture strategiche per la mobilità sostenibile, lo sviluppo territoriale e il turismo responsabile, affrontando una lacuna negli studi scientifici caratterizzati da frammentazione e mancanza di metodologie unificate. Il lavoro introduce un quadro integrato che combina strumenti di modellazione, simulazione e valutazione, con contributi originali in quattro questioni di ricerca. RQ1 presenta una metodologia per la classificazione dei sentieri, un nuovo concetto di ciclo di vita del percorso, una funzione di costo che tratta il tempo di percorrenza come beneficio, metodi di analisi della rete e della domanda e un’architettura di simulazione basata su Diagrammi a Loop Causali e System Dynamics. RQ2 sviluppa un set multidimensionale di indicatori per il Livello di Servizio, la valutazione dei rischi, l’equità, l’inclusione di genere e la sostenibilità. RQ3 definisce la “logistica dei cammini”, propone il Modulo PATHS e la metodologia P.A.T.H.S. per nuovi standard di progettazione e integra il concetto di smart trail con tecnologie Industria 4.0. RQ4 introduce le dimensioni di genere e inclusione come criteri strutturali, analizzando percezioni di rischio e modalità di utilizzo differenziate. Le prospettive di ricerca future, inquadrare attraverso la metodologia PATHS (Place, Accessibility and Inclusion, Technological Integration, Harmonization, Sustainability), prevedono applicazioni estese alla mobilità pedonale, ai contesti urbani, al monitoraggio avanzato, alla progettazione inclusiva e alla pianificazione strategica. Elevare l’infrastruttura pedonale a livello strategico migliora sicurezza, inclusività, sostenibilità ambientale, salute pubblica, economia locale e resilienza territoriale, posizionando la mobilità attiva come componente centrale di sistemi di trasporto sostenibili ed equi.

Gaetana Rubino

Analysis and design of pedestrian itineraries:
a multidimensional approach to sustainable mobility



Doctoral Programme in Civil, Environmental
and Industrial Engineering

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To my parents, my guiding light and example in life. To Benedetta, my life, for her patience.
To Roberta, for her discreet and silent support. To my supervisor, Prof. Domenico Gattuso, for
guiding me with wisdom and encouragement throughout this journey.
To the path, to slowness, to awareness: this work is the result of the road travelled both within
and beyond me.

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Al cammino, alla lentezza, alla consapevolezza: questo lavoro è frutto della strada percorsa
dentro e fuori di me.

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Abstract/Sommario

This research investigates long-distance walking routes as strategic infrastructures for sustainable mobility, territorial development, and responsible tourism, addressing a gap in scientific studies characterized by fragmentation and lack of unified methodologies. The work introduces an integrated framework combining modelling, simulation, and evaluation tools, with original contributions across four research questions. RQ1 presents a methodology for classifying trails, a novel concept of trail life cycle, a cost function treating travel time as benefit, network and demand analysis methods, and a simulation architecture based on Causal Loop Diagrams and System Dynamics. RQ2 develops a multidimensional set of indicators for Level of Service, risk assessment, equity, gender inclusivity, and sustainability. RQ3 defines "trail logistics," proposes the PATHS Module and PATHS methodology for new design standards, and integrates smart trail concepts with Industry 4.0 technologies. RQ4 introduces gender and inclusion dimensions as structural criteria, analysing differentiated risk perception and usage modes. Future research perspectives, framed through the PATHS methodology (Place, Accessibility and Inclusion, Technological Integration, Harmonization, Sustainability), envisage expanded applications for pedestrian mobility, urban contexts, advanced monitoring, inclusive design, and strategic planning. Elevating pedestrian infrastructure to a strategic level enhances safety, inclusivity, environmental sustainability, public health, local economy, and territorial resilience, positioning active mobility as a central component of sustainable and equitable transport systems.

La presente ricerca indaga i percorsi pedonali a lunga distanza come infrastrutture strategiche per la mobilità sostenibile, lo sviluppo territoriale e il turismo responsabile, affrontando una lacuna negli studi scientifici caratterizzati da frammentazione e mancanza di metodologie unificate. Il lavoro introduce un quadro integrato che combina strumenti di modellazione, simulazione e valutazione, con contributi originali in quattro questioni di ricerca. RQ1 presenta una metodologia per la classificazione dei sentieri, un nuovo concetto di ciclo di vita del percorso, una funzione di costo che tratta il tempo di percorrenza come beneficio, metodi di analisi della rete e della domanda e un'architettura di simulazione basata su Diagrammi a Loop Causali e System Dynamics. RQ2 sviluppa un set multidimensionale di indicatori per il Livello di Servizio, la valutazione dei rischi, l'equità, l'inclusione di genere e la sostenibilità. RQ3 definisce la "logistica dei cammini", propone il Modulo PATHS e la metodologia PATHS per nuovi standard di progettazione e integra il concetto di smart trail con tecnologie Industria 4.0. RQ4 introduce le dimensioni di genere e inclusione come criteri strutturali, analizzando percezioni di rischio e modalità di utilizzo differenziate. Le prospettive di ricerca future, inquadrare attraverso la metodologia PATHS (Place, Accessibility and Inclusion, Technological Integration, Harmonization, Sustainability), prevedono applicazioni estese alla mobilità pedonale, ai contesti urbani, al monitoraggio avanzato, alla progettazione inclusiva e alla pianificazione strategica. Elevare l'infrastruttura pedonale a livello strategico migliora sicurezza, inclusività, sostenibilità ambientale, salute pubblica, economia locale e resilienza territoriale, posizionando la mobilità attiva come componente centrale di sistemi di trasporto sostenibili ed equi.

Chapter 1

Methodological Approach

1.1 Research Background

1.1.1 Evolution of the mobility paradigm in favour of pedestrianism

Traditionally, transport engineering and urban planning have paid particular attention to motorized vehicle traffic, prioritizing projects that relegated pedestrian environments and infrastructure to "residual spaces" [1]. This historical prioritization of speed and cars, aimed at achieving efficiency and reducing travel times, has significantly influenced design, affecting both infrastructural systems and pedestrian mobility. At the beginning of this new century, a profound paradigm shift is underway, tending to overturn the mobility hierarchy (Figure 1.1), placing walking at the base as the most natural, healthy, equitable and sustainable mode of transport [2], as highlighted by the results of the second edition of the study on the urban mobility transition on costs and benefits, conducted by EIT Urban Mobility [3].

Figure 1.1 - Mobility Pyramid.



Source: Eit Urban Mobility

Pedestrian mobility, often also referred to as "slow" or "soft" mobility, is thus increasingly gaining importance in both urban centres and along tourist routes, due to its environmental, social and economic benefits. Promoting walking and cycling (active mobility) contributes to decongesting vehicular traffic, reducing energy consumption and pollutant emissions and improving public health, with significant economic benefits for the population [4].

As highlighted by CEREMA, the advantages of promoting active mobility involve several spheres [5]:

- health: promotion of active mobility aimed at physical well-being (calorie consumption, obesity reduction, muscle exercise, breathing fresh air, etc.), thus preventing diseases and benefiting public health;

- economic: the presence of pedestrians makes urban environments and neighbourhoods more liveable, increasing the value of economic activities and private properties;
- ecological: walking is the only mode of transport that does not impact the environment either directly or indirectly;
- intermodality: public transport is seen as "enhanced pedestrianism," i.e. infrastructure aimed at increasing pedestrians' ability to move on foot;
- accessibility: pathways accessible also to persons with reduced mobility (PRM) are additionally favourable for pedestrians. Therefore, the design of pedestrian infrastructure aims to enable access for the most vulnerable pedestrians (elderly, children, blind persons, wheelchair users, etc.);
- uses: it is important to understand pedestrian practices within the context; it is interesting to explore the elements present along a natural (trees) or artificial (benches, fountains, restrooms, etc.) route that positively influence attractiveness or, conversely, hinder it (e.g., presence of inconvenient parking); as well as the "perceived" elements, meaning the actual use practiced in the space, which influences pedestrian perception.

At the political level, the European Union and national governments have placed pedestrian mobility at the centre of strategies for sustainable cities. The European Green Deal and the Urban Mobility Framework (Sustainable and Smart Mobility Strategy) explicitly promote the strengthening of soft mobility. The European Commission includes active transport modes (walking and cycling) among key measures to improve air quality and reduce pollution and urban congestion [6].

This orientation is directly linked to the United Nations Sustainable Development Goals (SDG) [7]. SDG 11.2 requires that by 2030, a safe, affordable and sustainable urban transport system be guaranteed for all, with particular attention to the most vulnerable population groups (women, the elderly, children, persons with disabilities). Sensitivity towards active mobility and especially emerging inclusion in international policies, is also reflected in the scientific literature. Recent studies assert that walkability plays a key role in contemporary planning, being intricately connected to pedestrian safety, environmental sustainability and overall liveability. Pedestrian-oriented mobility and urban space design indeed promote active mobility, reduce dependence on private cars and foster healthier, more resilient communities [8]. About inclusion, different profiles of pedestrian infrastructure users are highlighted. For example, recent research shows that women, on average, make fewer work trips and more multiple trips related to family care tasks, relying more heavily on public transport and walking [9]. Furthermore, women's mobility choices are often influenced by safety concerns (harassment, theft, violence), which may lead to suppressing or postponing walking trips [10]. These findings underline the importance of a mobility approach centred on pedestrians' needs, which simultaneously considers gender differences and the needs of vulnerable groups.

1.1.2 Tourist and long-distance pedestrian mobility

Beyond the realm of daily urban trips, pedestrian mobility has gained considerable attention in the tourism sector, leading to the significant emergence and growth of "slow tourism" and long-distance walking routes. The walking tourism sector has become so relevant as to merit its own definition as a form of mobility "in which walking in the natural environment constitutes a significant part of the journey." It includes excursions, trekking and long-distance walks and

encompasses specialized techniques such as "Nordic walking" [11]. As stated by the World Tourism Organization (UNWTO): *"Walking tourism is now one of the most popular ways to experience a destination. It allows tourists to engage more with local people, nature and culture. It also meets recent travellers' need of physical and healthy activities during their travel. Walking tourism can be developed anywhere as a sustainable tourism offer with relatively small investment. It can bring about social and economic benefits to residents and communities if properly developed and managed."* [12].

This phenomenon, particularly evident in Italy since the early 2000s, manifests on itineraries designed to connect rural areas, historic towns and natural landscapes, promoting a deeper engagement with the territory. Long-distance routes, often ancient pilgrimage paths, can play a vital economic role globally, generating substantial revenue and attracting millions of visitors. These routes frequently combine religious, cultural and recreational motivations, offering participants forms of spiritual renewal, immersive cultural experiences and a profound search for personal meaning and well-being.

Pedestrian tourism, particularly through the development and promotion of long-distance "walking routes," acts as a powerful and increasingly recognized catalyst for sustainable regional development. These routes can help revitalize rural areas and historic towns, promoting economic growth within local communities through increased tourist flows, commerce and service provision; they directly contribute to job creation and the sustenance of local businesses, offering vital economic opportunities in regions otherwise prone to depopulation or economic stagnation. Through walking routes, economic benefits are highly connected to cultural preservation, environmental management and community well-being. A synergistic relationship in which the very act of walking fosters a deeper appreciation for the local context is created. Unlike many forms of mass tourism, which can be harmful to the environment, walking tourism promotes slow and experiential engagement. This mode of travel naturally encourages a more symbiotic relationship between tourists and local communities, where a virtuous circle links economic activity with the conservation of natural and cultural landscapes. The physical act of walking itself fosters a deeper and more mindful appreciation of the environment and local heritage, making it an ideal tool for sustainable development.

In addition to generating direct economic impacts, pedestrian tourism promotes the preservation and enhancement of cultural heritage, encouraging sustainable tourism practices that reverberate benefits for both visitors and local communities, fostering a deeper appreciation of the unique characteristics of the territories traversed. This form of tourism can also contribute to diversifying and stabilizing regional economies, reducing excessive reliance on seasonal tourism models.

Several studies have analysed and schematized the benefits of walking tourism [13], [14], [15], [16], [17]; among others:

- Cost-effectiveness and simplicity: minimal investments without the need for specific assets as required by other types of sports or adventure tourism;
- High market potential: an observed growing demand;
- Seasonality reduction: allows the balancing of tourist flows across multiple periods or the entire year;
- Complementarity and mitigation of overtourism: complements other forms of tourism and helps balance tourist flows geographically, countering concentration phenomena;
- Sustainability: if properly developed and managed;
- Economic development and quality-of-life improvement: the preservation of natural environments and cultural heritage primarily benefits residents, alongside the economic development generated by tourist flows;

- Active lifestyles: promote active mobility, reducing risks associated with sedentary-related pathologies (hypertension, obesity, etc.).

Some research has also highlighted benefits for the tourists themselves [18]:

- Convenience: requirement for inexpensive equipment;
- Flexibility: possibility of choices appropriate to demographic characteristics (gender, age) in terms of length and difficulty level;
- Health: physical and mental benefits related to the environmental context;
- Awareness: enables understanding of the heritage, environment and culture of the territories traversed, discovering the uniqueness of the places;
- Sociability: allows direct interaction with local communities;
- Holism: the individual is engaged entirely, through the five senses, in a unified mind-body experience.

However, it is crucial to recognize the importance of careful and strategic management of services to mitigate potential negative externalities, such as localized congestion, increased cost of living for residents in popular areas, or environmental stress if carrying capacities are exceeded. Therefore, the effective and sustainable promotion and management of these routes requires robust mechanisms for data collection and sharing to continuously monitor demand, supply and their multidimensional impacts (economic, social, environmental), thereby supporting the strategic planning of destinations.

1.1.3 Characteristics of pedestrian mobility compared to other transport modes

Pedestrian mobility possesses a set of distinctive characteristics that differentiate it from other transport modes and underline its growing importance (Table 1.1). Pedestrians are inherently defined by individual choices, highly variable movement dynamics and a marked vulnerability within the transport system. Their behaviour patterns are often less predictable than those of motorized vehicles, although high pedestrian densities can significantly constrain their optimal choice and freedom of movement. The intrinsic vulnerability and variable dynamics of pedestrians make it imperative to focus on highly qualitative and detailed infrastructure design elements, extending well beyond simple capacity metrics. This creates a logical sequence in which the unique human characteristics of walking require a more nuanced, perception-oriented approach to infrastructure, linking to the concept of "perceived safety." Since pedestrians are not enclosed in protective shells like vehicle occupants and their movement is highly adaptable and sensitive to the surrounding environment (e.g., they can choose different routes, stop and interact), the design of their environment cannot concern only capacity or speed. Instead, it must prioritize comfort, safety (both objective and subjective) and the quality of places. This means that factors such as surface regularity, adequate lighting and the presence of urban furniture become critical, as they directly mitigate vulnerability and influence pedestrian decision-making processes. Indeed, pedestrian movement is extremely sensitive to the qualitative conditions of the infrastructure. Factors such as sidewalk surface attributes (roughness, friction, texture, heat retention and maintenance) directly and significantly influence pedestrian comfort, safety and overall mobility choices. For example, poorly maintained, uneven, or slippery surfaces contribute to discomfort and increase the risk of accidents. Beyond surface quality, the usability and accessibility of sidewalks are shaped by a multitude of factors, including width, presence of obstacles, slope, availability of street furniture, trees, adequate lighting and essential accessibility features such as ramps and tactile pavements. A well-designed infrastructure system makes walking an attractive and viable alternative for short trips, reducing dependence on motorized transport and integrates

seamlessly with efficient public transport systems for longer journeys. As observed, the promotion of pedestrian mobility produces substantial benefits across multiple domains. However, in the dimension of long-distance pedestrian mobility, some distinctive characteristics emerge most strongly: the experiential component, the deep relationship with the traversed territory, the need for continuous and high-quality infrastructure and the extended physical, psychological and social benefits. The voluntary and often transformative nature of walking, combined with its environmental sustainability and increasing institutional and cultural recognition, makes it an emerging paradigm of soft mobility, capable of integrating dimensions of health, slow tourism and territorial regeneration. Comparing walking routes with other forms of mobility helps clarify the strategic role they can assume in sustainable mobility policies, requiring specific design, regulatory and evaluative approaches.

Table 1.1 - Key characteristics of pedestrian mobility vs. other transport modes.

CRITERION	MOTORIZED VEHICLE	BICYCLE	PEDESTRIAN MOBILITY (URBAN/DAILY)	LONG-DISTANCE PEDESTRIAN MOBILITY (WALKING ROUTES)
Primary function	Movement (efficiency, speed)	Movement (efficiency, speed)	Movement and place (sociality, recreation)	Immersive experience, inner well-being, territorial discovery
Vulnerability	Low (protected by the vehicle)	Medium (exposed but faster)	High	High (prolonged exposure, fatigue, climatic conditions)
Behaviour predictability	High (regulated by traffic rules)	Medium (regulated but with greater flexibility)	Low (personal choice, variable dynamics)	Low (autonomy of choice, personal motivations, flexible timing)
Space requirements	Minimum defined widths, dedicated infrastructure	Minimum defined widths, dedicated infrastructure	Perceived as flexible, but requires quality and ample spaces	Need for continuous, signposted, welcoming routes integrated with the landscape
Sensitivity to infrastructure quality	Low (focus on capacity and speed)	Medium (sensitive to surface and safety)	Extremely high (surface, width, obstacles, street furniture, lighting)	Very high (surface, resting stages, safety, services, landscape)
Environmental impact	High (emissions, noise, land consumption)	Low (zero emissions, sustainable)	Very low (zero emissions, sustainable)	Very low (slow walking, sustainability, territorial enhancement)
Health benefits	Limited or negative (sedentary behaviour, pollution)	Significant (physical activity)	Significant (psychophysical, reduction of chronic diseases)	Very high (psychological benefits, mental regeneration, deep prevention)
Dependence on fuel/energy	High	None (or minimal for e-bike)	None	None
Typical travel distance	Long	Short-medium	Short-medium (daily), long (touristic)	Long (over 50 km, multi-day)
Infrastructure priority (Historical → Contemporary)	Primary focus	Variable, increasing	Residual space → Focus of attention	Historically marginal → Growing institutional and cultural attention

1.2 Research gap

Despite the recognized benefits and the growing awareness of the importance of pedestrian mobility, significant and persistent challenges hinder the effective planning, design and

management of pedestrian infrastructure and services. Often treated in planning as a “residual” form of mobility or as a support to other modes of transport, pedestrian mobility is characterized by narrow or inadequate spaces with respect to several parameters, such as poor quality, insufficient width, numerous obstacles and inadequate maintenance, all factors that contribute to pedestrian discomfort and increase the risks of accidents [19]. Globally, more than 270,000 pedestrians lose their lives each year due to road accidents, with millions of others suffering injuries or permanent disabilities [20]. It has been observed that in road accidents, the most severe consequences often affect those outside the vehicle [21]. A complex interaction of factors contributes to pedestrian accidents, including the road environment, vehicle type and design; for example, larger SUVs and heavy trucks are associated with higher mortality risks [22], adverse weather conditions and risky behaviours both by drivers (e.g., speeding [23], drunk driving [24], distraction) and pedestrians (e.g., distraction due to mobile phones, non-compliance with signals [25]). The absence or poor design of critical pedestrian facilities, such as a lack of sidewalks, insufficient lighting and unclear or unsafe crossings (e.g., unmarked pedestrian crossings on multi-lane roads with high traffic volumes), significantly exacerbate these risks [20]. Furthermore, qualitative issues such as long waiting times at traffic lights, inadequate separation from high-speed vehicular traffic and poorly lit underpasses contribute to a risky or distressing pedestrian experience. It is evident, therefore, the strong contradiction between the multiple recognized benefits of pedestrian mobility and the significant shortcomings in terms of safety and quality in current infrastructural and planning practices, which are responsible for high mortality rates. This raises the question: if pedestrian mobility is so advantageous, why is it consistently underfunded, poorly designed and unsafe? It is therefore necessary to orient planning and design towards a better translation of the awareness of the importance of pedestrian mobility into specific policies and technical guidelines. To achieve this, an in-depth analytical exploration of the topic, supported by new simulations, is required.

For touristic routes and “walking itineraries,” specific challenges arise. First, there are no clear definitions of walking routes and trails, nor criteria for their classification. Furthermore, poor design of such infrastructures often results in widespread physical barriers such as unsuitable paths, irregular surfaces and excessive slopes, which are particularly problematic for people with disabilities. Moreover, although walking tourism generates significant economic benefits, it can also create negative externalities in popular destinations, such as congestion, increased cost of living for residents and rising property values, which can negatively affect the well-being of the local population [26]. The effective promotion and sustainable management of these routes are further hampered by the need for improved mechanisms for data collection and sharing, as well as comprehensive observatories to monitor demand, supply and multidimensional impacts [27].

This contradiction highlights the urgent need for research that not only identifies these problems but also develops practical, implementable and politically sustainable solutions. This includes the design of performance indicators and simulations capable of evaluating and comparing pedestrian infrastructures, the development of design guidelines and the exploration of innovative management strategies to overcome these systemic barriers.

Although in recent years there has been growing research interest in the topic of pedestrian mobility, a critical analysis reveals several interconnected gaps that justify further in-depth investigation.

1.2.1 Characteristics of pedestrian mobility and infrastructure design

Despite a contemporary shift towards human-centred design, the full and seamless integration of pedestrian needs into urban planning and design processes remains largely incomplete. Current

research acknowledges the distinctive characteristics of pedestrians, such as personal choice, variable dynamics and intrinsic vulnerability, as well as the critical importance of detailed infrastructural elements such as surface quality, width and accessibility features for comfort and safety [1]. However, a persistent challenge lies in effectively balancing the often-conflicting requirements arising from different personal characteristics (e.g., varying walking speeds with practical design parameters). The literature indicates that, although urban street design guidelines are well-developed for measuring space requirements for known pedestrian volumes in motion, they are less advanced in the planning of pedestrian infrastructures capable of actively encouraging pedestrian movement. There is a clear need for more comprehensive design guidelines that explicitly incorporate qualitative aspects such as adequate seating, shade, shelter, appropriate urban furniture and integrated greenery, recognizing their significant role as determinants of pedestrian activity and overall experience [1] both in urban and extra-urban contexts.

1.2.2 Evaluation of Pedestrian Level of Service (PLOS)

The concept of Pedestrian Level of Service (PLOS) is widely adopted to objectively quantify the operational quality of pedestrian facilities [28]. However, there is no agreement on the complete set of factors that should be included in PLOS calculations [29]. The first PLOS models, directly derived from road levels of service, were narrow and engineering-focused, relying heavily on volume-to-capacity ratios and freedom of movement. Although the concept has evolved over time to incorporate a wider range of variables (e.g., pedestrian, traffic and geometric characteristics) and there is growing interest in the built environment and urban landscape, a fundamental tension persists between objective and subjective measures. Many existing PLOS models depend on extensive pedestrian surveys, which may lead to subjective results and often fail to adequately capture pedestrians' desires or expectations. On the other hand, the Highway Capacity Manual (HCM) methodology [30], while providing quantitative metrics, has been criticized for not encompassing a sufficiently broad range of factors influencing PLOS. Although recent research has attempted to integrate both qualitative and quantitative factors, also employing innovative approaches such as machine learning to determine PLOS based on influencing factors such as interpersonal distance, vehicle volume, traffic noise and pedestrian path surface [29], there remains a lack of research based on revealed pedestrian perceptions or expert consensus. Furthermore, while physical safety factors are well documented, research on the crucial relationship between pedestrian safety perception and specific pedestrian environmental factors is still underdeveloped [31].

1.2.3 Safety and inclusion

As highlighted in the introduction, pedestrian safety remains a critical global issue, with a high incidence of deaths and injuries. Although the main risk factors (road environment, vehicle type, driver behaviour) are well analysed, there is a gap in considering pedestrians' subjective perception of safety. The existing literature highlights important demographic differences, noting that women are generally less satisfied than men with comfort and safety in pedestrian facilities [32] and that there are distinct preferences for pavement attributes among different age groups [19]. Despite the recognition of inclusive design principles such as "design for all," practical problems persist, particularly with physical barriers in natural areas and trails, which severely limit accessibility for persons with reduced mobility (PRM). At the root of the issue there is also the absence of clear and readily available information on accessible routes and their specific levels of difficulty for individuals with different mobility needs. Moreover, the need to address and reduce

economic barriers to make “walking itineraries” truly accessible, especially for vulnerable groups, is an identified area requiring further attention.

1.2.4 Tourist pedestrian mobility

The research gaps highlighted in pedestrian mobility become even broader with reference to tourist pedestrian mobility. Although various classifications exist for difficulty and accessibility, there is a lack of unified terminology and a basic classification between walking itineraries and trails. Furthermore, there is a gap in research regarding the effects of pedestrian mobility planning, particularly in the comprehensive quantification of such impacts from environmental, social and economic perspectives. Moreover, although the concept of the “product life cycle” is applied to tourist destinations in general [33], its specific and detailed application to the unique evolution, management and long-term sustainability of “walking itineraries” requires more dedicated exploration. Finally, with reference to tourist pedestrian mobility, there is a clear need to analyse and adapt the basic concepts of transport theory: from demand, to supply with its related cost function; from inclusiveness to risk perception; from safety and security to specific design criteria. Not to be forgotten is the absence of specific studies on the logistics of walking itineraries, another wide potential research field currently underexplored.

The gaps identified in infrastructure design, PLoS evaluation, safety, inclusivity and pedestrian tourism are not isolated but form an interconnected network, indicating a fundamental deficit in approaches to pedestrian mobility planning and management. This fragmentation of knowledge and methodologies hinders effective and systemic solutions. For example, the lack of comprehensive guidelines for qualitative design directly affects pedestrian comfort and perceived safety, which in turn negatively influences overall PLoS. Likewise, neglecting gender or disability perspectives in design leads to non-inclusive infrastructures, which then negatively affect user experience and potentially limit the broader socio-economic benefits of pedestrian tourism. The absence of robust and shared data further exacerbates these problems by hindering effective planning and monitoring. This framework highlights the need for an integrated methodological approach capable of bridging these disciplinary and methodological divides.

1.3 Motivations

With respect to the large research gap concerning pedestrian mobility, the present study focuses on walking itineraries and trails to address several emerging needs. On the one hand, recent sustainability and climate mitigation goals require the development of urban and tourist pedestrian infrastructures capable of decarbonizing mobility. On the other hand, demographic and social phenomena (population aging, greater female participation in economic life, demand for active tourism experiences) require more inclusive and personalized mobility solutions. Walking itineraries also represent an opportunity for territorial regeneration and the promotion of slow tourism, with positive impacts on the local economy.

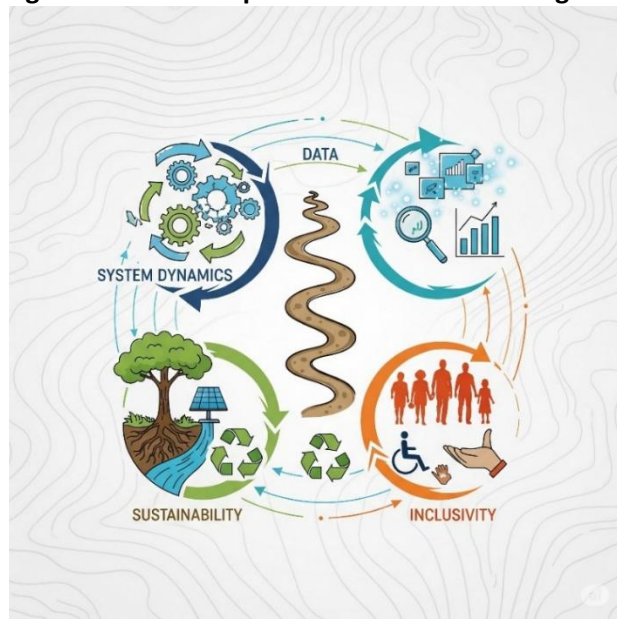
To seize these opportunities, it is necessary to equip research and practice with innovative analysis and design tools, including:

- **quantitative evaluation methods:** updated indicators and metrics to measure pedestrian route performance (pedestrian flow, level of service, comfort, accessibility). For instance, the literature identifies key criteria for effective pedestrian itineraries (safe, interconnected, pleasant and accessible routes for all) but there is a lack of integrated and standardized methods to quantify such aspects in different contexts;

- **advanced simulation models:** simulation tools at the micro (pedestrian behaviour models), meso (walking demand models) and macro levels that can reconstruct pedestrian flows in real-world scenarios. This implies considering variable speeds, stops, environmental influences and pedestrian interactions. It is necessary to develop calibrated models for specific touristic and urban contexts, integrating real data and user preferences;
- **updated design guidelines:** infrastructure design standards and recommendations that reflect current population needs (inclusion of different or vulnerable pedestrians, safety expectations, psychological comfort) and incorporate universal design principles. Such guidelines must stem from an interdisciplinary approach (transport engineering, urban planning, gender studies, public health) and be based on empirical and modelling evidence.

These motivations justify an integrated methodological approach (Figure 1.2): it is necessary to combine systemic approaches, field surveys (survey, direct monitoring) and pedestrian mobility simulations to achieve a comprehensive understanding of user behaviours. Only in this way will it be possible to develop updated, inclusive, sustainable and data-driven decision-making and design tools.

Figure 1.2 - Main aspects of the research at a glance.



1.4 Research questions and study phases

In summary, from the analysis of the literature and operational practices, some significant gaps emerge. First, there is a lack of specific quantitative studies on pedestrian mobility: compared to the abundant literature on vehicular traffic models, there are still few works that analyse pedestrian flows in depth, especially in the context of slow tourism and unconventional routes. Pedestrian-centred urban planning is deficient in terms of forecasting environmental, economic and social impacts. Second, consolidated tools for the evaluation of pedestrian performance are lacking; there is no unified framework of indicators (like roadway levels of service) to measure flow, comfort and safety of walking itineraries. Although it is known that interventions mostly of an urban type, such as pedestrian areas, raised crossings and speed bumps, reduce vehicle-pedestrian

collisions, there is still no systematic method to evaluate how such measures affect the overall performance of a route and which measures should be adopted when pedestrian infrastructure crosses both urban and extra-urban contexts. Finally, safety and inclusion aspects are not always fully integrated into decision-making processes: for instance, in the design of tourist walking routes, greater emphasis would be needed on the study of perceived safety and risk by several types of users, particularly the most vulnerable components of society.

In light of these gaps, some research questions clearly emerge:

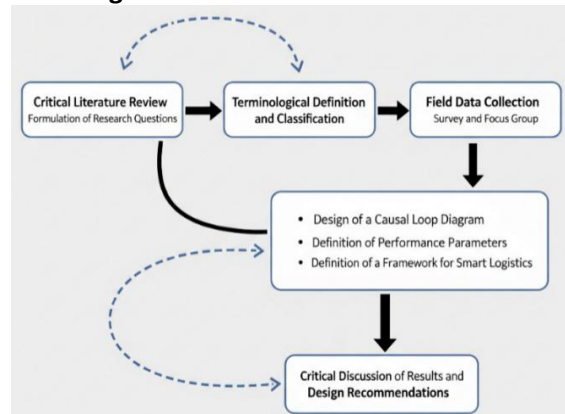
- **RQ1:** Which methodological approach, based on the integration of modelling, simulation and evaluation tools, can be developed to effectively analyse the interactions between demand and supply in long-distance walking itineraries? (Ch. 2,3,4,5);
- **RQ2:** How can performance, safety, sustainability and inclusiveness of a walking itinerary be defined, measured and integrated into a unified set of evaluation indicators? (Ch. 6);
- **RQ3:** Does a “logistics of walking itineraries” exist? How can the introduction of new design standards and innovative technologies address logistical, safety and inclusiveness issues, thereby improving the overall walker’s experience? (Ch. 7 and 8);
- **RQ4:** What are the gender and inclusion implications in tourist pedestrian mobility and how can they be integrated into the design, evaluation and management of walking itineraries? (Ch. 3, 4, 6 and 7).

These questions will guide the proposed integrated methodology, which combines a systemic approach (System Dynamics), field surveys, data analysis and simulation design, laying the foundation for the study of long-distance tourist pedestrian infrastructures.

In the course of this thesis, a process articulated in multiple sequential and integrated phases was adopted (Figure 1.3). First, a critical review of the existing literature was conducted, focusing on pedestrian mobility, tourist walking itineraries, performance evaluation tools and simulation models. This analysis made it possible to identify the main gaps, highlighting the absence of specific tools for the analysis of systemic, logistical and inclusive dynamics in long-distance walking itineraries and led to the formulation of the research questions discussed in the previous section.

Subsequently, terminological definitions and classification of the fundamental components of the mobility system related to long-distance walking itineraries were developed, a necessary step to build a shared conceptual basis. In parallel, field data collection was initiated, both quantitative and qualitative, through direct surveys on selected walking routes, administration of questionnaires to users, analysis of existing datasets and the conduction of interviews and focus groups with technical stakeholders, institutional actors and third sector representatives involved in the management and promotion of walking itineraries. These data served the dual purpose of validating the formulated hypotheses and elaborating an integrated set of indicators to evaluate the safety, sustainability, inclusiveness and overall performance of itineraries. Subsequently, a conceptual framework was developed based on the System Dynamics approach, defining key variables, causal relationships and feedback structures underlying the “walking itinerary system,” with particular attention to the interactions between demand, supply, safety, inclusion and infrastructures. Starting from this model, an evaluation methodology was designed that led to the identification of a set of specific indicators. Finally, logistical aspects and the application of smart tools were studied, concluding with a critical discussion of the results, highlighting their theoretical and operational implications and formulating design recommendations focused on the management of long-distance walking itineraries, with particular regard to gender, inclusion and sustainability issues, as well as their strategic use in the context of slow tourism and sustainable mobility.

Figure 1.3 - Phases of the research.



1.5 Conclusions

Long-distance walking routes, although often perceived as recreational activities, represent in all respects a complex mobility system that deserves in-depth analysis through the lens of transport engineering. As highlighted, it is possible to apply to this specific context the key concepts of the discipline, from demand characterization (analysing motivations, demographic profiles, expectations and route choice behaviours of walkers) to the definition of supply (the set of infrastructures and services), passing through the study of demand-supply interactions, performance evaluation and above all, the planning and design of new itineraries.

A crucial aspect that further elevates this analysis is the integration of innovative technologies. Digital tools, navigation platforms, sensors for flow monitoring and service management systems are no longer ancillary but fundamental elements that influence demand, optimize supply and improve the overall walking experience. The introduction of the topic of logistics, increasingly and pervasively supported by these technologies, demonstrates the necessity of a holistic vision.

With this perspective, the present research does not merely frame an emerging phenomenon but proposes an innovative and multidisciplinary methodological approach, demonstrating how transport engineering can address the challenges of sustainable mobility in a broader and more integrated way, positioning itself as a reference point for the future management of these important routes.

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Chapter 2

Introduction to pedestrian mobility and walking routes

2.1 Pedestrian mobility. Distinctive characteristics

Pedestrian mobility is the oldest form of transport, developed since the earliest stages of human civilization. Initially, walking was the only means of movement available in the context of the evolution of the first forms of urban organization, which often included pedestrian routes as main arteries for the movement of people [1]. Early civilizations, such as those of ancient Greece, Rome and Persia, built road networks and paths to facilitate pedestrian travel, many of which are still in use today [2]. Under normal conditions, walkers were able to cover between 15 and 40 km per day, depending on needs and the weight carried, while a well-organized army could advance up to 80 km daily. Until the 15th century, the use of wheeled vehicles for individual transport was very rare, so occasional long-distance travel occurred almost exclusively on foot or horseback [3]. Walking was linked to the search for something: initially something tangible, such as food, which drove the first humans out of Africa and later evolving into more metaphysical forms of search such as the discovery journeys of young Englishmen and pilgrimages, which represent the quintessential intangible quest. Over time, pedestrian mobility has been flanked by new forms of transport but has maintained its relevance, especially in dense urban environments and in contexts where other modes of transport were not feasible. Not only for human civilization, but also for the human being as an individual, walking represents a crucial moment. In fact, from the moment a child begins to walk upright, they become autonomous and walking becomes one of the first forms of personal mobility. In the 20th century, the evolution of transport infrastructures favoured the enhancement of speed for a few, mainly motorists, with huge investments aimed at drastically reducing travel times for conventional motorized transport. This led to the construction of “vehicle-centred” cities, where road networks dominate the urban fabric and pedestrians were relegated to a marginal role [4]. This approach overlooked economic, social and environmental consequences, disregarding collective well-being and long-term sustainability. Today, however, active mobility, which includes both walking and cycling, is gaining increasing importance. Pedestrian mobility is emerging as a crucial solution for personal and collective health, as well as for the environment. Walking, in fact, is no longer seen only as a functional means of moving from point A to point B, but as a choice aimed at obtaining broader benefits, ranging from the prevention of non-communicable diseases to the improvement of mental health and overall well-being [5]. In an increasingly sedentary society, walking represents one of the few activities that, in addition to enabling movement, also allows the achievement of health-related goals. Walking represents the most accessible and universal form of mobility, rooted in the human condition and closely linked to the historical and economic development of societies, as it does not imply initial costs nor maintenance expenses for vehicles. Despite the expansion of motorized transport modes, pedestrian mobility maintains a fundamental role, especially in short trips and intermodal connections. The benefits associated with walking are widely recognized: it contributes to the reduction of traffic and pollution, both atmospheric and acoustic, improves public and individual health and supports the vitality and social dimension of urban spaces [6], [7]. Moreover, the increase in pedestrian mobility has been incorporated into numerous urban policies, such as Sustainable Urban Mobility Plans in Europe, Pedestrian Safety Plans in the United States and the Walking Strategy in Australia, which aim to promote safe access to and use of pedestrian infrastructures. At the global level, the growing attention to sustainable mobility, supported by the

emergence of the debate on green mobility and the impact of the COVID-19 pandemic, has highlighted the importance of pedestrian networks in creating safer and healthier cities [8]. In this context, pedestrian infrastructures have become one of the crucial aspects of sustainable urban development, to the point of being considered one of the main elements for measuring the quality and liveability of an urban context, as they contribute to improving connectivity, accessibility and sustainability, while at the same time promoting the safety and health of citizens [9], [10]. Although alternative mobility solutions - such as electric micromobility, sharing services and collective transport - are constantly expanding, pedestrian mobility continues to represent a conscious and significant choice, both in urban and extra-urban spaces. Interest in walking trips is also expressed through the enhancement of tourist itineraries, natural routes and cultural walking paths, which embody the principles of slow, experiential and sustainable tourism. Walking is not only an accessible and sustainable mode of movement but also an experience that fosters the relationship with the territory, promotes health, stimulates social encounters and enhances the landscape. From daily life in city neighbourhoods to tourist and cultural routes in rural areas, walkability proves to be a strategic component of contemporary mobility. For these reasons, transport planning that effectively integrates pedestrian mobility is fundamental to ensuring more inclusive and resilient territories, oriented towards people's well-being and environmental sustainability.

2.2 Pedestrian infrastructures

Pedestrian infrastructures represent the set of elements designed to support and promote walking mobility under conditions of safety, comfort and accessibility. Their classification can follow different criteria; in this context, we distinguish eight criteria: functional and intended use; location; relation with vehicular traffic; morphology; continuity; accessibility; surface; equipment. And related categories of infrastructures are defined (Table 2.1).

Table 2.1 - Classification of Pedestrian Infrastructures.

Criterion	Category
1. Function	Functional mobility Voluntary mobility Mixed mobility
2. Location	Urban Extra-urban Mixed
3. Relationship with traffic	Fully segregated Partially segregated Shared
4. Morphology	Linear Punctual
5. Continuity	Continuous networks Fragmented networks
6. Accessibility	Accessible networks Non-accessible networks
7. Surface	Paved Natural or semi-prepared
8. Equipment	Equipped Non-equipped

2.2.1 Functional and intended use classification

Based on this criterion, we can distinguish between functional mobility and voluntary mobility, two fundamental dimensions of pedestrian mobility, but with different purposes and characteristics. Functional mobility refers to everyday pedestrian routes that are essential for regular urban travel, such as sidewalks, limited traffic areas (LTL) and pedestrian boulevards. These itineraries connect residences, workplaces, schools and other daily destinations, playing a crucial role in ensuring accessibility and safety in urban areas. The design of these routes focuses primarily on efficiency, safety and ease of use for all citizens, particularly in densely populated areas. Voluntary mobility, on the other hand, concerns short-, medium-, or long-distance routes, often linked to tourism, cultural, or recreational purposes. Representative examples are urban tourist pedestrian itineraries or historic walking routes such as the Camino de Santiago, as well as nature trails and greenways that offer immersive experiences in nature or history. Although less frequent compared to everyday functional pedestrian routes, these paths are increasingly valued within the framework of sustainable tourism and the culture of walking, attracting both tourists and outdoor enthusiasts. An interesting dimension emerges when mixed forms of mobility are considered, where integrated infrastructures allow the combination of functional and voluntary routes. An example of this type is represented by greenways [11] which, in addition to serving as natural leisure paths, are also designed to connect residential areas, urban centres and other daily destinations, creating a synergy between every day and touristic mobility. Such solutions can improve accessibility, foster multifunctional use of public spaces and promote sustainable and inclusive mobility.

2.2.2 Location and territorial classification

The territorial classification of pedestrian infrastructures distinguishes two main categories: urban and extra-urban, each of which responds to specific mobility needs and modes of territorial use. Urban infrastructures include routes such as sidewalks, squares, pedestrian areas and LTL, all designed to meet the needs of daily travel within urban contexts. These routes are conceived to ensure safety, accessibility and efficiency of movement, facilitating pedestrian transit in environments with high traffic density and complex infrastructures. They are fundamental for daily life, linking places of residence, work, commerce and culture. Extra-urban infrastructures, instead, include long-distance walking routes, nature trails, dirt roads and hiking itineraries, which mainly develop in rural, natural, or less urbanized areas. These routes are intended for recreational, touristic, or landscape exploration activities, offering opportunities to walk in less anthropized contexts, often immersed in nature or quieter and more isolated environments. They are essential to foster sustainable tourism and provide mobility alternatives away from urban areas. Moreover, there are long-distance routes, such as historical walking routes, cultural itineraries, or greenways, which cross both urban and extra-urban contexts. These itineraries are capable of connecting different geographical and cultural areas, offering an experience that combines natural and urban heritage. Walking along a long-distance route allows one to move from metropolitan contexts to peri-urban areas and finally to more remote zones, traversing varied landscapes and encouraging knowledge of different territorial, historical and cultural realities.

2.2.3 Relation with vehicular traffic

The criterion of relation with vehicular traffic classifies pedestrian infrastructures according to the degree of separation or interaction with motorized traffic. This distinction, which identifies infrastructures as fully or partially segregated versus shared, is crucial to ensuring safety and efficiency of pedestrian movement, especially in urban contexts with high traffic density. Fully

segregated infrastructures are designed to guarantee total separation between pedestrians and vehicles, minimizing risks associated with traffic. Examples include raised sidewalks, elevated pedestrian walkways and pedestrian underpasses. These paths are intended to offer maximum protection to pedestrians, completely isolating them from vehicle circulation routes, while ensuring continuous and safe pedestrian flow. Partially segregated infrastructures, instead, while maintaining separation between pedestrians and vehicular traffic, allow for a more or less integrated coexistence. Pedestrian-cycle paths and routes with signage differentiating pedestrians and cyclists are typical examples of this category. Although pedestrians are separated from automobile traffic, they share space with cyclists, creating a need for coordination among different road users. Appropriate signage and design are fundamental to ensuring the safety and efficiency of these routes. Finally, shared infrastructures are those where pedestrians, cyclists and vehicles share the same space. Examples of such solutions include so-called “shared spaces,” where interaction between different users is facilitated by a design that minimizes physical separation and encourages peaceful coexistence. In these areas, vehicle access is limited or regulated but not completely excluded, as in pedestrian LTLs, where vehicular traffic is reduced or managed to allow pedestrians to move freely while maintaining some interaction with local traffic. In these spaces, shared land use requires careful management of vehicle speeds and pedestrian behavior to ensure safety for all users. Another example of shared infrastructure, particularly developed in the Netherlands, is represented by *woonerf*, residential areas designed to prioritize pedestrian and cycling mobility, where motor vehicles may access but are subject to very low speed limits (generally 15 km/h) and to a street layout that discourages fast driving. In *woonerf*, the street becomes a multifunctional space where social activities, play and mobility coexist, strengthening the sense of community and improving the quality of urban space.

2.2.4 Morphology

The morphological criterion of pedestrian infrastructures focuses on the spatial structure and continuity of routes. The morphology of pedestrian routes significantly affects the user experience, safety and efficiency of movement. Linear infrastructures include routes that extend along a precise and continuous direction, such as sidewalks, long-distance walking routes, pedestrian-cycle paths and nature trails. These itineraries are essential for both daily and touristic mobility and their design focuses on creating pedestrian flows that unfold over long distances, often crossing urban and extra-urban areas without significant interruptions. Punctual infrastructures, instead, are those concentrated in specific areas, such as squares, resting areas, pedestrian crossings and intermodal nodes like public transport stops. These spaces give a supportive function for movement, offering rest areas, interconnections between different transport modes, or crucial crossing points.

2.2.5 Continuity

The continuity criterion concerns the degree of connection and fluidity of pedestrian infrastructures, that is, the ability of routes to ensure uninterrupted, safe and consistent movement along the entire journey. Continuous networks are characterized by well-designed pedestrian infrastructure that logically and seamlessly connects the various sections of the route. These networks include sidewalks, well-marked pedestrian crossings, accessible ramps, homogeneous segments and absence of architectural barriers. They offer a linear, safe and comfortable walking experience, facilitating travel even over long distances, both in urban and extra-urban contexts. Fragmented networks, on the contrary, present interruptions, sudden path changes, physical barriers, or lack of continuity among pedestrian sections. They may force

pedestrians to take unsafe detours, cross streets without protections, or walk on sections not designed for walking. These disconnections reduce the efficiency and attractiveness of pedestrian routes, discouraging active mobility and particularly penalizing people with reduced mobility (PRM) or specific needs.

2.2.6 Accessibility

The accessibility criterion refers to the ability of pedestrian infrastructures to be used by all people, regardless of age, physical abilities, or temporary conditions such as the presence of strollers, carts, or luggage. Based on this criterion, it is possible to distinguish between accessible and non-accessible networks. Accessible networks are those that guarantee continuity, safety and usability without barriers, thanks to the presence of ramps, sidewalks with moderate slopes, signalled crossings, regular paving, clear signage and tactile solutions for the visually impaired. These infrastructures enable all people to move freely and independently, fostering social inclusion and equitable mobility. Non-accessible networks, instead, present physical obstacles, discontinuities, uneven pavements, lack of signage, or specific infrastructures for people with disabilities. These limitations reduce the usability of public space, excluding certain categories of users from the possibility of moving independently. Accessibility thus represents a fundamental indicator of quality and spatial justice in the design of pedestrian networks.

2.2.7 Surface

The surface criterion refers to the type of pavement that characterizes a pedestrian route. These elements, together with the equipment to be considered subsequently, influence not only the quality and comfort of the pedestrian experience but also the functionality and safety of the routes.

Paved infrastructures include urban streets, sidewalks, paved squares and pedestrian-cycle paths. These routes are characterized by asphalted or solid, well-structured materials, ensuring a stable and safe walk, even in urban environments dense with traffic. Paving offers a superior level of comfort and durability, allowing users to move easily even in adverse weather conditions. In recent years, new types of paving designed for walking have started to emerge in literature: for example, pedestrian pavements with a mixture of asphalt and wood chips, which show high anti-slip properties and superior comfort compared to traditional brick pavements, especially in wet conditions [12]. Other innovative solutions include permeable pavements (such as porous concrete [13], porous asphalt and modular pavements with joints for water infiltration), employed in pedestrian and pedestrian-cycle contexts to improve stormwater management, environmental efficiency and mitigation of the urban heat island effect [14]. Natural or semi-prepared infrastructures refer to walking routes and trails that develop on more natural terrain, such as long-distance walking routes, hiking trails and dirt roads. These routes are not fully paved but present surfaces in compacted soil, gravel, or sand, which require greater attention during use. While offering a more immersive experience in nature, these paths can be less comfortable and more difficult to walk, especially in case of rain or unfavourable weather conditions; however, precisely the absence of pavement guarantees the authenticity expected by users. In some cases, dirt roads are even more comfortable underfoot compared to hard, hot asphalt, as they offer a softer surface and transmit less heat, an aspect many walkers appreciate, especially during the hot seasons.

2.2.8 Equipment

Based on equipment, infrastructures can be distinguished into equipped and non-equipped. Equipped infrastructures include routes provided with urban furniture such as benches, fountains,

lighting and signage. These additional elements improve user comfort and safety, creating more welcoming and functional spaces. The presence of good lighting, clear signage and resting furniture makes these routes more usable, especially in urban environments or in touristic contexts, where permanence or rest may be part of the walking experience. Non-equipped infrastructures, instead, refer to informal or marginal routes, such as mountain trails and provisional walking paths, which do not offer any additional equipment. These routes may be unofficial road sections, unmaintained trails, or areas not designed for regular pedestrian use, often resulting in less safe or comfortable conditions. Although used by pedestrians or hikers, these paths lack the services that could improve usability, such as resting points, signage, or well-maintained pavements.

2.3 Performance Assessment and Levels of Service

The assessment of transport infrastructures has evolved to measure not only operational efficiency but also the quality of experience and system sustainability. This has led to the distinction between two main approaches: evaluation by levels of service, which analyzes the performance of a single infrastructure on a hierarchical scale (such as LoS and PLoS) and evaluation by indicators, which uses composite indices to measure the readiness and functionality of an entire territory (such as Walkability).

2.3.1 Levels of Service (LoS and PLoS)

Estimating the capacity of pedestrian pathways is not an easy task, as people on public pathways and pedestrian spaces do not follow completely predictable movement patterns and sometimes do not move at all. To provide rationality to this situation, capacity analyses are separated into two distinct types:

- linear pathways, where movement is predominantly intentional, almost entirely bidirectional (such as sidewalks and corridors);
- areal situations, where movement can occur in any direction and participants may simply occupy the space for variable periods of time within a designated area (such as mezzanines and station platforms, open spaces used for any purpose and public squares) [15].

To operationalize capacity and link it to the Level of Service (LoS), it is necessary to calculate the degree of pathway saturation (1), defined as the ratio between the actual pedestrian flow (F) and the theoretical maximum capacity (C):

$$X = F/C \tag{1}$$

The value of X allows for the quantitative verification of the LoS: low values indicate free-flow conditions (LoS A-B), while values close to 1 indicate critical congestion (LoS E-F).

In this way, capacity does not remain a theoretical parameter but becomes a concrete tool to assess the performance of pedestrian pathways and to identify situations of overload or free flow.

The design and evaluation of pedestrian infrastructures originate from the criteria developed for vehicular infrastructures, adapting the Level of Service (LoS) concept to the specific characteristics of pedestrian mobility. The first systematizations were proposed by Fruin [16], whose qualitative classification of walking conditions still serves as a reference today and were subsequently codified and updated in the Highway Capacity Manual (HCM) [17], which defines a quantitative version based on measurable quantities..

Initially, the assessment of pedestrian space was based on a static analysis, focusing on the area occupied by a stationary individual. Fruin identifies three fundamental categories: minimum physical space (approximately 0.15 m²), body space (approximately 0.37 m²) and personal space (up to 0.75-1.00 m²), the latter necessary to ensure comfort and freedom of movement. However, this approach proves insufficient in dynamic contexts, where collective pedestrian behaviour strongly depends on interactions and temporal variations. For a complete evaluation, it is therefore necessary to adopt a dynamic approach, based on three fundamental variables:

- density (D), the number of pedestrians per unit area (ped/m²);
- average speed (V), the mean speed of pedestrian movement (m/min);
- flow (F), the number of pedestrians crossing a section per unit time and per linear meter (ped/min/m).

These quantities are related by the following fundamental relationship of pedestrian flow dynamics (2):

$$F = D \cdot V \quad (2)$$

While the available space per person (S), expressed in m²/ped, is inversely proportional to Density.

$$S = 1/D \quad (3)$$

The speed-density relationship has been studied empirically and can be expressed using the Weidmann model, according to which speed decreases with increasing density until values approach zero under saturation conditions:

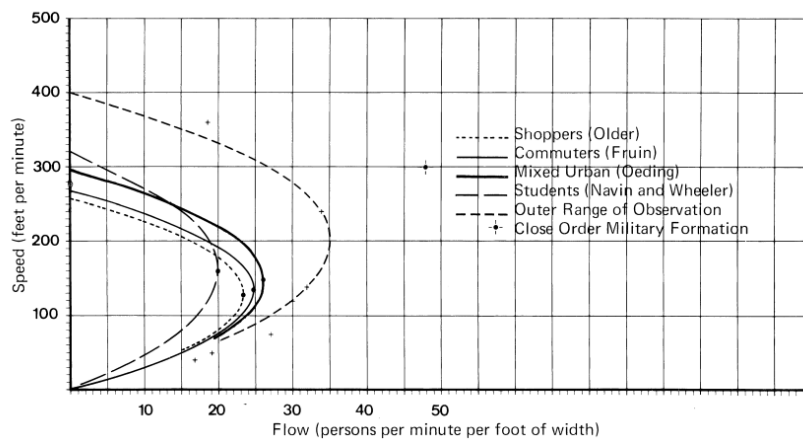
$$V(D) = V_0 \cdot \left(1 - \frac{D}{D_{max}}\right) \quad (4)$$

where:

- V_0 is the free speed, i.e., the speed in the absence of obstacles and interactions,
- D_{max} is the critical density beyond which movement is impeded.

The relationship between pedestrian speed and flow can be represented on a Cartesian plane with flow on the horizontal axis and speed on the vertical axis, assuming a shape that can be approximated as a parabolic curve (Figure 2.1). Maximum speed occurs when no pedestrians are present and flow is zero. As the number of pedestrians increases, mutual influence gradually reduces speed. Flow reaches its maximum at the vertex of the curve, at a point where speed is approximately half of the possible maximum speed. If speed drops below this level, flow can no longer increase but tends to decrease.

Figure 2.1 - Flow-Speed Relationship.



Source: Pushkarev & Zupan, 1975 [18]

There are also natural biological limits that determine walking speed. The typical speed voluntarily chosen by pedestrians ranges between 44 m/min and 122 m/min. Faster movements imply running, characterized by moments in which both feet are off the ground. Conversely, slower movements involve shuffling steps, where both feet remain on the ground for a brief instant. The latter walking mode is often observed among more vulnerable users.

Based on these concepts, the LoS of pedestrian infrastructures has been defined, on a scale from A (excellent conditions) to F (critical congestion). Table 2.2, accompanied by illustrative images (Figure 2.2), represents the levels of service for linear pedestrian pathways.

Table 2.2 - Characteristics of pedestrian flows along sidewalks.

Characteristics - Level of Service	A	B	C	D	E	F
Pedestrian flows (ped/min/m)	< 16,40	16,40-22,92	22,92-32,81	32,81-49,21	49,21-75,46	Variabile
Pedestrian space (m²/ped)	> 5,57	3,72-5,57	2,23-3,72	1,39-2,23	0,74-1,39	< 0,74
Walking speed (m/min)	> 77,72	76,20-77,72	73,15-76,20	68,58-73,15	45,72-68,58	< 45,72
Degree of saturation (F/C)	≤ 0,30, free flow	0,31-0,50, low crowding	0,51-0,70, moderate crowding	0,71-0,90, increasing congestion	0,71-0,90, high congestion	>1,00, critical saturation

Source: Transportation Research Board, Highway Capacity Manual 2000 (National Research Council, 2000), p. 18-4.

The pedestrian LoS describes the conditions of comfort and fluidity with which pedestrians can move in a public space, relative to the density and flow of people present. At level A, the context is ideal: everyone can walk completely autonomously without being influenced by others. No significant interactions occur with other pedestrians and movement is free and spontaneous. In these cases, the area available per person exceeds 5.57 m² and flow remains below 16 persons per minute per linear meter of width. At level B, a good degree of freedom is maintained: pedestrians can choose their own pace without significant obstacles, although occasional overtaking or minor interactions with other users may occur. The available area ranges between 3.37 and 5.57 m² per person, with a flow of 16-23 persons/min/m. Level C represents a more crowded but still acceptable situation. People can maintain a normal walking speed and overtake others, although intersections and direction changes begin to generate minor conflicts.

Available space ranges from 2.23 to 3.37 m²/person, with flow from 23 to 32 persons/min/m. At level D, freedom of movement begins to decrease significantly. Pedestrians must frequently adjust their pace to avoid obstacles or conflicts with others. Overtaking becomes difficult and position changes intensify. Available area ranges from 1.32 to 2.23 m²/person, with flows between 32 and 50 persons/min/m. Level E indicates high congestion: walking becomes strenuous, marching speed decreases considerably and manoeuvring possibilities are minimal. Overtaking is impossible and lateral or turning movements are very difficult. Individual space drops to 0.74-1.32 m², with flows between 50 and 75 persons/min/m. Finally, at level F, a critical condition is reached: movement is heavily slowed, pedestrians are almost blocked and every displacement requires significant effort. Continuous conflicts occur and movement resembles a queue, with frequent stops and starts. Available space is below 0.74 m²/person and, in extreme situations, may be as low as 0.20 m²/person, with discontinuous and unpredictable flows.

A different case arises in the assessment of pedestrian space capacity in particular areas such as enclosed contexts, like public building atriums or transit areas in transport infrastructures, for

example, subway mezzanines. Here, pedestrian behaviour tends to assume a certain regularity, as it is often influenced by physical constraints, scheduled times, or well-defined purposes guiding movement.

Figure 2.2 - Examples of pedestrian infrastructures in different LoS conditions.



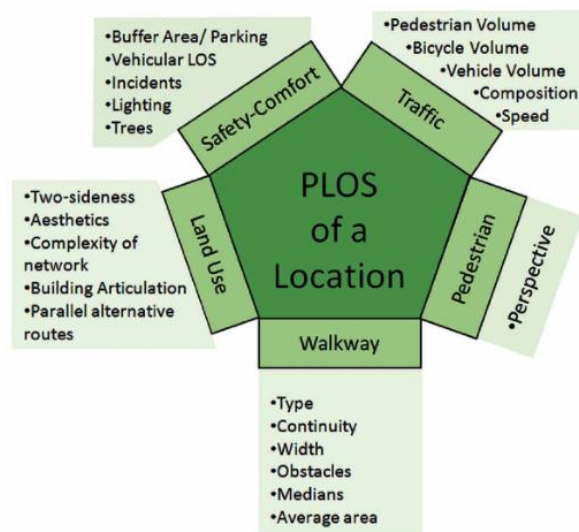
The application of LoS to pedestrian traffic (PLOS) has received increasing attention, evolving from a purely quantitative approach to a more holistic one. The PLOS application integrates quantitative verification through the F/C ratio, considering not only density and flow but also individual

characteristics (gender, presence of children or persons with reduced mobility) and group characteristics (people moving together), as well as pedestrians' subjective perception.

Subsequently, research expanded the field of investigation to include pedestrian perception. It was highlighted that the pedestrian experience is influenced by multiple variables that go beyond simple flow capacity. The 1990s saw planning shift toward a multimodal approach, including different types of indicators such as: presence and continuity of sidewalks and pedestrian paths; accessibility of facilities for persons with disabilities; linearity of pedestrian paths and road network connectivity; connections to frequent transport services; ease and safety of crossings; visual interest; perceived or actual safety [19]. The growing complexity of the concept generated a plurality of methodological approaches aimed at bridging the “gap” between transport planning, focused on mobility and urban planning, attentive to the quality of spaces. A pioneering integration attempt was proposed by Jaskiewicz [20], who extended the traditional LoS with nine qualitative and perceptual criteria, demonstrating how the evaluation of elements such as building articulation and the presence of trees can significantly modify the classification of a path.

Due to this complexity, research has identified five main categories for PLoS evaluation (Figure 2.3): Traffic, Pedestrians (their perspective), Infrastructure (geometry and condition of the path), Land Use (attractiveness and connectivity) and Safety-Comfort. Despite numerous proposed methods, there is still no universal consensus on a single evaluation methodology.

Figure 2.3 - Pedestrian Level of Service (PLOS) measures employed in current methods.



Source: H. Tuydes-Yaman and pınar karataş, 2018 [21].

2.3.2 Evaluation by indicators: Walkability

The assessment of the performance of pedestrian infrastructures has evolved beyond the measurement of flows, embracing an approach based on walkability indicators that aims to capture the overall quality of the walking experience. This change reflects the awareness that promoting active mobility requires not only the possibility of walking (flow capacity) but also that the environment is attractive and functional. This paradigm, which can be considered as a holistic evolution of pedestrian assessment, does not limit itself to measuring the usability of an infrastructure but investigates the capacity of the space to be perceived as safe, comfortable and stimulating by the user [22], [23].

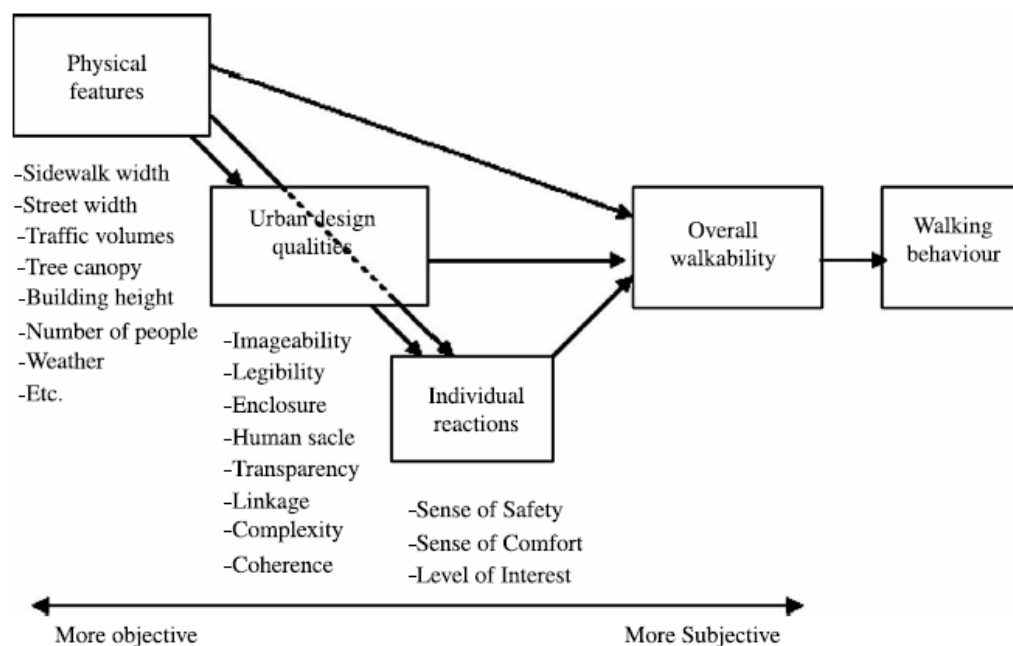
Unlike PLoS, which focuses on a specific path and often on physical variables such as density and speed, Walkability is a broader concept that evaluates the suitability of an entire territory (neighbourhood or city) to support pedestrian mobility. This multidimensional approach considers indicators related to health, economy, social inclusion and the environment, offering an overall measure of the liveability and sustainability of an urban area for walking trips. Since 2005, the literature has been enriched with studies that have proposed multidimensional indices, from the Global Walkability Index (GWI) by Krambeck [24] (Table 2.3), which allows macro-scale comparisons, to more detailed models such as those by Ewing and Handy [25] (Figure 2.4), which through the integration of quantitative and qualitative indicators aim to provide operational tools for planners.

Table 2.3 - The Global Walkability Index.

Component	Variables
Safety and Security	1. Proportion of road accidents that resulted in pedestrian fatalities
	2. Walking path modal conflict
	3. Crossing safety
	4. Perception of security from crime
	5. Quality of motorist behavior
Convenience and Attractiveness	6. Maintenance and cleanliness of walking paths
	7. Existence and quality of facilities for blind and disabled persons
	8. Amenities (e.g., coverage, benches, public toilets)
	9. Permanent and temporary obstacles on walking paths
	10. Availability of crossings along major roads
Policy Support	11. Funding and resources devoted to pedestrian planning
	12. Presence of relevant urban design guidelines
	13. Existence and enforcement of relevant pedestrian safety laws and regulations
	14. Degree of public outreach for pedestrian and driving safety and etiquette

Source: Krambeck, 2006 [24]

Figure 2.4 - Conceptual framework of the role of perceptions in mediation of physical features of the environment and walking behavior.



Source: Ewing & Handy, 2009 [25]

Recent research has further refined the methodologies, distinguishing variables into objective (replicable) and subjective (perception-based) categories, as highlighted by Maghelal and Capp [26]. New models, such as the "7 C" framework by Monteiro de Cambra (Table 2.4), have introduced innovative criteria such as Coexistence between pedestrians and vehicles and Institutional Commitment, proposing a multi-criteria and multi-scale analysis. In parallel, a line of research has closely linked walkability to the concept of sustainability, exploring its economic, environmental and social benefits [28]. The study by Rogers et al. [29] was particularly innovative in measuring social sustainability through the correlation between walkability and social capital, an area often overlooked. Finally, technological evolution has opened new frontiers for measuring walkability. Advanced tools such as 2D and 3D GIS [30], [31], remote sensing using Google Street View [32] (Table 2.5) and the integration of open data and machine learning [33] have allowed overcoming data and methodological limitations, providing the possibility of generating objective measures of perceptual and visual characteristics of pathways.

Table 2.4 - Walkability measurement areas of concern and key concerns.

Areas of concern	Key Concerns	Analysis scales
Accessibility	Connected	Global scale, at the city level;
	Convivial	
	Conspicuous	Macro scale, at the neighborhood level;
	Comfortable	
	Convenient	Meso scale, related to the pedestrian accessibility from/to a given point
	Coexistence	
Attractiveness	Commitment	Micro scale, at the street level;

Source: Monteiro de Cambra, 2012 [27]

Table 2.5 - Categories and indicators of the tool for route choice analysis.

Sidewalk	Sidewalk width, Sidewalk continuity, Sidewalk condition, Number of garbage bins located, Other obstruction (e.g., presence of poles, parked cars, building constructions, stair case), N. of tree shades, N. of benches, N. of fountains, N. of vending machines, N. of bus stops, Crowd level
Land use	Distance of building from footpath, Residential land use in the ground floor, Commercial land uses in the ground floor, Office/institutional land uses in the ground floor, industrial land uses in the ground floor, recreational land uses in the ground floor, vacant land uses in the ground floor, stop over activities, coffee shop, newspaper agent etc., Average building height
Traffic	Presence of crossing facilities, environment, Number of lane to cross at the end of street segment

Source: F. Shatu and T. Yigitcanlar, 2018 [32]

These technological developments have also led to the growth of more specific studies, which analyse walkability in relation to particular categories of users (elderly, children, women) or in specific urban contexts (campuses, gated communities, rapidly developing cities), demonstrating the centrality of the concept for the design of more liveable, healthy and inclusive urban environments.

The identified indicators often pertain to several dimensions, including:

- Infrastructure and connectivity: continuity and accessibility of paths, integration with public transport (intermodality) and presence of obstacles are evaluated;
- Urban planning and perception: visual attractiveness and aesthetics of the urban landscape, lighting, presence of street furniture and perceived safety by pedestrians are considered;
- Functionality and sociality: proximity and variety of services, building density and inclusiveness of spaces for all users, including the most vulnerable, are measured;

- Policy and management: traffic calming policies, dedicated resources and regulations supporting pedestrian mobility are analysed.

The objective is no longer simply to measure the possibility of walking, but to understand and improve the capacity of an area to promote and stimulate walking mobility for health, economic, social and environmental sustainability reasons.

2.3.4 PLoS and Walkability for Trails and Long-Distance Paths

A coherent evolution of the established transport engineering methods toward non-urban contexts may consist of extending the Level of Service (LoS) approach to trails and applying the Walkability index to long-distance paths. However, as seen, the LoS concept was developed to assess the performance of pedestrian infrastructures in urban environments, where pedestrian behaviour is largely predictable, guided by a specific purpose and constrained by physical space. Applying this model to natural trails requires an adaptation, shifting the focus from flow efficiency to the quality of the experience: the presence or absence of other users, the naturalness of the path, the degree of immersion in the environment and perceived safety become the new service metrics.

In parallel, the application of the Walkability index to an entire long-distance path allows a systemic assessment of the overall quality of the route. In this case, attention extends beyond the pedestrian route itself, including variables such as continuity and accessibility of the path, availability of services along the route, connection with public transport, interaction with cultural heritage and socio-economic impact on local communities.

This dual perspective, performance-based for individual segments and systemic for the entire itinerary, allows interpreting long-distance paths not only as active mobility infrastructures but also as complex territorial devices capable of generating cultural, social and environmental value.

2.4 Urban planning and spaces for pedestrian mobility

The increasing attention towards walkability is a response to the critical issues of contemporary urban development; among these, the phenomenon of “sprawl” - that is, the uncontrolled and dispersed expansion of cities - has generated significant consequences, including the drastic reduction of green spaces, the increasing land consumption and a growing dependence on private car use. This dependence is often due to the distance of essential services, workplaces and public transport access nodes, in an urbanized context that is too often lacking infrastructures dedicated to sustainable mobility. Such issues, with significant impacts on the environment and public health, are today the focus of attention both from institutions and the scientific community. At the political level, the United Nations 2030 Agenda [35] has identified in Goal 11 - “Make cities and human settlements inclusive, safe, resilient and sustainable” - a strategic objective for rethinking cities, promoting an approach that integrates sustainability needs into urban and transport planning. This implies a paradigm shift: cities must no longer be conceived as mere road networks functional to vehicular traffic, but as spaces designed to improve the quality of life, responding to the needs of a plurality of users in a multimodal perspective. In this scenario, the promotion of pedestrian mobility and the reduction of unnecessary car use become central elements, translated into urban planning tools adopted by an increasing number of countries. Promoting active modes of transport implies, however, a thorough analysis of the predisposition of the territory to accommodate and favour walking. Studies conducted on pedestrian accessibility and the morphological organization of urban spaces have highlighted the possibility of significantly improving walkability levels through targeted design interventions. Such interventions do not

necessarily require radical solutions, such as the complete pedestrianization of urban areas, but can also be implemented through more gradual strategies, such as traffic calming measures, capable of increasing the safety, continuity and attractiveness of pedestrian mobility.

Although both are based on walking, urban and extra-urban pedestrian mobility are distinguished by deeply different characteristics, purposes and planning implications. In urban areas, it develops within dense and multifunctional contexts, where residences, services, commerce and public transport coexist over short or medium distances. Urban pedestrian mobility primarily responds to daily needs (work, study, errands, leisure) and is at the center of planning strategies oriented towards sustainability, such as Sustainable Urban Mobility Plans (SUMP), which promote intermodality, safety and accessibility through the redevelopment of sidewalks, crossings and public spaces, as well as integration with public transport and limited traffic zones (LTZ).

Conversely, extra-urban pedestrian mobility occurs in less dense contexts, often rural or naturalistic, where distances are more variable and the presence of anthropic infrastructures is limited. Here, walking is often associated with recreational, touristic, or spiritual activities, such as hiking, trekking, or pilgrimages, and assumes an experiential value linked to the enjoyment of the landscape, physical and mental well-being and the rediscovery of the territory. Consequently, planning strategies focus on different tools, such as Cycling Mobility Plans or Strategic Plans for Sustainable Tourism, which include interventions for path safety, signage, trail maintenance, creation of resting areas and accessibility to areas of natural or historical value. Integrated enhancement practices such as River Contracts, Greenways and Landscape Plans are also added, recognizing walking as a tool to strengthen territorial identity and promote local economies based on slow tourism.

Pedestrian mobility plays a crucial and evolving role in the “transition from *cité* to *ville*” [36], profoundly influencing urban conception and its physical appearance. In the ancient and medieval *cité*, characterized by small dimensions and high density, it represented the predominant form of movement, shaping an inherently human-scale urban structure. Narrow and winding streets, squares as social hubs and short distances between urban functions were a direct consequence of the centrality of walking. The *cité* was conceived to be experienced and lived on foot, with key places of power, commerce and worship easily accessible. This predominance of pedestrian mobility favoured strong social interaction and a sense of community rooted in physical space.

However, with the dimensional growth of the modern and contemporary *ville*, the advent of new forms of motorized mobility has introduced significant challenges for walking. Greater distances, functional specialization of neighbourhoods and planning often oriented towards vehicular traffic have led to a partial marginalization of pedestrian spaces. Wide and straight streets have replaced organic paths and the separation of functions has made walking less practical for many daily needs. This renewed centrality is expressed in policies and planning tools oriented towards reclaiming urban space for pedestrians, through initiatives such as the creation of 15-minute cities, the design of safe home-school routes, participatory design of public spaces and the connection between pedestrian paths and cycling networks. In this framework, PUMS represent one of the most effective tools to promote an integrated and strategic approach to urban mobility, while Strategic Plans for Tourism and Landscape Plans offer opportunities to connect cities and territories in a broader vision, capable of integrating mobility, culture, environment and inclusion.

Extra-urban pedestrian mobility assumes characteristics and meanings distinct from the urban context. Far from being primarily a means for daily travel between urban functions, it is often configured as a recreational or touristic activity, or as a way to connect small settlements immersed in natural or rural contexts. The distances covered can vary significantly, from short walks in green areas to multi-day excursions along mountain trails or naturalistic paths. The main motivation is not so much the need to reach a specific functional destination, but the desire to

enjoy the landscape, practice physical activity, explore the natural or cultural environment, or simply experience a slower pace of life in contact with nature.

Consequently, the infrastructures and planning requirements for extra-urban pedestrian mobility focus on safety along roads that may be shared with vehicular traffic, clear and adequate signage of trails and paths, maintenance of the same to ensure usability and safety and the enhancement of the natural and cultural elements traversed. The creation of equipped resting areas, the availability of information on routes and points of interest and the promotion of sustainable tourism forms related to hiking and trekking become key elements. Moreover, in rural contexts, pedestrian mobility can represent an important way to maintain social ties between small communities and to access essential services in the absence of extensive public transport alternatives. The enhancement of historical paths, the Via Francigena and naturalistic trails not only promotes slow and sustainable tourism but also contributes to the rediscovery and protection of territorial heritage, offering economic development opportunities for less urbanized areas.

However, precisely in relation to extra-urban pedestrian mobility, particularly to the growing interest in long-distance routes, cultural walks and hiking trails, the need for integrated planning at the regional and interregional level emerges strongly, capable of coordinating different administrative, managerial and territorial competencies. The current framework is often fragmented: paths develop along heterogeneous infrastructures (dirt trails, rural roads, state roads, urban streets), each under the responsibility of different entities, generating issues in terms of management, maintenance and coordinated promotion.

The lack of a unified management also results in problems of route continuity, heterogeneity in signage, usability and safety and hinders the development of pedestrian networks consistent with sustainable mobility strategies. Questions thus arise about who is responsible for ensuring alignment between different administrative and geographic levels, especially when paths cross municipal, provincial, or even regional boundaries. In these cases, the absence of shared regulatory and operational tools risks compromising the systemic vision necessary to promote a structured and efficient offering.

The recent introduction of tools such as the National System of Tourist Cycle Routes and some experiences of inter-municipal or metropolitan planning for soft mobility offer replicable models also for the network of walking paths and trails. However, it remains fundamental to strengthen synergies between municipal urban plans, SUMP, regional landscape plans and tourism promotion tools, to fully integrate extra-urban pedestrian mobility within territorial and environmental policies.

Understanding these distinctions and addressing governance issues is fundamental to developing effective strategies consistent with the evolution of territorial use patterns, sustainable tourism and the growing demand for walking experiences. In this sense, pedestrian mobility is not only a means of transport but a key to rethinking the relationships between mobility, landscape and local communities in an integrated way.

2.5 Pedestrian mobility safety issues

Pedestrian safety today represents one of the main challenges within the broader context of road safety, as highlighted in the Global Status Report on Road Safety 2023 by the World Health Organization [37]. In the year 2021 alone, approximately 1.19 million people lost their lives due to road traffic accidents, with a rate of 15 deaths per 100,000 inhabitants. Of these victims, pedestrians constitute 21% globally, with strong geographical disparities: ranging from 40% in the African Region to 14% in the South-East Asia Region, highlighting infrastructural and systemic

vulnerabilities, especially in low-income countries. The Pedestrian Safety Manual, updated in May 2023 [38], emphasizes that pedestrian deaths increase at almost twice the rate compared to other road users and that the risk per kilometre travelled is nine times higher than that for motorists. Pedestrian fatalities are predominantly concentrated in low- and middle-income countries, which account for 90% of global road traffic mortality.

Alongside the human consequences, the economic impacts resulting from road accidents are significant and can reach up to 6% of national GDP, contributing to worsening poverty conditions among the most vulnerable social groups [37]. In response to this crisis, the United Nations launched the Decade of Action for Road Safety 2021-2030 with Resolution A/RES/74/299 [39], aiming to reduce road deaths and injuries by 50% through an integrated approach that includes infrastructural measures, regulations, data analysis and educational campaigns. This commitment was recently reinforced with Resolution A/RES/79/290 [40], which renews the call for multilevel cooperation to achieve the goals of the 2030 Agenda.

Despite the international framework, pedestrian safety remains a critical issue. According to Shrinivas et al. [41], pedestrians represent approximately 26% of road traffic accident victims. Through a meta-analysis, the authors identify the main variables affecting accident severity, including impact speed, pedestrian age and even factors such as dark clothing [41], [42]. These findings confirm the need for a multidimensional approach integrating behavioural, infrastructural and vehicular factors. However, while systematic global data exist for pedestrian safety, the same cannot be said for security, understood as exposure to intentional risks (thefts, assaults, harassment), whose data are often fragmented and linked to local surveys. Studies conducted at the urban level highlight that factors such as poor lighting, inadequate urban design and low surveillance can significantly increase the risk of criminal events against pedestrians.

In this context, it is essential to adopt an integrated vision of the concepts of safety and security, which must be addressed jointly in urban planning and in the definition of mobility policies. The European Union, in its approach to sustainable mobility, recognizes that walking is the basis of every trip [43], but denounces the limited space dedicated to pedestrian infrastructures. In urban contexts, where interaction between pedestrians and vehicles is frequent, vehicle speed is a decisive factor in accident severity. Consequently, the design of pedestrian paths must include traffic calming measures, such as the separation of pedestrian and vehicular flows, the introduction of reduced-speed zones and the implementation of protected crossings.

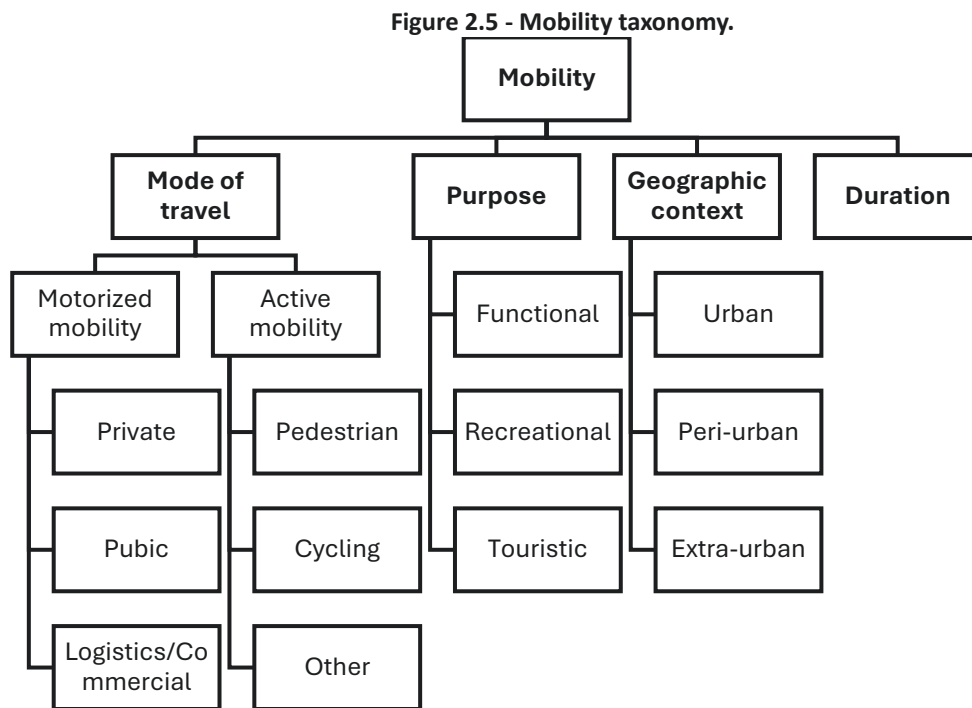
Even in extra-urban contexts, where walking increasingly spreads as part of slow tourism, risks related to the safety and protection of walkers deserve attention. A notable case is the Camino de Santiago, the first European cultural route in terms of historical recognition and number of walkers. In recent years, several fatal accidents and injuries have raised awareness about pilgrim safety along the route, which crosses rural areas, urban areas and mixed-traffic roads [44]. In particular, a study by the Spanish Dirección General de Tráfico identified over 7,000 km of critical routes, with points of particular danger at intersections with regional, provincial and national road networks, due to traffic intensity, vehicle speed and poor visibility [45]. The risks concern not only accidents (health problems, collisions with vehicles) but also personal safety: women and the elderly, for example, are more exposed to harassment and health issues, respectively. For this reason, the integrated analysis of risks along pedestrian paths, both urban and extra-urban, is essential to reduce walkers' vulnerability and increase path usability.

2.6 Definition of trail and classification

The need to effectively plan and manage pedestrian paths makes a clear definition of walks and a structured classification indispensable, which in this work is proposed below.

2.6.1 Mobility taxonomy

In the context of transport engineering, the analysis of mobility dynamics requires a rigorous and multidimensional classification that goes beyond the traditional focus on vehicular flows. For this purpose, the present research adopts a taxonomy that articulates movement along four interdependent conceptual axes (Figure 2.5) - mode of travel, purpose, geographic context and duration - allowing an analytical disaggregation capable of reflecting the increasing complexity and variety of mobility behaviours. This approach proves particularly useful for the study of active mobility and forms of slow tourism, emerging phenomena often overlooked by engineering literature, but relevant in terms of infrastructure design, environmental sustainability and territorial planning.



The axis of travel mode distinguishes between motorized and non-motorized mobility. Motorized mobility includes:

- private mobility (cars, motorcycles), characterized by high individual autonomy, schedule flexibility, but also significant environmental impact and congestion;
- public mobility (buses, trains, subways), which prioritizes efficiency in flows and sustainability, but is conditioned by service frequency and the infrastructure network;
- logistics or commercial mobility, with vehicles such as trucks and vans, functional to freight transport and heavily dependent on urban planning.

Non-motorized mobility, instead, includes:

- pedestrian mobility, with low environmental impact, flexible routes and highly inclusive, but limited by walkable distance and route safety;

- cycling mobility, faster and suitable for medium distances, requiring dedicated infrastructure and good physical condition of the cyclist;
- alternative forms such as scooters (traditional and electric), rollerblades, skateboards, or animal-powered transport (e.g., horse, mule), characterized by a strong recreational-experiential component, limited usability in spatial and regulatory terms and strong dependence on the infrastructure context.

The axis of purpose of travel distinguishes between:

- functional mobility, related to daily needs (work, study, errands) and characterized by regularity, tight schedules and low flexibility;
- recreational mobility, oriented to psychophysical well-being and leisure, generally not constrained by rigid time limits and often associated with natural or equipped routes;
- tourist mobility, which assumes multiple values depending on its subcategory:
 - slow tourism, focused on slowness and the experience of travel as a form of territorial exploration and awareness, often in pedestrian or cycling mode;
 - cultural tourism, focused on the enjoyment of historical, artistic and intangible heritage, such as museums, archaeological sites, historic villages, or identity events;
 - nature tourism, oriented to the exploration of natural environments such as parks, reserves, protected areas, with strong connection to sustainability and ecological awareness;
 - mountain and seaside tourism, respectively linked to the experience of high-altitude or marine environments, often with important seasonal and logistical implications for accessibility and services;
 - food and wine tourism, which motivates travel through the discovery and enhancement of local food identities, also connected to the promotion of rural territories and short supply chains;
 - spiritual or religious tourism, which shares with slow tourism the experiential approach and the centrality of walking, but with a primarily inner, spiritual, or devotional motivation;
 - emerging or hybrid tourism, such as experiential, sports, memory (or roots), or regenerative tourism, which combine multiple purposes and require a multidimensional reading of mobility.

The axis of geographic context considers mobility based on the type of environment crossed:

- urban area: develops in high-density settlement areas, characterized by complex infrastructure networks, wide availability of services, strict regulation and greater exposure to interference with motorized traffic;
- peri-urban area: concerns transition zones between compact cities and rural areas, with medium-low building density, alternation of main infrastructures and open spaces, mixed functions (residential, productive, commercial) and the need to ensure route continuity and crossing safety towards urban hubs;
- extra-urban area: develops in territories with low population density and reduced vehicle traffic interference, characterized by open landscapes and less frequent infrastructure, favoring movements primarily recreational, hiking, or touristic in nature.

Finally, the axis of duration allows distinguishing between:

- short trips of a few hours or at most one day, typical of functional mobility and many local recreational activities, characterized by short stay in the area and limited demand for auxiliary services;
- multi-day trips, typical of itinerant tourism or walks, requiring logistical planning, accommodation along the route and support services such as supply, luggage transport, or digital information.

This classification allows describing and designing forms of mobility with greater precision. For example, a walk is configured as pedestrian mobility, with slow tourism purpose, in a mixed context and lasting multiple days, whereas an electric scooter ride in the city can be described as alternative mobility, recreational or functional, in an urban environment and of short duration. Similarly, a cycle-touristic tour traverses all dimensions of the taxonomy, requiring integrated responses in terms of network design, services and public policies. The use of a taxonomic structure thus allows supporting technical and strategic decisions for sustainable mobility, enhancing alternative and active forms of travel as levers for territorial regeneration, public health and ecological transition.

2.6.2 Terminology and classification

In the context of pedestrian mobility, the Italian terms “*Cammini*” and “*Sentieri*” are often used interchangeably, but the conceptual and operational reality they underlie is profoundly different. It is necessary to overcome this ambiguity by rigorously defining these terms through a critical analysis of normative references, authoritative classifications and specialized studies.

The difference between “Path” (*Sentiero*) and “Trail” (*Cammino*) is not only terminological but also conceptual.

A. Path

Commonly, a path is a narrow way (less than 2.50 m in width), with a natural surface and formed by the frequent passage of humans and animals, among fields, woods, or rocks, both in plains, hills, or mountains. In Italy, the only legal definition of a path is found in the Road Code (Legislative Decree 30 April 1992, n. 285, art. 3 n. 48), which defines a path (or mule track or “*tratturo*”) as a “road with a natural surface formed by the passage of pedestrians and animals.” No specific regulation corresponds to this definition; moreover, assimilating the path into the broader category of “road” could lead to applying the Highway Code provisions to paths. Additional elements derive from case law, which has highlighted some distinctive features of paths, including their prolonged formation over time due to continuous trampling (Court of Cassation May 1996 n. 4265) and their visibility, permanence over time and certainty (unambiguous), so as to be recorded in cadastral maps (Court of Cassation 29 August 1998 n. 8633; Court of Cassation 21 May 1987 n. 4623). Commonly, the English word corresponding to “*sentiero*” is “path”.

The Italian Alpine Club (CAI), after adopting the normative definition of path given by the Highway Code, proposes its own further classification, distinguishing, albeit without strictly following the criteria of a correct taxonomy (exhaustiveness, exclusivity):

- tourist path: a local itinerary on carriageways, mule tracks, or evident paths, developed in the immediate vicinity of towns, tourist locations, or communication routes; used for easy cultural or recreational tourist walks;
- hiking path: a path without technical difficulties, corresponding largely to mule tracks created for agricultural or military purposes or access paths to shelters or connections

between valleys. It is the most widespread path type and the most frequented, representing, according to CAI, 75% of the entire organized trail network;

- mountaineering path: a path that develops in rugged areas and requires the hiker to have technical skills, physical abilities and proper equipment;
- iron path (*via ferrata*) or equipped path: an itinerary leading the mountaineer on rock walls or aerial ridges and ledges, previously equipped with ropes and/or ladders;
- historical path: a hiking itinerary retracing “ancient routes,” promoting historical knowledge and valorisation of the visited places;
- thematic path: an itinerary with a predominant theme (naturalistic, glaciological, geological, historical, religious) equipped with appropriate signage and observation points for educational purposes.

CAI also specifies that paths may constitute segments, more or less long, of various types of hiking itineraries, such as:

- long-distance itineraries (Sentiero Italia, European trails, Apennine ridges, etc.) lasting several days of walking and spanning hundreds of kilometres, generally easy and signposted, with necessary accommodation along the route;
- medium-distance itineraries (trekking, high routes), lasting several days of walking (usually 3-7) and covering 40-100 km, suitable for generally experienced hikers. They should be well signposted and equipped, supported by accommodation;
- short-distance itineraries (hiking paths, short circular routes), lasting a maximum of 1-3 days of walking, are the most widespread.

Long-distance itineraries, in English long-distance path, also assimilable to the Anglo-Saxon term “way” or the American term “trail”) are paths that mainly cross rural areas and differ from a simple path either because they cannot be completed in a single day or because their length exceeds 50 km.

Long-distance paths can be further classified, based on their nature, into:

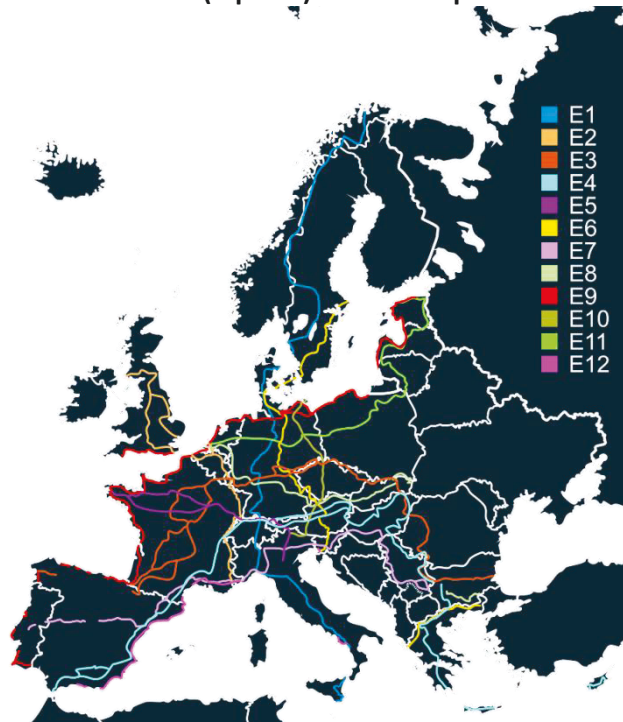
- river routes: characterized by a path running parallel to a riverbank, sometimes created because they were used as towpaths for pulling boats (e.g., New York State Canal System);
- coastal routes: whose path is entirely located along a territory’s coastal strip; examples exist worldwide, for instance in the United Kingdom: England Coast Path, South West Coast Path and Isle of Wight Coastal Path; in Canada: West Coast Trail and East Coast Trail; in South Africa: Otter Trail; in Australia: Gold Coast Oceanway;
- coast-to-coast routes: whose path starts on one coastal side of a region and ends on the opposite side (e.g., the Coast to Coast Walk in Great Britain);
- rail trails: the path runs parallel or overlaps former railway lines;
- mountain hiking routes (trekking): characterized by the exclusive or predominant crossing of mountainous areas;
- animal routes: long-distance paths designed to be traversed also with animals such as mule tracks or bridleways.

In Europe, there are also recognized, organized and managed long-distance hiking paths. These are the Grande Randonnée (GR) network, widespread in France, Belgium, the Netherlands and Spain. Paths are marked with a red stripe over a white stripe. In France, the network is managed by the “Fédération Française de la Randonnée Pédestre,” in Spain by the “Federación española de

deportes de montaña y escalada," and in Italy by the FIE. Many routes identified in the Grande Randonnée were later included in the broader European trail network.

The European trail network is a network of often pre-existing hiking paths of extremely long length that cross Europe. It is defined and managed by the European Ramblers' Association (ERA; Europäische Wandervereinigung - EWV; Fédération Européenne de la Randonnée Pédestre - FERP), a network of organizations promoting hiking, creating tourist trails, sharing cross-border knowledge and travel experiences and defending the right of walkers to free access to natural heritage. The purpose of creating the European trail network is to enable "on foot" crossings of the entire continent, connecting populations of different states (thus prioritizing crossing national borders). To date, the European Paths identified and verified by the European Ramblers' Association are 12, totalling 75,000 km, the most recently added being path E12, starting from the north-western coast of the Mediterranean Sea (Figure 2.6).

Figure 2.6 - Verified electronic routes (E-paths) of the European Ramblers' Association.



B. Trail

More difficult to define is the Trail ("*Cammino*"). The trail could, in fact, fall within the broader definition advanced by the European Union of "cultural itinerary" (Cultural route of the Council of Europe). The Cultural Routes programme was launched in 1987 with the Declaration of Santiago de Compostela; indeed, the Camino de Santiago de Compostela was the first cultural itinerary to be recognized. A cultural itinerary is defined as "a cultural, educational heritage and tourism co-operation project aiming at the development and promotion of an itinerary or a series of itineraries based on a historic route, a cultural concept, figure or phenomenon with a transnational importance and significance for the understanding and respect of common European values" [46]. Therefore, unlike the Path, strongly based on infrastructure, the cultural itinerary is a "transnational cooperation project" that can be entirely based on the sharing and commonality of intangible aspects. The itineraries are subject to a strict certification process [47] that occurs in 5 steps: the first step is the identification of a theme that is representative of European values and common to at least three European countries; the second consists of

identifying the elements of tangible and intangible heritage linked to the itinerary theme and defining a common narrative for the sites recognized as part of it; the third step is creating a legally recognized network composed of locations and stakeholders involved in the itinerary; the fourth step consists of coordinating common actions aimed at encouraging cultural cooperation and stimulating scientific and social debate around the main theme of the itinerary, particularly in five areas of action (cooperation in research and development; valorisation of memory, history and European heritage; cultural and educational exchanges for European youth; contemporary cultural and artistic practice; cultural tourism and sustainable cultural development); finally, the last step is creating a shared image based on the use of a single logo. The certified itinerary is subject to certain obligations following certification itself (Annual reporting; Triennial evaluation; Communication; Participation; Information).

Therefore, moving from the path to the itinerary, the requirement of tangibility is no longer mandatory, while intangible cultural aspects increase. It emerges that not all itineraries are trails, whereas some itineraries, if infrastructure and equipped by connecting the relevant locations in a continuous line, can be qualified as trail. A definition of trail (“Cammino”) was given by the Ministry of Cultural Heritage and Activities and Tourism (MIBACT) in 2016, in the Directive establishing the Year of trails and the Atlas of trails. For the first time, trails are defined as “cultural itineraries of particular European and/or national relevance, traversable on foot or by other sustainable soft mobility means, representing a way of enjoying the widespread natural and cultural heritage, as well as an opportunity for valorising natural and cultural attractions and the territories involved.” MIBACT specifies that, in line with the vision of the Council of Europe, “trails cross one or more regions, may be part of European routes and are organized around themes of historical, cultural, artistic, religious, or social interest”. Therefore, this definition for the first time includes both the mode of enjoyment (on foot or by other sustainable soft mobility means) and cultural aspects and the Directive itself highlights, for the first time, some fundamental aspects of a trail, including the aspect most relevant at this initial stage of definition, i.e., the route (others are: managing entity; belonging to international/European networks; presence of tourist-cultural facilities and services; promotional and valorisation initiatives carried out and planned in the short term). Subsequently, a Committee composed of the Ministry, Regions, Autonomous Provinces and ANCI will develop the criteria to admit individual itineraries proposed by the Regions into the subsequent Digital Atlas of trails (as we will see, among the 11 requirements is a maximum of 40% paved roads).

The trail, therefore, corresponds to the definitions of long distance path, route, way.

It can be agreed, therefore, on the definition of trail as a cultural itinerary mainly based (at least 60%) on paths. The path could thus be represented as the basic infrastructural element for the existence of a trail, seen as a set of paths to which paved segments are added, generally in peri-urban or urban areas. Another distinctive element is length/duration: generally, a path can be traversed in a single day or less, whereas the trail, being composed of multiple segments, has a longer duration, generally quantified as a minimum of three days. Also in this case, the Anglo-Saxon terminological difference, based on the duration of enjoyment (directly proportional to the length of the route), distinguishes “hike” as an excursion lasting a maximum of one day and “trekking” as a walking experience extending over multiple days.

C. Other types

The topic of pedestrian mobility is enriched by a variety of route types that fall into a hybrid zone between extra-urban and urban contexts. While paths are traditionally understood as predominantly extra-urban routes and trails as mixed routes also crossing inhabited centres,

research and planning have generated more specific categories to describe these experiences, such as Urban Green Paths and Metropolitan Paths.

Urban Green Paths represent a peculiar experience of “urban walking” developed along green lines that permeate the city fabric, such as parks, gardens and riversides. An example is the Turin project connecting the city boundaries to its centre, valorising an existing green infrastructure. On the other hand, the Metropolitan Path, inspired by the Faro Convention and first developed in Marseille, explores the peri-urban zone with an interface between city and countryside. This route, 365 km long and crossing 38 municipalities, obtained accreditation as a "Chemin de Grande Randonnée" (long-distance path) despite its peri-urban nature making it incompatible with standard criteria (which require over 70% of the route to be outside built-up areas). The ease of creating these routes lies in their development on existing public road networks, minimizing impact on protected natural areas. A concept of fundamental importance, located at the crossroads of mobility and territorial planning, is that of the greenway. Proposed by Turner [48] and enshrined in the Lille Declaration [49], the greenway is defined as an “environmentally pleasant route,” closed to motorized traffic and intended for all types of non-motorized users. Its design, responding to the 3D principles (Density, Design, Diversity of choices), is based on the recovery of existing infrastructures such as abandoned railways and riverbanks, aiming to preserve the territory and promote sustainable development. The term greenway, originally introduced by Frederick Law Olmsted in 1876 with the notion of “parkways” to describe broad tree-lined roads for recreational purposes, evolved into two distinct theoretical approaches. The American approach conceives it as a large natural corridor not necessarily traversable, while the European approach [50] defines it as a concrete route dedicated to soft mobility and aimed at connecting communities with territorial resources (natural, agricultural, historical and cultural).

Based on the European approach, greenways are distinguished by a series of characteristics: recovery of existing infrastructure, valorisation of the natural environment, universal accessibility, safety (physical separation from motorized traffic), multi-use and connection between urban and rural areas. These infrastructures are now widespread worldwide (e.g., Trans Canada Trail, Vias Verdes) and represent strategic tools for promoting slow and sustainable tourism.

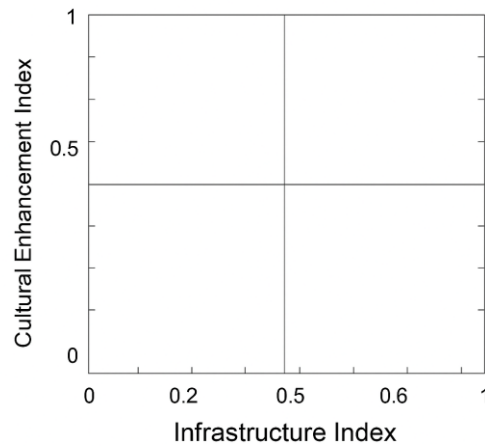
Surpassing the qualitative description of individual types, an analytical framework is necessary to evaluate and compare routes in a homogeneous way. To this end, a classification matrix of pedestrian routes based on the infrastructure index and the cultural valorisation index is proposed (Section 2.6.3).

The proliferation of these different types of extra-urban pedestrian routes, however, makes evident the need for a more detailed and objective classification. Although several taxonomies have been proposed at international and national levels, research is increasingly moving towards certification systems. These, unlike simple classification, attempt to evaluate routes based on high-quality standards and the characteristics most appreciated by walkers, aiming to ensure a high-level experience [51].

2.6.3 Classification matrix of pedestrian itineraries based on the infrastructure index and the cultural enhancement index

Overcoming the terminological ambiguity and methodological fragmentation that characterize the classification of pedestrian routes, a two-dimensional matrix (I-C Matrix) is proposed as an analytical tool for transport engineering (Figure 2.7). This model, functional to an objective classification, evaluates routes not only based on their intrinsic nature but also on their function and the overall experience they offer. The axis I is the Infrastructure Index, the axis C is the Cultural Enhancement Index.

Figure 2.7 - Classification matrix of pedestrian itineraries



This I axis quantifies the physical dimension of the route, measuring the degree of anthropic intervention and the quality of the infrastructure. The index, with a value ranging from 0 to 1, is calculated as a composite metric reflecting how “built” the route is compared to how “natural” it is. Key parameters for its evaluation include:

- percentage of non-natural surface: a high value indicates an infrastructure with predominantly artificial surface (e.g., asphalt), while a low value is typical of a route with a natural surface (e.g., dirt path);
- route width: greater width is indicative of a more developed and accessible infrastructure;
- average slope: a lower slope makes the route more accessible and engineered;
- signage and maintenance: the presence and quality of signage and maintenance reflect the level of care of the infrastructure;
- presence of structures: the presence of bridges, walkways, or steps indicates significant structural intervention.

A low index on this axis corresponds to a path with a predominantly natural surface and limited infrastructure, typical of a mountain trail. Conversely, a high index indicates a well-structured and maintained route, such as a greenway on a former railway.

The C axis measures the integration of the route with the intangible and cultural context of the territory. Also with a value ranging from 0 to 1, the index assesses the experiential potential of the route. Parameters for its measurement include:

- official recognition: membership in European networks (e.g., Cultural Routes of the Council of Europe) or national networks (e.g., MIBACT Atlas of Cammini) carries significant weight;
- density of Points of Interest (POI): the number of historical, religious, natural, archaeological sites and cultural attractions per linear km;
- availability of services: the presence and type of accommodation, refreshment points and tourist information offices;
- presence of narrative: availability of content that tells the history and culture of the place (e.g., apps, information panels, audio-guides);

- coordinated management: the existence of an official managing entity (association, consortium) coordinating promotion and maintenance.

A low Cultural Enhancement Index is found in routes whose attractiveness is linked almost exclusively to the landscape and nature. A high index, instead, denotes the presence of historical, monumental, or spiritual narratives that enrich its value beyond mere physicality.

The combination of these two indices allows for the identification of four macro-categories of routes, each with specific characteristics and implications for planning and management:

- bottom-left quadrant (low Infrastructure/low Cultural Enhancement): paths. Corresponds to routes with a strong natural imprint and little or no organized cultural elements. User motivation is linked to adventure and contact with nature. Example: an unmarked hiking path in a natural park;
- top-left quadrant (low Infrastructure/high Cultural Enhancement): cultural itineraries. Represents a type in which the cultural and intangible element is predominant, but the basic infrastructure remains natural. The user experience is focused on discovering historical and cultural heritage. Example: the Via Francigena before investments in infrastructure and services.
- bottom-right quadrant (high Infrastructure/low Cultural Enhancement): long-distance hiking routes. This quadrant includes well-structured and maintained routes (such as former railways converted into cycle paths) that rely on recreational and sport use. Example: a greenway running along a disused railway;
- top-right quadrant (high Infrastructure/high Cultural Enhancement): *cammini*. This is the quadrant where routes combining well-defined infrastructure with a strong cultural, historical or spiritual connotation are positioned. The presence of support services and integrated management makes them a true low-speed transport system, the main subject of this study. Example: the Camino de Santiago or the Via Francigena.

This matrix not only facilitates the analysis and classification of existing routes but also becomes a planning tool for future development. It allows, in fact, to identify the desired strategic positioning for a route and to direct investments toward the dimension (infrastructural or cultural) intended to be enhanced.

2.6.4 Classifications and Certifications of trails at the global level

Interest in pedestrian routes and trails is a global phenomenon, manifesting across all five continents through classification and certification systems specific to different geographic and cultural contexts. These standards are fundamental to ensuring safety, quality and recognizability, both for walkers and institutions. Clarifying examples from each continent will be provided.

A. Europe

At the European level, no univocal directives have been approved regarding standards for the use of terminology and trail classification, as occurs overseas. In fact, the overlap of voluntary classification schemes (at every level) often coincides with state and/or regional regulations, generating a situation of considerable confusion. For this reason, a scientific approach to the subject is necessary to guide, structure and standardize regulatory production.

Among European examples of route classification and qualification, we recall the European Ramblers' Associations initiative, named "Leading Quality Trails - Best of Europe", launched to maintain high-quality standards.

The "Leading Quality Trails - Best of Europe" (LQT-BE) program, promoted by the European Ramblers' Association, represents a virtuous example of voluntary standardization for trail certification. In the absence of univocal European directives, the initiative aims to guarantee high-

quality standards and to overcome regulatory fragmentation, offering walkers a safe, enjoyable and accessible hiking experience through natural paths, scenic landscapes and historic villages.

The program is divided into three main categories: LQT-BE Day Walk, for day hiking routes with a length between 4 and 25 km; LQT-BE, for long-distance routes exceeding 50 km; and LQT-BE Regions, which certifies entire areas with a network of pedestrian routes. Certification criteria differ according to the route length, with particular attention to infrastructure quality, signage and territorial valorisation.

For long-distance routes (over 50 km), criteria are evaluated in 4 km segments and include specific requirements for the route, such as a minimum of 35% on natural trails and a maximum of 3% on busy roads. Moreover, the presence of at least two different landscape formations and four attractions for each 4 km section is required. Accessibility is ensured by at least two daily public transport connections at the start and end of the route and by the possibility to book luggage transport. Signage is standardized, with clear panels at the start and end of the route and markers every 250 m.

Short-distance routes (Day Walk), instead, aim to guarantee a “perfect hike experience” and are divided into eight thematic categories, each with specific qualitative and quantitative requirements. These include: Winter Bliss, for snow-covered routes (4-12 km) with high-contrast signage; Nature Delight, natural trails (4-25 km) in quiet places with breathtaking landscapes; Cultural Experience, routes (4-25 km) with at least 30% on natural trails and focused on cultural heritage; Discover Tour, tours (4-15 km) with cultural narration and discovery of local products; Dream Tour, longer excursions (4-25 km); Urban Walk, urban routes (4-25 km) with at least 20% on trails and easily reachable by public transport; Comfortable Hike, paved trails (2-7 km) also suitable for persons with reduced mobility (PRM), with handrails on steps and benches every kilometre; and Family Pleasure, safe routes (2-10 km) with at least 30% trails, attractions and rest areas suitable for children. For all these short-distance categories, basic criteria are also provided, such as adaptability to specific target groups, surface quality, presence of informative points of interest and, where possible, route loops, refreshment points and quality informational materials.

Trail Cadastre, Digital Atlas of Trails, Catalogue of Religious Trails

With reference to Italy, it is interesting to report the example of the Trail Cadastre and the Atlas of Trails. The Digital Cadastre of the Italian Trail Network (REI), called INFOMONT, is implemented by the CAI based on the experiences of regional Trail Cadastres and is intended to promote the set of trails crossing the Peninsula and to present them to those who generally hike in the mountains. Therefore, the included trails are primarily characterized by their peculiarity of being “mountainous.”

The creation of INFOMONT derives from an agreement signed between CAI and Wikimedia Italia in 2016 (three-year, renewed in February 2021), to promote and improve the ways the public can access geographic data related to the mountain environment, thus facilitating its dissemination and use. Specifically, CAI, through the Trail and Cartography Operational Structure (SOSEC), committed to entering geographic information related to hiking routes, refuges and bivouacs into the OpenStreetMap database, making it freely accessible to all; while Wikimedia provides a server to test cartographic and informational tools. The INFOMONT database derives from OpenStreetMap data, with subsequent reprocessing and is open data, distributed under the Open Data Commons Open Database License (ODbL).

The criteria for including trails in the cadastre, indicated by CAI, prioritize the following elements: interval connections preferably starting from towns and on existing roads; access to refuges, active alpine huts and accommodation facilities; the historical-natural value of itineraries useful for preserving elements of knowledge and representativeness of the historical substance, not only

of roads but also of the human and natural landscape of the traversed territories; connection with nearby hiking networks; environmental sustainability in relation to trail construction and use.

Given the extensive expertise and experience of CAI, the classification proposed by this entity is generally used in hiking, dividing routes based on three parameters: characteristics, skills and competencies, equipment (Table 2.6).

Based on this classification, three types of routes are identified: Tourist (T), Hiking (E), Experienced Hikers (EE). As the difficulty level increases, the classification moves to Ferrata routes, which are not relevant to the present study.

As part of an Interreg Italy-Switzerland project, the FIE (Italian Hiking Federation) Lombardy developed a self-assessment questionnaire aimed at trail networks and long-distance routes with a length greater than 20-30 km. This tool makes it possible to evaluate each individual stage of a route, subsequently calculating the overall value as the average of the partial scores. The evaluation system focuses on three main objectives, namely attractiveness, safety and usability of the routes.

Table 2.6 - Classification of routes according to CAI.

ROUTE	CHARACTERISTICS	SKILLS AND COMPETENCES	EQUIPMENT
T = Tourist	Routes on cart tracks, mule tracks, or obvious paths without uncertainties or orientation problems; modest slopes and limited elevation gains	Basic hiking knowledge; physical preparation for walking	Suitable clothing; appropriate footwear
E = Hiking	Routes on mule tracks, paths and sometimes tracks; terrain varies depending on geomorphological and vegetational context (e.g. pastures, undergrowth, scree, stone fields); generally marked; may include steep sections, easy passages on rock, not exposed, requiring the use of hands for balance; any exposed points are generally protected; may cross flat or slightly inclined areas on residual snow	Sense of orientation; hiking experience; adequate training	Suitable equipment with particular attention to footwear
EE = Experienced Hiker	Routes almost always marked, requiring ability to move along paths and tracks on impervious and/or treacherous terrain (steep and/or slippery grassy slopes, small rocks, or rocky debris), often unstable and uneven; may include exposed sections, traverses, ledges, or rocky sections with slight technical difficulties and/or equipped (excluding via ferrata); medium-high slopes; possibility of sections on snow (excluding glaciers)	Excellent hiking experience; orientation ability; knowledge of mountain environment characteristics; surefootedness and absence of vertigo; evaluative and decision-making ability; adequate physical preparation	

These objectives are measured through fifteen specific criteria, which include the variety of environments, the connection to public transport, the crossing of valuable areas, the type and surface of the route, the conditions of the path and the conformity of signage. The evaluation also considers the availability of support points, the legal status of the route, the information provided, connectivity along the trail, socio-economic value, overall accessibility and that specifically for people with disabilities and finally multifunctionality, meaning mixed use of the network (Table 2.7).

To assign differentiated weight to the various aspects, the methodology attributes a specific relevance to the criteria: the first two (the variety of environments and the connection to public transport) have a maximum cumulative weight of 40%. The criteria related to the crossing of

valuable areas and the type of route each contribute an additional 20%, while the remaining 20% is distributed among all other parameters. According to FIE Lombardia, a route is of quality only if its overall evaluation reaches at least 70% of the total value.

Table 2.7 - FIE Lombardia Self-Assessment Questionnaire.

What to observe?	Evaluation	Judgment
Variety of environments: alternation of woods - countryside/meadows, ascent, slope, distant and close views, marked changes of direction, etc. Attractions: natural and cultural	Great variety and richness of attractions: each route/stage offers on average two attractions per hour of walking on the trail (ensuring a direct and logical route)	Very good
	Fair variety: each route/stage offers on average one attraction every 60 minutes of walking (ensuring a direct and logical route)	Good
	Poor variety: each route/stage offers on average less than one attraction every 60 minutes of walking (ensuring a direct and logical route)	Sufficient
	No variety	Insufficient
Connection to public transport: at least two daily public transport connections, or at least parking for motor vehicles	At both ends, the route/stage is connected to a public transport stop	Very good
	At one end, the route/stage is connected to a public transport stop	Good
	At both ends, the route/stage is not connected to a public transport stop but has "convenient" parking	Sufficient
	At both ends, the route/stage is not connected to a public transport stop and has no "convenient" parking	Insufficient
Crossing of valuable areas: Presence of National, Regional, or Local Parks of supra-municipal interest, Eco-museums, Biotopes, historical settlements, monuments, art, historic sites, natural monuments, characteristic Italian landscapes, endemic species, etc.	Great importance: National and Regional Parks	Very good
	Medium importance: biotopes, local emergencies	Good
	No particular relevance	Sufficient
	Crossing degraded areas	Insufficient
Type of route: whether it is on a path, mule track, trail, restricted/regulated traffic road, or open road	Over 90% of the network develops on paths, mule tracks, trails and forest roads	Very good
	At least 80% of the network develops on paths, mule tracks, trails and forest roads	Good
	Less than 80% of the network develops on paths, mule tracks, trails and forest roads	Sufficient
	Less than 60% of the network develops on paths, mule tracks, trails and forest roads	Insufficient
Surface of the route: type of surface, whether natural, cobbled, unpaved forest road, asphalt, concrete	The entire route has a natural surface without paved sections and without passing on forest roads	Very good
	The entire route has a natural surface without paved sections and with stretches on forest roads (natural surface)	Good
	The route has a natural surface with paved sections for less than 20%	Sufficient
	The route has a natural surface with paved sections for more than 20%	Insufficient
Route conditions: condition of the trail surface and existing works (drains, steps, walls, equipped sections)	The entire route and works are in perfect condition	Very good
	Partly accessible for disabled / different types	Good
	The route has sections and works to be repaired but that do not compromise walkability and enjoyment	Sufficient
	The route has sections and works to be repaired that may create difficulties or make some passages unsafe and potentially dangerous	Insufficient
Information and communication: ease of access to trail information, through guides, maps, magazines, internet	Comprehensive information on the web, updated publications and topographic maps, easily accessible, consistent with field conditions	Very good
	Available only on paper, updated guides and maps - difficulties consistent with reported	Good
	Information only on onsite information boards	Sufficient
	Not available or too outdated, or web/paper sources inconsistent with actual route difficulties	Insufficient
Connectivity on the trail (web-app information): availability of 2.0 tools on the trail, advanced connectivity (NFC, QR code) for real-time information on	The trail is equipped with connectivity from hot points along the entire route for NFC (near field contact) and others. Hot spots positioned along the routes are entirely made of recyclable, biodegradable, eco-friendly materials and use existing vertical signage structures. Updated GPS	Very good

environmental, naturalistic, historical-cultural, ethnographic aspects, mountaineering history, practical support and emergencies	tracks are available online for free	
	The entire route is covered by connectivity for access to QR codes readable by smartphones and tablets	Good
	The route at the beginning and end is equipped with QR codes readable by smartphones and tablets	Sufficient
	The route is only partially covered by connectivity or not equipped with QR/connection	Insufficient
Socio-economic value: CAI/Public Institution synergy: • Integration with regional/local sustainable development policies • Connection between valleys • Historical/ethnographic value • Enhancement of rural and natural landscapes as sustainable tourism	Structural connection with the plans of the local tourism authority	Very good
	Socio-economic impact on local micro-economy	Good
	Involvement of valley tourist/accommodation facilities (e.g. product clubs)	Sufficient
	Does not meet any of the above conditions	Insufficient
Accessibility: Ease of access to the trail, connectivity, walkability, multifunctionality: pedestrian, bicycle, horse	“Easy”: access to the trailhead must be logical and intuitive, easily identifiable thanks to signage and spatial arrangement in relation to roads, inhabited areas, woods or meadows/cultivated areas. The trail is always identifiable and walkable on foot, by bike/MTB and horse. Connectivity on at least 50% of the route. Interconnection with public transport network	Very good
	The trail does not have perfect signage but is always easily identifiable and walkable, not multifunctional. Connectivity on 25% of the route	Good
	The trail is walkable but with some uncertainties due to poor maintenance or lack of vertical signage; horizontal signage is sufficient. Sporadic connectivity	Sufficient
	Absence of vertical signage at junctions, approximate horizontal signage, possible orientation issues without updated GPS; no connectivity	Insufficient
Accessibility for disabled: Ease of access for disabled, connectivity, walkability and tools for sensory experiences	Within the network, at least some itineraries are identified for quality “easy” experiences for disabled people. The trail complies with prescribed standards for safe and pleasant accessibility for disabled and their companions (structures, slopes, barrier removal, support strategies). Structures for sensory/perceptual experiences. 100% connectivity. On-site guide service available by reservation. Interconnection with public transport	Very good
	The trail complies with prescribed standards for safe and pleasant accessibility for disabled and their companions (structures, slopes, barrier removal, support strategies). 50% connectivity. No other services	Good
	The trail complies with minimum prescribed standards for safe accessibility for disabled and their companions	Sufficient
	No special facilities to foster sensory experience	Insufficient
Multifunctionality - Mixed use of the trail network; trail usable by pedestrians, cyclists and horse riders; connectivity; suitable equipment along the route for bicycles and horses	The trail network also includes routes usable for mixed use (pedestrian-bike-horse) that meet the following: - physical (trail width, moderate slope, geomorphology, surface type), - ecological (environments crossed, biodiversity impacts, soil/landscape fragility), - hiking/mountaineering (safety of users in both directions and crossings). The route is suitable for multiple users: on foot, MTB/e-bikes, horse. Connectivity over 50%. Stalls/equipment for bikers and riders along route/start or end points. Signage for variant stretches or mandatory crossing on foot	Very good
	Route structurally suitable for multiple use but with poor/sporadic services for bicycles and horses. Connectivity <50%	Good
	Route structurally suitable for multiple use but without services. Sporadic connectivity	Sufficient
	Route structurally unsuitable for multiple use, reserved exclusively for hiking. No services for bicycles/horses. No or poor connectivity	Insufficient

The Digital Atlas of the Paths of Italy, launched by MIBACT in 2016 and integrated in 2018, represents the first official mapping of the country’s walking routes. Its importance lies in having identified for the first time eleven specific criteria for the definition and inclusion of a path. These requirements range from the physical nature of the route (which must be linear, safe and

accessible, with a percentage of paved roads not exceeding 40%) to its management and communication, which require the presence of a governing body, maintenance, a constantly updated website and georeferencing. The Atlas also emphasizes essential services, which must be available within 5 km of the route, including accommodation and catering and signage.

In 2018, the Atlas was enriched with the inclusion of cycle routes and historic railways, as well as the identification of specific strategic points. Among these, Points of Interest (PoI) are prestigious places such as UNESCO sites or villages, Intersection Points serve as junctions between different routes and Entry Points coincide with infrastructures of the National Integrated Transport System (SNIT), such as airports and ports.

Subsequently, in 2022, the Catalogue of Religious Paths was introduced, adding new requirements for access, such as the prevalence of low-traffic roads, a distinctive logo and the availability of certification tools for pilgrims such as the credential. However, the absence of objective indicators has made this classification very broad, even including routes that are not strictly religious. At the institutional level, the Senate, recalling the need for homogenization, introduced the definition of “interregional paths”, understood as itineraries that cross several regions and are distinguished by cultural value *lato sensu*. Currently, a Draft Law in the Senate aims to promote the paths as cultural itineraries, proposing a Steering Committee for their mapping and a Permanent Consultation Table.

Finally, noteworthy is the recent initiative of the Touring Club Italiano (TCI), which introduced a certification standard based on the twenty-year experience of the Orange Flags. The goal is to promote slow and conscious tourism through a high-quality travel experience. At the core of this certification is the Walking Routes Analysis Model (M.A.C.), which applies to routes of at least 20 km and assesses more than 200 indicators summarized into seven areas of analysis: Mobility and Signage, Tourist Services, Tourist Attraction Factors, Environmental Management, Hospitality, Governance and Promotion and Structure and Walkability of the Route. To date, four routes have been certified by TCI.

Regional Catalogues and Atlases in Italy

Although MIBACT (now Ministry of Culture) has defined an action plan for paths at the national level, the competence in the matter of trails and paths remains in fact under the responsibility of individual Regions. This autonomy has generated significant heterogeneity and regulatory misalignment between territories. While it is true that most Italian regions, thanks above all to the action of the Italian Alpine Club (CAI), have regional laws and trail registries, the situation changes radically with regard to walking routes: only eleven out of twenty regions have approved specific legislation for their recognition. Although in almost all these cases the creation of a Register or an official catalogue is envisaged, only three regions have made their Atlas accessible online and only one, Veneto, has developed an official dedicated application. This situation of fragmentation highlights the need for a more coordinated approach (Table 2.8).

Table 2.8 - Regional Catalogues and Atlases in Italy.

REGION	Regional law on walking routes	Law on trails/Trail cadastre	Atlas of walking
Abruzzo	L.R. 20 November 2017	No	Provided for by law but not available
Basilicata	No	Regional Law 51/2000 Rules for programming, development and regulation of minor roads and trail systems in Basilicata	No
Calabria	Regional Law 15 March 2023, n. 12	http://www.caicalabria.it/sentieri-calabria/	Provided for by law but not available
Campania	DGR 688/2022 - Atlas of walking routes - Public notice of expression of interest for the recognition of Campania walking routes in the Regional Atlas of Walking Routes. GUIDELINES FOR THE RECOGNITION OF CAMPANIA WALKING ROUTES - Managerial Decree 518 12/07/2023	Regional Law 24 June 2020, n. 14. "Rules for the enhancement of trail systems and minor roads"	Provided for by law but not available
Emilia Romagna	Project dedicated to the promotion of slow tourism with a focus on the Experiential Tourism of Walking Routes and Pilgrimage Routes, launched by Apt Servizi in 2015 in agreement with the Regional Department of Commerce and Tourism, in line with the MIBACT Directive which identified 2016 as the year of the "Paths of Italy" with attention to promoting initiatives for sector development, the use of such routes and the creation of the Digital Atlas of the Paths of Italy	https://ambiente.regione.emilia-romagna.it/it/geologia/cartografia/rete-dei-sentieri	https://camminiemi.liaromagna.it/it The Circuit of Walking Routes of Emilia Romagna with its 20 routes:
Friuli Venezia Giulia	Regional Law 09 December 2016, n. 21 - CURRENT TEXT from 07/03/2023 - Coordinated text with Regional Law 3 March 2023 n. 10	https://www.cai-fvg.it/sentieri-cai-fvg/	Yes, in textual format
Lazio	L. 2/2017 Provisions for the creation, maintenance, management, promotion and enhancement of the network of walking routes of the Lazio Region. Amendments to Regional Law 6 August 2007, n. 13 concerning the organization of the Lazio tourist system and subsequent amendments. BUR 19 November 2019, n. 93. Current text as of: 14/05/2021 - Implementing Regulation of Regional Law 10 March 2017, n. 2 (Provisions for the creation, maintenance, management, promotion and enhancement of the network of walking routes of the Lazio Region. Amendments to Regional Law 6 August 2007 n. 13 concerning the organization of the Lazio tourist system and subsequent amendments)	https://gr.cailazio.org/catasto/	https://www.visitlazio.com/cammini/
Liguria	No	https://www.regione.liguria.it/homepage-ambiente/cosa-cerchi/natura/rete-escursionistica-ligure.html	
Lombardia	No law	Regional Law 27 February 2017, n. 5 Trail network of Lombardy and measures for the enhancement of mountain roads and trails of historical interest (1)	No law but project financed by the Lombardy Region, included on the basis of the Walking Routes Analysis Model of the Touring Club Italiano within the LinC project. Contains 16 routes
Marche	No specific law on walking routes	Regional Law 22 November 2021, n. 29 Title: Support for integrated initiatives for the redevelopment and enhancement of villages and historic centers of the Marche and promotion and development of widespread and sustainable tourism	https://www.consiglio.marche.it/banche-dati-e-documentazione/leggi/dettaglio.php?idl=1639
Molise	No	https://psr.regione.molise.it/node/166	No
Piemonte	No, Francigena project for all http://gruppopd.cr.piemonte.it/web/2017/01/24/promozione-sostegno-della-via-francigena-dei-cammini-percorsi-storico-devzionali-del-piemonte/	https://www.regione.piemonte.it/web/temi/ambiente-territorio/montagna/patrimonio-outdoor/rete-escursionistica-piemonte	No
Puglia	RESOLUTION OF THE REGIONAL COUNCIL 22 November 2021, n. 1890 Recognition of Walking Routes and Cultural Itineraries - Guidelines	https://pugliacon.regione.puglia.it/web/sit-puglia-sit/catasto-della-rete-escursionistica-pugliese	Under development

Sardegna	Yes https://www.regione.sardegna.it/atti-bandi-archivi/atti-amministrativi/liste-elenchi/registro-dei-cammini-di-sardegna-e-degli-itinerari-religiosi-e-dello-spirito	https://portal.sardegna.sira.it/i-sentieri-forestali	
Sicilia	Regional Law Sicily 13 April 2022, n. 7 (1). Rules on recognition, use and enhancement of Walking Routes	https://www.sitr.regione.sicilia.it/geoportale/it/metadata/details/791	Provided for by law but not available
Toscana	Regional Government Implementing Regulation of the law for the recognition and enhancement of regional walking routes, LR 35/2018, aimed at promoting stage itineraries. STRATEGIC OPERATIONAL DOCUMENT "The Walking Routes of Tuscany" (2018 Resolution n.663 of 18-06-2018=) DECREE OF THE PRESIDENT OF THE REGIONAL GOVERNMENT 9 April 2020, n. 22 Implementing regulation of Regional Law 10 July 2018, n. 35 (Provisions for the recognition, enhancement and promotion of regional walking routes). (GU 3rd Special Series - Regions n. 37 of 26-09-2020)	http://www502.regione.toscana.it/geoscopio/sentieristica.html updated to 2005	https://www.reporterinviaggio.it/atlant-e-dei-cammini-scoprire-la-toscana-a-passo-lento/
Trentino Alto Adige	No	https://www.sat.tn.it/sentieri/mappa-sentieri/	
Umbria	Regional Law 10 July 2017, n. 8 Regional tourism legislation. Publication: Official Bulletin n. 28, S.o. n. 1 of 12/07/2017 https://leggi.alumbria.it/mostra_atto.php?id=183168&v=FI&m=5	https://www.regione.umbria.it/documenti/18/2324573/Disciplinare+tecnico+rete+dei+sentieri.pdf/b0a2f920-b610-4d3e-b8a7-6e83760e33de	Provided for but not available
Val d'Aosta	No	https://catastosentieri.regione.vda.it/	No
Veneto	BUR n. 15 of 04 February 2020 REGIONAL LAW n. 4 of 30 January 2020 Provisions for the recognition, enhancement and promotion of Veneto walking routes. RESOLUTION OF THE REGIONAL COUNCIL N. 1072 OF 30 AUGUST 2022 Adoption of the "Regional Program for the Tourist Enhancement of Veneto Walking Routes", pursuant to art. 7 of Regional Law 30 January 2020, n. 4 "Provisions for the recognition, enhancement and promotion of Veneto Walking Routes"	https://www.regione.veneto.it/web/en-ti-locali/sentieri-bivacchi-casere	APP Veneto Outdoor

B. America

An innovative classification of walking itineraries is the one proposed by the Trans Canada Trail organization, funded by Canadian public institutions, recognized as the "world's longest network of multi-use recreational trails" since it connects more than 28,000 km from coast to coast of Canada. First of all, the definition of trail is provided: "A trail is a defined type of infrastructure that is purposefully designed and used for one or more recreation activities or for active transportation. To be recognized as a trail, it must be approved by the landowner, mapped and marked, as well as actively managed and maintained" and then the complementary definition of "trail experience", from the user's point of view: "The ability for a visitor to engage in a desired trail activity, at a desired level of challenge, within a desired recreation setting and in a desired natural region". In fact, the classification process, starting from the limits of the classical classification, is reversed in order to be centred on the user's point of view. The process, of a "step-by-step" type, is divided into three phases (Table 2.9). In the first phase, on the basis of a list of classification parameters, the desiderata are chosen and documented on the Trail Management Objective (TMO) form. In the second phase, if the trail already exists, its characteristics are compared with the objectives identified in phase one. If a misalignment is found, it will be necessary to intervene on the constructive characteristics of the trail using as design parameters the characteristics identified in the TMO. Then, in the third phase, the characteristics identified in the TMO are used as communication elements of the trail to potential users through the various usable channels (website, trail signage, maps, mobile device applications and other channels).

Table 2.9 - Trans Canada Classification.

Step 1	Season	Summer; Winter; All season
	Mode of travel	Not Motorized; Motorized; Mixed Use
	Type of Use	Single-use; Multi-use; Activity-optimized
	Activity Type(s)	Non-motorized (Pedestrian (walking, hiking, Running); On-road cycling; Leisure cycling; Mountain biking; Adaptive cycle, mountain; Biking; Small-wheeled; Equestrian; Equestrian drawn vehicle (buggy, cart, wagon, sleigh); Cross-country skiing (classic, skate); Snowshoeing) Motorized (On-road cycling; Mountain biking; Off-road motorcycle, dual sport motorcycle Motorized vehicle - width 1.5m (60") or greater than 1.5m (60") but less than 1.83m (72") ; Motorized vehicle - width greater than 1.83m (72"); Snowmobile or snowbike - width 1.5m (60") or less; Snowmobile - width greater than 1.5m (60")
	Level of Challenge	Easiest (beginner); Moderate (intermediate); Difficult (advanced); Very Difficult (expert)
	Preparedness	Standard (visitors should make standard preparations to travel the trail safely (e.g., trip plan, clothing, water, etc.); Enhanced (Visitors need to make enhanced preparations in order to travel the trail safely. Triggers include, but are not limited to: specialty equipment required to travel the trail safely (water purification, avalanche beacon/probe/shovel, etc.); specialty skills required in order to travel the trail safely (navigation, wildlife awareness, backcountry travel, mountaineering/route selection, avalanche, etc.); enhanced fitness required in order to travel the trail safely; hazards on or near the trail (avalanche, swift water crossing, etc.) that require visitors to be aware of and prepare for, in advance of their trip in order to travel the trail safely)
	Level of Development (Recreation settings: Developed; Frontcountry; Midcountry; Backcountry Trail infrastructure (bridges, boardwalks, curbs, handrails, etc.); Access: Major trailhead; Minor trailhead; rustic trailhead) Signage & Wayfinding: Major trailhead signs with maps; Minor trailhead signs with maps; Trail markers/Directional signs; Regulatory/Caution/advisory signs; Interpretative signs; Comfort & Convenience: Flush toilet; Composting toilet; Vault toilet; Waste receptacles; recycling receptacles; Benches; Picnic tables; Off-loading ramps)	Developed; Moderately developed; Minimally developed
Step 2	Design Parameters (Select based on activities with highest design needs)	Clearing Limits (Clearing Height; Clearing Width); Travelled Surface Width Tread Surface Type & Compaction (Asphalt, Concrete, Pavers; Aggregate - Firm surface; Aggregate - Loose surface; Natural - Firm surface; Natural - Loose surface); Trail Tread Obstacles (Obstacle Frequency; Obstacle Height) Grades (Target Grade; Maximum Grade; Maximum Grade Proportion) Cross Slope (Target Cross Slope, Maximum Cross Slope; Maximum Cross Slope Proportion); Sight line (Sight line distance)
Step 3	Minimum information about trail classification to provide before the trail experience	Trail information to provide before and during the trail experience
	Season of use (mode of travel; whether the trail is optimized for a particular activity permitted trail activities using standardized representational icons; prohibited trail activities using standardized; representational icons technical level of challenge using the class rating symbol preparedness rating, standard preparedness statement as well as any enhanced preparations; physical design parameters of the trail including: length; elevation gain and loss; typical and minimum tread and clearing width; tread surface, firmness and stability; typical grade, maximum grade and maximum grade proportion; typical cross slope, max. cross slope and max. cross slope proportion; tread obstacle frequency and height; amenities available on/along the trail and whether they are universally accessible	Trail length; surface type, firmness and stability; typical and minimum tread width; typical and maximum grade and maximum grade proportion; • typical and maximum cross slope; frequency and height of obstacles; trail map; washrooms and other facilities and amenities present along the trail; infrastructure barriers to accessing the trail, such as width-limiting or right-angle; gates; any other barriers that could impact a visitor's experience

The communication will concern both the class of the trail (type, permitted activities, level of challenge, level of development and preparedness) and the trail's physical characteristics (e.g., length, surfacing widths, grades, etc.) (Table 2.10).

Table 2.10 - Trail Design Parameters for Pedestrians.

Category	Criterion	1 - Easiest (Beginner)	2 - Moderate (Experienced)	3 - Difficult (Very Experienced)	4 - Very Difficult (Expert)
Tread Width	Travelled Surface Width	> 1.5 m	1.0 - 1.5 m	0.3 - 1.0 m	< 0.3 m
	Technical Trail Features - Width	None or not allowed	Allowed - off the main trail, optional	Allowed - within the trail, optional available	Allowed - across the entire width, not optional
Surface	Surface Type	Paved	Aggregate - Compacted Surface	Natural - Compacted Surface	Natural - Unstable Surface
	Obstacle Frequency	None	Occasional	Frequent	Frequent
	Obstacle Height	< 0.025 m	0.025 - 0.05 m	0.05 - 0.15 m	> 0.15 m
Sightline Clearing	Clearing Width	> 2.0 m	1.5 - 2.0 m	0.5 - 1.5 m	< 0.5 m
	Clearing Height	> 3.0 m	> 3.0 m	2.5 - 3.0 m	< 2.5 m
Inclines / Grades	Trail Grade	< 3%	3 - 10%	10 - 15%	> 15%
	Maximum Grade (short)	< 7%	7 - 15%	15 - 25%	> 25%
	Maximum Grade Proportion	< 10%	10 - 15%	15 - 20%	> 20%
Cross Slope	Target Cross Slope	< 2%	2 - 8%	8 - 15%	Natural
	Maximum Cross Slope	< 2%	2 - 10%	10 - 15%	> 15%
Oversight	Maintenance	Weekly	Monthly	Seasonal	Annual
	Identified Hazard Response	Immediate	Within one month	Within several months	Annual or never
Segment Length	Segment Length	< 5 km	5 - 10 km	10 - 30 km	> 30 km
Facilities	Facilities	Parking / drinking water / restrooms	Parking / drinking water	Parking	None
Geography	Geography	Frontcountry	Midcountry	Midcountry	Backcountry

In the USA there are 30 National Scenic and National Historic Trails designated by Congress, with a total extension exceeding 88,000 km. These routes connect a widespread network of natural and cultural resources, including seventy wildlife refuges, eighty national parks, ninety Bureau of Land Management offices, ninety national forests, one hundred twenty-three wilderness areas and one hundred major metropolitan areas.

In 2011, the approval of the Federal Trail Data Standard (FTDS), developed by the Federal Geographic Data Committee, introduced a univocal terminology for the classification of trails at the federal level. Starting from this standard, in 2022 the Federal Trail GIS Schema (Table 2.11) was elaborated, conceived to be adopted by all institutions and partners operating in the sector, with the aim of defining a common and coherent GIS structure, applicable to any type of trail, including the National Scenic Trails (NST) and the National Historic Trails (NHT).

The Federal Trail Data Standard defines a trail as “a linear route managed for human-powered, stock, or off-highway vehicle (OHV) forms of transportation, or for historical or cultural purposes.” The classification is structured on a continuum of five classes (Trail Class 1: Minimally Developed, Trail Class 2: Moderately Developed, Trail Class 3: Developed, Trail Class 4: Highly Developed, Trail Class 5: Fully Developed) determined according to the degree of development of five fundamental parameters: Tread & Traffic Flow, Obstacles, Constructed Features & Trail Elements, Signs and Typical Recreation Environs & Experience, including the settings of the Recreation Opportunity Spectrum (ROS) and the Wilderness Recreation Opportunity Spectrum (WROS).

For the National Historic Trails, moreover, a specific classification has been prepared, able to consider the presence and relevance of historical evidence along the route.

Table 2.11 - Federal Trail GIS Schema.

Trail Attributes	Trail Class 1 Minimally Developed	Trail Class 2 Moderately Developed	Trail Class 3 Developed	Trail Class 4 Highly Developed	Trail Class 5 Fully Developed
Tread & Traffic Flow	• Tread intermittent and often indistinct • May require route finding • Single lane, with no allowances constructed for passing • Predominantly native materials	• Tread continuous and discernible, but narrow and rough • Single lane, with minor allowances constructed for passing • Typically native materials	• Tread continuous and obvious • Single lane, with allowances constructed for passing where required by traffic volume in places where there is no reasonable opportunity to pass • Native or imported materials.	• Tread wide and relatively smooth, with few irregularities. • Single lane, with allowances constructed for passing where required by traffic volume in places where there is no reasonable opportunity to pass • Double lane where traffic volume is high and passing is frequent. • Native or imported materials • May be hardened	• Tread wide, firm, stable and generally uniform. • Single lane, with frequent turnouts where traffic volume is low to moderate • Double lane where traffic volume is moderate to high • Commonly hardened with asphalt or other imported material
Obstacles	• Obstacles common, naturally occurring, often substantial and intended to provide increased challenge • Narrow passages; brush, steep grades, rocks and logs present	• Obstacles may be common, substantial and intended to provide increased challenge • Blockages cleared to define route and protect resources. • Vegetation may encroach into trailway	• Obstacles may be common, but not substantial or intended to provide challenge • Vegetation cleared outside of trailway	• Obstacles infrequent and insubstantial • Vegetation cleared outside of trailway	• Obstacles not present • Grades typically < 8%
Constructed Features & Trail Elements	• Structures minimal to non-existent • Drainage typically provided without structures • Natural fords • Typically no bridges.	• Structures of limited size, scale and quantity; typically constructed of native materials • Structures adequate to protect trail infrastructure and resources • Natural fords • Bridges as needed for resource protection and appropriate access	• Structures may be common and substantial; constructed of imported or native materials • Natural or constructed fords. Bridges as needed for resource protection/appropriate access	• Structures frequent and substantial; typically constructed of imported materials • Constructed or natural fords • Bridges as needed for resource protection and user convenience • Trailside amenities may be present.	• Structures frequent or continuous; typically constructed of imported materials • May include bridges, boardwalks, curbs, handrails, trailside amenities and similar features
Signs	• Route identification signing limited to junctions • Route markers present when trail	• Route identification signing limited to junctions • Route markers present when trail	• Route identification signing at junctions and as needed for	• Route identification signing at junctions and as needed for user	• Route identification signing at junctions and for user reassurance

	location is not evident • Regulatory and resource protection signing infrequent • Destination signing, unless required, generally not present • Information and interpretive signing generally not present.	location is not evident • Regulatory and resource protection signing infrequent. • Destination signing typically infrequent outside wilderness areas; generally not present in wilderness areas • Information and interpretive signing uncommon	user reassurance • Route markers as needed for user reassurance • Regulatory and resource protection signing may be common • Destination signing likely outside of wilderness; generally not present in wilderness areas • Information and signs may be present outside of wilderness	reassurance • Route markers as needed for user reassurance • Regulatory and resource protection signing common • Destination signing common outside of wilderness; generally not present in wilderness areas • Information and interpretive signs may be common outside wilderness areas • Accessibility information likely displayed at trailhead.	• Route markers as needed for user reassurance • Regulatory and resource protection signing common • Destination signing common • Information and interpretive signs common • Accessibility information likely displayed at trailhead
Typical Recreation Environs & Experience	• Natural and unmodified • ROS: Typically Primitive to Roaded Natural • WROS: Typically Primitive to Semi-Primitive.	• Natural and essentially unmodified • ROS: Typically Primitive to Roaded Natural • WROS: Typically Primitive to Semi-Primitive.	• Natural and primarily unmodified • ROS: Typically Primitive to Roaded Natural • WROS: Typically Semi-Primitive to Transition	• May be modified • ROS: Typically Semi-Primitive to Rural • WROS: Typically Portal or Transition	• May be highly modified • Commonly associated with visitor centers or high-use recreation sites • ROS: Typically Roaded Natural to Urban • Generally not present in wilderness areas

C. Oceania

Australia has a wide and diversified network of routes, often characterized by uncontaminated natural environments, ranging from tracks of less than 1 km to itineraries of over 5,300 km, such as the Bicentennial National Trail (5,330 km) which crosses four states. The classification adopted at national level is voluntary and is called the Australian Walking Track Grading System (AWTGS) (Table 2.12), based on five classes and six evaluation parameters.

In the Australian context, the terms Track and Trail are used interchangeably, as highlighted in the regulation: Track “roadway with a single carriageway. A roadway through a natural bushland region” and Trail “see Track”. The interpretation of both terms therefore refers to roadways, although in many areas, such as Tasmania, they are commonly associated with walking routes rather than vehicular ones.

The AWTGS classifies the routes into five grades, in accordance with the Australian standards for the construction of walking tracks (AS 2156). This system was funded and developed on the initiative of the Victorian Government, in collaboration with governmental and non-governmental agencies across the country, including the New South Wales National Parks. The classes range from the first, designed to guarantee accessibility even for people with reduced mobility (including those in wheelchairs assisted by a companion or parents with strollers), up to the fifth, intended for expert hikers.

The evaluation parameters consider both physical and topological aspects of the route (distance, slope, etc.) and management elements (e.g., presence and quality of signage), as well as the overall user experience. The final classification is not obtained by calculating the average of the scores on the parameters but is based on the most demanding level detected: consequently, a route may present characteristics consistent with a simpler grade while having one parameter that determines a higher overall grade. The five classes are illustrated in the following table.

Table 2.12 - Australian Walking Track Grading System.

	Grade 1 - suitable for the disabled with assistance	Grade 2 - suitable for families with young children	Grade 3 - recommended for people with some bushwalking experience	Grade 4 - recommended for experienced bushwalkers	Grade 5 - recommended for very experienced bushwalkers
Distance	Less than 5km.	Less than 10km.	Less than 20km.	May be greater than 20km. Distance does not influence grading.	May be greater than 20km. Distance does not influence grading.
Gradient	Suitable for a person in a wheelchair.	Generally no steeper than 1:10	May exceed 1:10	May have arduous climbs and steep sections. May include long steep sections exceeding 1:10	May have arduous climbs and steep sections. May include long steep sections exceeding 1:10
Quality of path	Broad, hard surfaced track of path suitable for wheelchair use	Generally a modified or hardened surface	Formed earthen track, few obstacles. Generally a modified surface, sections may be hardened	Generally distinct without major modification to the ground. Encounters with fallen debris and other obstacles are likely. Walkers may encounter natural obstacles (e.g. tides)	No modification of the natural environment
Quality of markings	Track head signage & route markers at intersections	Track head signage & route markers at intersections	Track head signage & route markers at intersections and where track is indistinct.	Track head signage and route markers	Signage is generally not provided
Experience required	Users need no previous experience and are expected to exercise normal care regarding their personal safety.	Users need no previous experience and are expected to exercise normal care regarding their personal safety. Suitable for most ages and fitness levels.	Users need no bushwalking experience and a minimum level of specialised skills. Users may encounter natural hazards such as steep slopes, unstable surfaces and minor water crossings. Responsible for their own safety.	Users require a moderate level of specialised skills such as navigation skills. Users may require maps and navigation equipment to successfully complete the track. Users need to be self-reliant, particularly in regard to emergency first aid and possible weather hazards	Users require previous experience in the outdoors and a high level of specialised skills such as navigation skills. Users will generally require a map and navigation equipment to complete the track. Users need to be self-reliant, particularly in regard to emergency first aid and possible weather hazards.
Steps	Steps with ramp access	Minimal use of steps	Steps may be common	Steps do not influence grading	Steps do not influence grading

There are no evident examples in the Asian continent of univocal and widely adopted governmental classification systems of routes; therefore, only two examples of classification detected at national level will be provided, in Japan, where one of the longest and oldest trails in the world exists (the Kumano Kodo pilgrimage) and in China, where the largest system of National Parks is being established, also aimed at the creation of trails.

The Kumano Kodo is the oldest and most popular pilgrimage in Japan, together with the Shikoku pilgrimage (the path of the 88 temples). To understand its importance, it is enough to consider that it is twinned with the Camino de Santiago to the point that it is possible to walk both with a single Dual Pilgrimage certificate. The Kumano Kodo is composed of four pilgrimage routes, to be walked exclusively on foot (bikes and horses are not allowed). Within the Kumano Kodo area, the Kii-Hanto peninsula, operates the Tanabe City Kumano Tourism Bureau. It is precisely the Tanabe City Kumano Tourism Bureau that describes the possible offer of walking routes in the area, differentiating them by difficulty, from short leisurely walks to multi-day treks, including the Kumano Kodo pilgrimage route network (Table 2.13) [52].

The difficulty evaluations are calculated with the combination of the following 6 criteria: Distance, Time, Elevation gain and descent, Type of terrain, Accessibility, Isolation. Based on these parameters the routes are divided into five classes, specifying the limits.

Table 2.13 - Kumano Kodo Classification.

	Difficult Ranking 1	Difficult Ranking 5
Distance	Short distance	Long distance
Time	Minimal time to walk	Full day walk
Elevation gain and descent	Minimal elevation gain and descent	Steep elevation gain and descent
Type of terrain e.g. mountain trail or paved road	Easy terrain e.g. pavement or well maintained trail	Difficult terrain eg. roots, steep uneven staircases, etc.
Accessibility e.g. public bus routes	Very accessible e.g. bus stops are nearby	Limited accessibility
Isolation e.g. if there are people nearby	Settled area e.g. people live along the trail or nearby	Remote area
There are many variables that can dynamically change the difficulty of the route including; Weather Time of day Time of year Direction routes are walked Amount of luggage being carried Physical condition and experience of walker		

Another interesting example from Japan is the one provided by the Prefecture of Nagano, although it is more applicable to mountainous areas rather than to trails differentiated as a whole. In the classification carried out by the Prefecture of Nagano (Table 2.14), as many as 123 trails were classified on the basis of a matrix that provides on the vertical axis the level of physical effort and, at the same time, the duration of the trail (considering them directly proportional, an assumption not always correct). The scale is divided into 10 levels of difficulty concerning physical effort and four classes concerning duration (A day trip is possible; One night or longer; 1-2 nights or longer; 2-3 nights or longer). The horizontal axis instead provides for the technical level required, as one moves to the right the level increases, thus identifying five columns: A, B, C, D, E). With respect to the x-axis, an exemplary matrix is also reported with two rows (trail; technique & ability) and five columns, in which the various types of trails are exemplified for the different abilities and techniques required. This results in a general scheme in which 50 classes derive, in which the individual mountains are classified by crossing the level of the x-axis and the y-axis.

Although no classification and certification system of routes is found in China, great attention is paid by the Government to protected natural areas and by the academic world to the impact that activities such as hiking can have on these areas [53].

Among the proposed itineraries, however, two historical itineraries stand out: the "Dr Sun Yat-sen Historical Trail", located in Hong Kong and centered on the figure of the revolutionary leader Dr Sun and the Meiguan Historical Trail [54] located on the South China Historical Trail [55], which covers a network in Guangdong with 202 roads and involves 1320 villages. According to Chinese sources, the existing sections of ancient roads in Guangdong province amount to 233, equal to 710.44 km in length, of which 135 sections have been recently discovered. Great attention must be paid to the establishment of hiking and trekking routes on the new network of natural parks being organized [56].

Table 2.14 - Prefecture of Nagano Classification.

TRAIL	Well-maintained most of the section. ◇Small possibility of falling and sliding down if you trip. Small possibility of getting lost.	There are streams, cliffs and snowy valleys in some trails. ◇Steep ups and downs Some sections of a trail are not clearly indicated. Some possibility of falling and sliding down if you trip in some sections.	There are some sections with ladders or chains. Some trails have snowy valleys and streams to walk across. Carelessness may lead to falling and sliding accidents in some sections. Some sections do not have enough signs.	There are some difficult rocky ridges, unstable scree slopes. Some sections have ladders or chains and thickets to push your way through. Some trails have snowy valleys and streams to walk across. Steep ups and downs where you need to use your hands. Artificial support including ladders, chains and signs are limited. Many dangerous sections with possibility of falling and sliding down.	Continuous ups and downs on intense and difficult rocky ridges. Dangerous sections with possibility of falling and sliding down continue. There may be a series of deep thickets to push your way through.
TECHNIQUE, ABILITY	Trekking equipment necessary	Trekking experiences necessary Map-reading ability desirable	Map-reading ability and physical strength to climb a ladder/chain necessary	Map-reading ability, balance and technique to steadily go across rocky and snowy sections necessary Route-finding technique necessary	Map-reading ability, balance and technique to steadily go across rocky and snowy sections necessary Route-finding technique and sound judgment necessary Some trekkers need to use a rope for safe climbing in some sections.

E. Africa

The only trail accreditation system in Africa, although not governmental but voluntary, is the independent Green Flag accreditation system [57] (Table 2.15). It was promoted as the official accreditation system of the Hiking Organisation of Southern Africa and receives support from the World Trails Network (WTN) and major conservation agencies in South Africa [58]. The Green Flag accreditation system, created in 2006, is spreading worldwide. It is based on the evaluation of responsible management and trail marketing. The trail description for the attribution of the Green Flag is made on the basis of twelve attributes [59].

Among the attributes, noteworthy is the novel caloric-based approach that measures the energy expenditure of trail users according to a ten-point effort scale divided into four ranges: Easy (from 1 to <4; i.e., 0 to <1125 calories), Moderate (from 4 to <7; i.e., 1125 to <2250 calories), Difficult (from 7 to 10; 2250 to <3375 calories) and Extreme (10+; >3375 calories).

Table 2.15 - Green Flag accreditation system.

Attribute	Classification			
Technical difficulty	Walk	Scramble (use hand)	Climb/ladder	Free rock Climbing
Energy rating	Easy	Moderate	Difficult	Extreme
Guiding	Guide (Registered)	Guide (Learner)	Local Hike Leader	Self-guided
Catering	Fully catered	Semi-catered	Self catered	No overnight
Trail format	Linear	Circular	Network (Base camp)	Open-ended
Trail type	Ramble (max. 3 h)	Day walk	Overnight Trail	Portaged
Path character (accessibility)	Handicapped Wheelchair/Blind	Constructed footpath/trail	“Free range” with guide	“Free range” with GPS
Accommodation	Luxury	Excellent	Standard	Rustic (bush camp) optional
Environmental Char.	Pristine	Natural	Rural	Semi-urban
Facilities	Excellent	Acceptable	Poor	No facilities
Environmental education	Curriculum based	Guided/Brochure	Standard info on trail	No Environmental education
Safety	Safe	Safe - heed warnings	Risky	Unsafe

2.7 Proposed classification of pedestrian tourist itineraries

In light of the above, it is intended to converge on clear and univocal definitions of the concepts of “path” and “trail” (Table 2.16).

A “path” (*Sentiero*) is defined as a pedestrian route with a width of less than 2.50 m, whose path is safe and in good condition, with a predominantly natural surface (100% unpaved if shorter than 10 km; at least 80% unpaved if equal to or longer than 10 km) and with stage lengths that can be covered within a single day (length between 2 and 25 km).

For a trail to be recognized and official, it must meet the following requirements:

- be managed by a clearly identifiable public or private entity;
- feature passage through at least 2 territorial environments (e.g., forest, countryside, village);
- include at least 2 points of interest (cultural, natural, architectural, religious, etc.) according to the philosophy of identifying the most interesting route rather than the shortest;
- be characterized by distinctive and walkers-friendly vertical and/or horizontal signage and by information panels at the start and end of each stage indicating main information (stage length, elevation gain, notable sites, presence of fountains and/or refreshment points, etc.);
- have adequate refreshment sites (at least one fountain or rest area or refreshment facility at the start and end of each stage, within 15 km);
- have an official website with standard informational parameters, including multiple itineraries;
- provide the opportunity to freely download a technical sheet and the GPX track of the route;
- be reachable by public transport with terminals at the start and end points of the route.

A path could thus be assumed as a basic infrastructural element to create also a medium- and long-distance trail.

On the other hand, a “trail” can be seen as a set of dirt path integrated with stages on paved roads located in peri-urban or urban areas. A “trail” (*Cammino*) is therefore defined as an itinerary walkable on foot or using other forms of slow and sustainable mobility, without motorized transport, exceeding 50 km in length and comprising at least 3 stages, crossing urban centres and extra-urban areas. The trail must meet the following minimum requirements:

- be managed by a clearly identifiable public or private entity;

- stages characterized by the presence of a common aspect that is cultural, historical, religious, etc.;
- have a safe and well-maintained path with at least 40% of the route unpaved;
- be predominantly in natural environments and feature a variety of landscapes;
- include at least 3 points of interest (cultural, natural, architectural, religious, etc.) for each stage, according to the philosophy of identifying the most interesting route rather than the shortest;
- be characterized by distinctive and walkers-friendly vertical and/or horizontal signage and by information panels at the start and end of each stage indicating main information (stage length, elevation gain, notable sites, presence of fountains and/or refreshment points, etc.);
- have accommodation and refreshment facilities (at least one accommodation facility with at least 8 beds and one refreshment facility at the start and end of each stage, within 15 km);
- have an official logo;
- have an official website with standard informational parameters;
- provide the opportunity to freely download a technical sheet and the GPX track of the route;
- be reachable by public transport with terminals at the start and end points of the route;
- involve the territory (sign at least one memorandum of understanding or agreement with public or private entities based in or competent for the stage territory, other than food and lodging facilities, e.g., municipalities, museums, parishes, etc.);
- have a system for tracking walkers (e.g., during the delivery of the Testimonium/Certificate of completion);
- develop an action plan to be implemented over time.

Table 2.16 - Proposed Classification of Path and Trail.

Characteristic	Path	Trail
Definition	Footpath with width < 2.50 m, safe, in good condition, predominantly natural surface (100% unpaved if < 10 km; ≥ 80% unpaved if ≥ 10 km), stage length 2-25 km, walkable in a single day	Route walkable on foot or with soft and sustainable mobility, without motor vehicles, length > 50 km, minimum 3 stages, crossing urban centres and extra-urban areas
Management	Managed by an identifiable public or private entity	Managed by an identifiable public or private entity
Environments crossed	At least 2 different territorial environments (e.g., forest, countryside, village)	Predominant passage through natural environments, variety of landscapes
Points of interest	≥ 2 for the entire path, of cultural, natural, architectural, religious, etc. nature	≥ 3 for each stage, of cultural, natural, architectural, religious, etc. nature
Trail philosophy	Based on the interest of the route rather than brevity	Based on the interest of the route rather than brevity
Surface	Predominantly natural (see definition)	At least 40% of the route unpaved
Signage	Distinctive vertical and/or horizontal, walkers friendly; information panels at the start and end of the stage with data on length, elevation gain, notable sites, fountains and/or refreshment points	Distinctive vertical and/or horizontal, walkers friendly; information panels at the start and end of the stage with data on length, elevation gain, notable sites, fountains and/or refreshment points
Minimum services	At least one fountain or rest area or refreshment point at the start and end, within 15 km	At least one accommodation facility (≥ 8 beds) and one refreshment point at the start and end of the stage, within 15 km
Accessibility	Reachable by public transport, terminal at start and end	Reachable by public transport, terminal at start and end
Online information	Official website with standard informational parameters; free download of technical sheet and GPX track	Official website with standard informational parameters; free download of technical sheet and GPX track
Identity features	—	Presence of official logo
Territorial involvement	—	At least one memorandum of understanding or agreement with public/private entities (e.g., municipalities, museums, parishes)
Trail tracking	—	Tracking system (e.g., for issuance of Testimonium/Certificate)
Planning	—	Action plan to be implemented over time

2.8 Trail lifecycle

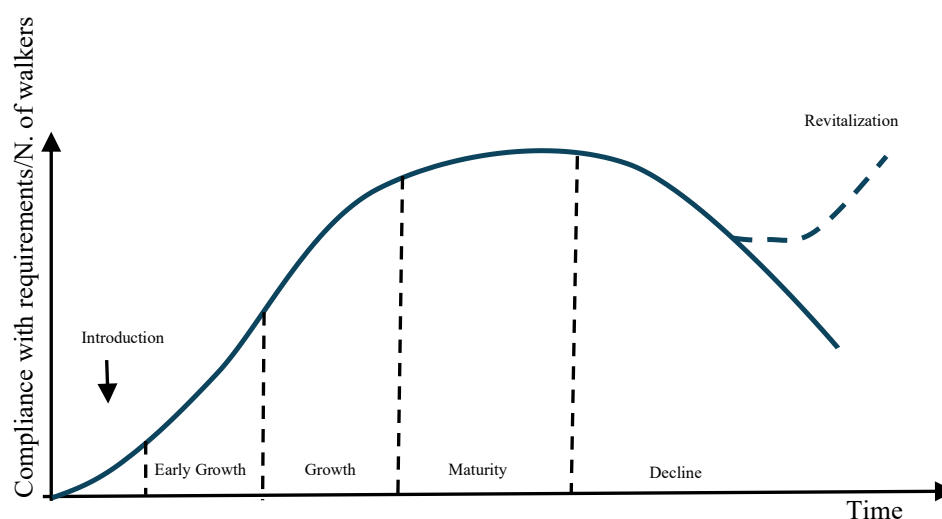
Based on the progressive possession of technical-organizational and infrastructural requirements, it is possible to outline a “Lifecycle of trail” (Figure 2.8), articulated in operational phases that reflect the degree of development, consolidation and sustainability of the itinerary. This approach, derived from lifecycle analysis models typical of territorial marketing and infrastructural design, allows a dynamic assessment of the route in terms of offer quality, usability and attractiveness.

The six proposed phases are:

In design: the initial phase in which the route is defined but is not yet certified or officially accessible. At this stage, the itinerary may exist only on paper, without adequate supporting infrastructure and is subject to modifications and preliminary evaluations by local authorities and stakeholders.

In launch phase (introduction): the trail meets all identified criteria (e.g., signage, safety, hospitality, storytelling, governance) in a proportion between 20% and 50% of the stages. This is the moment when external communication is initiated, the route is promoted and the first flows of walkers are experimented.

Figure 2.8 - Trail lifecycle.



In progress (Early Growth): compliance with the criteria extends to between 50% and 75% of the stages. This is a consolidation phase in which quality standards are implemented more systematically and a significant increase in public interest begins to be recorded.

Accessible (Growth): at least 75% of the stages fully meet the quality criteria. The trail becomes stably accessible, with good overall organization and an efficient hospitality network, capable of ensuring coherent experiences along the route.

Mature (Maturity): all criteria are satisfied for the entire itinerary. The trail has acquired a consolidated reputation, is frequently chosen by walkers and represents a stable tourist product, able to generate significant economic, social and cultural impacts on the traversed territory.

Saturated (Decline): although formally all criteria are maintained, the trail may present criticalities related to overcrowding, anthropic pressure, or unsustainable use of local resources. This phase may involve a loss of perceived quality and reduced attractiveness in the medium-long term, thus requiring revitalization strategies, such as diversification of the offer, access regulation, or integration with other less frequented itineraries.

Analytically, the lifecycle representation can be effectively schematized on a Cartesian axis system in which:

- the horizontal axis represents time, i.e., the evolution of the trail from the ideation phase to maturity and beyond;
- the vertical axis reflects the degree of fulfilment of technical-organizational and infrastructural requirements, combined with the number of walkers who actually use the route.

This representation highlights a non-linear relationship between the development of the trail and the growth of demand: the progressive structuring and promotion of the itinerary generally corresponds to an increase in walker flows, but this can generate imbalances when the offer is not adequately scaled. In fact, the most frequented trails, in the absence of proportional adjustment of infrastructure, accommodation capacity, or services, may face saturation phenomena, with negative impacts on the territory and on the walker's experience, such as congestion, environmental degradation, or loss of authenticity.

To ensure a reliable classification of the maturity level of a trail, it is also appropriate to consider the overall duration of the itinerary. Trails exceeding seven days should be divided into functional segments, each evaluated individually against the quality criteria. This approach allows not only avoiding penalization for longer routes but also precisely identifying areas requiring specific interventions, promoting a modular and adaptive vision of planning and governance of trails.

2.9 Economic, environmental and social impacts of long-distance walking trails

Long-distance walking trails today constitute a form of sustainable tourism that acts simultaneously on three dimensions: economic, social and environmental. Each trail generates a complex network of interactions among tourist flows, host communities and the territory, requiring an integrated vision to understand benefits and criticalities.

2.9.1 Economic impacts

The economic impacts generated by long-distance walking trails can be distinguished into direct, indirect and induced impacts. Direct impacts derive from the expenditure of walkers along the trail, including accommodation, meals, local transport, ancillary services (such as backpack transport or bicycle rental) and the purchase of local or artisanal products. Indirect impacts relate to the expenditure of economic operators benefiting from the presence of pilgrims (e.g., suppliers of goods for accommodations, local food and wine producers, construction companies for the maintenance of trails and facilities). Finally, induced impacts refer to effects on the local economy generated by income received by those employed in trail-related sectors, which is subsequently spent in the territory in other areas.

In the case of the Camino de Santiago, one of the most studied internationally, these three levels of impact have been subject to in-depth economic evaluation. Infrastructure investments in the 1990s aimed at improving signage, refuges and rural roads facilitated the economic revival of the areas crossed [60]. In 2010 alone, the trail generated between €60 and €100 million in gross value added and supported between 1,362 and 2,162 direct jobs [61].

Research on the economic and social impact of pilgrims highlights a tourism model significantly different from conventional tourism. Unlike traditional tourists, who allocate around 23% of their budget to transport, pilgrims spend almost nothing in this category, directing their financial resources directly into the territory. This behaviour generates a significantly higher economic impact: pilgrims represent 2.3% of total tourist expenditure in Galicia, with an economic impact

per person 2.3 times greater than that of a domestic visitor. This multiplier effect is evident as every euro spent by a pilgrim can generate up to 11% additional economic output and contribute to an 18% increase in employment. Pilgrim expenditure is particularly focused on local products: 61% of their budget is allocated to food and beverages, compared to 26% of non-resident tourists, demonstrating greater integration with the local economy. Finally, the positive reception by the local population, with over 90% of residents perceiving favourable economic impacts and the role of long-distance walking trails in curbing rural depopulation, confirm the strategic value of this type of tourism for sustainable territorial development [62].

Similar analyses have emerged in other contexts such as the Portuguese Way or the Via Francigena [63]. Beyond direct expenditure, trails generate transversal economic effects including the creation of new businesses (e.g., *albergues*, hostels, guiding services, artisan workshops), an increase in female employment in hospitality services and the enhancement of local cultural and landscape capital. In many rural areas, trails have encouraged the return of young people and families who see sustainable tourism as a life and work opportunity.

However, impacts are not exclusively positive. Some studies highlight the risks of excessive *touristification*, with consequent loss of authenticity, increased local prices and transformation of the identity of the communities crossed [64], [65].

2.9.2 Environmental impacts

Long-distance walking trails, by their nature, constitute a form of low-impact tourism, promoting slow mobility, conscious landscape enjoyment and a more balanced relationship between humans and the environment. However, despite their sustainable vocation, the growing popularity of these itineraries can generate significant environmental impacts, especially in contexts lacking planning, maintenance and visitor flow management strategies.

Environmental impacts can be distinguished into physical, ecological and infrastructural. Physical impacts concern trail deterioration due to repeated foot traffic, soil erosion, compaction and the formation of ruts altering natural water drainage [66]. Ecological impacts include disturbance of wildlife, dispersion of alien species and pressure on native vegetation, particularly in protected or ecologically fragile areas [67]. Infrastructural impacts may result from unregulated or excessive construction of support facilities (hotels, parking lots, picnic areas), which can irreversibly modify the rural landscape and compromise the integrity of the crossed territory.

An emblematic example is the Camino de Santiago, which in 2023 exceeded 438,000 registered pilgrims: anthropogenic pressure is now comparable to that of some urban tourist destinations [68]. Studies conducted in Galicia have revealed a significant increase in solid waste along the trails, particularly in summer months, despite numerous environmental awareness campaigns. In parallel, the massive presence of pilgrims has generated intensive consumption of natural resources, such as water, in rural refuges inadequately equipped for sustainable management.

Waste management is particularly critical on longer and less urbanized trails, where accommodations are often isolated or not served by regular collection systems. In the absence of dedicated services, there is a risk of improper disposal, leading to soil and groundwater pollution. The phenomenon of unauthorized camping, common in some contexts, can also have negative effects on the natural environment, compromising sensitive habitats and increasing the risk of wildfires.

However, in the presence of good environmental management practices, long-distance walking trails can become true laboratories of sustainability. In Galicia, for example, an integrated environmental monitoring system has been implemented, including pilgrim flow control, regular trail maintenance and promotion of ecologically responsible behaviour among pilgrims [69].

Similarly, the European Green Pilgrimage project has promoted guidelines for reducing emissions and energy consumption of facilities along spiritual trails, with positive results in environmental efficiency [70].

Methodologically, there is a growing application of quantitative environmental indicators (such as ecological footprint or visitor carrying capacity) and the adoption of GIS and LCA (Life Cycle Assessment) models to evaluate the cumulative impact of hiking and religious trails on the territory [71]. These tools are essential for guiding public policies toward sustainable trail planning, capable of integrating environmental conservation with economic-cultural valorisation.

2.9.3 Social impacts

Long-distance walking trails, in addition to economic and environmental effects, generate a wide range of social impacts affecting both the crossed territories and local communities as well as the walkers themselves. These impacts, often difficult to quantify immediately, manifest in the long term through cultural, relational and identity transformations, contributing to the construction of new social dynamics and the regeneration of local social capital [72]

A first level of impact concerns the strengthening of community sense. Trails, especially those structured in networks and integrated with local economies, encourage cooperation among residents, local administrations, associations, tourism businesses and third-sector actors. This fosters the emergence of new participatory governance practices and greater social cohesion, particularly in marginalized or depopulated contexts [73]. In many rural Italian areas crossed by trails - for example the Via Francigena - renewed community engagement in land care and promotion of cultural heritage, both tangible and intangible, has been observed. Better preservation and valorisation of cultural heritage are among the positive social impacts of long-distance walking trails [74], [75].

In parallel, trails generate opportunities for social inclusion and activation of vulnerable categories. Along numerous routes, accessible tourism projects, solidarity hospitality experiences and initiatives involving people with disabilities, migrants, or youth in disadvantaged situations are multiplying. In this sense, the trail becomes a tool for empowerment and regeneration [76].

Another social impact is attributable to the psychophysical well-being and personal growth of walkers, who often experience the trail as an opportunity for introspection, detachment from daily routine and reconnection with themselves and the environment. Numerous studies, including clinical and psychological ones, confirm that walking in natural contexts can reduce stress, improve mood, stimulate creativity and enhance self-efficacy [77], [78]. In some therapeutic experiences, such as trails organized by associations for cancer patients or people with mental disorders, structured hiking has been recognized as an effective tool for social and individual rehabilitation [79].

Finally, the potential of trails in promoting education for active and sustainable citizenship should be mentioned. In many school and university experiences, the trail has been integrated as a pedagogical methodology to develop transversal skills, promote experiential learning and raise awareness of environmental and civic issues. "Education on the trail," increasingly recognized in the international debate, fits into a training paradigm that prioritizes direct contact with places, slowness, observation and personal responsibility [80]. In this sense, the Strade Maestre project represents a virtuous example of how education can be rethought through the slow travel experience. Replacing traditional classrooms with Italian trails, the initiative demonstrates that learning is not solely linked to a physical place, but nourished by direct contact with the territory, communities and history. Through the trail, students develop not only academic but also social and personal skills, learning to live together, solve problems and face real-world complexity. The

experience contributes to forming more aware citizens, capable of appreciating their country's cultural and natural heritage and acting responsibly.

However, it should not be underestimated that the growing interest in long-distance walking trails can also produce ambivalent social effects, especially in territories more exposed to mass tourism. In some areas, increased walker flows, coupled with the progressive transformation of local identities, loss of cultural authenticity and emergence of conflicts between residents and visitors, have been observed [81], [82]. These phenomena are often amplified by the absence of regulation policies and by a commercial, stereotyped narration of trails, which empties their original spiritual or experiential meaning.

In conclusion, long-distance walking trails represent a powerful and sustainable economic lever, capable of combining territorial valorisation, social cohesion and local development, provided they are accompanied by balanced management policies, able to protect the territories and communities involved.

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Chapter 3

Pedestrian Mobility Infrastructures and Services

The transport system is defined as the set of components and their mutual interactions that determine the mobility demand of people and goods between different points in the territory and the supply of transport services to satisfy such demand [1]. It can be decomposed into the two subsystems of supply and demand. Transport supply consists of all infrastructures, vehicles, technologies, services, rules and prices that allow movement from one point to another in the territory. Transport demand is the set of mobility needs expressed in each territory.

Specifying this concept in the field of pedestrian mobility, pedestrian supply can be defined as the set of infrastructures (linear and punctual), equipment and services aimed at guaranteeing walking mobility under conditions of safety, comfort, accessibility and continuity. It can be assessed by measuring the quantity and quality of spaces dedicated to pedestrians and how these spaces facilitate and make walking movements attractive.

The following sections analyse the main categories of pedestrian infrastructures (linear, punctual and auxiliary) with the related technical specifications and accessibility and safety requirements, derived from consultation of scientific literature and regulations, including the Highway Code, D.M. 236/1989 and UNI standards.

3.1 Linear infrastructures

Linear infrastructures include all physical elements that constitute the network of paths intended for pedestrian mobility, characterized by longitudinal development. Among the design and construction requirements are continuity, safety, universal accessibility and comfort of use, taking into account the needs of different types of users. Examples include sidewalks; pedestrian paths; pedestrian ramps; underpasses, overpasses, pedestrian bridges and footbridges; long-distance walking trails and extra-urban paths (Table 3.1).

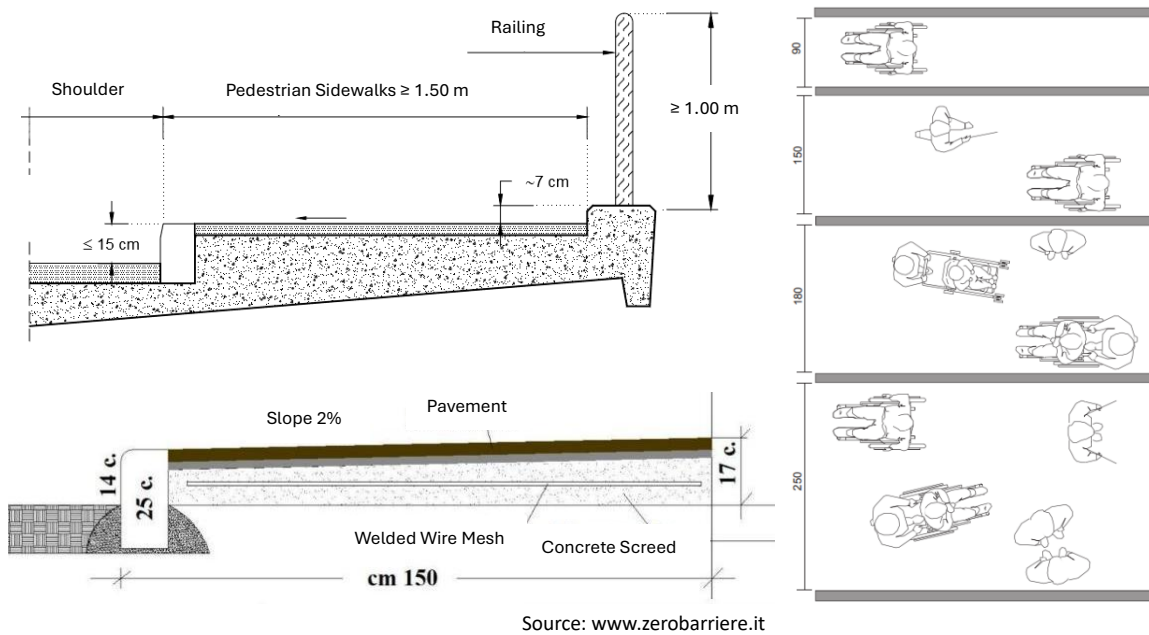
Sidewalks

Sidewalks are fundamental elements in urban areas, spaces reserved for pedestrian mobility, separated from the roadway intended for vehicles by protective elements such as curbs, flowerbeds, or others. The main dimensional parameters (Figure 3.1) are the effective width, which, according to the most widely adopted guidelines, must be at least 1.50 m to allow two pedestrians to pass each other; however, the optimal width depends on the expected pedestrian flow, its length and its location relative to services and destinations. The curb height is generally between 12 and 15 cm to ensure protection from vehicular traffic but reduced to 2 cm at accessible crossings.

The minimum width that allows a person with mobility issues to use the pedestrian path is 90 cm. This minimum width is considered compatible in limited spaces, especially in historic centres, provided that the pavement is free of irregularities, the transverse slope relative to the walking direction does not exceed 1% and the paths are not excessively long (paths with lengths not exceeding 10 meters or interrupted by sufficiently dimensioned manoeuvring spaces are recommended). The transverse slope should not exceed 2% to avoid water stagnation, while the longitudinal slope is linked to terrain morphology and must comply with accessibility regulations.

The walking surface must be regular, non-slip and free of discontinuities, made of wear-resistant and weather-resistant materials. Additionally, lateral to the pedestrian path, safety conditions must be ensured, such as containment curbs, deterrents, or other elements that do not hinder directional changes. It is also important that excessive path widths and high pedestrian density do not create orientation difficulties, hence the usefulness of easily perceivable horizontal signage or acoustic signage.

Figure 3.1 - Dimensional characteristics and pavement layering of sidewalks.

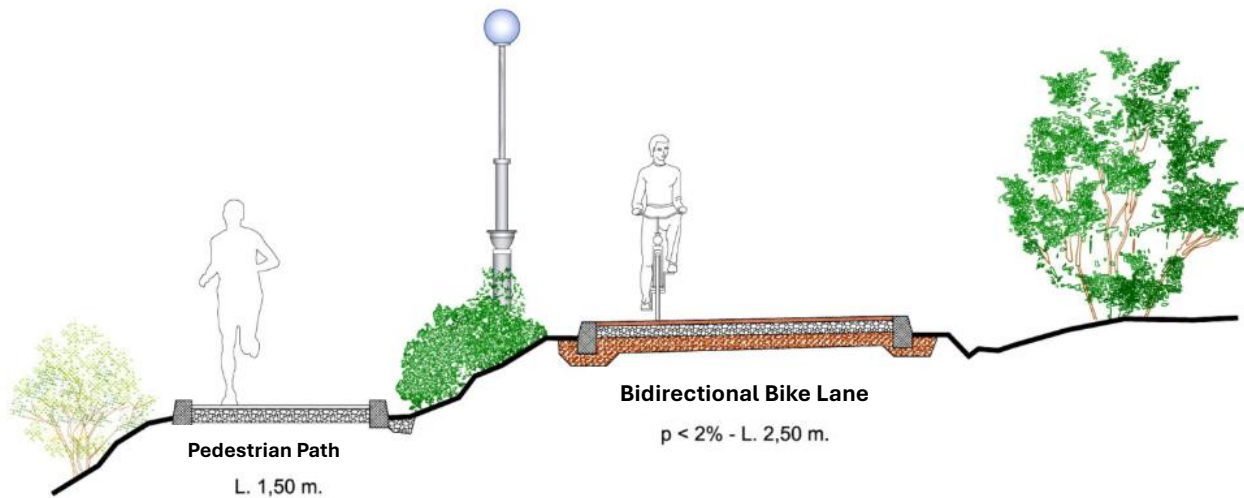


The sidewalk layering must comply with regulations for the removal of architectural barriers, durability and safety, such as those contained in D.M. 236/1989 and specific technical standards, which define thicknesses, slopes, widths and the need for accessible transitions. The layering consists of a sub-base (stabilized material on which the entire system rests), a reinforced screed (homogeneous layer of concrete or mortar, usually reinforced with a metal mesh, providing strength and a safety margin against shrinkage and deformation) and the pavement (visible and walkable layer, composed of tiles, natural stone, or other durable and non-slip materials), each with specific requirements for strength, drainage and finish, ensuring compliance with user needs.

Pedestrian paths

Pedestrian paths are configured as dedicated routes, physically separated from both vehicle traffic and any cycling paths, often located in natural areas, waterfronts, or green spaces (Figure 3.2). The width varies depending on the expected pedestrian traffic volume and intended use: recreational-tourist paths may require larger sections to allow coexistence of groups, people with bulky backpacks, or mobility aids. The route must ensure continuity, adequate slope and absence of obstacles, with possible night-time lighting and dedicated signage. The design of a pedestrian path can include additional safety measures, such as physical barriers, curbs, railings, traffic separators, underpasses, overpasses, or elevated areas.

Figure 3.2 - Example of a pedestrian path adjacent to a bike lane.

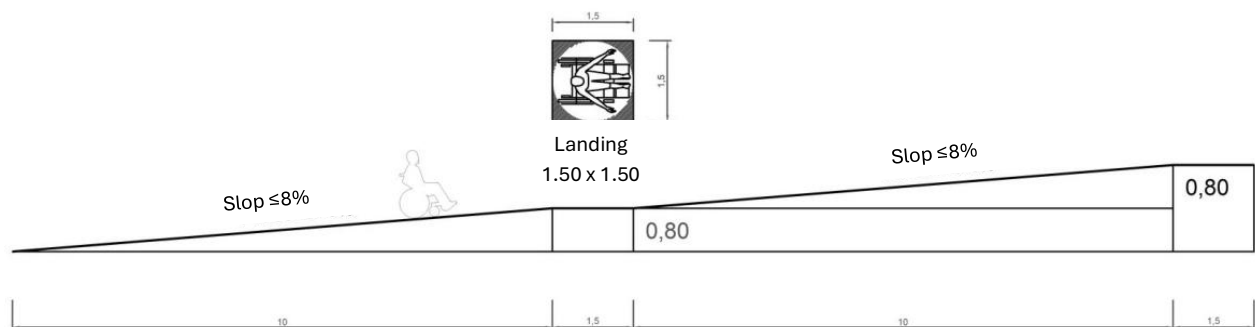


Source: <https://www.archweb.it/>

Pedestrian ramps

Ramps allow overcoming elevation differences, both in urban areas (connection between sidewalk and crossing) and in more complex contexts (access to underpasses, bridges, or elevated infrastructures). They must comply with maximum slope requirements (generally $\leq 8\%$ for short stretches and $\leq 5\%$ for prolonged paths) and include rest landings every approximately 10 m. The recommended minimum width is 1.50 m to allow wheelchair passage and crossing between users (Figure 3.3).

Figure 3.3 - Example of ramp with 8% slope and manoeuvring landing.



Source: <https://www.archweb.it/>

Underpasses, overpasses, pedestrian bridges and footbridges

These structures maintain the continuity of the pedestrian network by overcoming physical barriers such as roads, railway lines, watercourses, or valleys. Design must consider not only geometric dimensions (clear height, effective width, ramp and stair slopes) but also safety, visibility and comfort, with adequate lighting, video surveillance and finishes that reduce degradation risk and perception of insecurity. Pedestrian bridges are generally more complex and permanent structures, designed to ensure safe crossings over larger natural or artificial obstacles (rivers, valleys, main roads). They require careful evaluation of structural actions (wind, water, dynamic

loads), durable materials and often significant architectural and landscape integration. Footbridges, on the other hand, are smaller structures, usually light and slender, intended for minor obstacle crossings or to connect urban fabric parts (Figure 3.4). While maintaining safety and accessibility criteria, they prioritize functionality and rapid construction, being less expensive than bridges.

Figure 3.4 - Example of a pedestrian bridge.



Trails and extra-urban long-distance walking trails

In natural or rural contexts, pedestrian paths assume geometric characteristics adapted to the orographic and landscape context (Figure 3.5). Widths can range from 0.80 m for hiking trails to over 2.00 m for highly frequented long-distance walking trails. Design must consider surface stability, natural water drainage, erosion resistance and integration with the environmental context, minimizing visual impact and ensuring walker safety. In all linear infrastructures, path continuity and integration with access nodes (e.g., crossings, public transport stops) are determining factors for the effectiveness of the pedestrian supply. Material choice scheduled maintenance and compliance with universal accessibility regulations are essential conditions to ensure adequate performance throughout the infrastructure's life cycle.

Figure 3.5 - Examples of trails and long-distance walking trails.



Table 3.1 - Main technical characteristics of linear pedestrian infrastructure.

Type	Minimum Clear Width	Cross Slope	Longitudinal Slope	Other Functional Requirements	Regulatory Notes
Sidewalks	≥ 1.50 m (≥ 2.00 m in high-density areas)	≤ 2%	Variable, according to terrain morphology and accessibility standards	Regular and non-slip surface; curb height 12-15 cm (reduced to ≤ 2 cm at accessible crossings); continuity of path	D.M. 236/1989, Urban Accessibility Guidelines, UNI 11168
Pedestrian Paths	1.50-3.00 m (depending on pedestrian flow and intended use)	≤ 2%	≤ 5% (except in steep terrain)	Physical separation from vehicular and cycling traffic; dedicated lighting and signage	Road and regional technical standards; accessibility standards
Pedestrian Ramps	≥ 1.50 m	≤ 2%	≤ 8% (short sections), ≤ 5% (long paths)	Landings every 10 m; non-slip surface; handrails h ≥ 1.00 m	D.M. 236/1989, UNI EN 17210
Pedestrian Underpasses	≥ 2.00 m	-	Ramps compliant with maximum allowable slope	Free height ≥ 2.20 m; continuous lighting; video surveillance; effective drainage	Road and railway infrastructure regulations
Pedestrian Overpasses	≥ 2.00 m	-	Ramps/stairs compliant with accessibility standards	Handrails h ≥ 1.20 m; lateral protections; non-slip pavement; night lighting	D.M. 236/1989, structural safety standards
Pedestrian Bridges	≥ 3.00 m (in main urban areas; ≥ 2.50 m in extra-urban areas)	1-2%	≤ 5% (otherwise with ramps/elevators)	Durable handrails, lighting, pavement	Structural regulations NTC 2018; accessibility DM 236/89
Pedestrian Walkways	≥ 1.50-2.00 m	1-2%	≤ 5-8%	Lateral protections, lighting	Minor structural regulations; DM 236/89
Long-Distance Walking Trails	0.80-2.50 m (depending on expected volume)	Adapted for natural drainage	Adapted to topography	Stable and draining surface; directional signage; periodic rest areas	CAI Guidelines, regional trail standards

Note: The indicated values refer to the main Italian regulations for pedestrian design: D.M. 236/1989 and Urban Accessibility Guidelines for sidewalks, ramps and overpasses; UNI 11168 and UNI EN 17210 for accessible paths; road and regional technical standards for pedestrian paths; NTC 2018 for bridges and walkways; CAI Guidelines and regional standards for extra-urban trails.

3.2 Point infrastructures

Point pedestrian infrastructures constitute those elements spatially defined and located at nodal points. They can serve various functions, including access or resting and generally support the flow and safety of pedestrians. They are fundamental to ensuring continuity, accessibility and comfort of pedestrian routes, especially at intersections, level changes, or gathering points. Among the main point pedestrian infrastructures, the following can be distinguished: pedestrian crossings and safety islands; moving walkway; resting areas and gathering points; elevators and stairlifts for pedestrians.

Pedestrian crossings and safety islands

The pedestrian crossing is a crucial element of urban mobility, going far beyond its mere function as a road signal. Designed to be a safe interface between the world of vehicles and that of pedestrians, it embodies the principle of priority for the most vulnerable. Its correct design, signalling and integration into the road network are not only a matter of regulatory compliance but also a fundamental indicator of the civility and attention a city dedicates to its citizens, particularly those moving on foot, including the elderly, children and people with reduced mobility (Figure 3.6).

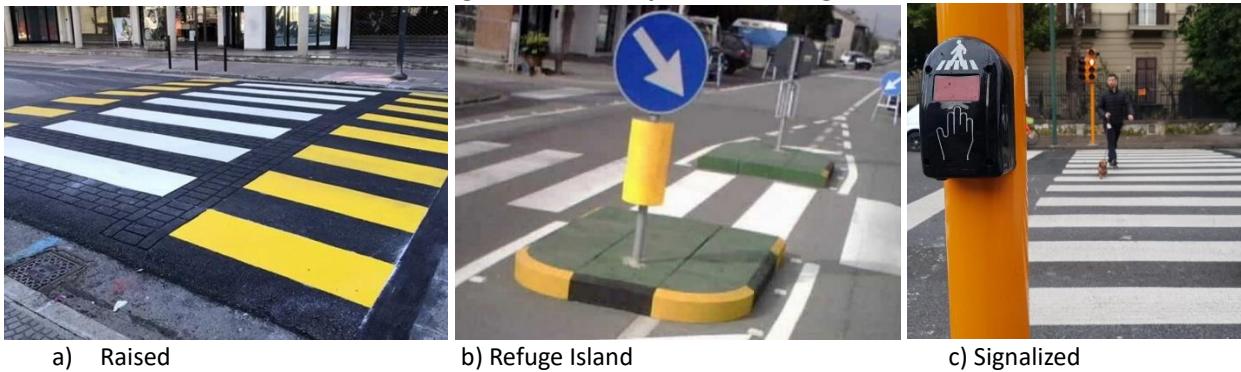
In Italy, the Highway Code and its implementing regulations define the characteristics of pedestrian crossings, including horizontal signage (typical "zebra" with white reflective stripes parallel to the direction of vehicle travel). To improve safety, crossings can be preceded by a yellow zig-zag stripe where stopping is prohibited and to be accessible also to people with disabilities, they can include lowered curbs up to 2 cm.

For nighttime safety, supplementary lighting is recommended to make the pedestrian visible to drivers.

In addition to standard crossings, there are several types designed to increase safety:

- raised pedestrian crossing: It is a raised platform intended to slow down vehicle speed;
- crossing with safety island: Allows pedestrians to cross the road in two phases, focusing on one traffic direction at a time;
- signalized crossing: Regulated by a pedestrian traffic light that assigns priority to pedestrians and vehicles according to light cycles.

Figure 3.6 - Examples of crossings.



Moving walkway

The moving walkway, also called conveyor belt or travelator, is a mechanized device located to facilitate pedestrian transit in high-traffic nodes or in contexts requiring assisted mobility. Designed according to UNI EN 115-1, it must integrate safety systems such as emergency buttons, side barriers and anti-entrapment sensors, with a typical operating speed between 0.5 and 0.75 m/s (Figure 3.7).

Figure 3.7 - Examples of movable sidewalk - Exterior and interior view.



Rest areas and gathering points

Spaces equipped with seating, street furniture, lighting and informational signage, fundamental to improving the pedestrian's experience and usability (Figure 3.8). They must comply with ANCI standards and guarantee non-slip surfaces and universal accessibility.

Figure 3.8 - Example of rest and gathering area - Spello (Italy).



Elevators, stairlifts and platform lifts

To make urban spaces accessible to everyone, it is essential to remove physical barriers using vertical solutions to overcome architectural obstacles and significant level differences, in compliance with UNI EN 81-70 standards and laws for barrier removal (Law 13/1989 and DM 236/1989). In this context, devices such as elevators, stairlifts and platform lifts are crucial tools:

- the elevator is a vertical transport system that moves people and loads between different floors of a building or between different floor heights. It is the most complete solution and is installed in a dedicated shaft (Figure 3.9a);
- the stairlift moves along a rail fixed to the staircase and, thanks to a chair, allows people with mobility difficulties to ascend and descend the steps autonomously (Figure 3.9b);
- the platform lift has a function like the stairlift but is equipped with a platform that allows the transport of wheelchair users, eliminating the need for transfers (Figure 3.9c).

Figure 3.9 - Examples of devices for overcoming elevation differences.



a) Elevator



b) Stairlift

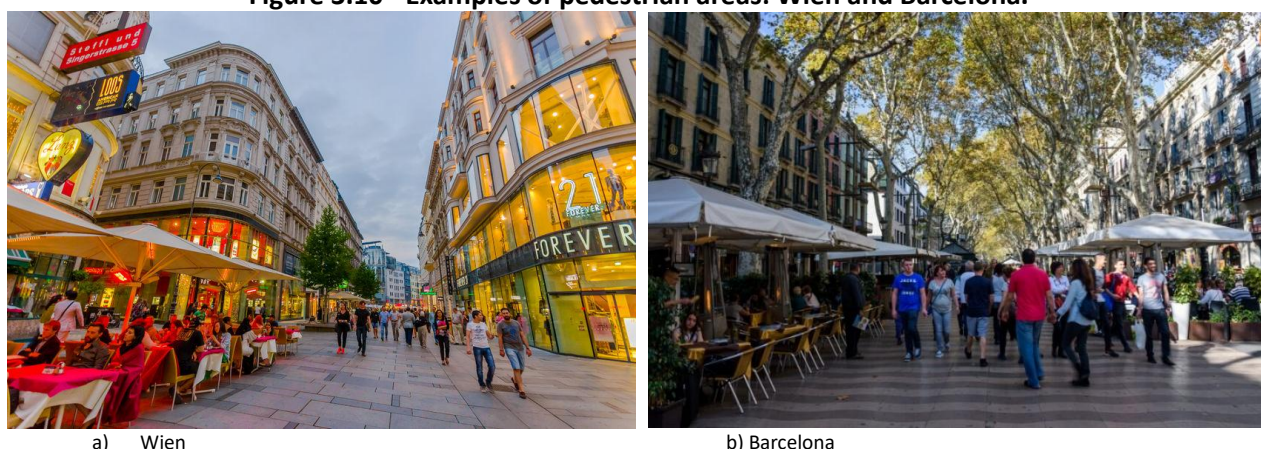


c) Platform lift

Pedestrian areas

Pedestrian areas, although not typically considered point infrastructure in the traditional sense, can be configured as extended infrastructures that serve as nodes or pedestrian gathering spaces (Figure 3.10). They can appear in linear configurations, such as long pedestrian streets, or areal configurations, such as squares and urban open spaces entirely dedicated to pedestrian circulation and resting, with exclusion or strong limitation of vehicular traffic. Pedestrian areas must be designed with non-slip and durable pavements, equipped with street furniture and lighting compliant with CEI 34-21 standards and must ensure universal accessibility according to Law 13/1989 and DM 236/1989. The regulation of vehicular circulation and access is governed by the Highway Code (Table 3.2).

Figure 3.10 - Examples of pedestrian areas: Wien and Barcelona.



Source: a) <https://www.vienna-trips.at/it/il-graben-di-vienna> b) <https://www.barcellona.org/cosa-vedere-barcellona/ramblas/>

Table 3.2 - Main technical characteristics of point pedestrian infrastructure.

Type	Minimum usable width	Functional requirements	Regulatory notes
Pedestrian crossings	≥ 2.50 m (urban areas)	Reflective white stripes; lowered curbs ≤ 2 cm; optional refuge islands; adequate lighting	Italian Highway Code and implementation regulations
Safety islands	≥ 1.50 m	Protect pedestrians during multi-phase crossing; equipped with curbs and bollards	Italian Highway Code regulations
Moving walkways	≥ 0.90 - 1.20 m per lane	UNI EN 115-1 compliant; emergency buttons; side barriers; anti-trapping sensors; operating speed 0.5 - 0.75 m/s	UNI EN 115-1
Rest areas and gathering points	Variable	Equipped with seating, urban furniture, lighting and signage; non-slip surfaces; universal accessibility	ANCI standards; accessibility regulations
Elevators	$\geq 1.20 \times 1.50$ m cabin	UNI EN 81-70 compliant; emergency systems; accessibility for people with reduced mobility	UNI EN 81-70; Law 13/1989; DM 236/1989
Stair-lifts (chair-lifts)	≥ 0.80 m seat	Guide rail anchored to staircase; equipped with seat and safety belt	Law 13/1989; DM 236/1989
Platform lifts	$\geq 0.90 \times 1.20$ m platform	Designed for wheelchairs; anti-slip platform; safety barriers	Law 13/1989; DM 236/1989
Pedestrian areas	Variable	Paved with durable, non-slip surfaces; equipped with urban furniture and lighting CEI 34-21 compliant; universal accessibility guaranteed	Italian Highway Code; CEI 34-21; Law 13/1989; DM 236/1989

3.3 Auxiliary equipment and services

Auxiliary equipment and services supporting pedestrian provision represent a set of infrastructures and accessory facilities aimed at ensuring usability, safety, comfort and accessibility of pedestrian routes. These services are fundamental to promote pedestrian mobility, especially in urban and peri-urban contexts and must be designed in compliance with current technical and safety regulations. They may include simple and intuitive elements such as signage or more complex and even innovative systems. Among the main services supporting pedestrian provision are: pedestrian signage; public lighting; urban furniture and resting facilities; video surveillance and security systems; information and communication systems; charging systems; maintenance and management; smart services for pedestrian mobility (Table 3.3).

Pedestrian signage

Pedestrian signage includes vertical signs (information panels, priority signs, prohibitions) and horizontal markings (pedestrian crossings, symbols, arrows). In Italy, design must comply with the indications of the Highway Code and DM August 10, 2009, which prescribe dimensions, colours, reflective materials and positioning to ensure visibility and comprehensibility even in low-light conditions (Figure 3.11).

Figure 3.11 - Examples of vertical and horizontal pedestrian signage.



Public lighting

The lighting network dedicated to pedestrian routes and trails must ensure adequate levels of uniform illumination, reducing shadow areas and increasing the perception of safety along the entire route. In extra-urban or natural trails, design must balance visibility and safety with environmental protection, minimizing impact on the surrounding ecosystem and reducing light pollution. Design follows CEI EN 13201 (Road lighting) standards, with particular attention to minimum illuminance levels (lux), glare, control of light pollution and energy saving, adapting technical solutions to the natural and orographic characteristics of the trails.

Urban furniture and resting facilities

Urban furniture serving pedestrians includes benches, bicycle racks, waste bins, waiting shelters, public toilets, fountains and information points. These elements must be designed with resistant, non-slip and easily maintainable materials, complying with accessibility standards for users with disabilities and ensuring harmonious integration into the urban context.

Video surveillance and security system

The installation of surveillance cameras along pedestrian routes contributes to increasing actual and perceived safety. Such systems must comply with privacy regulations (GDPR - EU Regulation 2016/679) and national directives for urban safety, ensuring adequate coverage and image quality.

Information and communication services

To facilitate the travel experience along pedestrian routes and ensure equity among users, it is essential to provide clear, accessible and timely information systems. These services include digital or static information panels, multimedia totems and acoustic signalling systems for the visually impaired. Their function is not limited to providing directions but contributes to the perceived level of service (LoS), affecting safety, comfort and orientation. Design must comply with universal accessibility standards, ensuring readability, adequate colour contrast and multisensory usability.

Charging systems

Along pedestrian routes, charging points for mobile devices or electric bicycles may be integrated. These facilities must comply with CEI 0-21 standards for active user connection and current electrical safety regulations.

Maintenance and management

An effective ordinary and extraordinary maintenance service is essential to ensure the efficiency and safety of pedestrian infrastructures. Periodic interventions must be scheduled for cleaning, pavement repair, signage verification and lighting inspection, in compliance with the technical guidelines of local authorities and the provisions of the Highway Code.

Figure 3.12 - Examples of lighting, urban furniture, video surveillance, communication and charging.



Smart Services for pedestrian mobility

The integration of digital technologies and intelligent systems represents an advanced frontier to improve the management and experience of pedestrian mobility. Among the most widespread smart services are:

- Assisted pedestrian navigation through mobile applications that use high-precision GPS systems (accuracy less than 3 meters), integrated with updated digital maps and 3D

models of urban environments, compliant with OGC (Open Geospatial Consortium) standards;

- Real-time monitoring of route quality, carried out through IoT (Internet of Things) sensors for detecting environmental parameters (temperature, humidity, air quality) and vibration or pressure sensors to assess pavement condition. These devices communicate via MQTT or CoAP protocols on LPWAN (Low Power Wide Area Network) ensuring low latency and optimized energy consumption;
- Dynamic lighting management with smart systems based on presence and brightness sensors, capable of modulating light intensity according to pedestrian flow and environmental conditions, in compliance with CEI EN 13201-2;
- Alert and integrated communication systems for immediate reporting of anomalies, accidents, or emergency situations, through mobile apps and digital panels. These systems implement cybersecurity standards compliant with European directives (NIS Directive 2016/1148) and GDPR for personal data protection;
- Predictive analysis and pedestrian flow management through artificial intelligence and machine learning algorithms that analyse historical and real-time data to optimize resource distribution and plan interventions such as preventive maintenance.

Table 3.3 - Main technical characteristics of auxiliary equipment and systems.

Auxiliary Service	Description	Main Technical Characteristics	Reference Regulations
Pedestrian signage	Vertical and horizontal signage for orientation, safety and regulation of the path	High-visibility retroreflective materials, compliant dimensions, strategic positioning, weather resistance	Italian Highway Code, DM 10/08/2009
Public lighting	Lighting system for pedestrian paths	Uniform illuminance levels (>10 lux in urban areas), glare control, energy efficiency	CEI EN 13201, DM 18/12/2014
Urban furniture and resting services	Benches, waste bins, bicycle racks, shelters, public toilets, fountains	Durable, non-slip, accessible materials, easy maintenance	Law 13/1989, DM 236/1989
Video surveillance	Security systems with cameras along the paths	Resolution ≥1080p, full coverage, secure storage system, GDPR-compliant privacy protection	GDPR 2016/679, EU Directive NIS 2016/1148
Information and communication	Information panels, multimedia totems, acoustic systems for the visually impaired	Readable displays, high contrast, multilingual support, acoustic signaling compliant with disability regulations	Law 104/1992, DM 236/1989
Electric charging points	Charging stations for mobile devices and electric micromobility	Type 2 or CCS connection standards, 3-22 kW power, overload and short-circuit protection	CEI 0-21, CEI EN 61851
Maintenance and management	Cleaning, repair and infrastructure monitoring services	Scheduled maintenance, rapid interventions, use of management software for condition monitoring	ANCI guidelines, local regulations
Moving walkway (travelators)	Mechanical solutions to facilitate walking in critical points	Adjustable speed, anti-slip safety, lateral protective barriers, emergency stop sensors	EN 115 Standard (lifts and moving walkways), Machinery Directive 2006/42/EC
Smart services	Digital systems for navigation, monitoring, dynamic management and communication	GPS accuracy <3 m, IoT sensors, AI for data analysis, secure communication, protocol interoperability	OGC, GDPR, CEI EN 13201, ISO/IEC 27001

3.4 Paths and trails for tourist mobility

Within the framework of sustainable mobility, paths and trails play a peculiar role as a mode of pedestrian travel with a predominantly tourist purpose, capable of combining experiential dimension and territorial enhancement. Their use differs from everyday mobility because it is mainly set within a medium-long term horizon, with experiential, recreational and territorial knowledge purposes. To ensure an adequate level of service and safe and inclusive use, it is necessary to consider the set of infrastructures that enable their utilization. For this purpose, as previously, three main categories are distinguished: linear pedestrian infrastructures, which

constitute the backbone of the route; point infrastructures, which support rest and hospitality; and auxiliary infrastructures, which facilitate orientation and accessibility.

3.4.1 Linear pedestrian infrastructures for paths and trails

Linear pedestrian infrastructures for paths and trails represent the fundamental elements to ensure continuity, safety and accessibility of tourist pedestrian mobility (paths and trails) and are designed according to specific technical and regulatory criteria.

From a dimensional perspective, the minimum width of a pedestrian trail for tourist paths should generally be between 1.20 m and 1.50 m to allow for two-way traffic or easy passing between pedestrians, as indicated in national guidelines for pedestrian path design (for example, Ministry of Infrastructure Decrees or ANAS guidelines). In sections with higher user flow or where access for persons with reduced mobility is expected, the width should increase up to 2.00 m. The longitudinal slope should preferably be kept within 5% to ensure adequate walkability, while in particular cases it may reach peaks of 8-10% over short sections, if they are interspersed with rest areas. Regarding transverse slope, this should not exceed 2% to avoid water stagnation and ensure stormwater drainage.

Pavement may vary depending on the environmental context: in natural contexts, draining surfaces such as stabilized gravel, compacted soil, or crushed stone are preferred, with an adequate thickness (from 10 to 30 cm depending on soil characteristics) to ensure stability and resistance to erosion. In urban areas or sections with high frequency of use, porous concrete pavements or natural stone slabs may be used, always with attention to adherence and anti-slip safety (coefficient of friction > 0.6 according to UNI EN 13451-1).

Safety is ensured through protective elements such as handrails or guardrails in the presence of drops greater than 50 cm, in compliance with UNI 10804:2016. At critical points, such as crossings or exposed sections, vertical signage compliant with the Highway Code is mandatory, while horizontal signage must be made with retroreflective materials to ensure visibility even in low-light conditions.

Finally, the design of linear infrastructures must comply with accessibility regulations, such as Law 13/1989 and DM 236/1989, which provide for the elimination of architectural barriers and the adoption of solutions that facilitate use by people with motor or sensory disabilities, including ramps with a maximum slope of 6%, non-slip surfaces and tactile signals for visually impaired users. However, in mountainous contexts or rugged areas characterized by irregular morphologies, strict application of such requirements is often impracticable. In these cases, accessibility is combined with environmental protection and safety through a flexible approach that includes the creation of limited and specific accessible sections, the use of lightweight construction techniques and natural materials, the integration of auxiliary supports such as ergonomic handrails and the design of alternative or simplified routes for users with reduced mobility. The use of assistive technologies and transparent communication of route characteristics also help facilitate conscious and inclusive use. In this way, while respecting natural constraints and ensuring safety, it is possible to offer tourist pedestrian mobility that enhances the peculiarities of mountainous territory, fostering an experience accessible to the greatest possible number of users.

In the heart of mountainous contexts and rugged areas, trails often do not originate from a project, but naturally take shape over time, traced by the constant passage of people. These spontaneous paths are not classified as infrastructures in a formal sense unless they are recognized and managed by a competent authority.

Unlike an infrastructure, which is a structured and planned system, a spontaneously "born" path is a natural trace. Its characteristics, such as reduced dimensions and irregular surface, depend on terrain and frequency of use.

However, these traces may evolve into true pedestrian infrastructures (Figure 3.13). This occurs through targeted interventions aimed at improving their safety and usability. Institutions, in this process, must strike a balance between the need to make the route safe and accessible and the duty to preserve the natural environment.

The objective is to ensure adequate walkability without altering the landscape, with precise and selective actions:

- soil consolidation to prevent landslides;
- installation of vertical signage indicating dangers and directions;
- placement of handrails or guardrails in the most exposed points.

These interventions are intended to combine safety and environmental respect.

Figure 3.13 - Examples of unpaved natural trails without infrastructures. Cammino di Assisi.



3.4.2 Point infrastructures for paths and trails

Point pedestrian infrastructures along paths and trails represent localized support elements at specific nodes of the route, essential to ensure comfort, safety and functionality of the tourist pedestrian experience. These include equipped rest areas, panoramic observation points, information areas, sanitary facilities, refreshment points, temporary shelters, transport access points and emergency stations.

From a dimensional perspective, rest areas must have surfaces sufficiently large to accommodate groups of users, typically 15-25 m², with spatial distribution that does not obstruct pedestrian flow. They must be equipped with benches, tables, bicycle racks and, where possible, shaded areas, in compliance with current regulations.

Panoramic observation points must provide safety guardrails with a minimum height of 1.1 m (UNI EN 14122-3) and anti-slip pavements (coefficient of friction ≥ 0.6 according to UNI EN 13451-1). Access must ensure accessibility for people with disabilities, in compliance with DM 236/1989, with ramps at a maximum slope of 6%, anti-slip surfaces and manoeuvring spaces of at least 150 × 150 cm for wheelchairs.

Sanitary facilities must comply with sanitary-hygienic regulations (D.P.R. 14 January 1997, no. 37, in Italy) and include at least one accessible module with minimum internal dimensions of 150 × 150 cm, horizontal and vertical support bars and easy-opening doors.

Refreshment and shelter areas must be located at strategic points, with availability of drinking water, protection from weather and shaded areas. They must comply with fire safety Italian regulations (DM 10 March 1998) and sanitary regulations for food service (EC Reg. 852/2004). Emergency stations, such as telephones or first-aid points, must be accessible, clearly signposted and compliant with Legislative Decree 81/2008, with visible and easily identifiable signage. Reception points for food and lodging, including refuges, hostels, farmhouses and restaurants, constitute essential point infrastructures for rest, refreshment and overnight stay. Their location must consider accessibility, safety and integration with the territory, with distances typically planned every 15-25 km, consistent with the daily stages of tourist paths. Drinking water fountains can be considered point or auxiliary infrastructures depending on their function and location. If present as single resting points, they fall within point infrastructures; if distributed along the trail as continuous support, they constitute auxiliary infrastructures. They must comply with sanitary-hygienic regulations (Legislative Decree 31/2001) and ensure accessibility and protection throughout the year.

Medical services and rescue points represent further point infrastructures strategically positioned at nodes, high-traffic areas, or risk zones. They must comply with health and safety regulations (Legislative Decree 81/2008) and be equipped with adequate signage for rapid identification. These include first-aid stations, automatic defibrillators (AED), ambulances and, if possible, direct connections with local emergency medical services.

3.4.3 Auxiliary infrastructures for paths and trails

Auxiliary pedestrian infrastructures for paths and trails constitute an integrated support system indispensable for ensuring safety, orientation, management and usability of tourist pedestrian routes. Among these infrastructures are mainly vertical and horizontal signage, lighting systems, safety devices, charging points for electronic devices, waste collection areas and equipment for path maintenance and management.

Vertical signage must comply with the prescriptions of the Highway Code and UNI EN ISO 7010 technical standards for the representation of safety symbols, ensuring visibility and readability

even in difficult environmental conditions. Panels have variable dimensions between 40x40 cm and 60x60 cm depending on type and position, made with weather-resistant materials (aluminium, rigid PVC, or composite materials) equipped with high-visibility retroreflective films and anti-glare treatments. In hiking contexts, Italian Alpine Club (CAI) signage represents a consolidated reference: the white-red-white markers are positioned at regular intervals (typically every 100-200 meters or at each junction) and are accompanied by directional and difficulty indications, compliant with CAI guidelines. Vertical signage may also include boards with maps, panels with information on environmental and cultural heritage and safety indications.

Horizontal signage, if present on paved or consolidated sections, must be made with high-durability retroreflective paints and thicknesses of 0.3 to 0.5 mm, in compliance with UNI 10667 standard. It includes boundary lines, directional arrows and warning symbols, useful to guide pedestrian flow and highlight critical points such as intersections or route changes.

In addition to formal signage, there is the use of informal signals such as painted marks on trees or rocks, arrows left by walkers, or signalling objects (small piles of stones, coloured ribbons). Although useful as temporary support, these signals do not follow technical standards and may create ambiguity; therefore, their presence must be integrated and, if possible, replaced by official signage to ensure uniformity and safety of the route.

Lighting systems are designed to ensure safety and orientation in urban or peri-urban sections with user presence even in evening hours. Lighting must be LED with high energy efficiency, with an average illuminance of at least 20 lux on the entire pedestrian surface (according to UNI EN 12464-2 standard), positioned at a height between 3 and 5 meters to optimize light distribution and reduce light pollution.

Safety devices include surveillance cameras, alarm systems, emergency buttons and first-aid stations, installed in compliance with safety regulations (Legislative Decree 81/2008) and privacy regulations (EU GDPR 2016/679). These systems must be placed at strategic points along the route to ensure rapid intervention and deterrence against unlawful behaviour.

Waste collection areas must be equipped with differentiated bins compliant with UNI EN 840 standard, with variable capacity (from 80 to 360 litres) and ergonomic characteristics to facilitate collection and emptying. Their distribution must be planned to minimize visual and environmental impact, encouraging proper waste management.

Finally, maintenance equipment for the route, such as temporary drainage systems, cleaning tools and pedestrian surface maintenance tools, as well as devices for temporary signalling of ongoing works, must comply with specific technical regulations (e.g., UNI EN 131 for portable ladders and lightweight scaffolding).

3.5 Gender perspective in the provision of services and infrastructures

The gender perspective in the provision of pedestrian services and infrastructures plays a strategic role in ensuring fair, safe and functional access to paths and trails for all users, considering physiological, psychological and socio-cultural differences that influence pedestrian mobility. At the design stage, it is necessary to adopt universal design criteria that respond to the specific needs of women, who statistically demonstrate greater sensitivity to personal safety, risk perception and the need for auxiliary services, such as childcare.

From an infrastructural point of view, the width of paths must ensure the possibility of walking side by side and easy transit even with strollers or companions, respecting minimum widths of at least 1.5 m on medium-traffic paths and 2 m in high-traffic points, in compliance with national and international guidelines (e.g., UNI 11337, ADA Standards). Slopes of ramps and sections with

gradients must be kept within limits below 6% to facilitate walkability for people with different physical capacities and with loads (e.g., lighter backpacks or childcare equipment), as provided by accessibility regulations (D.M. 236/1989).

Lighting along paths must be designed to ensure uniform illuminance, with minimum levels above 20 lux, especially in urban and peri-urban areas, to reduce the perception of insecurity and increase the visibility of potential obstacles or threats. In addition, active surveillance devices such as cameras, emergency buttons and first-aid stations must be strategically distributed, prioritizing nodal points and isolated areas, in compliance with safety and privacy standards, to ensure rapid intervention times and effective deterrence.

From a services perspective, it is essential to have rest areas equipped with ergonomic seating and sufficient space for family groups, with accessible fountains and inclusive sanitary facilities, including facilities for baby changing and childcare, in line with UNI EN 16181 indications on outdoor well-being equipment. The location of refreshment points and accommodation facilities must consider the needs associated with family load management, facilitating frequent breaks and reducing gradients to be faced on longer sections.

Finally, signage must integrate clear and understandable informational elements, positioned at regular intervals, with universally recognized symbols and bilingual texts where necessary, with attention to avoiding ambiguity.

3.6 Inclusive trails and pathways

The growing demand for experiential and outdoor tourism has focused attention on the need to develop trails and pathways that are usable by a heterogeneous public. In this context, it is fundamental to distinguish between the concepts of accessibility and inclusion, while recognizing their close interdependence. Accessibility, in its technical and formal meaning, refers to the condition of an environment, product, or service that can be reached and used by people with a wide range of abilities. It is a measurable and regulated prerequisite, which focuses on the removal of physical and sensory barriers.

At the regulatory level, UNI EN 17210:2021 establishes the requirements for accessibility and usability of the built environment. A concrete example could consist in the installation of double-height handrails and step-free bridges to ensure accessibility for wheelchairs and strollers.

Inclusion, on the contrary, is a broader concept. Starting from the principles of accessibility, it aims to ensure that every individual not only can access a place, but also feels welcomed, safe and can fully participate in the experience. Therefore, the concept of inclusion does not only guarantee physical access, but integrates social, cultural and psychological aspects. An example of inclusive design could include multisensory signage, including QR codes with audio information and benches at different heights along the route.

The realization of a fully inclusive pedestrian offer requires strict compliance with design standards. The pedestrian network must be conceived with regular and stable surfaces that allow the safe movement of mobility aids and the smooth progression of the elderly. Accessibility does not only apply to the pathway, but extends to all punctual infrastructures, such as rest areas and sanitary facilities, making them functional for all users.

Finally, the design of inclusive trails presents an inherent trade-off between accessibility requirements and the need to preserve the natural environment. A virtuous example is that of wooden walkways built over wetlands to allow access without damaging the ecosystem, balancing usability with sustainability.

3.7 Cost Functions for pedestrian mobility

To analyse the transport system, mathematical models are now widely used that allow the analysis of the system's performance for descriptive or predictive purposes.

The transport supply system is modelled through network theory and represented by graphs. A graph G consists of a set of nodes N and a set of pairs of nodes belonging to N , called branches or links L ; in a synthetic way one can write: $G = (N, L)$. The graph becomes a transport network when quantitative transport characteristics are associated; typically, arcs and nodes of the graph are associated with impedances or "cost functions" (CF), for example, a travel time or other burdens borne by those moving on the network.

Ultimately, one can assume a network as $R = (N, L, CF)$.

The transport cost of a link is defined as a scalar quantity that summarizes the various cost components borne by users as perceived and evaluated by them. Therefore, in the literature, the cost of movement measures users' aversion to traveling along the link itself. Since transport cost generally includes quantities that are not homogeneous among themselves, it is standard practice to carry out a process of homogenization of variables. To the most used quantity (time) other different types of quantities (economic cost, stress, etc.) may be added, after conversion into the same unit of measurement through reciprocal substitution coefficients. In this way, a "generalized cost" of transport is obtained, a cost perceived on average by users.

Generally, reference is made to an average user, assuming a single cost function for all users on a link or at a node.

At the transport network scale, a vector of link costs can be defined, that is, a vector $\mathbf{c}$ whose generic component c_{ij} is the transport cost on link (i,j) . The cost may simply be travelling time or a generalized cost.

The quantities referred to the link can also be referred to a path, that is, a concatenated sequence of arcs. The path cost C_k will be defined as the cost perceived by the average user to travel an itinerary k and it will be calculated as the summation of the costs of the arcs that make up the itinerary.

$$C_k = \sum_i a_{ik} c_i \quad (1)$$

That is, in matrix form $\mathbf{C} = \mathbf{A}^T \mathbf{c}$

where $\mathbf{C}$ is the vector of path costs with components C_k , $\mathbf{A}^T$ is the transpose of the link-path incidence matrix and $\mathbf{c}$ is the vector of link costs. The link-path incidence matrix $\mathbf{A}$ is a matrix in which each row represents an link of the graph and each column corresponds to an itinerary; the element of the matrix in position ij (a_{ij}) is equal to 1 if the link corresponding to the i -th row is part of the itinerary corresponding to the j -th column; otherwise, it is equal to zero.

The transport cost perceived by a user is actually not constant, but depends on several factors; for this reason, it is preferable to assume a cost function associated with a branch of the network; this function is the tool that allows calculating an average transport cost for a generic user (vehicle) traveling a given link as a function of the flows of users (vehicles) traveling on that same branch.

Each branch of a network could be characterized by a specific cost function; however, this would make the analyst's work particularly burdensome; in general, it is preferable to assume representative cost functions by type of infrastructure or network node. The cost function becomes a cost model when calibration is performed, i.e., when the scalar parameters associated with the individual variables of the function are determined.

It should be noted that cost functions in transport system theory differ from cost functions used in microeconomics. In fact, while in economics the cost function relates the production cost of a good

or service to the quantity produced, in the case of transport the function links the cost borne by the users of a transport system to the number of users themselves. In the first case, therefore, it is a production cost, while in the second case it is a usage cost.

Over time, the relationship between some variables that compose the transport cost of an link and the flow of users using the infrastructure has become evident, due to mutual interference among various users, which generates congestion phenomena. There is a maximum limit of users on the infrastructure in a unit of time (capacity), such that as the flow approaches this maximum value, travel time for users increases. The generalized transport cost consists of a fixed component and a variable component, which depends, due to congestion, on the other flows present on the infrastructure or on the network node.

As mentioned, to standardize the cost components that affect the generalized cost, a homogenization procedure must be carried out. The concept of Value of time is often considered, converting time components into a monetary value or vice versa.

Numerous cost functions have been identified by transport engineering with reference to road transport, public transport and pedestrian transport. With reference to road transport, cost functions are often expressed as a function of the degree of saturation, i.e., the ratio between flow on the link and its capacity. In the case of pedestrian mobility, however, some assumptions may be modified.

3.8 Cost functions for tourist pedestrian mobility on walking itineraries

For pedestrian mobility, cost functions assume specificities related to the nature of human movement: walking is not only a mechanical displacement, but it implies energy consumption, perception of time, physical effort and environmental conditions.

Pedestrian cost functions represent a set of mathematical and empirical models aimed at estimating walking speed or travel times in relation to physical, environmental and individual variables. They can be classified according to the methodological approach adopted: empirical, biomechanical, GIS-based, microscopic, or probabilistic (Table 3.4).

The first historical contributions belong to the empirical-discrete category, in which the relationships are expressed through simple rules, often formulated for hiking purposes. Among these is Naismith's rule, dating back to 1892 [2], which links travel time to path length and positive elevation gain and Langmuir's subsequent extension [3], which also integrates the effects of descent. Along the same line is the Swiss method [4], used in Alpine hiking maps, which introduces a tabular system to estimate times as a function of slope and trail difficulty and the Brazilian method [5]. These approaches are defined as discrete because they translate the relationship between variables and walking times into scalar rules or thresholds, rather than continuous functions.

Conversely, empirical-continuous models, such as the well-known Tobler function [6], describe walking speed as an exponential function of slope, ensuring greater adaptability to GIS tools and territorial simulations. The models developed by Minetti et al. [7], [8], of a biomechanical nature, also belong to continuous methods, but they are based on energetic and physiological measurements that make it possible to estimate the optimal speed according to slope and fatigue. Further developments can be found in multiple GIS models [9], which combine slope with additional variables such as surface type and presence of obstacles and in microscopic agent-based models, adopted in pedestrian simulation software, which consider interactions between pedestrians and with the surrounding environment [10]. To these can be added probabilistic models, which introduce stochastic variability to represent uncertainty and individual differences.

Table 3.4 - Methodological approaches to the cost function in pedestrian mobility.

Method	Type of Approach	Variables Considered	Accuracy / Application
Naismith (1892)	Discrete empirical	Route length L, positive elevation gain Δh	Simple, useful for manual hiking
Langmuir (1984)	Discrete empirical	Length, positive/negative elevation gain $\Delta h+$, $\Delta h-$	Improvement of Naismith; more realistic estimates for ascent/descent
Swiss method	Discrete empirical	Slope, length, trail difficulty	Hiking maps and quick estimates; discrete
Brazilian method	Discrete empirical	Slope, length, environmental conditions	Hiking planning in tropical areas; practical estimates
Tobler (1993)	Continuous empirical / GIS	Slope s	High accuracy for GIS and microscopic pedestrian simulations
Energy models	Biomechanical, continuous, energetic	Slope, fatigue, load	Speed optimization models; scientific research
Multiple GIS models	GIS, continuous	Slope, surface type, obstacles, fatigue	Urban and natural predictive models
Agent-based / microscopic models	Microscopic, simulation	Local density ρ , slope s, agent interactions	Pedestrian simulation software
Energy models	Biomechanical / energetic	Slope, speed, carried load	Predictive models based on energy consumption; scientific research
Stochastic / probabilistic models	Statistical	Individual variability, slope, density	Simulations with uncertainty; advanced agent-based

A walking itinerary can be defined as a path k composed of an ordered set of stages, such that each stage i is represented by a branch. Generally, a stage takes place over the span of a day. The tourist in motion spends time and energy and will also have to bear expenses. Therefore, time and monetary cost components can be distinguished. The total time spent on a stage can be assumed to consist of the sum of two parts: walking time i.e. travel along stage i (T_{Pi}) and stop time (T_{Si}).

$$T_i = T_{Pi} + T_{Si} \quad (3)$$

These two quantities could be considered as a composition of partial times, if one considers that a stage could be divided into sub-phases of movement (branches) and rest pauses (nodes). It could therefore be assumed:

$$T_{Pi} = \sum_x T_{Pxi}, \quad (4)$$

$$T_{Si} = \sum_x T_{Sxi} \quad (5)$$

with T_{Pxi} walking time on a section x of stage i
e T_{Sxi} pause at the end of section x on stage i .

According to the classical formula linking time to distance travelled and the speed required to travel it, it is possible to calculate travel time by relating distance L_i to speed v_i :

$$T_{Pi} = L_i / v_i \quad (6)$$

Average speed can be expressed [11] as a function of the type $v_i = f(\text{user, type of path, load, environment})$.

In fact, different types of users can be distinguished (young and experienced, young but inexperienced or athletic, child or elderly, walker), but this does not exclude the possibility of including in the study subjects with specific needs (pedestrians with children, persons with reduced mobility, women, visually impaired or blind, etc.). Walking speed may also vary according to infrastructural characteristics such as: type of path (dirt road, asphalt, etc.); steepness and total elevation gain; safety and presence of obstacles (roots, sand, crossings, fords, shared use of the path with roads open to other vehicles, etc.); comfort (lighting, tree cover, presence of water sources, etc.); ease of orientation (absence of signage, GPS tracks, symbolic signage). Average speed is also influenced by individual load conditions (light or heavy backpacks), as well as contingent environmental conditions such as altitude, season and weather parameters (temperature, humidity, wind, rain).

In modelling practice in urban contexts, the average speed of an ordinary walker is assumed to be 3.6 km/h (1 m/s), but in reality different values could be assumed in relation to the above factors. A trained hiker can proceed at a pace of about 3.5-4 km per hour on a flat or undulating path; however, speed changes uphill and downhill or at altitudes above 2800-3000 m.

Stop time T_{Si} is also variable and depends on both the type of excursion and the users; for example, pedestrians more interested in physical and sporting performance will reduce stop times; conversely, conscious hikers will be more interested in the places visited, landscapes, culture and visiting so-called Points of Interest (PoI), to the point that stop time may become as significant as walking time.

The time related to an entire path K will be given by the summation of the times related to the branches (stages) belonging to the path itself; denoting by I_K the set of branches belonging to path K :

$$T_K = \sum_i T_i \quad \text{with } i \in I_K \quad (7)$$

It may also be useful to split the two components (walking time and stop time) for the entire journey in order to analyse them separately:

$$T_{Pk} = \sum_i T_{Pi} \quad \text{with } i \in I_K \quad (8)$$

$$T_{Sk} = \sum_i T_{Si} \quad \text{with } i \in I_K \quad (9)$$

In addition to time costs, monetary costs can also be considered.

The monetary cost for a generic user referring to the entire path K can be expressed as:

$$C_K = C_g + C_v + C_p \quad (10)$$

with C_g cost for guide services, C_v cost for food, C_p cost for accommodation in lodging facilities. For organized trips, these costs are generally referred only to the path and not to the individual stages.

The generalized cost function (CG_K) referring to the entire path must take into account both time and monetary cost components, through parameters capable of representing time in monetary units:

$$CG_K = C_K + \alpha T_K \quad (11)$$

where parameter α represents the substitution rate of time into monetary units.

Generally, in modeling practices in urban contexts, with trips motivated by professional reasons, in Italy this parameter assumes a value of about 8-12 euros per hour. In the case of mobility on hiking itineraries, the value of α may be very low or even null, since in such cases travel time is not perceived as an impedance/sacrifice, but as an advantage, a utility inherent to the reason for the trip.

Depending on the groups of users of the path, we may have:

$$CG_K = C_K + \alpha T_{Pk} + \beta T_{Sk} \quad (12)$$

If the group is composed of athletes, it may be found that parameter α is modest and parameter β has a significant value, since stop time represents an undesirable impedance.

On the contrary, if the group is composed of conscious hikers not interested in simple physical performance, we could assume both α and β as null; or even a negative value for β , which means considering stop time (for example to admire a panorama or a historical site, or to enjoy the scent of an aromatic plant) not as a cost, but rather as a benefit.

The modelling approach based on cost (or utility) functions offers a series of advantages, since it allows analysis of the interaction between demand and supply of mobility, but also the possibility of comparing two or more itineraries, in order to measure the degree of difficulty of a path in quantitative terms. The availability of significant models, i.e., calibrated and validated cost functions, makes it possible to use effective tools both in the planning phase, as a decision support tool, in order to guide the project choice towards some itineraries compared to others with worse economic-organizational impacts; and in the design phase, to regulate itineraries in relation to the type of expected users.

3.9 Network analysis and performance indicators for the evaluation of regional walking itineraries: an application

Pedestrian cost functions thus constitute the theoretical and methodological basis for estimating time, effort and accessibility along an itinerary. However, their application is not limited to the evaluation of individual routes: they assume an even more significant role when used within a systemic approach, in which walking itineraries are not analyzed as isolated entities, but as part of an interconnected network. In this perspective, it becomes essential to integrate cost models with network analysis tools, which allow evaluating the relationships between different itineraries and identifying the most suitable performance indicators to measure the overall effectiveness of the offer. In this regard, the applied case of the regional walking itineraries of Calabria is particularly significant to observe how a set of paths, enhanced through coordinated strategies, can transform into a network capable of generating economic, cultural and environmental value for the entire territory [12]. Trails and itineraries that, as seen, often follow the route of ancient walkways, historical roads, or panoramic paths, can represent an important heritage for a region. A well-constructed strategy allows promoting sustainable tourism, creating economic opportunities for local communities through visitor hospitality, promotion and sale of local products and the creation of services related to walking tourism. Moreover, walking itineraries can serve as a vehicle for enhancing local history and culture, promoting heritage conservation and environmental education. A synergistic and coordinated approach, involving institutions, local associations and relevant stakeholders, is fundamental to maximize the positive impacts of such

itineraries, while preserving the surrounding ecosystem and improving the quality of life of the involved communities.

To this end, it is important to move from an analysis of individual itineraries to the study of the region's walking paths as an integrated network offer.

The analysis of walking itineraries cannot be limited to evaluating individual routes but must be oriented towards understanding the overall network that develops across the regional territory. Considering walking paths as an interconnected system increases managerial and planning complexity but simultaneously enhances their value. A well-organized network of itineraries can generate synergies between different locations, fostering tourist and cultural exchanges and promoting a more balanced distribution of economic and social benefits. This reduces the risk of tourist overcrowding in some areas and marginalization in others, allowing a more harmonious development of the entire regional territory.

The network approach also enables more efficient planning and management of resources, including the transport system, accommodation facilities, signage, trail maintenance and promotional activities. This framework contributes to creating a more complete and satisfying travel experience, where visitors can explore the regional territory in an integrated manner, enjoying a broader range of cultural, naturalistic and gastronomic opportunities. Ultimately, viewing walking itineraries as part of an interconnected network constitutes a valorisation model capable of maximizing the positive impact of slow tourism, while ensuring more sustainable resource management.

From a methodological point of view, this implies that strategic planning should not focus exclusively on the characteristics of each path but must assess the interconnection potential between different itineraries. Geographic proximity, historical-cultural affinities and logistical opportunities are fundamental variables for structuring an integrated offer. Likewise, the tourist offer must be conceived in a coordinated manner, including accommodation services, events, local products and experiential activities distributed across the entire network, thus ensuring a continuous and coherent experience for travellers.

In this perspective, the creation of the "Network of Walking Itineraries and Trails of Calabria" has been initiated, an institutional body aimed at coordinating and integrating the regional walking offer. The Network represents entities and associations engaged in the creation, maintenance, promotion and protection of slow and sustainable tourism itineraries, pursuing a plurality of strategic objectives:

- realization and promotion of initiatives aimed at enhancing the walking itineraries present in the regional territory;
- spread of active mobility as a contribution to sustainability objectives promoted at national and international levels;
- enhancement of natural, historical, archaeological, cultural and productive heritage, with particular reference to the agricultural and artisanal sectors, through pedestrian use;
- promotion of walking safety and accessibility;
- education on walking as a tool for personal growth and the formation of new generations;
- active involvement of citizens and local stakeholders to increase awareness of the benefits associated with slow mobility and sustainable tourism;
- development of research and study activities dedicated to active mobility in urban and extra-urban contexts, aimed at increasing scientific knowledge and supporting sustainability strategies.

The overall offer of routes included in the Network of Walking Itineraries and Trails of Calabria is shown in Figure 3.14. The cartographic representation, produced using Google Maps and based on

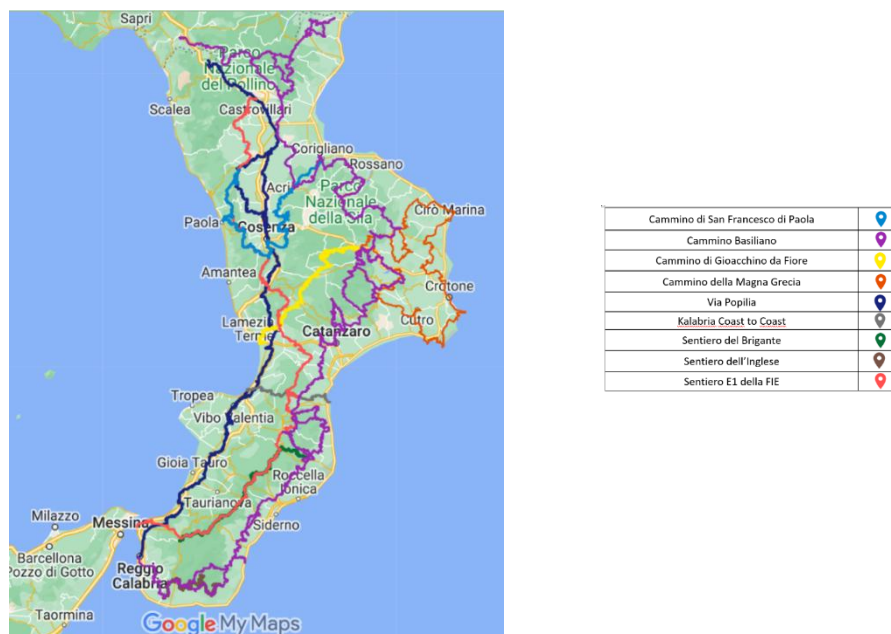
the GPX tracks of individual itineraries, constitutes a faithful and functional reproduction for the planning and valorisation of the regional walking network.

The network has the following characteristics:

- the Network integrates 9 itineraries among Walking Itineraries and Trails;
- it extends over a total distance of 3,283 km;
- it comprises a total of 167 stages to be covered in as many days;
- it passes through 287 municipalities of the region;
- it crosses 3 national parks (Sila National Park, Pollino National Park, Aspromonte National Park); a UNESCO MAB area; two regional parks (Serre Regional Park and Vergari Regional Park); a Marine Protected Area (Capo Rizzuto Island Marine Area); a Regional Marine Park (Bay of Soverato); two nature reserves (Tarsia Nature Reserve, Angitola Nature Reserve); archaeological areas (Rocca Angitola Archaeological Area; Capocolonna Archaeological Area); several SIC and SIN areas;
- all routes have their signage;
- all routes except one have an officially registered brand;
- all routes except one have their Pilgrim Passport and completion certificate.

To study this system, the pedestrian transport offer is modelled as a geolocated graph, composed of nodes representing the starting points, endpoints and intermediate stages of the routes and arcs representing their connections.

Figure 3.14 - Network of Walking Itineraries and Trails of Calabria.



The analysis of this graph provides a set of performance indicators crucial for strategic planning. Below (Figure 3.15) the geolocated graph of Calabria's walking itineraries and trails is shown. The graph was produced using the Gephi platform, open-source software widely used for the analysis and visualization of complex networks. Gephi allows importing tabular or GIS data, transforming them into a graph and applying spatial layout algorithms and calculating main centrality measures to highlight relationships and hidden structures within the network.

The graph was created following these steps:

- a) identification of starting, ending and stage points for each route;
- b) creation of the node table, associating to the points above their geolocation (indicating latitude and longitude according to the Mercator system);
- c) creation of the incidence matrix indicating the arcs;
- d) removal of duplicate nodes and arcs;
- e) upload to Gephi using the Geo Layout plugin. The Geo Layout plugin automatically positions network nodes based on their geographic coordinates, allowing a realistic spatial representation of the network and facilitating analysis of the distribution of nodes and connections across the territory. In the case of Calabria's walking itineraries and trails, the plugin allowed geolocating each node, corresponding to stages, clearly showing the overall network structure and interconnections between the various itineraries;
- f) graph analysis according to specific parameters.

Figure 3.15 - Graph of Walking Itineraries and Trails of Calabria.



The graph consists of 129 nodes and 151 arcs. A set of indicators can be defined to describe the structure and characteristics of the walking network, providing quantitative information useful for planning, management and territorial valorisation. These indicators allow identifying strategic nodes, points of interconnection between itineraries, most accessible locations and more peripheral or isolated areas, thus providing a complete picture of connectivity, territorial coverage and usage opportunities for walkers.

The **average degree of connection** (sum of incoming and outgoing arcs per node divided by the number of nodes) is 1.144, with some intermediate nodes having a high degree (6), e.g., Bova and some nodes having a low degree of 1, as they are starting or ending points of only one itinerary. It should be noted that the value reported by Gephi is about half of the theoretical value, given by twice the number of arcs divided by the number of nodes ($2E/N=302/129\approx2.34$), since the software considers the network as directed and calculates the average degree separately on incoming or outgoing arcs.

It is interesting to focus on certain nodes, such as Serra San Bruno (degree 5) or San Giovanni in Fiore (degree 4), for which the substantial number of incoming and outgoing arcs highlights that these locations are stages included in multiple itineraries of one or more paths. These locations thus act as true “hubs” connecting various flows occurring along the network branches.

The **network diameter** measures the maximum distance among all vertex pairs in the graph, where the distance between two vertices is the length of the shortest path between them. The unit of measurement for the diameter is the number of arcs in the shortest path, since in an unweighted graph each link has length 1. In this case, the network diameter is 57, while the average distance (also measured in number of arcs) is 18.66.

It is also interesting to consider centrality measures. Betweenness Centrality (Figure 3.16), which measures the frequency with which a node appears on the shortest path (minimum path) between two nodes, indicates that certain nodes, such as San Vito Ionio, are more important for connecting different parts of the network, acting as “bridges” between multiple itineraries. At these nodes, for example, signage will need to be improved to allow walkers to follow the chosen itinerary or switch from one itinerary to another.

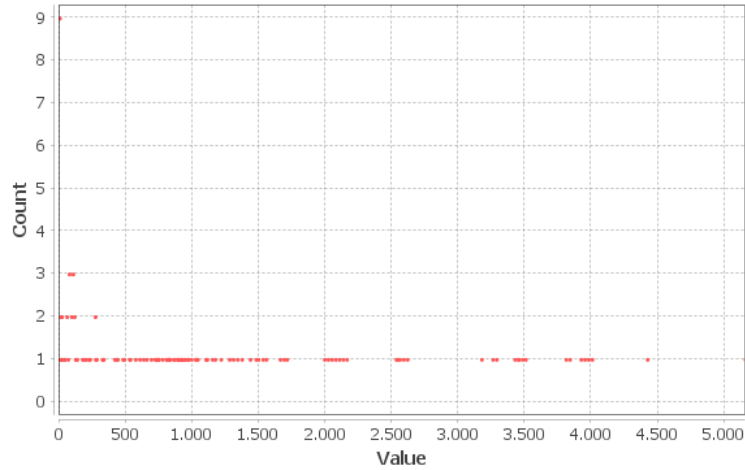
Betweenness Centrality is a fundamental network analysis measure that quantifies the extent to which a node acts as a “bridge” or critical connection point between other pairs of nodes. Formally, it measures the frequency with which a node lies on the shortest path connecting all other node pairs in the network. A high Betweenness Centrality value not only indicates a central position but signals that a node is essential for connectivity and the flow of information or resources within the system, as its removal or functional disruption would significantly compromise network integrity.

$$C_B(v) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(v)}{\sigma_{st}} \quad (13)$$

where σ_{st} is the total number of shortest paths from node s to node t and $\sigma_{st}(v)$ is the number of those paths passing through v (excluding v as an endpoint).

The Betweenness Centrality analysis applied to the Calabria walking itineraries graph provides strategic insights for management and planning. As shown in Figure 3.16, certain nodes, such as San Vito Ionio, have high betweenness centrality. This outcome is not coincidental: it highlights that these locations are not only stages but actual “junction points” connecting different itineraries. Their importance lies in serving as connectors between otherwise disconnected itineraries, channelling walker flows across different geographic areas. Practically, high Betweenness Centrality at these nodes suggests that they are critical points for the efficiency of the overall network. Therefore, strategic planning must ensure particular attention to service quality, signage and infrastructure maintenance, to guarantee smooth transitions between itineraries and maximize the interconnection potential of the entire regional network.

Figure 3.16 - Betweenness Centrality Distribution.



Closeness Centrality is a measure quantifying a node’s accessibility within the network, reflecting its average distance from all other nodes. Unlike metrics focusing on the busiest paths, closeness centrality assesses how easily a node can be reached from every other part of the system via shortest paths. A high value indicates that a node is in a strategic position, with short paths connecting it to every other point in the network, making it a high-accessibility hub. This is a crucial planning indicator, as it identifies locations that can serve as efficient starting or ending points for walkers, minimizing overall travel time to explore the network. It is expressed as:

$$C_c(v) = \frac{1}{\sum_{t \in V} d_G(v, t)} \quad (14)$$

where $d_G(v, t)$ denotes the distance between vertices v and t , i.e., the minimal length of any path connecting v and t in G .

The analysis of *Closeness Centrality distribution* on the Calabria walking itineraries graph, shown in Figure 3.17, provides important insights into network structure and efficiency. The distribution shows that most nodes fall within a high-value range (0.35-0.40), with a peak around 0.375. This suggests that the network has good overall connectivity and most stages are relatively well integrated and easily reachable from other parts of the system. However, the presence of a “tail” of nodes with very low closeness centrality values (below 0.15) indicates that there are still paths or locations rather isolated from the rest of the network. Such nodes, while potentially offering more remote experiences, require strategic planning to improve their connection, e.g., through creating new links or enhancing local public transport, to fully integrate the region’s tourist offer.

A dot plot showing the distribution of 'Value' for 'Category' 0. The x-axis is labeled 'Value' and ranges from -1 to 1. The y-axis is labeled 'Count' and ranges from 0.0 to 3.0. The plot shows counts for values 0, 0.25, 0.5, 0.75, and 1.0. The counts are: 0: 3.0, 0.25: 2.0, 0.5: 2.0, 0.75: 2.0, 1.0: 3.0.

$$e(v) = \max_{t \in V} d(v, t) \quad (15)$$

With the walking itineraries graph available, it is possible to propose an application that allows potential walkers to set a starting point and the number of available days to identify all possible itinerary alternatives.

The significance of centrality measures becomes more evident when the graph is overlaid on the regional territory (Figure 3.19).

Figure 3.18 - Eccentricity Distribution.

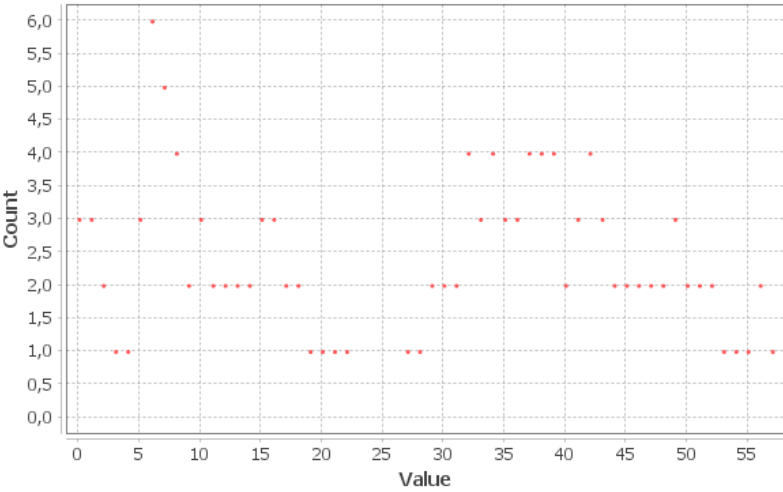
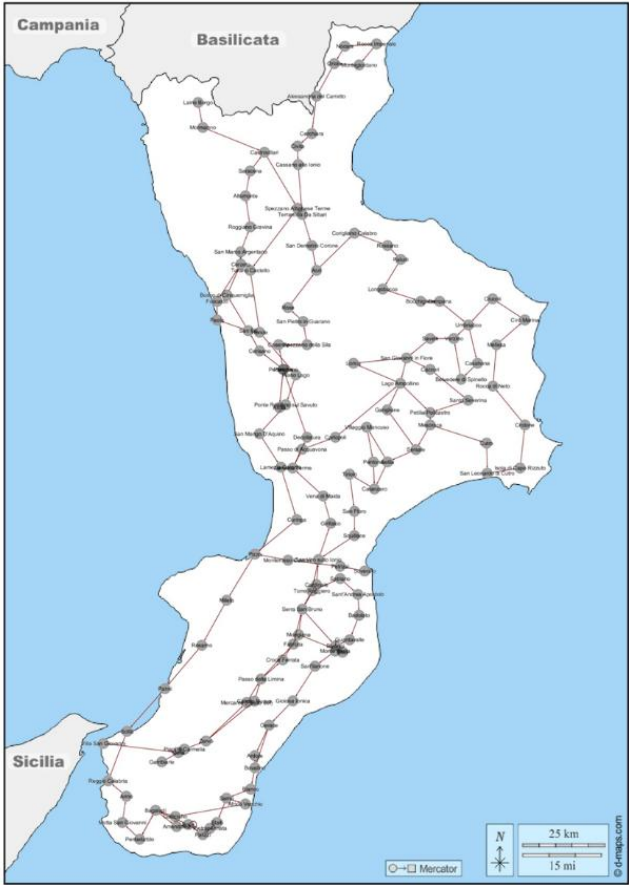


Figure 3.19 - Application of the graph to the regional territory map.



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Chapter 4

Approach to the analysis of pedestrian mobility demand

4.1 Characterization of Pedestrian Mobility Demand

Demand estimation represents a fundamental element in the analysis of transport systems, as it allows the quantification of traffic flows and guides design and management decisions. Among its components, tourist demand, defined as the set of trips made by individuals intending to use tourist facilities and services outside their places of residence and work [1], plays a significant role. Tourism and transport systems constitute an interdependent system: the increase in infrastructural capacity stimulates tourist accessibility, while the growth of tourist flows induces infrastructural developments [2]. This interaction produces direct impacts on economic development and territorial planning, being particularly relevant in the management of regional tourist flows.

Global tourist demand is continuously increasing, also supported by the emergence of new forms of travel such as Walking Tourism. Experiences related to the discovery of places through walking itineraries and paths are multiplying, offering travellers innovative and engaging modes of visit.

This expansion is favoured by several elements, including:

- the progressive disaffection towards traditional forms of tourism, often expensive and standardized; walking itineraries instead allow more authentic experiences, directly connecting the tourist with nature, culture and local communities;
- an increasing focus on environmental sustainability; walking paths reduce environmental impact and contribute to the protection of the territory; the physical and psychological benefits derived from walking outdoors, an activity perceived as light but healthy;
- the emergence of new cultural values; moving on foot facilitates interaction with local populations, allowing a closer understanding of traditions, customs and lifestyles;
- the enhancement of lesser-known and less-frequented territories, which allows a better distribution of tourist flows, reducing overcrowding in the most visited hubs;
- the rediscovery of rural tourism, promoting slow travel closely connected with nature and supporting the economic development of local communities through the sale of typical products, handicrafts and hospitality offerings;
- the possibility of structuring itineraries around specific themes that enhance the territory, such as history, spirituality, gastronomy, or the environment.

In recent decades, people's mobility issues have gained renewed centrality. On one hand, solutions are sought to reduce the dominant weight of motorized vehicles in increasingly congested and polluted cities; on the other hand, more sustainable forms of connection are promoted even for short- and medium-distance trips in extra-urban areas, such as the inner areas of Italian territories, characterized by continuous depopulation. To regenerate these territories and preserve their infrastructural and natural capital, pedestrian mobility can constitute a strategic tool, integrating tourist accessibility with territorial enhancement. However, before planning, it is necessary to know the potential demand and its distribution across territories. In this regard, the adoption of quantitative models for estimating pedestrian tourist demand allows

the design of itineraries, optimization of flow distribution and evaluation of intervention scenarios aimed at improving the efficiency and sustainability of the local and regional transport system. In transport systems theory and practice, numerous methodological and modelling approaches concerning the estimation of demand for passenger and freight mobility in a given territory are now available. In general, a transport demand model can be defined as a mathematical relationship that allows associating a given system of activities and transport supply with the average value of demand flow in a given reference period along with its demand characteristics [3]. Each trip results from a series of choices made by the user, the pedestrian in the considered case. The choices determining mobility demand are multiple and depend on the available alternatives (choice dimensions) and their attributes.

One of the issues most analysed by sector analysts is the measurement of the spatial distribution of trips, particularly the emission and attraction capacity of trips from specific areas, i.e., the number of users moving from an origin zone (within specific time windows, for a particular purpose, using a certain mode of transport) to a destination zone; this is referred to as Origin/Destination (O/D) matrix estimation. A wide literature exists on this topic. A widely used model is the four-stage model [3], with partial rates, according to which the trip demand expressed by users of category i wishing to move from the origin o to the destination d , for purpose s , in the time period h , with mode m , following route k , can be evaluated using the following expression (1):

$$d_{od}^i(s, h, m, k) = d_o^i[sh] \cdot p^i[d/osh] \cdot p^i[m/oshd] \cdot p^i[k/oshdm] \quad (1)$$

which is articulated into 4 sub-models, where:

$d_o^i[sh]$ is the trip generation (or production) model, providing the average number of trips made by users of category i from origin zone o in period h for purpose s ;

$p^i[d/osh]$ is the distribution model, providing the percentage of users of category i who, departing from zone o , for purpose s , in time period h , go to destination d ;

$p^i[m/oshd]$ is the mode choice model, providing the share of trips of users of category i who, moving from zone o to zone d , for purpose s , in time period h , use transport mode m ;

$p^i[k/oshdm]$ is the route choice model, providing the share of trips of users of category i who, moving from zone o to zone d , for purpose s , in time period h , with transport mode m , follow route k among the many alternatives (possible or more efficient).

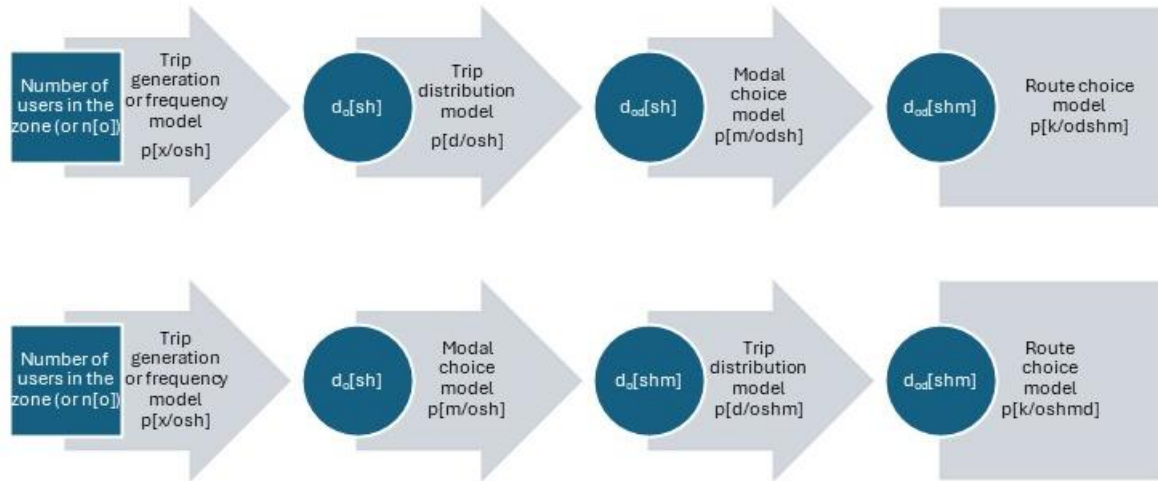
The model can be calibrated on different spatial-temporal dimensions; for example, it can be applied to study vehicular flows on an urban road network, or it could be aimed at studying the relationships between States or Regions on a monthly or yearly dimension. If interested in tourist flows, only the demand component related to travel for tourism purposes will be considered.

In the context of walking tourism, the classical four-stage transport model can be adapted to analyse pedestrian tourist flows in an urban or regional territory. It could be structured into a higher hierarchical scale model, when considering tourist inflows into the area of interest and a lower scale model for analysing pedestrian mobility within the area of interest.

In the first case, only the first three stages are considered, in order to determine tourist flows between the outside and the study area (the result will be a vector of demand values attracted by the area of interest); typical modes of transport will be car, airplane, train, ship. In the second case, downstream of the first, the tourist user components from access points to the

area of interest (ports, airports, highway interchanges, railway stations), assumed as origins, are distributed within the territory (destination zones). In this case, a reverse order may be assumed in modelling practice; that is, first estimating mode choice and then, once pedestrian mobility demand is determined, estimating the spatial distribution of this single component (Figure 4.1).

Figure 4.1 - Comparison between classical Four-Stage Model and proposed Four-Stage Model.



4.1.1 Generation Model (Demand Production/Attraction)

In the four-stage model, the first phase corresponds to demand generation, i.e., the estimation of the number of trips produced by the different geographical areas considered in the study. In the classical context, mainly referring to daily mobility, demand generation is linked to socio-demographic variables of the origin zones (resident population, family composition, age, gender), socio-economic variables (income, employment, education level) and functional variables (distribution of activities, location of workplaces, presence of services). In this framework, demand is represented as the result of objective and generally stable factors, explaining the propensity to travel according to the characteristics of origin and destination zones. In the case of tourist demand, the logic remains similar but the spectrum of explanatory variables is broadened. Travel production derives from the different origin areas of flows (national and international markets), while the propensity to travel depends not only on structural factors but also on subjective elements, such as availability of free time, cultural, spiritual, or naturalistic motivations and the tourist's spending capacity.

A simple descriptive model of the "index per category" type or a regression model per category can be used:

- Category index models, which assign average trip generation values to each group of population or tourist activity. For example, families, young travelers, international tourists, or walkers can be treated as categories with different average trip production coefficients. It is a simple approach, often adopted in the preliminary phase or in the absence of detailed data;
- Regression models per category, which allow correlating the number of trips with socio-demographic, economic and territorial variables. In this case, statistical methods are used to estimate travel propensity for each population group. Generally, multiple linear regression is applied in this phase to estimate the average number of trips produced as a function of continuous variables (e.g., income, average age, tourist expenditure).

Compared to the classical model applied to daily mobility, the use of regression per category in tourist demand allows capturing greater heterogeneity of behaviours, linked not only to socio-economic characteristics but also to travel motivations and cultural preferences of tourists. This makes demand generation in tourism more complex but also more realistic, as it can integrate intangible factors alongside structural ones.

The general form of a multiple linear regression model (1) for estimating tourist demand generated externally and attracted to a given territory can be expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \varepsilon \quad (1)$$

where:

- Y represents the dependent variable, i.e., tourist demand (e.g., number of arrivals or presences);
- $X_1, X_2, \dots, X_k$ re explanatory variables, which may include economic factors (available income, exchange rates, transport costs), demographic and qualitative factors;
- $\beta_0, \beta_1, \dots, \beta_k$ are the coefficients quantifying the relationship between the explanatory variables and demand;
- ε is the stochastic error term, capturing the influence of unmeasured or unpredictable factors.

Thus, tourist demand attracted to the territory can be considered distributed according to the access points of the area, as demand emitted from the same entry points and directed inward.

These models, starting from linear regression approaches, have evolved to incorporate the complexity of tourism phenomena, integrating multiple variables and more complex relationships. For walking itineraries in particular, demand is closely linked to the origin of tourists, with studies showing a high propensity from specific markets such as the United Kingdom, France and Germany towards Italian destinations.

Although disposable income and transport costs continue to play a role, their relevance is reduced compared to qualitative and perceptual elements. Studies on the Italian tourism sector highlight that low revenue growth is not primarily attributable to unfavourable price trends, but rather to non-price factors, such as service quality, infrastructure provision, safety and accessibility. Destination attractiveness is also influenced by specific aspects such as art, natural beauty, cuisine and the friendliness of local inhabitants [4].

A crucial aspect in analysing slow tourism demand is the influence of external and unexpected events. The tourism sector, being based on people's mobility, is inherently vulnerable to exogenous shocks such as global health crises [5]. Traditional econometric models, based on historical series, may struggle to predict the effects of such events, which have no comparable historical precedents. However, the pandemic acted as a catalyst, pushing tourists to favour nearby destinations and outdoor activities, thus promoting slow and walking tourism. This suggests that, unlike other segments, walking tourism has demonstrated greater resilience. A robust predictive model cannot be limited to structural variables but must include scenario factors or "dummy" variables capable of capturing the impact of health, climatic, or geopolitical crises [6]. In this sense, the analysis must evolve from simple volume estimation to an assessment of demand elasticity and resilience in response to changing contexts.

4.1.2 Modal and spatial distribution model

The main critical issue in modelling slow tourism demand is the lack of granular and precise data on walkers' flows [7]. Often, available administrative data, such as accommodation statistics, do not distinguish walkers from other tourists. To overcome this limitation, it is necessary to integrate official data with alternative and innovative sources.

Once the overall demand is estimated, the second stage of the model focuses on predicting the tourist's choice to undertake a walking itinerary compared to other travel modes. Discrete choice models can be employed for this purpose, particularly Logit models. Based on random utility theory, these models estimate the probability that an individual chooses a given option (e.g., walking) based on the characteristics of that option and individual preferences.

The probability that an individual n chooses a given alternative i from a set of alternatives J is given by the multinomial Logit model formula (2):

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j=1}^J e^{V_{nj}}} \quad (2)$$

Where V_{ni} is the deterministic (or "systematic") component of the utility function:

- P_{ni} is the probability that individual n chooses alternative i ;
- V_{ni} is the systematic utility of alternative i for individual n (deterministic part of utility), which depends on the characteristics of alternative i and the characteristics of individual n ;
- the sum in the denominator is over all J alternatives.

The total utility U_{ni} of alternative i is given by:

$$U_{ni} = V_{ni} + \epsilon_{ni} \quad (3)$$

where V_{ni} is the observable (deterministic) component, usually linear:

$$V_{ni} = \beta_0 + \beta_1 x_{1ni} + \beta_2 x_{2ni} + \dots + \beta_k x_{kni} \quad (4)$$

and ϵ_{ni} is the unobservable random component.

Originally applied to study transport demand, Logit models can be adapted to analyze the choice of a sustainable tourism mode, considering variables that influence the perceived utility of walking, such as psychographic motivations and quality of experience. The choice of a walking itinerary is rarely driven by a single motivation [8]. Psychographic analysis reveals a complex set of drivers, which can be classified into different categories. Central psychographic motivations include the pursuit of personal growth, well-being and spirituality, understood as an inner search aimed at balancing body, mind and spirit. The walking itinerary is perceived as an "inner journey" and an opportunity for personal "transformation," an experience qualitatively different from daily life. These are complemented by social and environmental motivations, such as the search for authenticity, immersion in nature and opportunities for socialization with other walkers [9]. Finally, there are more utilitarian or secular motivations, such as the desire to face a physical challenge, explore the cultural territory and seek pure "pleasure" [5].

A fundamental aspect, challenging the assumption of fixed motivations in traditional models, is the dynamic nature of walker behaviour. The concepts of "pilgrim" (driven by religious or spiritual motivations) and "tourist" (guided by secular motivations) are not rigid categories but poles of a continuum along which the traveller can move. A casual tourist, for instance, may transform into a tourist with a defined spiritual motivation during the walking itinerary itself. Studies on the

Camino de Santiago show that the pilgrimage experience can realign personal values toward altruism, ethical engagement and sustainability, reducing the importance of motivations oriented toward success or power [10].

Once the pedestrian mobility component is determined, it is possible to estimate the distribution, i.e., construct an Origin/Destination matrix, where origins correspond to the access points to the study area and the destination focuses on the tourists' selection of a specific walking itinerary based on attraction factors (e.g., scenic beauty, historical-cultural heritage, or the itinerary's reputation).

The distribution phase can be addressed using two different modelling approaches: descriptive models and behavioural models. The former are based on empirical relationships, often aggregated, capable of representing observed flows based on statistical regularities without explicitly referencing individual decision-making. The latter are based on a microeconomic representation of preferences and behaviours, assuming that individuals choose their destination based on expected utility maximization.

Within descriptive models, a central role is played by the gravity model, which finds application in various fields, from international economics to migration flows. It is based on an analogy with the law of universal gravitation, assuming that the intensity of movement between an origin area O and a destination D is proportional to the "attractive mass" of the two areas (e.g., population, economy, attractiveness) and inversely proportional to the generalized travel resistance. The model can be adapted to compare walking itineraries and predict walkers' distribution. The main challenge in applying the gravity model to walking itineraries is the correct quantification of destination attractiveness.

The attractiveness of a walking itinerary is not a single value but a composite index integrating tangible and intangible factors [11]. Tangible factors include measurable elements such as the presence of UNESCO sites, path length and density of accommodation and catering services along the route. A detailed analysis of the Via Francigena in Tuscany demonstrated the value of georeferencing accommodation facilities, showing an increase in tourist presences directly attributable to proximity to the itinerary [12]. The study results highlighted an 88% increase in arrivals for facilities located less than one kilometre from the route, with growth percentages decreasing as distance increases, normalizing beyond 20 km.

Intangible factors, although more difficult to measure, are equally crucial. These include the itinerary's notoriety (amplified by films and media), its symbolic or spiritual value and its reputation (derived from reviews and word-of-mouth) [13].

The attractiveness of a destination d can be obtained from the formulation of potential tourist demand attracted to destination d :

$$p[d/oshm] = \frac{\exp(\beta_1 A_d - \beta_2 C_{od})}{\sum_{d'} \exp(\beta_1 A_{d'} - \beta_2 C_{od'})} \quad (5)$$

where A_d and C_{od} represent, respectively, an attraction variable for area d and a cost variable for the od relation.

In applications, the logarithmic transformation of attributes is generally used:

$$p[d/oshm] = \frac{A_d^{\beta_1} C_{od}^{-\beta_2}}{\sum_{d'} A_{d'}^{\beta_1} C_{od'}^{-\beta_2}} \quad (6)$$

The attraction variable for a given destination d can be expressed as the sum of three components: a social share SOC ; an economic share EC ; and an environmental share AMB :

$$A_d = SOC + EC + AMB \quad (7)$$

The social component can be specified as:

$$SOC = \sum_i (\alpha_i \cdot SOC_i) \quad (8)$$

where SOC_i are social attributes and α_i are model parameters.

Among social attributes, the following can be considered: population (P), historic centers (CS), villages (B), museums (Mu), archaeological parks (PA), artistic heritage (BA), architectural heritage (BAT), hospitals (SH), religious structures (SR), accommodations (H), spa facilities (ST), golf courses (CG) and characteristic gastronomic sites (EG). Thus:

$$SOC = \alpha_1 \cdot P + \alpha_2 \cdot CS + \alpha_3 \cdot B + \alpha_4 \cdot Mu + \alpha_5 \cdot PA + \alpha_6 \cdot BA + \alpha_7 \cdot BAT + \alpha_8 \cdot SH + \alpha_9 \cdot SR + \alpha_{10} \cdot H + \alpha_{11} \cdot T + \alpha_{12} \cdot G + \alpha_{13} \cdot EG \quad (9)$$

The economic component can be expressed as:

$$EC = \sum_j (\mu_j \cdot EC_j) \quad (2)$$

where EC_j are economics attributes and μ_j are model parameters.

Among economic attributes, the following can be considered: Gross Domestic Product (GDP) and the level of presences in accommodation facilities (PH). Thus:

$$EC = \mu_1 \cdot GDP + \mu_2 \cdot PH \quad (3)$$

The environmental component can be expressed as:

$$AMB = \sum_k (\gamma_k \cdot AMB_k) \quad (12)$$

where AMB_k are environmental attributes and γ_k are model parameters.

Among environmental attributes, the following can be considered: number of remarkable sites (SN), number of Blue Flag beaches (BB), number of lakes (LD), climate (CLI : cold, mild, hot), air quality (QA). Thus:

$$AMB = \gamma_1 \cdot SN + \gamma_2 \cdot BB + \gamma_3 \cdot LD + \gamma_4 \cdot CLI + \gamma_5 \cdot QA \quad (4)$$

Finally, the cost variable can be expressed considering three attributes: actual distance (D) between origin and destination, travel cost (CT) and cost-of-living level at the destination (CV).

Thus:

$$C_d = \delta_1 \cdot D + \delta_2 \cdot CT + \delta_3 \cdot CV \quad (5)$$

with $\delta_1, \delta_2, \delta_3$ as substitution parameters.

4.1.3 Route choice model and demand assignment

The allocation of demand to routes (stage 4) consists of distributing tourist flows to the individual segments composing the selected itineraries, taking into account the specific characteristics of each (e.g., difficulty level, length, or availability of services). This methodological approach

provides a structured framework for planning and managing walking tourism, allowing the prediction and optimization of the use of existing infrastructures.

This operation can be facilitated by GIS models or specific simulation software capable of integrating territorial and structural data (such as slope, terrain type, points of interest) and evaluating the quality of the walking experience. These tools not only map routes but also estimate the pressure on segments based on expected demand. A more in-depth discussion of the dynamic interaction between demand and supply, also in relation to the causal cycles arising from it, is developed in the next chapter.

It is crucial to distinguish assignment models for walking itineraries from traditional vehicle traffic models, which are based on minimizing travel time and speed. Walker behaviour is not speed-oriented but focused on optimizing experience. A route assignment model for walking must therefore focus on different variables, such as the identification of “risk points” that may compromise the experience. Furthermore, while vehicle models aim to maximize flow, those for walking must consider that potential congestion would not compromise infrastructure accessibility as much as the authenticity of the experience.

Moreover, the application of the assignment model to walking itineraries cannot ignore the concept of “carrying capacity,” which evaluates the number of visitors a trail can sustain without negative impacts. Carrying capacity is not limited to social overcrowding, which compromises the quality of the tourist experience, but also includes ecological impact, such as soil compaction or vegetation loss [14], [15].

Assignment in walking itineraries must integrate capacity constraints, shifting the focus from flow maximization to its balanced distribution. Therefore, the analysis is based not only on parameters such as elevation difference or travel time but also on the intrinsic capacity of each segment to sustain a given number of visitors without compromising the experience and the environment.

4.2 Motivations and demographic profiles of walkers

The phenomenon of walking itineraries is gaining prominence both in Italy and internationally, with demographic and motivational profiles that, while showing common elements, exhibit peculiarities related to cultural and geographical contexts. It is consolidating as a travel model that is not only rapidly growing but also more mature and diversified, capable of generating economic, social and environmental value for territories.

According to the 2024 dossier “Italy, Country of Walking Itineraries”[16] by Terre di Mezzo in collaboration with Cammini d’Italia, nearly 200,000 people undertook a walking itinerary in Italy, marking an increase of 29% compared to 2023. The demographic profile shows a slight female prevalence (51%), with the most represented age groups between 56-65 years (30%), followed by 46-55 (22%) and over 65 (15%). Walkers under 35 years represent 18% (with the 26-35 component alone accounting for 14%) but show a strong orientation toward itineraries such as the Via degli Dei, which combine “challenge, sharing and cost containment.” Regarding origins, although Italian walkers constitute the majority on national routes (about 80% for the Via Francigena), the presence of foreign tourists is steadily increasing. The main countries of origin are Germany, France and the United States, demonstrating growing appreciation for the cultural and landscape heritage offered by these itineraries. The main declared motivations are immersion in nature, mental well-being, territorial knowledge and inner exploration, with about a quarter of walkers (25%) motivated by religious or spiritual reasons.

It is noteworthy that a good percentage of those who undertook a walking itinerary in the last survey year completed at least one other (39%) or two others (23%). The consolidation of the

walking habit is explicitly declared, as respondents state that after discovering a walking itinerary they cannot do without it (24%) and that they undertake at least one itinerary per year (32%). For broader considerations, it is appropriate to refer to an international context, specifically the Camino de Santiago (Figure 4.2), as it is the first walking itinerary to receive the recognition of “European Cultural Route” [17], granting it considerable historical and spiritual value. It is also one of the most frequented routes worldwide [18]. Furthermore, the availability of detailed historical data by gender, origin and travel motivation enables in-depth comparative analysis [19]. Historically linked to spirituality, the Camino has undergone a transformation in the composition of motivations. Analysing overall participation data for the Camino de Santiago from 2003 to 2023, a significant growth trend emerges for both men and women, with the total number of pilgrims reaching 436,015 in 2023 (Figure 4.3).

Figure 4.2 - Maps of the Camino de Santiago.



a) Main ways in Spain



b) Cultural Route of the Council of Europe

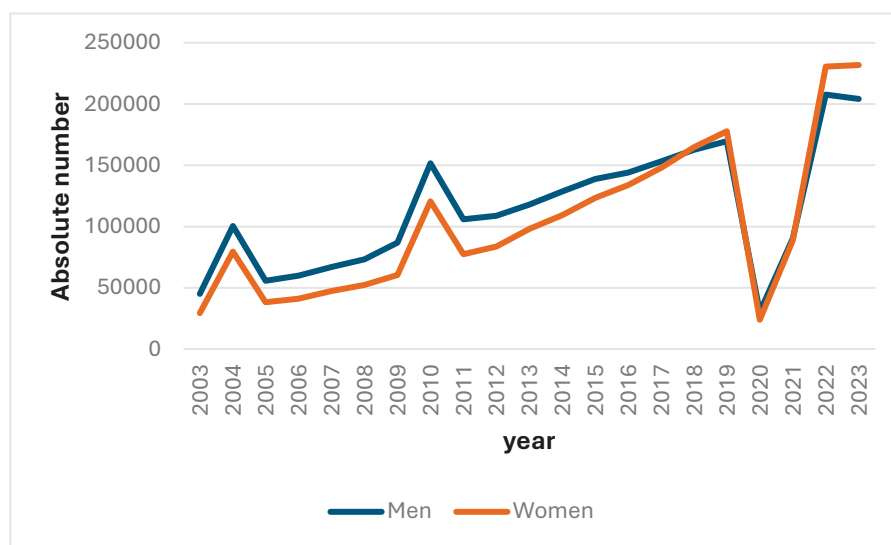
Source: a) Encyclopædia Britannica b) European Federation of Saint James Way; Cultural Route of the Council of Europe (certified 1987).

This trend is particularly evident in recent years' data, showing a constant increase in female participation. This represents a reversal compared to the early years of the century, when male participation far exceeded female participation. In 2003, Camino participation was predominantly male, with about 61% male pilgrims. By 2023, this trend reversed, with women representing approximately 53% of pilgrims, highlighting a steady increase in female participation over the years. In the 1980s, over 80% of pilgrims cited religious reasons, but recent data indicate a different trend: about 43% still religious, 50% religious-cultural, 20-5% secular or personal motivations [20]. Current motivations include the search for meaning, inner experience and overcoming personal crises, while specific religiosity appears less dominant. Given similar demographic profiles (average age, strong female presence), Italian walkers show a predominance of mature adults, while the Camino attracts larger shares of younger people.

Internationalization of the movement is more pronounced along the Camino, but in Italy, slow tourism is rapidly growing, with gradual openness to new youth segments.

The economic impact of walking itineraries is increasingly recognized. A walker spends on average between 40 and 60 euros per day for accommodation, food and services, generating significant economic benefits for local economies, especially in rural areas and locations not frequented by mass tourism. This tourism model contributes to counteracting depopulation and enhancing small artisanal and agricultural activities. Environmental sustainability is another key aspect; slow tourism is inherently low-impact and contributes to landscape conservation and the reduction of transport-related pollution.

Figure 4.3 - Total number of walkers on the Camino de Santiago - Years 2003-2023, by gender (based on Santiago de Compostela Pilgrim's Reception Office statistics).



Overall, there is a diversification of motivations, with a decreasing weight of purely religious reasons in favour of well-being, cultural exploration, or sporting challenge and an increasing use of technology by walkers, who rely on GPS, dedicated apps and social media for planning, navigation and sharing experiences. The popularity of shorter routes or specific stages, also suitable for those with limited time, reflects a further evolution of the phenomenon.

4.3 Gender perspective in pedestrian mobility

Gender is not merely a category of biological sex but a social construct that profoundly influences how people move [21]. Gender norms and social roles, often defined by stereotypes and expectations, limit people's movements in space and time, their perception and experiences of mobility, as well as access to resources and use of infrastructure. A generalist approach that does not consider these differences risks creating transport systems and public spaces that do not adequately meet the specific needs of all, particularly women, children and the elderly.

The persistent gender gap in mobility derives from a combination of structural and social factors. The division of tasks, often based on gender, leads to different mobility patterns, such as the more complex "trip chains" that women must undertake to manage household chores and family care [22]. Another key factor is the subjective perception of safety, which disproportionately affects women's mobility, especially at certain times and in specific places. This perception limits their freedom of movement and use of public spaces.

The gap in gender-disaggregated mobility data leads to incomplete analysis that fails to capture the life realities of those who do not fit the male standard. The consequences are mobility policies and infrastructures that do not address existing inequalities and, in some cases, exacerbate them, leading to suboptimal urban mobility solutions for all.

Urban planning can improve pedestrian mobility by adopting an inclusive approach sensitive to the needs of all social groups. It is essential to create safe, accessible and well-connected infrastructure, such as wide sidewalks, well-marked pedestrian crossings and adequate lighting, to enhance the perception of safety, particularly for women. Additionally, proximity to essential services, such as schools, shops and public transport, is important to reduce the need for complex trips. Integrating green spaces and rest areas along pedestrian routes can improve the overall experience, making walking mobility more attractive and sustainable. Finally, one-third of mobility companies do not collect information on users' age, gender, or residence [23]: collecting gender-sensitive data and information on citizens' diverse needs allows designing solutions that reflect everyone's daily reality.

Despite growing interest in gender mobility, academic research has focused mainly on daily urban trips, often neglecting leisure or tourism trips in peri-urban or rural contexts, such as those associated with long-distance trails. While studies on urban gender mobility have increased, research on gender dynamics along long-distance trails and in rural environments remains scarce. This gap is particularly evident in contexts such as the Camino de Santiago, where most existing analysis has focused on the route's economic impact, largely overlooking gender-related aspects. Consequently, understanding the personal walking experience is limited, particularly regarding both individual characteristics of pilgrims and the specific infrastructure and logistical requirements needed to support them efficiently. Therefore, when analysing trails through the lens of gender equity, it is essential to consider not only individual experiences but also the social and cultural dynamics that influence participation and access.

Section 4.6 will analyse in detail gender differences in access and use of trails, risk perception, participation motivations, safety strategies adopted and possible measures to improve itineraries, detected through a dedicated international comparative survey.

4.4. Inclusivity in demand

4.4.1 Needs of different groups

The analysis of pedestrian mobility demand, within transport engineering, requires an inclusive approach that recognizes users as a heterogeneous set, presenting differentiated needs according to gender, age, physical condition, socio-cultural background and economic availability. In this direction is the concept of smart city: intelligent cities that, through information and communication technologies, facilitate the movement of all citizens, free from any architectural barriers or physical disabilities, finding accessibility that meets their special needs and preferences. The imperative is to consider all life stages of all types of users (Figure 4.4).

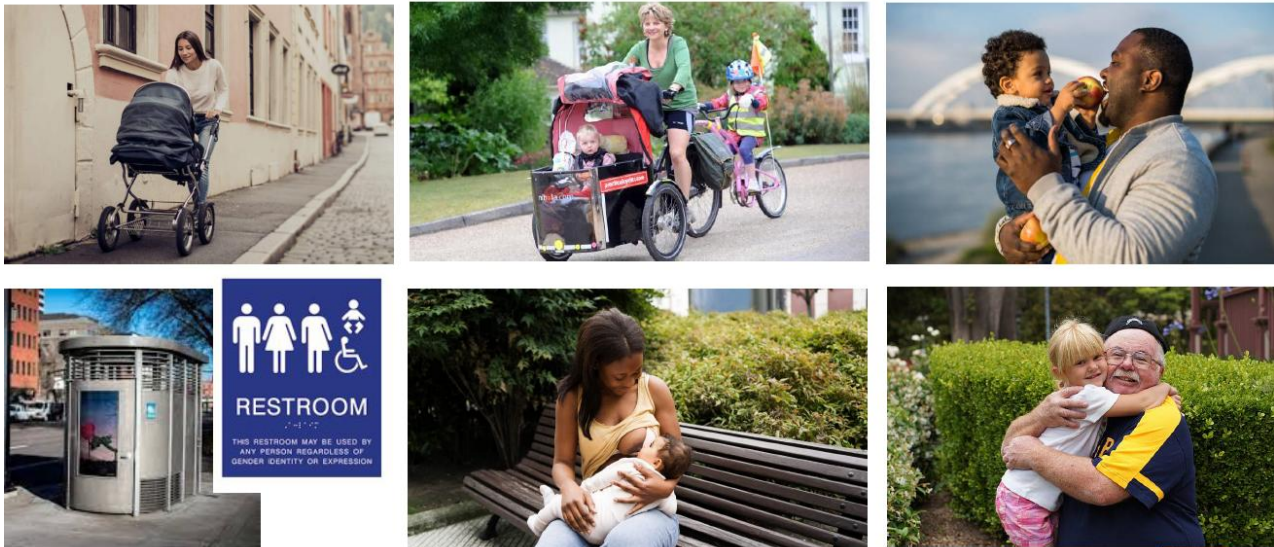
These variables significantly affect not only access to long-distance walking itineraries but also the daily use of pedestrian mobility at the urban level, representing two complementary scales of slow mobility.

In urban contexts, pedestrian mobility represents a fundamental right and forms the basis for ensuring equitable access to services, public spaces and socialization opportunities. An inclusively designed urban environment, with accessible sidewalks, safe crossings, adequate lighting and continuous pathways, is essential so that everyone, including people with disabilities, the elderly, families with children and women who express greater safety concerns, can move freely. The

inclusive city is therefore the first level of access to walking itineraries: without a safe and integrated urban pedestrian network, the experience of walking along longer itineraries remains limited to a small segment of the population.

Long-distance walking itineraries amplify inclusion challenges. They require logistical and infrastructural organization capable of responding to heterogeneous needs: young people tend to prioritize immediacy of experience and use of digital tools for orientation, while the elderly need segmented routes, support services and easily accessible accommodations. Families with children, instead, prefer safe segments, equipped rest areas and intermodal options facilitating return or transport if necessary.

Figure 4.4 - Examples of users of different age groups, with specific needs.



Source: Sáenz de Tejada [24]

Gender differences manifest transversally, influencing both urban pedestrian mobility and the use of walking itineraries. In cities, women show greater sensitivity to perceived insecurity at certain times or in specific contexts, which conditions route and timing choices. On walking itineraries, family care and management responsibilities can limit opportunities to undertake long-duration experiences unless logistical solutions (such as luggage transport, support services, or the possibility to complete only some stages) are provided to reduce these barriers.

Inclusion also concerns socio-economic and cultural aspects. Access to walking itineraries cannot be limited to those with high economic resources: hence the importance of accommodations with differentiated costs and networks of solidarity hospitality, as well as the availability of multilingual information and accessible digital tools. Similarly, in cities, the adoption of universal signage, barrier-free paths and intuitive digital systems contributes to making urban pedestrian mobility an inclusive experience for all.

Urban pedestrian mobility and long-distance walking itineraries thus represent two dimensions of slow mobility that must be analysed jointly. The first constitutes the prerequisite for widespread accessibility, ensuring that walking is feasible and safe for everyone in daily life; the second is an extended and touristic mobility experience, requiring specific solutions to accommodate a diverse user base. Only an integrated approach, capable of enhancing both scales, can result in true inclusion of pedestrian mobility demand and full valorisation of walking itineraries as sustainable transport infrastructure.

Transport planning, traditionally focused on efficiency and flow capacity, has often neglected the mobility needs of all social groups. Demand analysis, from an inclusivity perspective, requires a thorough understanding of how factors such as age, physical conditions and socio-economic status influence choices and travel patterns, especially in pedestrian mobility.

4.4.2 Elderly people and persons with reduced mobility

The elderly population and people with disabilities represent an increasing percentage of pedestrian path users.

Therefore, while urban planning is striving to design spaces accessible to PMR (Persons with Reduced Mobility), thus improving the “wheelability” of cities, applied research is simultaneously working determinedly on technologies capable of making life easier for people with disabilities. It is projected that approximately 6.25 billion people will live in urban centers by 2050, of which 15% will have disabilities according to the United Nations. Therefore, urbanization can be a lever to achieve sustainable and inclusive development if the urban agenda prioritizes accessibility for all. At the international level, there are several instruments aimed at guiding truly inclusive urban development for PMR. In 1982, the United Nations World Programme of Action concerning Disabled Persons identified accessibility as the main tool to achieve its objectives of "full participation" and "equity." Further clarification was provided in 1993 by the Standard Rules on the Equalization of Opportunities for Persons with Disabilities and in 2006 by the Convention on the Rights of Persons with Disabilities (CRPD).

The United Nations, through the 2030 Agenda, focused on sustainability in its three pillars (economic, social and environmental), proposing 17 goals; the theme of accessibility is directly mentioned 11 times in the target areas and explicitly in Goal 11: “Make cities and human settlements inclusive, safe, resilient and sustainable”.

This translates, on one hand, into the planning of cities accessible to all through the concept of Universal Urban Design (“A well-designed city is well-designed for everyone”) and on the other, into the measurement of city accessibility for wheelchairs (wheelability) and, simultaneously, from the user perspective, into the design of aids that best meet user needs. The right to mobility has been enshrined by the United Nations and defined as the maximum possible independence for persons with disabilities and should be guaranteed by member states both by facilitating personal mobility and by promoting the production of mobility aids that enhance the mobility of persons with disabilities. This has led to the development of national or supranational legislation aimed at considering and safeguarding mobility needs from the user perspective, such as circulation on urban roads, accessibility to indoor spaces, public transport on road and rail and air and maritime transport. The purposes of mobility can be multiple, but at the core is the right to express one’s human potential within an inclusive social context. Wheelchair mobility entails various issues related to urban accessibility, such as circulation on urban roads, access to indoor spaces, public transport and air and maritime transport.

According to the United Nations, accessibility means the degree to which an urban environment allows access to the greatest number of people, including PMR. Specifically regarding wheelchair users, to facilitate their movement on urban streets, this has led to a series of international standards, adopted, more or less fully, in national legislations.

For example, in Italian legislation (DM No. 236/1989 and DPR No. 503/1996), the circulation of wheelchair users on urban streets includes, among other things, the design of specific features with reference to sidewalks, pedestrian crossings and parking spaces. In particular, the sidewalk width must be at least 150 cm and the height difference between adjacent areas must not exceed 2.5 cm, with a bevelled or rounded edge. The slope of inclined sections must not exceed 5%.

Furthermore, the pavement must be well-levelled and made of non-slip material. Obstacles, such as elements that could narrow the passage or limit/block the wheelchair movement (e.g., grates), must be avoided along sidewalks. When the height difference is equal to or greater than 2.5 cm, a ramp must be built, ensuring easy mobility, including the possible presence of a curb. Regarding pedestrian crossings, when underpasses or overpasses are not provided, accessibility must be ensured and pedestrian safety must be guaranteed, for example, by installing a green light to allow passage for wheelchair users. Finally, regarding parking areas, the width of the space must be at least 3 m.

Regarding indoor spaces, modern Italian legislation (DM 236/89) provides three different qualitative levels of usability of spaces for PMR: accessibility, understood as the possibility, even for people with reduced or impaired motor or sensory capacity, to reach the building and specific spaces, enter easily and use spaces and equipment safely and autonomously; visitability (possibility of accessing social spaces and at least one restroom in each housing unit); adaptability: possibility to modify the built space over time at limited cost, making it fully and easily usable. Accessible tourism is not only an ethical imperative but also a huge market opportunity. The market of travellers with disabilities and their companions represents an annual expenditure of over 100 billion dollars in the United States [25]. At the European level, the organization Open Doors estimates a value of 70 billion dollars in Europe and the United States:

- approximately 50% of people over 60 have a disability and almost two-thirds of people with disabilities in developed economies have the means to travel;
- these travellers tend to move with 2-3 companions, multiplying the economic impact;
- yet, 67% of them find it difficult to obtain reliable information and 36% describe trip planning as “frustrating”.

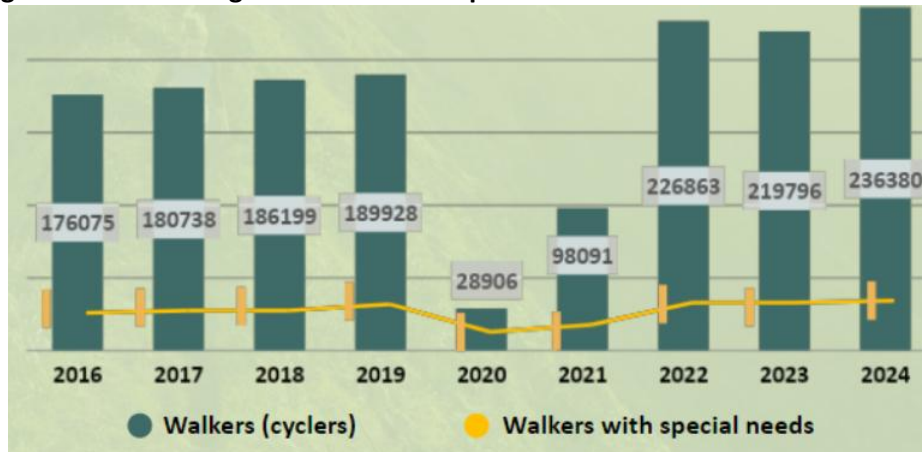
According to statistics from the Oficina del Peregrino, the number of pilgrims with special needs on the French Way is increasing, thanks to improvements made to the route. These include more accessible trail sections with moderate slopes, more accommodations and services adapted to various needs (Figures 4.5).

The challenge is not only to remove environmental barriers limiting mobility (excessive slopes, uneven surfaces, narrow passages, or poorly visible signage...) but especially behavioural barriers, as inadequate assistance or improper staff attitudes can represent significant obstacles. For this reason, staff awareness and training, along with careful planning that considers the needs of all travellers (for example, offering services such as early check-in or equipment rental), are essential to create a truly welcoming environment.

A famous example is Justin Skeesuck and Patrick Gray, who completed the Camino de Santiago together, one on a wheelchair and the other pushing. This example demonstrates that limitations should not preclude participation in long-distance routes. Their initiative led to the founding of "Accessible Caminos," a travel service offering customized tours for people with special needs, addressing every aspect of the journey: transport, accommodation, meals, routes and support. This model has demonstrated that accessibility can become a profitable and sustainable business, generating positive social impact and high demand from both travellers and volunteers. In Italy, a similar reality exists: the Free Wheels Association, founded by Pietro Scidurlo, author of numerous guides on accessible paths. Another interesting experience is the project "Ammappa l'Italia," which offers a platform to share and map hiking routes, with particular attention to accessibility. The initiative allows anyone to contribute by submitting routes via an online form or sending an email with essential details, such as description, duration and difficulty. Routes are classified by difficulty according to the parameters of the Italian Alpine Club (CAI), which considers elevation gain, distance and signage. Categories range from "Touristic" (T), for simple and well-marked trails, to

"Experienced Hikers" (EEA), for via ferrata requiring specific equipment. A key aspect of the project is the introduction of "Inclusive Routes" and "Wheelchair Accessible Routes," designed for people with disabilities (Figure 4.6). These routes, managed by a volunteer called the "Route Expert," provide detailed information on potential hazards, specific fears (e.g., related to mental disorders), need for accompaniment and accessibility. The expert collects essential data such as terrain type, slope, presence of obstacles and charging points for motorized wheelchairs, making the nature experience safer and more accessible for everyone.

Figure 4.5 - Percentage of walkers with special needs on the Camino de Santiago.



Source: Detour Project

Figure 4.6 - PMR on the Camino de Santiago.



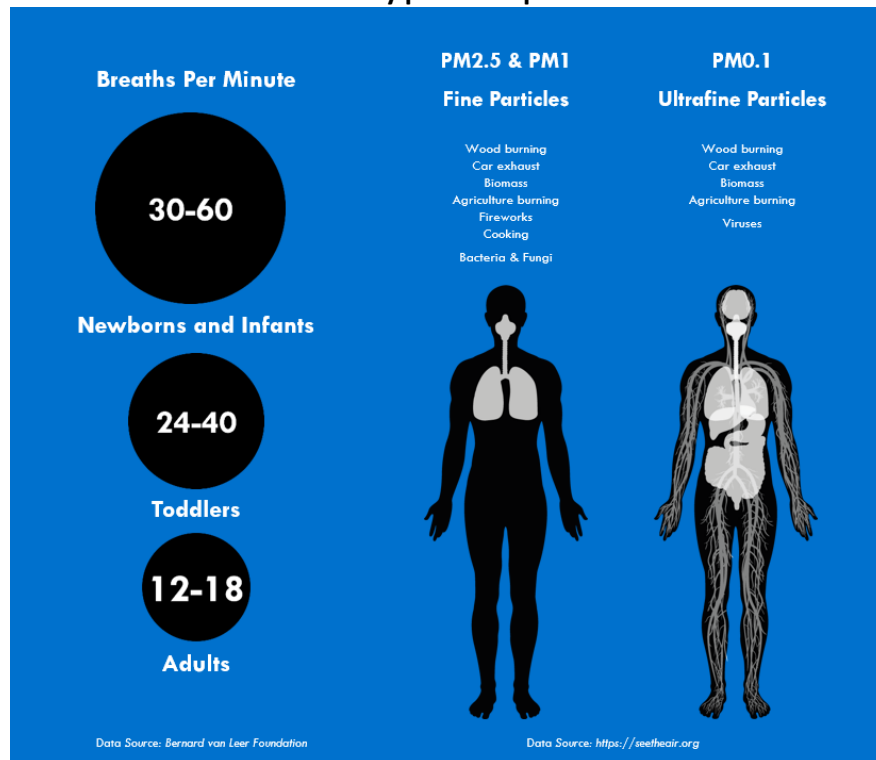
Source: web

4.4.3 Families with children

A crucial aspect for sustainable and inclusive urban development is the consideration of the needs of the most vulnerable groups, particularly families with children. As highlighted by recent studies, health is not primarily determined by genetics but 80% by socio-economic and environmental factors [26]; consequently, the place of residence has a profound and lasting impact on well-being [24]. Air pollution is responsible for over one-third of all cases of childhood asthma in Europe [27]. Globally, 93% of children breathe polluted air [28]. Children attending schools in areas with high traffic noise levels show slower cognitive development [29]. Furthermore, over 4% of summer mortality is attributable to urban heat islands [30]. Unsafe conditions limit opportunities to play and develop autonomy. One in three children aged 7-9 is overweight or obese, a prevalence that increases with age [31].

Unfortunately, contemporary urban planning, which has often favoured automotive infrastructure, has generated environments that compromise children's health. Increased traffic, for example, not only limits children's autonomy, pushing parents to accompany them by car instead of walking, but, as seen, also exposes them to significant health risks. Air and noise pollution are associated with respiratory diseases such as childhood asthma and can slow cognitive development, as children breathe more frequently than adults (Figure 4.7).

Figure 4.7 - Comparison of breaths per minute by age group and body areas affected by pollutant particles.

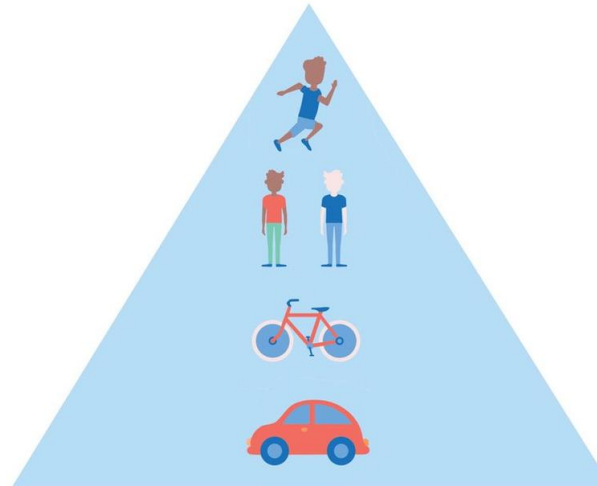


Source: Thomson, 2025 [32]

Simultaneously, the lack of green spaces and the density of gray infrastructure intensify the "heat island" effect, contributing to summer mortality, while the scarcity of safe places for play and movement promotes overweight and obesity. To address these issues, a structural change in the alternative mobility pyramid is necessary, proposing a hierarchy that prioritizes children, considering them the first priority in urban planning (Figure 4.8).

This model reverses the traditional order, which often places cars at the top. Instead, it places children, followed by pedestrians and cyclists, at the apex of the pyramid, while cars are at the base, emphasizing their secondary role in a people-centred city. Cities must be designed not only to ensure survival but to allow children to thrive.

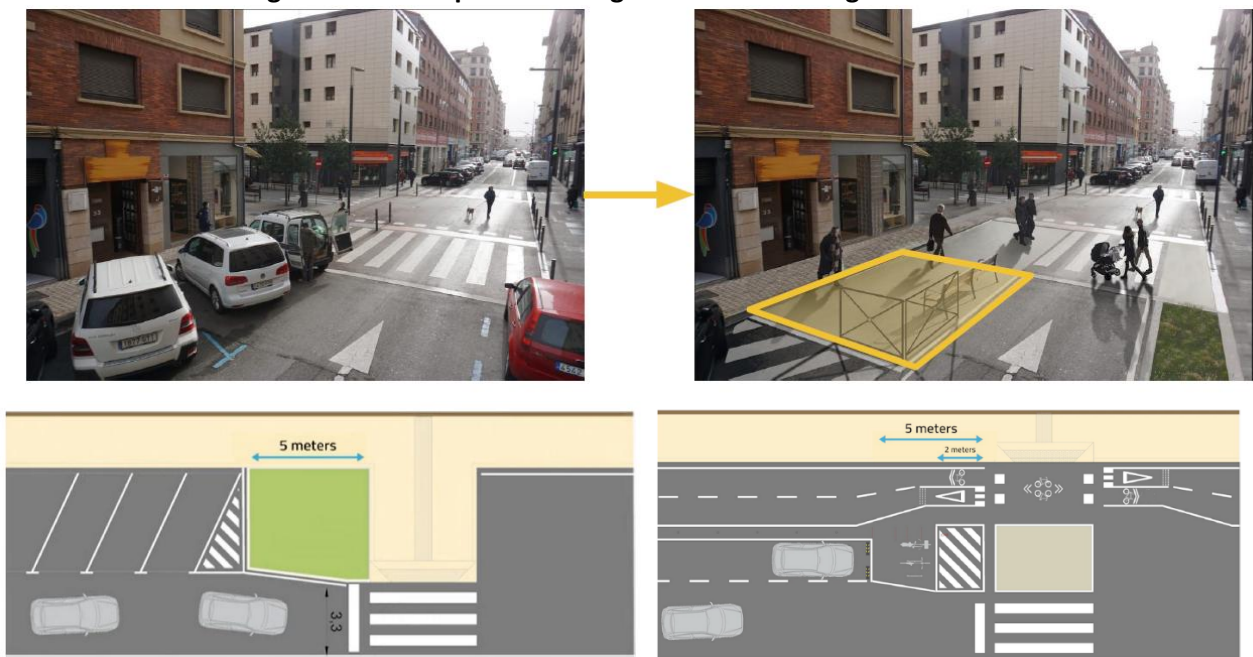
Figure 4.8 - Alternative approach to the mobility pyramid.



Source: Dinah Bornat, ZCD Architects

For example, the redesign of a crossing in Barcelona aimed to create a safety area free of parking in front of the crossing to preserve pedestrian visibility, particularly for short-stature pedestrians such as children (Figure 4.9).

Figure 4.9 - Example of Redesign of a Safe Crossing in Barcelona.



Source: Sáenz de Tejada [24]

Effective strategies include Universal Design, considering the needs of every life stage, from infants to adolescents and pregnant women. Moreover, it is essential to "activate" public spaces and streets, transforming them into dynamic and safe environments, as demonstrated by successful initiatives such as Copenhagen's "staffed playgrounds" (Figure 4.10) or Ghent's "Living Streets" (Figure 4.11). The Copenhagen project involves the creation of public playgrounds, often free, managed by qualified staff, including educators, animators, or volunteers, with the aim of providing a safe, educational and stimulating environment for children, where they can play and

interact under adult supervision. Ghent’s “Living Streets” represent a unique urban initiative that temporarily transforms residential streets into human-scale public spaces. This is not a permanent solution but an experimental and participatory project aimed at giving back the street to residents, encouraging social interaction and creative use of public space. The concept is based on a bottom-up approach: residents of a street apply for the project and once approved, are tasked with co-designing and managing the transformation of their street for a limited period, usually one or two months during the summer.

Figure 4.10 - “Staffed playgrounds” in Copenhagen (Denmark).



Source: Sáenz de Tejada [24]

Figure 4.11 - Living Street in Ghent (Belgium).



Source: Ghent Stadt [33]

Other interesting initiatives include the adoption of Asphalt Art practices, which have reduced the accident rate involving pedestrians or other vulnerable users by 50% (e.g., Figure 4.12) [34]. Asphalt Art is a form of tactical urbanism that uses art and design to regenerate public spaces and improve road safety. The initiative, promoted internationally by organizations such as Bloomberg Philanthropies, is based on the idea that transforming road surfaces can have a positive aesthetic and functional impact on urban life. Asphalt Art interventions can be implemented on various surfaces, including: roads and intersections (application of geometric patterns, bright colours and creative designs on streets can induce vehicles to slow down, reducing accidents); pedestrian crossings (crosswalks are transformed into actual works of art, increasing pedestrian visibility and making crossings safer and more enjoyable); squares and public spaces: asphalt art can contribute to creating more welcoming and liveable squares, encouraging people to linger, socialize and reclaim the space.

Simultaneously, active community involvement, through projects promoting road safety and accessibility, is essential to create a sense of belonging and collective responsibility. Finally, strict monitoring and continuous evaluation of initiatives are indispensable to measure the impact of urban policies and adapt strategies based on the results obtained.

Figure 4.12 - “Inclusion crossroad” in Kessariani, Greater Athens (Greece).



Source: Asphalt Art [35]

A concrete example of how this vision translates into a real project is the redevelopment of Great Ormond Street in London [32], an initiative developed in collaboration with the eponymous paediatric hospital and the architecture firm LDA Design (Figure 4.13). Before the intervention, the street was dominated by vehicular traffic, with air pollution levels exceeding World Health Organization guidelines and high noise pollution, representing a serious threat to the health of young patients. The project aimed to transform this street into a "healthy hospital street," rebalancing space in favour of people. The approach involved reclaiming street areas to create green, welcoming and playful public spaces. These urban "gardens" were designed to be places for convalescence, socialization and escape, offering a rich sensory experience and benefiting the physical and mental health of patients, families and residents. The initiative not only aims to improve air quality and reduce noise but also serves as an exemplary model to demonstrate how healthcare can integrate with the surrounding community, transforming degraded infrastructure into a valuable resource for everyone's well-being.

Figure 4.13 - Great Ormond Street. Current Situation, Project Rendering.



Source: Great Ormond Street [32]

4.4.4 Socio-economic determinants of pedestrian mobility

Income and socio-economic status have a direct impact on pedestrian mobility demand. Often, low-income population groups rely more on pedestrian paths for their daily movements, such as access to work, school, or essential services. However, pedestrian infrastructures in these areas are often of lower quality or unsafe [36]. Inclusive planning must aim to rebalance the distribution of resources, investing in safe and well-maintained pedestrian paths even in peripheral neighbourhoods, ensuring equal mobility opportunities for all citizens. An equitable pedestrian transport system must be not only physically accessible but also economically accessible and socially safe. In conclusion, a demand analysis that considers the diverse needs of user groups and their specificities is essential to design pedestrian transport systems that are not only efficient but also equitable, inclusive and sustainable for the entire community.

4.5 In-depth analysis of risk perception and gender differences in walking itineraries

Within the scope of the present research, an exploratory survey was conducted to analyse gender differences in access to and use of walking itineraries. The objective was to explore the different experiences of men and women and to identify factors that can facilitate or hinder female participation. Furthermore, the survey aimed to identify concrete strategies and measures to improve gender equity, making the itineraries more inclusive and accessible to all. The survey, conducted online between June and September 2024 in collaboration with Boku University of Vienna and the University of Constantine in Algeria and with the Italian National Network of Women on the Move, involved participants of all ages in Algeria, Austria and Italy. The questionnaire, consisting of 35 multiple-choice questions (Figure 4.14), was developed based on existing literature and reviewed by a group of 15 experts. The survey collected socio-demographic information and focused on experienced walkers. In particular, risk factors and safety perception were examined, analysing 21 key risks (Table 4.1) and measuring fear, risk probability and severity of impact on a Likert scale. The most risky situations encountered and external concerns were also investigated. The research further explored participants' personal experiences and motivations, such as the number of completed itineraries, the presence of children during hikes, individual motivations and factors considered important. Finally, the segment of walkers who modified their plans or abandoned a hike was examined to understand the main reasons, especially those related to fear of perceived risks.

Figure 4.14 - Survey Structure.

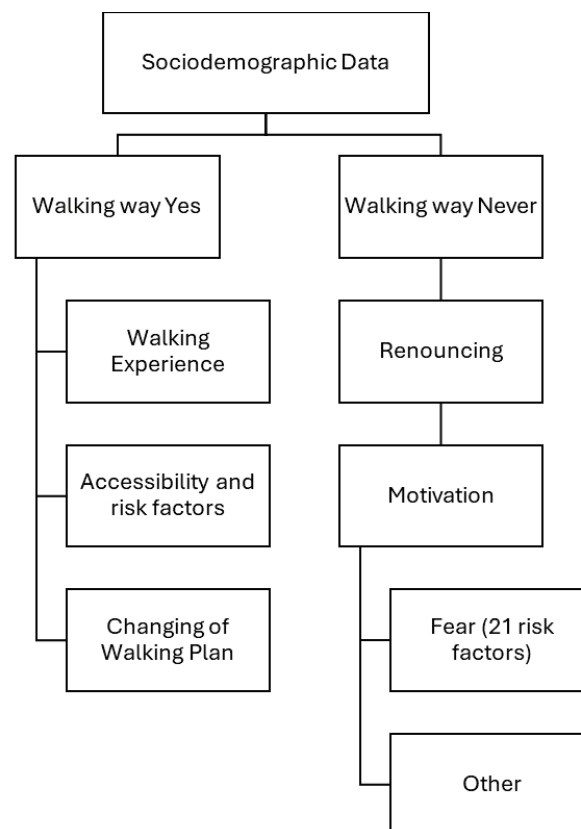


Table 4.1 - Risk factors.

1. Physical obstacles	2. Illness, injury or similar
3. Difficulty of the route	4. Lack of accommodation
5. Length	6. Lack of food or shopping points
7. Isolation	8. Lack of water sources
9. No cell phone connection	10. Fires
11. Lack of signage	12. Bedbug/insect/snake/tick bites
13. Getting lost	14. Natural disasters
15. Insufficient illumination	16. Sudden weather events
17. Criminals, attacks, sexual violence	18. Hunters
19. Aggressive animals	20. Being run over
21. Being robbed	

The survey involved 400 participants from Italy, Austria and Algeria, showing a predominance of women (66.5%) (Table 4.2). 59.3% of respondents had prior experience with walking itineraries, with evident differences in participation among the countries, partly related to the differing development of hiking tourism. Most participants have a high level of education and an average income between 1,000 and 2,000 euros per month.

Table 4.2 - Participants in the survey divided by walking experience, by country of residence and gender.

		Walking experience								TOTAL
		No				Yes				
		Man		Woman		Man		Woman		
		n.	%	n.	%	n.	%	n.	%	
Country	Algeria	8	40.0%	12	60.0%	2	66.7%	1	33.3%	23
	Austria	11	36.7%	19	63.3%	5	38.5%	8	61.5%	43
	Italy	25	22.5%	86	77.5%	81	38.2%	131	61.8%	323
	Other	1	50.0%	1	50.0%	1	11.1%	8	88.9%	11
TOTAL		45	27.61%	118	72.39%	89	37.55%	148	62.45%	400

Note: The percentages should be read row by row

Motivations and preferences for itineraries differ according to gender. Women tend to prioritize psychophysical well-being and contact with nature, whereas men prefer spiritual and social motivations. In logistical choices, women show a preference for shorter itineraries (101-300 km), unlike men who choose longer and more challenging routes. Most participants prefer walking in company, but a significant percentage of men opt for autonomy, while women show a greater preference for professional guides, perceived as a safety factor.

From a safety perspective, women attribute greater importance to factors that reduce uncertainty, such as the availability of online information and the difficulty of the itinerary. Moreover, 8.8% of women reported encountering social resistance in their walking projects, compared to 5.6% of men. Nevertheless, both genders enjoy broad social support in their choice to undertake a walking itinerary.

The analysis of gender differences in perceived fear regarding itineraries reveals significant disparities between men and women (Table 4.3). In general, men report feeling less fear than women for various factors. Respondents who had already completed a route were asked to assess the frequency of fear experienced for each of the 21 risk factors during their walk ("How often did you feel fear during the walk?", using a six-point Likert scale from 0: Never to 5: Always). Although the most frequently reported fears are largely similar between sexes (such as lack of signage, absence of drinking water sources, potential presence of aggressive animals), other factors seem to worry women more than men. The most significant differences concern trail difficulty (both

distance and elevation) and the potential presence of hunters. However, the largest discrepancy emerged regarding fear of crime, including criminal assaults and sexual harassment. This was considerably higher among women (average score of 1.56) compared to men (1.03), reflecting a marked gender difference in perceived vulnerability to such risks. Overall, these differences highlight that, compared to men, women show greater awareness of various risks associated with walking itineraries, including threats to personal safety, security and the environment (Table 4.3).

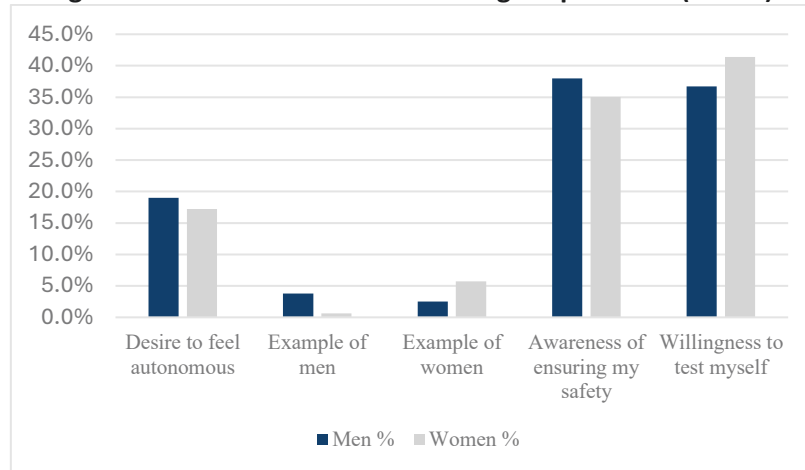
Table 4.3 - Main fears of those who have walked a trail per gender (Average value “How often did you feel fear during the walk?”; 6-point Likert scale from 0 - Never to 5 - Always).

Fear of:	Men	Women
Safety		
Lack of signage	2.14	2.19
Lack of water sources	2.08	2.08
Illness, injury or similar	1.80	1.75
Bedbug/insect/snake/tick bites	1.73	1.63
Sudden weather events	1.56	1.56
No cell phone connection	1.49	1.60
Getting lost	1.49	1.63
Lack of accommodations	1.49	1.42
Isolation	1.38	1.52
Lack of food or shopping points	1.22	1.28
Fires	1.22	0.90
Difficulty of the route	1.19	1.57
Insufficient illumination	1.18	1.44
Natural disasters	1.15	1.18
Physical obstacle	1.03	1.27
Length	0.97	1.42
Security		
Aggressive animals	2.06	2.08
Hunters	1.04	1.47
Criminals, attacks, sexual violence	1.03	1.56
Being robbed	0.80	0.99
Being run over	0.80	0.90

The main reasons for deciding to walk despite fears reveal that both men and women value the awareness of having managed actions aimed at preserving their safety together with the desire to challenge themselves, with women being more motivated to take on challenges than men (Figure 4.15). Women are more inspired by other women who have completed the itinerary, while men are more inspired by other men. A stronger desire for independence is observed in men compared to women. Consistent with international standards (ISO 31000), 21 risk factors were assessed for both perceived impact and probability, analysing both safety aspects (protection from accidents and accidental physical harm) and security aspects (protection from intentional threats, such as crime).

The analysis of risk perception and experience on walking itineraries shows significant gender differences. Women tend to perceive higher levels of fear compared to men, particularly for risks related to personal safety such as assaults and sexual harassment, but also for environmental factors such as trail difficulty and the presence of hunters.

Figure 4.15 - Main reasons for walking despite fears (n=236).



This increased sensitivity is also reflected in the evaluation of risk impact (Table 4.4): women attribute greater severity, especially to the potential presence of aggressors, while recognizing that the probability of such events is low (Table 4.5). This discrepancy between perceived impact and probability suggests that women maintain alert behaviors typical of urban contexts even in natural environments.

Table 4.4 - Impact of risk factors by gender (mean and median values, 6-point Likert scale from 0= no impact to 5=extreme impact; n=237).

	Men		Women	
	Mean	Median	Mean	Median
Safety				
Physical obstacle	1.52	1.00	1.60	1.00
Difficulty of the route	1.70	1.00	1.72	1.00
Length	1.62	1.00	1.60	1.00
Isolation	1.75	2.00	1.69	1.00
No cell phone connection	1.82	2.00	2.08	2.00
Lack of signage	2.38	2.00	2.67	3.00
Lack of orientation factors	2.44	2.00	2.66	3.00
Insufficient illumination	1.57	1.00	1.78	1.00
Sudden weather events	1.86	1.00	2.10	2.00
Illness, injury or similar	2.25	2.00	2.25	2.00
Lack of accommodation	2.01	2.00	2.00	2.00
Lack of food or shopping points	1.70	1.00	1.89	2.00
Lack of water sources or purchase points	2.48	2.00	2.58	2.00
Fire	1.57	1.00	1.63	1.00
Insect (bedbugs, ticks)/snake bites	2.04	2.00	1.81	1.00
Natural disasters	1.63	1.00	1.84	1.00
Security				
Aggressive animals	2.33	2.00	2.32	2.00
Potential assailants	1.52	1.00	1.96	2.00
Thefts	1.27	1.00	1.43	1.00
Hunters	1.62	1.00	1.87	1.50
Dangerous road sections	1.75	1.00	1.80	1.00

Table 4.5 - Likelihood of risk factors by gender (mean and median value on a 5-point-scale from 0 - Never to 4 - Two or more times for each walk; n. 237).

Risk factors:	Men		Women	
	Mean	Median	Mean	Median
Safety				
Physical obstacle	0.58	0.25	0.48	0.25
Difficulty of the trail	0.66	0.50	0.57	0.25
Excessive path length	0.49	0.25	0.40	0.25
Isolated or little frequented route	0.62	0.25	0.51	0.25
No cell phone connection	0.66	0.50	0.56	0.25
Absence of signage	0.53	0.25	0.50	0.25
Absence of orientation factors	0.30	0.25	0.30	0.25
Poor lighting	0.17	0.00	0.25	0.00
Thefts	0.03	0.00	0.08	0.00
Illness, injury or similar	0.24	0.25	0.23	0.25
Lack of accommodation	0.19	0.00	0.19	0.00
Lack of food or shopping points	0.25	0.25	0.23	0.00
Lack of water sources or purchase points	0.31	0.25	0.32	0.25
Fire	0.05	0.00	0.07	0.00
Insect (bedbugs, ticks)/snake bites	0.18	0.00	0.22	0.00
Natural disasters	0.08	0.00	0.16	0.00
Security				
Aggressive animals	0.39	0.25	0.34	0.25
Presence of potential assailants	0.08	0.00	0.11	0.00
Sudden weather events	0.21	0.25	0.29	0.25
Presence of hunters	0.17	0.00	0.24	0.13
Dangerous stretches of road	0.34	0.25	0.35	0.25

This can trigger increased alert behaviors, particularly in response to gender-based safety concerns. For each risk factor (among the 21 identified), the estimated risk (15) was calculated as the product of average impact (S_i) and average probability (P_i):

$$R_i = S_i * P_i \quad (15)$$

The estimated risk provides a measure of the importance of each risk, combining the impact of the problem with its probability. To better represent group differences in risk assessment, a new formula for calculating perceived risk (16) is also proposed, which includes the “fear” factor (F_i), i.e., the average level of fear associated with each risk and obtained from the previously mentioned Likert scales (Table 4.3). The formula is:

$$Rp_i = F_i * S_i * P_i \quad (16)$$

with F_i representing the average level of fear associated with risk factor i , understood as the emotional intensity attributed by survey participants.

Perceived risk adds a subjective dimension to risk calculation, incorporating the emotional response (fear) which can amplify or reduce the importance of the estimated risk. This is particularly useful for designing targeted interventions and communications that take gender-specific fears into account.

Both formulas were applied to the mean values by gender to identify gender differences in risk perception and evaluation (Table 4.6).

Table 4.6 - Estimated and perceived risks.

	Men					Women				
	Fear	Impact	Lik.	Estim.	Perceived	Fear	Impact	Lik.	Estim.	Perceived
Physical obstacles	1.03	1.52	0.58	0.88	0.90	1.27	1.60	0.48	0.78	0.99
Difficulty of the route	1.19	1.70	0.66	1.11	1.32	1.57	1.72	0.57	0.98	1.53
Length	0.97	1.62	0.49	0.79	0.77	1.42	1.60	0.40	0.64	0.91
Isolation	1.38	1.75	0.62	1.08	1.49	1.52	1.69	0.51	0.86	1.31
No cell phone connection	1.49	1.82	0.66	1.20	1.79	1.60	2.08	0.66	1.37	2.19
Lack of signage	2.14	2.38	0.53	1.26	2.69	2.19	2.67	0.50	1.32	2.90
Lack of orientation factors	1.49	2.44	0.30	0.73	1.10	1.63	2.66	0.30	0.79	1.29
Insufficient illumination	1.18	1.57	0.17	0.26	0.31	1.44	1.78	0.25	0.45	0.65
Potential assailants people	1.03	1.52	0.08	0.12	0.12	1.56	1.96	0.11	0.21	0.33
Presence of animals	2.06	2.33	0.39	0.91	1.89	2.08	2.32	0.34	0.79	1.65
Thefts	0.80	1.27	0.03	0.04	0.04	0.99	1.43	0.08	0.12	0.11
Illness, injury or similar	1.80	2.25	0.24	0.54	0.97	1.75	2.25	0.23	0.52	0.91
Lack of accommodation	1.49	2.01	0.19	0.39	0.58	1.42	2.00	0.19	0.38	0.53
Lack of food/shopping	1.22	1.70	0.25	0.43	0.52	1.28	1.89	0.23	0.44	0.56
Lack of water sources	2.08	2.48	0.31	0.77	1.60	2.08	2.58	0.32	0.83	1.73
Fire	1.22	1.57	0.05	0.08	0.10	0.90	1.63	0.07	0.12	0.11
Insect/snake bites	1.73	2.04	0.18	0.37	0.64	1.63	1.81	0.22	0.40	0.66
Natural disasters	1.15	1.63	0.08	0.13	0.15	1.18	1.84	0.16	0.29	0.34
Sudden weather events	1.56	1.86	0.21	0.39	0.61	1.56	2.10	0.29	0.62	0.96
Presence of hunters	1.04	1.62	0.17	0.28	0.29	1.47	1.87	0.24	0.44	0.65
Dangerous stretches of	0.80	1.75	0.34	0.59	0.47	0.90	1.80	0.35	0.63	0.56

The survey shows that women are more likely to modify their plans for safety reasons. Women have a slightly higher probability of deciding to travel in groups (8.1% of women versus 5.6% of men). This suggests that women may feel safer or more comfortable traveling with others. Similarly, 8.7% of women decided to undertake the itinerary at a different time, such as a different season or time of day, compared to 6.7% of men. This decision may reflect greater attention among women to external factors such as weather or time of day during planning. Women are also more likely to organize differently for the same itinerary (4.7% versus 3.4% of men). This category may adopt additional precautions, such as carrying self-defence tools, indicating that women may perceive or face greater risks, prompting them to take extra safety measures. Conversely, men have a slightly higher probability than women of choosing a completely different itinerary, with 10.1% of men reporting having changed an itinerary, compared to 7.4% of women.

Overall, while both men and women tend mainly to maintain their initial plans, women appear more likely to make modifications that enhance their safety, such as traveling in groups, changing the timing of their walk, or taking additional precautions.

The survey on accessibility and trail safety highlights significant gender differences regarding the reasons for cancelling walking plans before departure. Overall, 25.8% of all respondents (n=400) reported abandoning the idea of walking a trail, with a higher prevalence among women (29%) compared to men (17.9%). The reasons cited show a different distribution of abandonment factors between the two sexes.

Women report a broader range of motivations, with particular emphasis on issues related to solitude and fear, both more evident compared to men. Physical or health problems also affect women more than men. A distinctive aspect is family and cultural obligations: women more frequently mention the inability to leave children or relatives and the inaccessibility of the trail for the family. Furthermore, cultural or physical factors, such as the inability to carry a backpack or lack of cultural support for long-distance walks, are reasons specifically mentioned by women.

Men, on the other hand, are more likely to abandon due to logistical reasons, such as the absence of comfort during overnight stays or inability to leave someone under care. Other reasons reported by men reach 24%, suggesting motivations that are less easily classifiable or less explicitly declared.

Among those citing fear as the main reason for abandonment, specific differences emerge. Men are more concerned with trail length, the presence of dangerous animals, route isolation and lack of connectivity. Women, instead, express a wider variety of fears, including the risk of crime or violence, danger of being hit by vehicles and the presence of natural obstacles or hunters, fears not mentioned by men.

Data on experienced risk in different walking itineraries provide a nuanced perspective on actual safety incidents encountered along various trails, distinguishing them from perceived risk. As shown in Table 4.7, women reported feeling at risk more frequently than men when undertaking long walking itineraries (over 50 km with at least three stages).

Table 4.7 - Perceived risk while walking: comparison between long and short itineraries.

		Feeling at risk on a trail (>50 km, at least 3 stages)				Feeling at risk on a different walking itinerary (≤50 km; < 3 stages)			
		No		Yes		No		Yes	
		n.	%	n.	%	n.	%	n.	%
Gender	Man	63	79.7	16	20.3	55	69.6	24	30.4
	Woman	115	72.8	43	27.2	108	68.8	49	31.2

However, most respondents in both groups do not perceive these itineraries as dangerous, most likely due to careful planning and safety measures. For shorter itineraries (≤50 km, fewer than three stages), the gender difference in risk is less pronounced, with men and women reporting similar levels of concern. These data show a similar overall trend, but with a higher proportion of individuals perceiving risk on shorter walks compared to longer ones. This could suggest that shorter trails, despite their lower complexity, present specific challenges or hazards that some individuals perceive as riskier, or that they are more influenced by fears and safety concerns that both men and women experience during urban mobility in cities. However, risk perception has not always translated into actual hazards, as demonstrated by the frequency of risky situations occurring. Nonetheless, according to the data, there is undeniably a different level of exposure for women. The data indicate that 22% of women reported having experienced at least one of the listed risks, compared to 14% of men. These risks include harassment, witnessing threats or violence against other women, theft, the need to contact the police, call an ambulance and request mountain rescue or fire brigade interventions. In general, women have experienced more risks, particularly harassment and theft, while men have requested mountain rescue or similar interventions.

The analysis of preferences and habits related to preparation and safety on the trails reveals significant differences between men and women (Table 4.8).

Both groups place great importance on essential safety tools and measures, but their choices and behaviours reflect distinct approaches to risk management and planning. Men and women agree on the importance of appropriate clothing and footwear and a water supply, considered essential for tackling the itineraries. However, technological preferences show a division: men tend to use GPS on smartphones or navigation apps more frequently than women. Regarding specific equipment, such as trekking poles, ropes and carabiners, women report a slight predominance in use, likely due to different needs or priorities. Both genders show similar interest in preliminary study of the itinerary, indicating a point of convergence in the planning phase. A notable aspect is the use of first aid kits, which is more common among men, indicating a higher level of

preparedness. On the other hand, the practice of informing family or friends before departure is similar between sexes. Conversely, significant disparities were observed in the use of paper maps, preferred by men and insect repellent sprays, used more frequently by women. Furthermore, safety measures show additional distinctions: men are more likely to carry auditory devices, such as whistles, while women tend to use thermal blankets more frequently. Availability of emergency contact numbers is slightly more common among women. Adoption of measures such as institutional rescue apps, insurance and seeking travel companions shows less pronounced gender differences. Conversely, satellite devices and advanced training courses, such as first aid, orientation, or survival training, are used more frequently by men, suggesting a higher level of interest in specialized skills and advanced equipment.

**Table 4.8 - Protective measures used by gender
(percentage value; possible multiple answers; n. 237).**

	Safety	Security	Women	Men	Global
Appropriate clothing/shoes	x		91.22	88.76	90.30
Water supply	x		89.19	92.13	90.30
Food supply	x		68.92	69.66	69.20
GPX files on a smartphone or an app	x		60.81	68.54	63.71
Specific equipment for hiking (pole, ropes, hooks,	x		64.19	61.80	63.29
Itinerary guide	x		58.78	58.43	58.65
Review the itinerary before departure	x		52.03	69.66	58.65
First aid KIT	x		54.73	60.67	56.96
Notify family or friends of departure and stay in	x	x	54.73	56.18	55.27
Paper map	x		45.95	52.81	48.52
Insect repellent sprays and products	x		46.62	41.57	44.73
Whistle or other sound devices	x		37.16	49.44	41.77
Thermal sheet	x		25.68	30.34	27.43
Carry emergency contact numbers	x	x	26.35	24.72	25.74
Searching for travel companions	x	x	22.30	24.72	23.21
Institutional rescue app on a smartphone	x		22.30	22.47	22.36
Insurance	x	x	8.11	8.99	8.44
Satellite device	x		4.05	11.24	6.75
Pepper spray		x	4.73	3.37	4.22
Weapon (Swiss Army Knife or other)		x	3.38	3.37	3.38
First aid course	x		1.35	4.49	2.53
Orientation course	x		1.35	4.49	2.53
Survival course	x		0.00	3.37	1.27

Another interesting aspect of the survey concerns trail interventions that could improve safety, a key issue in transport engineering, especially regarding the design and management of walking itineraries (Table 4.9). Responses highlight differences between men and women regarding measures that could contribute to improved safety and protection, suggesting possible interventions by institutional bodies or management associations. Although both men and women agree on the priority of improving signage, maintenance and placement of water sources, women express greater concern than men for safety from hunting activities, with 53.1% considering hunting bans essential to protect walkers. Men, on the other hand, place greater emphasis on the importance of accommodation points along the trail (52.3%), which could influence perceived safety in case of emergencies or the need for rest. Another important safety measure for both sexes is the introduction of alert systems for sudden weather events, with a greater preference among women (40%) compared to men (28.4%). Furthermore, improving visibility and tracking walkers through monitoring technologies (30.3% of women and 21.6% of men) is seen as crucial to

ensuring safety along the trails. In general, the design and management of trails from a transport engineering perspective should consider these interventions to enhance safety, with particular attention to signage, maintenance, availability of drinking water sources, adoption of monitoring technologies and the introduction of regulations to protect walkers from potential hazards. The approach should be inclusive, addressing the specific needs of different groups of walkers to make the itinerary safer and accessible to all.

**Table 4.9 - Improvement actions able to increase the perception of safety
(percentage values; possible multiple answers; n. 233).**

Improvements	Safety	Security	Man	Women	Global
Better signage	x		68.18	62.76	64.81
Better itinerary maintenance	x		65.91	61.38	63.09
Better positioning of drinking water sources	x		55.68	57.24	56.65
Hunting ban on trails and in neighbouring areas		x	38.64	53.10	47.64
Greater presence of accommodation points	x		52.27	33.10	40.34
Monitoring of the presence of animals on the route and appropriate		x	28.41	42.07	36.91
Greater ways safety (routes for walkers only, areas 30 in urban		x	27.27	42.07	36.48
Presence of walker warning systems in case of sudden	x		28.41	40.00	35.62
Better telephone reception	x	x	26.14	31.72	29.61
Presence of walker tracking systems	x	x	21.59	30.34	27.04
Supervision of hygiene in accommodations/Improve the	x		18.18	23.45	21.46
Presence of distributors in areas with a lack of sales points	x		21.59	14.48	17.17
First aid kits or emergency telephone points/Presence of healthcare	x		11.36	14.48	13.30
Safety deposit boxes for personal or valuable items in hostels/hotels		x	10.23	13.10	12.02
Increased presence of law enforcement or video surveillance	x	x	6.82	11.03	9.44
Improvement of the hydrogeological characteristics of the itineraries	x		7.95	10.34	9.44
Creation of simpler itineraries	x		9.09	8.28	8.58
Better lighting	x	x	6.82	9.66	8.58
Better fire prevention	x		9.09	6.90	7.73
Shorter itineraries	x		7.95	6.90	7.30
Itineraries in more frequented areas	x	x	9.09	5.52	6.87

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Chapter 5

Interactions between supply and pedestrian mobility demand

5.1 Introduction

Most existing models of interaction between pedestrian tourist mobility demand and transport supply focus on urban contexts or short-range tourist flows, where travel behaviour and infrastructure performance can be monitored within compact spatial and temporal dimensions. Long-distance trails/walks involve extended, multi-day itineraries, with high variability in user profiles, motivations and seasonal demand peaks. The sustainable design and management of these routes require a deeper understanding of the interactions between pedestrian demand and infrastructure supply.

The following sections analyse the specific characteristics of pedestrian mobility on trails, the most suitable methodological and simulation approaches to represent walker flows and propose an integrated model capable of supporting the planning and sustainable management of trails throughout their entire life cycle.

5.2 Specific characteristics of pedestrian mobility on trails

On long-distance trails, the volume and type of users directly affect the natural environments in which the trail infrastructures are inserted, the availability of services and the perceived quality of the experience, factors that, in turn, influence future demand patterns. These feedback loops and delayed effects challenge static planning approaches and require dynamic modelling techniques. In this regard, System Dynamics (SD) provides a valuable framework to simulate how trail conditions, management policies and user flows co-evolve over time.

A central element in managing such complexity is the concept of tourist carrying capacity, which, according to the World Tourism Organization, is “the maximum number of people who can visit a tourist destination simultaneously without causing the destruction of the physical, economic, socio-cultural environment and an unacceptable decrease in visitor satisfaction quality”. The destination’s carrying capacity is intrinsically linked to the capacity of pedestrian infrastructure, such as trail width, surface quality, signage and support facilities. When pedestrian infrastructure is insufficient or overloaded, it becomes a critical bottleneck that can accelerate degradation, reduce safety and decrease visitor satisfaction. Conversely, well-designed infrastructure can distribute user flows more evenly, helping mitigate environmental impacts and extend the destination’s carrying capacity. When demand approaches or exceeds these capacity thresholds, the system enters a state of saturation, triggering negative impacts such as overcrowding, reduced user satisfaction and long-term resource deterioration. Integrating carrying capacity and infrastructure constraints into dynamic models is therefore essential to anticipate critical thresholds and inform adaptive planning strategies that balance access, conservation and quality.

Long-distance trails crossing heterogeneous territories over multiple days and involving non-ordinary motivations (spiritual, recreational, cultural) ask specific methodological challenges, requiring overcoming the static approaches typical of planning.

In this context, understanding the transport system and the interaction between demand and supply becomes central. As seen, a transport system is defined as the set of components and their interactions that determine the demand for movements between different points in a territory and

the supply of services to satisfy that demand [1]. Specifically, demand is given by the set of travellers and goods moving within a given area using the offered transport service, while transport supply represents the set of infrastructures and organizational elements that enable movements. As seen in the previous chapter, pedestrian mobility demand, whether urban, tourist, or related to long-distance trails, is a complex phenomenon influenced by a network of interconnected factors.

Indeed, for urban pedestrian mobility, demand is mainly driven by proximity and the presence of essential destinations such as schools, shops, parks and public transport stops, as well as neighbourhood characteristics. At the individual level, the intrinsic qualities of pedestrian routes, such as surface conditions, continuity, perceived safety and comfort, together with socio-economic factors such as age, gender and income, determine the propensity to walk. However, elements such as high-speed limits and heavy traffic volumes can act as deterrents, reducing perceived safety and comfort [2], [3]. Tourist demand, more generally, is shaped by a complex interaction of trip characteristics (purpose, group composition, luggage), traveller attributes (income, age, gender) [4] and external market factors such as service prices, income levels and promotional campaigns. This demand is known for its high elasticity, making it highly sensitive to price and quality variations. In the specific context of long-distance trails, walker motivations are more in-depth, including psychological, social and spiritual drives [5], as well as the pursuit of escape, personal fulfilment and challenge. Route choice is strongly influenced by the aesthetic quality of the landscape, trail difficulty, surface and presence of points of interest.

To measure and understand this complex demand, different methodologies are employed. Traditional methods include surveys conducted at entry/exit points or accommodation facilities, effective in capturing demographic data, origin/destination information, length of stay and activities undertaken. The advent of Big Data, derived from mobile devices (interactions with cell towers, GPS data), IoT sensors and video analysis, offers innovative approaches to track population movements and mobility patterns in real time, overcoming the limitations of traditional surveys. GPS trajectory data of walkers can estimate individual walking capacities and travel times, while automatic counters on trails provide continuous traffic counts in remote areas [6].

Finally, Geographic Information System (GIS) tools are useful for estimating population growth near trails, prioritizing projects and effectively managing existing systems [7]. The synergistic integration of these methods, both qualitative and quantitative, is crucial for a comprehensive understanding and proactive management of pedestrian mobility demand in all its contexts [8] and to improve the sustainability of urban tourism [9].

At the same time, as seen in Chapter 3, the mobility supply is articulated in different components depending on whether it concerns urban contexts, general tourist contexts, or specific long-distance trails, each with its peculiarities but with deeply interconnected elements. For urban pedestrian mobility, the supply is defined by a set of physical and environmental elements aimed at ensuring functionality and attractiveness. Infrastructures include unobstructed sidewalks or traffic-free areas. Safety features are crucial, such as well-marked and non-slippery pedestrian crossings, accessible ramps for people with disabilities and safety islands. Urban design elements such as sidewalk extensions (“bulb-outs”) reduce crossing distances and increase visibility, while adequate lighting, clear signage, benches and trash bins are vital for comfort and usability [10].

The supply of tourist mobility in a broader sense is a complex, multifactorial system, encompassing the full range of activities, goods and services available at a destination to meet visitors’ needs. Modes of transport (air, rail, road, maritime, pedestrian) are a fundamental pillar for tourist movement to and from destinations. Accommodation options, catering services, attractions (natural, cultural, or otherwise) and a range of support services are indispensable. A critical

component is the “built environment,” divided into basic infrastructure (water, electricity, communications, roads) and “superstructures” (hotels, restaurants, museums, entertainment venues). The “spirit of hospitality” and “cultural resources” also represent an intangible but vital part of the tourism supply, with both public and private sectors playing significant roles in their provision and coordination.

For long-distance hiking trails, the supply is intrinsically linked to the quality and completeness of specific trail infrastructures [11], which include the physical path [12], information and signage, staff assistance and dedicated information centers [13]. Trail design and construction involve path clearing, levelling and selection of appropriate materials, considering soil composition for durability and erosion. Beyond physical infrastructure, effective supply includes a network of well-integrated support and accommodation services, such as lodging (with increasing importance for sustainable options), integrated public transport (for access and mobility along the trail) [14], [15] and digital information (web, mobile apps for planning and safety). Management of these trails is based on principles of constant maintenance for safety and user experience [16], environmental sustainability (integration with natural topography, habitat protection) and universal accessibility (Universal Design principles to accommodate all abilities) [17].

It is evident that the interaction between demand and supply is dynamic: a high-quality, safe and accessible mobility supply tends to stimulate and positively shape demand, while lack of supply can limit or redirect it. On trails, demand is subject to strong seasonal and social fluctuations, while supply is defined by a complex set of infrastructures, services and natural resources. This dynamic relationship can generate saturation phenomena and compromise the sustainability of trails, understood as a form of tourism that fully considers its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities [18]. This highlights the need for tools capable of representing feedback loops between user flows, infrastructure quality and trail attractiveness. The concept of carrying capacity becomes crucial to assess sustainable use limits and guide management policies.

5.3 Different approaches to simulating walker flows

Simulation of pedestrian flows on walking itineraries is a fundamental tool for analysing the interaction between demand and supply, predicting future impacts and supporting planning and management decisions. The scientific literature and operational applications show a plurality of approaches, differing in level of detail, mathematical structure and software tools.

A first approach is **macroscopic**, representing walker flows in an aggregated form, assimilating pedestrian flow to a fluid. In this context, formulations derived from fluid dynamics are employed, such as the mass conservation equation. The mass conservation equation states that the mass of a closed system remains constant over time, regardless of the processes occurring within it. In the case of traffic mobility, it refers to the relationship whereby the number of vehicles entering a road segment must equal the number of vehicles exiting plus those remaining inside, causing congestion. These models allow estimating capacity and level of service along road segments, focusing on aggregated quantities such as density, speed and flow and identifying critical overcrowding thresholds. They do not consider individual behaviour but evaluate the system as a whole. The macroscopic approach is computationally efficient, ideal for large-scale analyses such as planning entire urban areas, evaluating the roads capacity and critical links in a network in relation to bottlenecks or saturation degree; however, it cannot capture interpersonal dynamics,

such as collision avoidance or queue formation, which are crucial for safety and comfort at the local level.

Software such as VISUM or traditional assignment models are sometimes adapted for this purpose. Such software uses demand-supply equilibrium equations, with generalized cost functions where travel time depends on flow, like the BPR (Bureau of Public Roads) function (1):

$$t = t_0 \left(1 + \alpha \frac{q}{Q}\right)^\beta \quad (1)$$

where:

- t is the actual travel time, i.e., the time a vehicle takes to traverse the road segment, taking congestion effects into account;
- t_0 is the free-flow travel time, i.e., the minimum time a vehicle would take to traverse the same segment in the absence of traffic (i.e., at the maximum allowed speed);
- q is the flow;
- Q is the capacity of the infrastructure, i.e., the maximum number of vehicles that the road segment can handle in one hour under ideal conditions;
- α and β are calibration parameters, i.e., constant values used to calibrate the model based on the type of road and traffic behavior.

The Flow/Capacity ratio is an indicator of congestion. If it is less than 1, it means that the flow is below the capacity of the route and traffic flows relatively smoothly; if it is close to 1, the flow approaches maximum capacity and congestion begins to appear; if it is greater than 1, the route is saturated and overcrowded: speed drops drastically and travel time increases significantly.

These concepts are described in the Highway Capacity Manual [19], which provides official guidelines for analyzing roadway capacity and Level of Service (LoS).

The second approach is the **microscopic** one, which describes pedestrians as individual entities and analyses their movements in space. The simulation is based on individual behavioural rules, such as optimal route choice, tendency to maintain a safe distance from other pedestrians and obstacles and response to external signals. This approach offers a high level of detail and accuracy, making it indispensable for the design of spaces with complex interactions. It is the ideal tool for evaluating safety at pedestrian crossings, managing flows in narrow corridors, or analysing queues and bottlenecks; however, it requires considerable computational power and is more sensitive to the calibration of behavioural parameters, which may vary according to cultural and environmental factors.

Among the most widely used models is the Social Force Model [20], in which the motion of each pedestrian is described by an equation of the type:

$$m_i \frac{dv_i}{dt} = f_i^{des} + \sum_{j \neq i} f_{ij}^{soc} + \sum_W f_{iW}^{obs} \quad (2)$$

where:

- m_i is the “mass” of pedestrian i , representing inertia and acceleration capability;
- v_i is the instantaneous velocity of pedestrian i ;
- f_i^{des} is the desired force, i.e., the pedestrian’s drive toward their goal (e.g., exit, destination) at a desired speed v_i^0 ;
- f_{ij}^{soc} represents the social interaction forces between pedestrian i and another pedestrian j , modelling the tendency to avoid collisions and maintain a comfortable distance;
- f_{iW}^{obs} represents repulsion forces from obstacles (walls, street furniture), analogous to social interactions but with fixed objects.

These models are applied in the management of flows in critical concentration areas such as squares, access points, or narrow trail segments. Among the most used software are PTV Viswalk, Legion and MassMotion. An evolution is represented by agent-based approaches (ABM), in which pedestrians are modelled as autonomous agents with individual characteristics (age, gender, experience, motivations) and decision-making capabilities. Each agent interacts with the environment and with other agents, generating emergent dynamics.

The **mesoscopic approach** in transport modelling occupies an intermediate position between the macroscopic and microscopic levels, combining elements of both to balance detail and computational scalability; it allows the representation of traffic and mobility flow dynamics with greater detail than macroscopic models, but without the complexity of microscopic models that simulate individual vehicles or pedestrians.

Conceptually, the mesoscopic approach describes groups of vehicles or pedestrians as aggregated units rather than individuals, but considers local dynamic variables such as density, speed and interactions between groups, allowing phenomena such as queues, local congestion, or real-time flow variations to be captured. Computationally, mesoscopic models are more efficient than microscopic ones, enabling simulations over larger areas and longer time horizons, while maintaining sufficient resolution to evaluate traffic or design interventions. Typical applications include urban and suburban flow simulation, planning pedestrian or cycling routes and analysing real-time demand and capacity scenarios.

SD-based approaches operate at a more aggregated and strategic level, modelling flows as stocks and flows connected by feedback relationships. Differential equations governing SD systems allow analysing the temporal evolution of demand and supply of services related to trails.

Finally, hybrid approaches are becoming widespread, combining different paradigms to capture the complexity of the phenomenon. An example is the combination of agent-based models with system dynamics to simultaneously analyse individual pedestrian behaviour and the aggregated effects on infrastructure capacity and local economy. In this context, AnyLogic represents the most versatile tool, thanks to the possibility of integrating micro-simulation, SD and GIS in a single environment.

Simulation approaches in transport can also be distinguished based on the calculation mode, i.e., whether the system is represented continuously or discretely. Macroscopic models use aggregated quantities such as density, speed and average flow, updated continuously over time or space, providing a global view of the system without distinguishing individuals or groups. Mesoscopic models combine features of macro and micro models, treating flows of groups of entities and updating the system state at significant events, such as congestion or speed changes, integrating both continuous and discrete calculations. Microscopic and agent-based models instead adopt a discrete approach, in which everyone or agent generates events that modify the system state, allowing local interactions and emergent dynamics to be captured with high granularity.

The choice of approach depends on the simulation objective: macroscopic models are more suitable for large-scale capacity assessments, microscopic ones for local safety and comfort analysis, agent-based models for representing pedestrian heterogeneity, SD for long-term scenarios, while hybrid approaches constitute the frontier for integrated and multidimensional studies of walking trails.

5.4 System Dynamics for trail analysis

System Dynamics (SD) is rooted in System Thinking, i.e., a systemic vision that interprets phenomena as sets of interconnected elements, characterized by feedback loops and nonlinear relationships. Introduced by Jay W. Forrester at MIT in the 1960s [21], SD represents its quantitative evolution, providing a formal language and mathematical tools to model and simulate the behaviour of complex systems over time. The approach, based on constructs such as state variables (stocks), flows and time delays, allows analysing the emergent dynamics generated by the interaction between demand and supply, overcoming the static view typical of traditional models. Applied to pedestrian mobility on long-distance trails, SD allows capturing cumulative and feedback effects arising from intensive infrastructure use, walker motivations and management policies. In this way, it provides a solid methodological basis for building predictive scenarios and evaluating trail sustainability. The following sections present this approach through the construction of a conceptual and computational model capable of representing the main variables, causal relationships and feedback loops governing trail evolution, with particular reference to interactions between demand, supply and socio-environmental impacts.

5.4.1 The proposed approach

This research aims to overcome the methodological limitations cited in Section 4.1 by adopting an SD approach. By analysing the behaviour of complex systems characterized by interdependencies, feedback loops and time delays, this approach is particularly suitable in contexts where demand and supply dynamics evolve through mutual adaptation, as occurs on long-distance hiking trails, where infrastructure conditions, available services and user flows influence each other.

The use of Causal Loop Diagrams (CLD) has already been widely and successfully applied in mobility and logistics sectors [22], particularly for modelling complex systems where short-term decisions generate long-term effects that are difficult to predict using traditional approaches [23]. In SD literature, CLDs are often used in the qualitative analysis phase to represent system behaviour before proceeding to mathematical or computational formalization. As a central tool in the SD approach, CLDs allow identifying feedback structures, reinforcing and balancing loops and help decision-makers understand how different variables interact over time within a dynamic system. In particular, a CLD allows mapping the main variables and causal relationships governing the evolution of long-distance trails, providing a conceptual framework useful for understanding demand-supply dynamics and representing the complex feedback loops between user flows, infrastructure quality and trail attractiveness. Therefore, it forms the basis for subsequent simulations and adaptive planning strategies.

SD is structured in several phases: problem definition, causal mapping, stock-and-flow model construction, calibration with empirical data and simulation of alternative scenarios. In this research phase, attention is focused on the development of a CLD to identify the key variables involved and the causal relationships governing their interaction.

The conceptual model of the long-distance pedestrian mobility system was developed through a CLD, using Vensim PLE (Version 10.1.3), which overcomes the limitations of static approaches by capturing the complex feedback mechanisms that govern trail evolution. The model is structured around a set of key variables, each measurable through specific indicators, which interact dynamically (Figure 5.1).

These variables include:

- trail attractiveness: a composite index reflecting how desirable the trail is [24];

Analysing the sustainability and evolution of a hiking trail through the SD approach, four feedback loops can be identified. These feedback loops, one positive reinforcement and three negative balancing, describe a complex system where variables such as attractiveness, number of walkers and management interact constantly. Understanding these mechanisms is crucial for proactive and sustainable management.

The first is the Virtuous Growth and Development Cycle (Positive Reinforcement Loop), where a high level of Trail Attractiveness attracts more walkers. This growing flow generates greater economic benefits and strong local support, which in turn translate into increased management efforts. This loop describes a feedback mechanism that amplifies growth. The main state variable, Trail Attractiveness, acts as an input for the Number of Walkers. An increase in this flow produces an increase in financial and social capital (Local Economic Benefits, Local Support) that can be reinvested in Management Efforts and infrastructure maintenance. This investment improves Service and Infrastructure Quality, directly reinforcing initial Attractiveness. This feedback loop creates a growth dynamic that drives the system toward a higher development state until a limiting factor intervenes.

The second is the Dissatisfaction and Decline Cycle (Negative Balancing Loop), in which the trail's success may trigger its own decline. This loop represents a negative feedback mechanism that stabilizes the system by limiting growth. An increase in the Number of Walkers inevitably leads to an increase in visitor density and, consequently, Congestion. This variable is directly related to a decrease in perceived experience quality and Walker Satisfaction. Reduced Satisfaction translates into a deterioration of Trail Reputation, acting as a negative input on Trail Attractiveness. Consequently, the Number of Walkers decreases, balancing demand pressure.

Another balancing mechanism is the Overload and Supply Deterioration Cycle (Negative Balancing Loop), an additional feedback loop acting on the system's physical capacity. A growing Number of Walkers accelerates infrastructure wear and Environmental Impact, degrading the trail's physical conditions and the natural context. This physical deterioration reduces intrinsic Infrastructure Quality, negatively influencing overall trail Attractiveness. Lower Attractiveness causes a reduction in the Number of Walkers, relieving infrastructure pressure and balancing the system.

Finally, the Community-Walker Tension Cycle (Negative Balancing Loop) is a negative feedback loop illustrating how overcrowding may undermine local community support, reducing management efforts and further compromising service quality and attractiveness, in a mechanism that alleviates pressure but highlights a loss of social consensus. An increase in the Number of Walkers beyond a social sustainability threshold generates tension and a perception of overload within local communities. This tension erodes social capital and Local Support, which are essential for trail Management Efforts and maintenance. Reduced support leads to lower Infrastructure Quality, which in turn reduces trail Attractiveness. This results in a decrease in the Number of Walkers, reducing social pressure but at the cost of long-term sustainability loss.

The delays integrated into the diagram are crucial for representing inertia and the temporality of relationships between variables and are fundamental for understanding the system's dynamic behaviour over time and anticipating responses to management measures. They indicate that the effects of a cause are not immediate but manifest only after a certain period. For example, an improvement in Infrastructure Quality may not instantly translate into higher Walker Satisfaction or Trail Attractiveness; similarly, the Environmental Impact of an increase in the Number of Walkers may not be immediately visible but only after some time.

For trail management and promotion managers, understanding these cycles is essential. Strategies cannot be limited to encouraging growth (Loop 1) but must balance this drive with actions aimed at mitigating the risks of balancing loops (2, 3 and 4).

The diagram analysis can lead to several recommendations for policymakers and management entities:

- monitor sustainability thresholds: it is vital to identify “breaking points” beyond which walker flow generates negative effects. Management entities should implement monitoring systems to detect signs of overcrowding, dissatisfaction and trail wear, acting before balancing loops trigger irreversible decline;
- differentiate the supply: to avoid congestion, alternative or thematic routes can be created to distribute visitor flow. Promoting less-known trail segments or off-season periods can relieve pressure on more frequented areas;
- invest in proactive management: the economic and social benefits generated by the trail should be strategically reinvested. Rather than merely reacting to problems, funds should be allocated for preventive maintenance, signage improvement and training of professional figures (e.g., guides, maintenance staff) who can preserve the quality of the experience and infrastructure;
- actively involve local communities: social consensus is a critical resource. Decision-makers must establish dialogue and participation mechanisms involving residents in trail planning and management. Benefits must be distributed fairly and local community concerns (e.g., impact on infrastructure, services) must be addressed transparently to prevent erosion of social support, which represents one of the greatest threats to long-term sustainability.

By understanding and actively managing the interaction of these four loops, decision-makers can transform trails from mere tourist attractions into sustainable and resilient systems capable of generating lasting value for visitors and local communities. The model integrates the three main impact dimensions generated by long-distance trail use (economic, social and environmental) to provide a systemic and multi-level representation of pedestrian mobility system evolution. In this way, decision-makers are provided with an interpretive framework that helps them understand the complex dynamics developing along long-distance trails, systematically evaluating how the three dimensions interact and influence overall system development.

The analysis provides a solid basis for understanding system dynamics but presents some limitations and could be integrated with other factors such as seasonal variability, walker differentiation, or unexpected external events (e.g., pandemics, natural disasters) that could significantly impact this highly elastic type of demand.

However, the potential of the research lies in its applicability to various contexts, from natural trails to historical routes, particularly suggesting a conceptual framework for identifying critical sustainability thresholds and developing more effective management strategies. The integration of quantitative data (walker flows, management costs, environmental impact indicators) and qualitative data (walker satisfaction, local community perception) will be useful to move from a descriptive analysis to a predictive tool capable of supporting long-term planning and management decisions.

5.4.2 An application

The Camino de Santiago, with its millenary history and profound cultural and spiritual resonance, represents an emblematic example of how a pilgrimage experience can transform into a global tourism phenomenon. Its sustainability, however, is not a given, but the result of a delicate balance between growth, management and conservation. To understand the challenges that the Camino faces today, it is useful to analyse its dynamics through the lens of feedback loops, which describe how the path’s very success can trigger decline mechanisms if not carefully managed.

Before the pandemic, the Camino de Santiago was in a phase of significant growth. Trail Attractiveness was very high, fuelled by a global reputation and a consolidated service network. In 2019, the number of pilgrims receiving the Compostela was 347,566 [26], with an average of over 1,700 pilgrims per day during the month of July. This massive flow generated a considerable economic impact on local communities, estimated in millions of euros per year, which allowed the maintenance of hostels, signage and hospitality services [27]. Social support was strong, with communities benefiting from tourism and investments. Increased pilgrim satisfaction and improved services in turn reinforced Attractiveness, creating a virtuous cycle [28].

Post-pandemic recovery saw an explosion in numbers. In 2022, the number of pilgrims reached 438,307, surpassing pre-Covid levels and in 2023, the number continued to rise to 446,091. This success began to reveal the system's limits, activating balancing loops. High inflow created a sense of overcrowding, especially along the French Way and in the last 100 km, particularly the section from Sarria [29]. The perception of a solitary and spiritual experience decreased, potentially reducing satisfaction for some pilgrims. Although the total number continues to grow (also thanks to new routes and a diversification of the offer), the attractiveness of the "authentic Camino" may be perceived as declining by a certain niche of walkers, pushing them to seek alternative paths [30].

With nearly half a million people traversing the trails, ground wear and environmental impact (waste, erosion) increase significantly. Despite maintenance efforts, constant pressure threatens the physical quality of the path. This degradation could influence the Camino's attractiveness for those seeking an experience immersed in pristine nature, potentially leading to a future decrease in flow if not properly managed [31], [32].

The increase in pilgrim flow had contrasting effects. While it generated higher profits, it could also cause tension in small rural communities, whose infrastructures (roads, parking, healthcare services) are put under pressure. The perceived "commodification" of the Camino can reduce spontaneous social support (e.g., free hospitality), a fundamental historical and cultural element, undermining the very soul of the pilgrimage.

For decision-makers of the Camino de Santiago, these numerical data may represent a serious warning signal to consider based on the following strategies:

- **monitoring and diversification:** the significant increase in pilgrim flow, concentrated on certain sections and periods of the year (such as from Sarria onwards), requires careful management. Decision-makers should continue promoting less frequented routes, such as the Camino Primitivo and encourage walkers to start from different points or in off-season months, to distribute pressure more evenly;
- **sustainability assessment:** attendance data are important but must be integrated with environmental and social sustainability indicators. Measuring ground impact, waste production and local community satisfaction is crucial to prevent tourism success from compromising the Camino's spiritual and environmental value;
- **preservation of authenticity:** the greatest challenge is maintaining the balance between economic growth and the conservation of the Camino's authenticity. Decision-makers must prevent the path from becoming a "theme park" for mass tourism, investing in strengthening its historical and spiritual identity and supporting traditional hospitality that underpins its success.

These strategic guidelines highlight the need for a dynamic modelling approach to explore the long-term impacts of current trends and potential interventions. From this perspective, an SD model supports the design of sustainable management strategies, while future developments could enrich the model by including alternative routes and replicability to other pilgrimage trails.

To illustrate the systemic dynamics described in the previous section, a simplified quantitative simulation was developed using data from the Camino de Santiago, an emblematic case of transformation from pilgrimage route to global walking destination. The model integrates the four feedback loops identified in the causal diagram (virtuous growth, dissatisfaction and decline, infrastructure deterioration and community tension) using a discrete-time System Dynamics formulation with yearly time steps.

The system's core variables are the number of walkers W_t , the trail attractiveness A_t and the walker satisfaction S_t , whose yearly evolution follows:

$$W_{t+1} = W_t \left[1 + g_0(A_t + S_t - 1) - \gamma \frac{W_t}{K} \right] \quad (1)$$

$$A_{t+1} = A_t + \alpha(B_{\text{norm}} - \frac{W_t}{K}) - \beta E_t \quad (2)$$

$$S_{t+1} = S_t + \delta(A_t - C_t - 0.5) \quad (3)$$

where:

$$C_t = \frac{W_t}{K}, E_t = 0.5 C_t \quad (4)$$

and the parameters are:

- K : carrying capacity of the trail: represents the maximum sustainable number of walkers that the Camino can host without causing degradation or service saturation. In the simulation, it is set at 500,000 walkers, approximately corresponding to the observed levels in 2024;
- g_0 : base growth rate: expresses the natural annual increase in the number of walkers, independent of other factors such as attractiveness or satisfaction. A value of 0.15 corresponds to a potential 15% yearly increase under optimal conditions.
- γ : sensitivity to congestion: measures how strongly the number of walkers is affected by overcrowding. A higher γ indicates that growth slows down rapidly as the trail approaches its capacity limit;
- α : responsiveness of attractiveness to management efforts: reflects how effectively investments in maintenance and infrastructure contribute to maintaining or improving attractiveness. A moderate value of 0.10 indicates a slow but positive impact of management;
- β : degradation effect of environmental impact: quantifies how much attractiveness declines due to environmental degradation (erosion, waste, overuse). The value 0.05 represents a gradual but cumulative loss.
- δ : adjustment rate of satisfaction: represents how quickly walker satisfaction reacts to changes in attractiveness and congestion. A value of 0.20 indicates a fairly responsive behavioral adjustment.
- B_{norm} : normalized management effort: represents the relative level of management and maintenance effort, normalized between 0 and 1. The simulation assumes $B_{\text{norm}} = 0.8$, indicating a generally high but not maximal level of management effectiveness.

At each time step, congestion ($C_t = W_t/K$) and environmental impact ($E_t = 0.5 C_t$) are recalculated, affecting both satisfaction and attractiveness.

The simulation starts from the empirical conditions observed in 2019, with $W_0 = 347,000$ pilgrims, $A_0 = 0.85$ and $S_0 = 0.90$. The following table reports the simulated evolution of the system over ten years, calibrated to reflect the most recent official data showing 499,176 pilgrims in 2024 and 504,700 in 2025.

Table 5.1 - SD simulation of the Camino de Santiago (2019-2028): evolution of key variables.

Year	Walkers W_t	Attractiveness A_t	Satisfaction S_t	Congestion C_t
2019	347,000	0.85	0.90	0.67
2020	384,000	0.86	0.91	0.74
2021	412,000	0.87	0.91	0.79
2022	438,000	0.88	0.90	0.84
2023	446,000	0.88	0.88	0.86
2024	499,000	0.86	0.85	0.96
2025	505,000	0.84	0.83	0.97
2026	490,000	0.82	0.80	0.94
2027	470,000	0.80	0.78	0.90
2028	450,000	0.78	0.76	0.87

The results describe a dynamic pattern consistent with observed trends. In the early years, high attractiveness and satisfaction reinforce each other, producing strong growth (virtuous loop). By 2024-2025, when congestion approaches the carrying capacity ($C_t \approx 0.97$), satisfaction starts to decline, activating the balancing loops of dissatisfaction and infrastructure deterioration. Reduced satisfaction and attractiveness gradually slow growth, leading to stabilization and a mild decline in walker numbers. This outcome occurs unless measures are adopted to expand the system's accommodation capacity, which, however, may entail a trade-off in the form of potential natural and landscape deterioration.

From a management perspective, this simulation highlights how feedback-driven growth can evolve into self-limiting dynamics if infrastructure capacity and environmental quality are not adequately managed. The satisfaction index decreases from 0.90 to 0.76 (–15%) and attractiveness drops from 0.85 to 0.78, reflecting a measurable reduction in perceived quality. Although the number of walkers increases by about 45% between 2019 and 2025, overcrowding and environmental pressure ultimately dampen the trend, confirming the existence of saturation thresholds.

The analysis was calibrated using official data from the Pilgrims' Office of Santiago de Compostela (2019-2025), ensuring coherence between simulated and observed flows. Parameter tuning was performed through iterative adjustment to replicate the historical growth trajectory while maintaining internal consistency with the estimated carrying capacity.

However, this model remains under refinement. Further researches will allow more robust scenario analyses and support the definition of adaptive management policies for sustainable pilgrimage tourism.

This quantitative experiment confirms the interpretative potential of the System Dynamics approach, demonstrating how the interplay between demand, satisfaction and management can generate both virtuous and degenerative feedbacks. Incorporating such a calibrated model into the governance framework of the Camino de Santiago could enable predictive, data-driven management, helping decision-makers balance growth, sustainability and the preservation of authenticity.

5.5 A discrete simulation model for the analysis of walker flows

The study of pedestrian mobility along long-distance itineraries requires tools capable of capturing the complexity of individual behaviours and interactions with available infrastructures and services. In this context, Discrete Event Simulation (DES) represents a particularly suitable approach, as it allows walkers to be modelled as autonomous entities, each characterized by its own attributes and decisions and dynamically reproduces the processes that develop along the stages of a trail. The possibility of integrating physical, logistical and behavioural aspects in a single

simulation environment makes this paradigm an effective support for the design and sustainable management of walking itineraries.

5.5.1 Model objectives

The model aims to:

- understand the dynamics of pedestrian mobility along long-distance itineraries, considering individual variability among walkers;
- analyse the interaction between walkers and detailed characteristics of the stages (physical, infrastructural, service-related);
- predict risk factors and critical points such as congestion and dropouts;
- evaluate the impact of infrastructure quality, crowding, accommodation availability and environmental conditions on overall walker satisfaction;
- explore **dynamic feedback** phenomena that influence trail reputation, attractiveness and local economic benefits;
- provide a decision-support tool for the management and enhancement of walking itineraries.

5.5.2 Model description

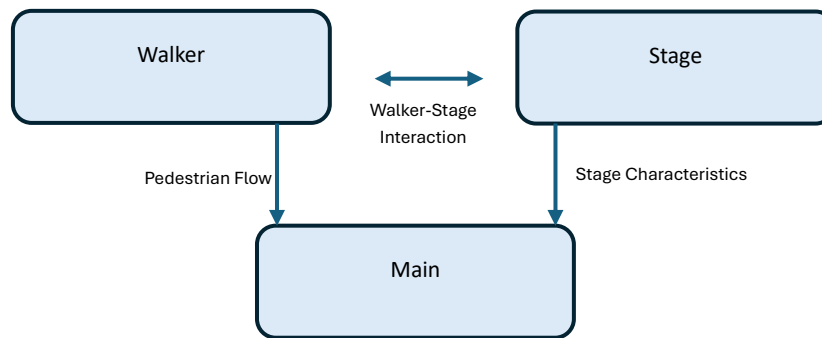
Based on the previously mentioned CLD and to deeply understand and analyse pedestrian mobility dynamics along long-distance itineraries, the PATHS (Pedestrian-Accessible Trail & Hostel Simulator) simulation model was developed. The model, implemented in the AnyLogic environment, is based on the discrete event simulation (DES) approach and is designed to realistically represent walker movement and their interactions with the physical, infrastructural and service characteristics of the different stages composing a trail.

PATHS aims to meet multiple objectives: understand pedestrian mobility dynamics along multi-stage itineraries, accounting for individual walker variability; analyse interaction between walkers and the physical and infrastructural characteristics of stages, including service and accommodation availability; predict risk factors and critical points such as dropouts or congestion phenomena; assess the impact of elements such as infrastructure quality, crowding, accommodation availability and environmental impact on individual and collective satisfaction; explore possible feedback phenomena such as overall trail reputation and local economic benefits; and finally, provide a decision-support tool for optimal management and valorisation of walking itineraries.

The DES approach is particularly suited for modelling pedestrian mobility along staged trails. Focusing on entity flow allows representing walkers as entities moving through a sequence of processes corresponding to the stages. Attention to time and queue management allows precise measurement of travel times, delays due to environmental or infrastructural factors (e.g., slopes or congestion) and potential queues linked to scarce resources, such as available hostel beds. Another distinctive aspect of DES is the ability to model interaction with shared resources, simulating allocation and release of beds or other services. Each walker is also characterized by variable attributes such as speed, experience level, individual satisfaction, or crowding tolerance, which evolve dynamically along the path. This approach allows representing significant heterogeneity among subjects, indispensable for simulating realistic scenarios. Finally, the computational efficiency of DES is a decisive advantage, enabling simulation of a large number of walkers over extended time horizons without excessive computational costs.

The PATHS model is structured into three main components: Walker, Stage and Main (Figure 5.2).

Figure 5.2- Conceptual scheme of the PATHS model.



The Walker (**The Walker Agent**) represents the subject traversing the itinerary. It is characterized by a set of attributes describing both intrinsic characteristics and evolution during the walk. Key attributes include satisfaction level, average speed, experience level (beginner, intermediate, expert), current stage identifier, variables related to accommodation availability, days spent traveling and the possibility of having experienced incidents. The Walker's behaviour unfolds in a sequence of actions: moving along stages, consuming resources, updating satisfaction level and operational decisions, such as abandoning the path or continuing despite encountered difficulties.

Stage (The Stage Agent) is represented as an autonomous agent with attributes describing geographic location (latitude and longitude for GIS integration), physical characteristics and service endowment. The stage constitutes the element through which walkers move, interacting with its specific configuration. The collection of stages is managed as a matrix or a list of objects, allowing sequential organization of the trail.

Stage attributes are divided into thematic classes:

- **track:** includes variables such as percentage of unpaved trails, elevation change, stage length and total trail length;
- **itinerary:** includes indicators related to landscape quality, path quality in urban areas, number of points of interest and route variety;
- **orientation:** describes the availability of orientation tools, from physical signage to printed maps and GNSS tracks;
- **services and infrastructures:** evaluates the presence of accommodation and dining facilities, availability of support services, guides, rest points and potable water sources;
- **communication:** includes variables such as availability of initial and final certifications, existence of dedicated apps or websites and the possibility of interacting with local contacts;
- **accessibility:** measures the accessibility of the starting point via public transport.

The Main level (**The Simulation Environment**) represents the overall model environment. It integrates the GIS map, the collection of Walkers and the collection of stages. Global parameters such as arrival rates, accident probability and satisfaction thresholds are managed at this level and global variables such as trail reputation, attractiveness, local economic benefits and congestion degree are updated. Main also coordinates agent flow along the **stage matrix**, regulating the interaction between demand (walkers) and supply (stages and resources). The stage matrix constitutes the heart of the model. It provides specific data for each trail segment and directly influences walker behaviour and experience. Implementation occurs through the definition of a Stage agent and the creation, at the Main level, of a collection (e.g., `ArrayList<Stage>`) or an

internal database. This structure allows associating variables related to physical conditions, landscape quality, accessibility, orientation, available services and infrastructures with each stage. Integrating the stage matrix with Walker agents allows the model to dynamically and realistically represent interactions between walkers and the environment, generating indicators useful for evaluating overall itinerary performance and comparing itineraries. Table 5.2 summarizes the main model classes, their attributes and their role within the PATHS simulation framework.

Table 5.2 - Structure of the PATHS Model Classes.

Class	Main attributes	Role in the Model
Walker (Pedestrian Agent)	satisfaction, avgSpeed, ExperienceLevel, idCurrentStage, foundAccommodation, daysWalking, hadAccident	Represents the individual walker, with variable characteristics and decisions evolving along the route
Stage (Stage Agent)	idStage, StageName, latitude, longitude	Represents each segment of the trail, integrating physical, qualitative and service attributes
Track	percDirtPath, Altitude, StageLength, lTotalLenght	Describes the physical and morphological characteristics of the trail
Itinerary	QualLandscape, QualUrbanPath, nPOI, PathVariety	Evaluates the tourist and attractiveness aspects of the stage
Orientation	Signs, PaperGuide, GNSS	Indicates the level of support available for walker orientation
Services & Infrastructures	nRestaurants, nAccommodations, AccomCapacity, avgAccommodation, StoppingPoints, WaterSource	Represents the services and infrastructures available along the stage
Communication	credential, certification, app, WebSite, directContact	Describes the communication and certification modalities linked to the trail
Accessibility	PublicTransport	Measures the accessibility of the stage via public transport
Main (Simulation Environment)	GISMap, walkers, Stages, trailReputation, localEconomicBenefits, congestionLevel	Central environment of the model, coordinates Walker and Stage, updates global variables, manages agent flow

5.5.3 System dynamics: interconnections and feedback

The model does not merely reproduce individual paths, but integrates a series of feedback loops that connect local and global variables:

- walkers satisfaction → trail reputation: the trail's reputation is periodically updated based on the average satisfaction of walkers who have completed or abandoned the route;
- trail reputation → trail attractiveness: the trail's attractiveness, which influences the arrival rate of new walkers, depends directly on the accumulated reputation;
- number of walkers → congestion/overcrowding: overcrowding is calculated by monitoring walker density in key areas or the length of queues for critical resources such as hostels;
- congestion/overcrowding → walkers satisfaction (negative): as overcrowding increases, individual satisfaction tends to decrease;
- congestion/overcrowding → local support (negative): the perception of discomfort by local communities reduces support for the trail;
- local support → management efforts (positive): higher local support translates into more resources dedicated to the management and maintenance of the trail;

- management efforts → infrastructure quality (positive): investment in management can improve the quality of infrastructure and services along the stages;
- number of walkers → local economic benefits (positive): the overall flow of walkers generates direct and indirect economic benefits;
- availability of hostels → walkers satisfaction: the possibility of finding adequate accommodation strongly influences satisfaction and the decision to continue or abandon.

5.5.4 Operational logic of the model

The operational logic of the model is structured into several components that describe the sequential functioning of the simulation. These components define the mechanisms through which agents are generated, move along the trail, interact with environmental and infrastructural features, update their satisfaction and contribute to the overall system dynamics.

Agent generation

Walkers are generated from a Source, with an arrival rate dependent on the overall attractiveness of the trail. Each Walker is initialized with individual attributes (average speed, experience level, initial satisfaction) and positioned on the GIS map.

Movement between stages

Movements are modelled through MoveTo blocks integrated with the GIS network. Effective speed depends both on individual attributes and stage characteristics (slope, surface, length). AnyLogic automatically calculates the route and duration.

Satisfaction update

Upon completing each stage, the walker's satisfaction is updated considering positive factors (landscape quality, points of interest, path variety) and negative factors (steep slopes, unpaved sections, lack of services). The impact of each factor is modulated by individual experience.

Incident and abandonment management

After each stage, a SelectOutput Incident block evaluates the probability of adverse events, dependent on stage difficulty and length. If an incident occurs, the walker abandons the route and suffers a satisfaction penalty.

Accommodation management

Upon arrival at a stage, walkers attempt to acquire a bed in a ResourcePool of hostels. If they find accommodation, their satisfaction remains stable or increases; otherwise, they incur a penalty. The stay duration is parameterized and at the end, the bed is released.

Final decision

A SelectOutput Decision block determines whether the walker:

- Continues, if satisfaction remains above a minimum threshold and/or accommodation was found;
- Abandons, if satisfaction falls below the threshold or conditions are too adverse;
- Completes, if the final stage is reached.

Global feedback

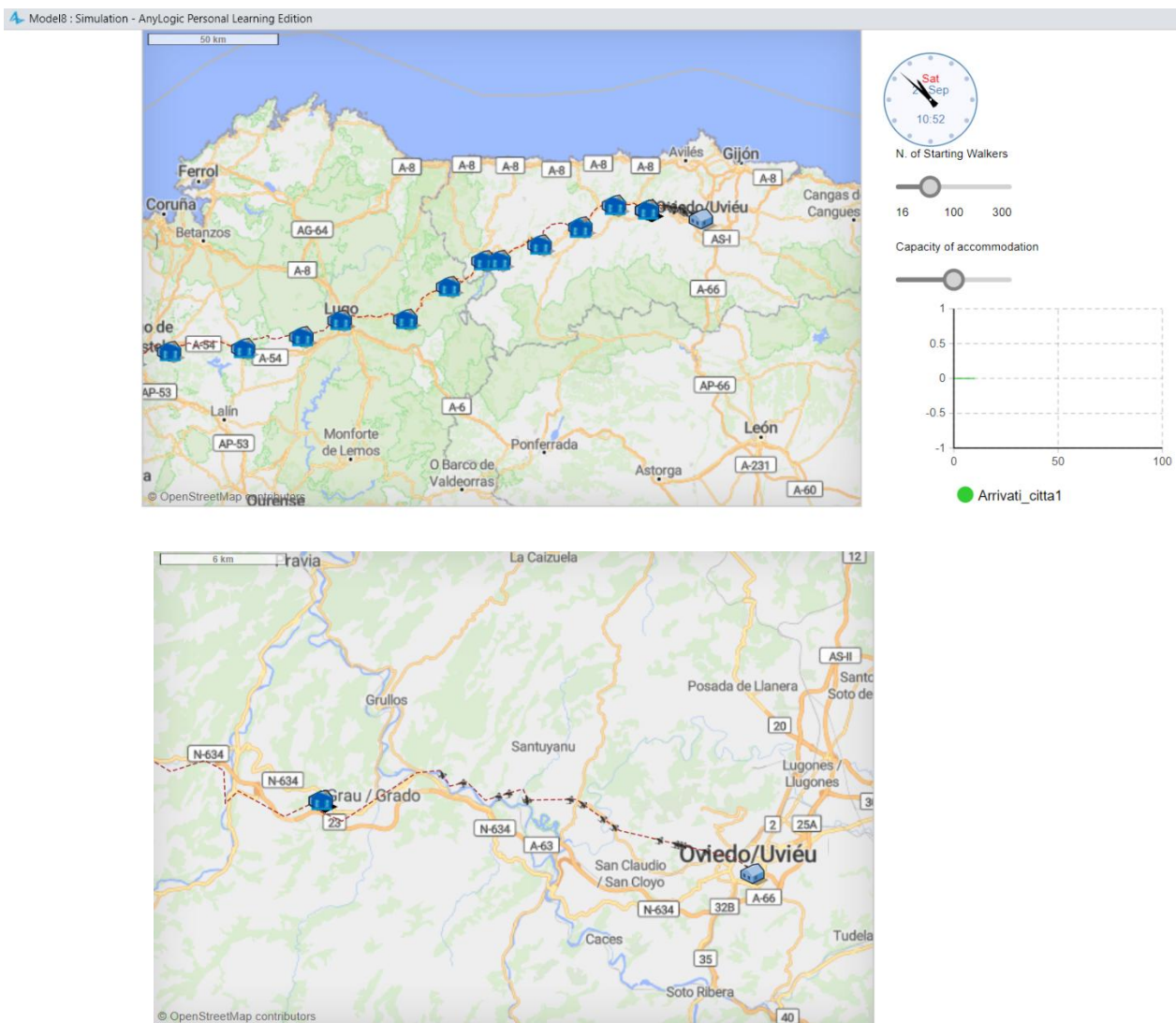
Global variables in Main (trailReputation, trailAttractiveness, localEconomicBenefits, congestionOvercrowding) are updated in real time based on aggregate walker behavior. These

feedbacks determine system evolution in the medium-to-long term, influencing both trail management and individual experience.

5.4.5 PATHS Model Implementation in AnyLogic

The PATHS model (Pedestrian-Accessible Trail & Hostel Simulator) was implemented in AnyLogic through the definition of a set of agents and data structures that reproduce walker behaviour and interactions with the stages (Figure 5.3).

Figure 5.3 - Implementation of the PATHS model in Anylogic and focus on a stage of the Camino Primitivo.



The Walker agent was created as the main entity, with customizable attributes (average speed, experience, satisfaction, days on the trail) and behaviour logic that dynamically updates according to the conditions encountered along the path. Each Walker follows a discrete event flow, moving cyclically through the Stage Matrix, where each stage is represented by the Stage agent.

Stages are organized in an `ArrayList<Stage>`, populated within the Main agent, which acts as the simulation environment. Each stage in this list is characterized by physical, infrastructural and qualitative attributes, organized into subclasses (Track, Itinerary, Orientation, Services & Infrastructures, Communication, Accessibility). The integrated GIS Map in AnyLogic allows stages

to be spatially located using geographic coordinates (latitude and longitude), enabling visualization of pedestrian flows on the real territory.

The discrete event simulation (DES) paradigm was implemented using standard AnyLogic logic blocks (Source, Delay, Queue, Resource, Sink). Walkers are generated from a Source block, move through the different stages with travel times conditioned by physical factors (slope, length, surface type) and may encounter limited resources (beds in hostels) modelled through the ResourcePool block. Interaction with these resources can produce queues and waiting times, affecting overall walker satisfaction.

Global variables such as trailReputation, localEconomicBenefits and congestionOvercrowding are dynamically updated by Main and depend both on aggregate Walker behavior and stage infrastructural parameters. This allows integration of system dynamics feedback loops (e.g., higher overcrowding → lower satisfaction → reduced reputation) within a DES context.

In this way, the simulation provides a flexible and expandable tool to analyse alternative scenarios, evaluate criticalities and support decision-making in the design and management of long-distance walking itineraries.

System performance measurement and evaluation are conducted through a set of analytical and statistical tools implemented in AnyLogic. Key monitored metrics include temporal trends of walker numbers, average participant satisfaction, trail reputation (Trail Reputation), congestion levels overall and per stage, local economic benefits and hostel utilization. To support these analyses, probability distributions for individual walker satisfaction at system exit are generated, abandonment rates quantified and average and maximum stay durations per stage and for the entire itinerary are calculated. The model's key output allows assessment of stage characteristics, such as slope, infrastructure quality and service availability, on walker satisfaction, identification of critical overcrowding thresholds and their effect on satisfaction and abandonment and analysis of hostel capacity in relation to mobility and perceived well-being. Furthermore, the model allows estimating the effectiveness of management and investment strategies and quantifying the relationship between walker numbers and local economic benefits. Future developments include model calibration and validation with real or empirical data, simulation of "what-if" scenarios for infrastructural interventions or hostel service expansion, introduction of simulated climate variations and targeted marketing campaigns. Other extensions include detailed spatial integration with GIS map visualization of movements, introduction of walker types with heterogeneous behaviours and preferences and a deeper economic analysis of local benefits, considering specific expenditures on services and products along the itinerary.

5.4.6 An application

The PATHS (Pedestrian-Accessible Trail & Hostel Simulator) model was applied to the Camino Primitivo, divided into 10 stages from Oviedo to Santiago de Compostela. Each walker is modelled as an autonomous agent, characterized by average walking speed, experience level, initial satisfaction and probability of incidents. Stages are described by distance and positive elevation gain, as well as hostel availability.

The effective walking speed for each walker is calculated using the Naismith rule (1892):

$$v_{eff} = \frac{L}{\frac{L}{v_0} + \frac{\Delta h}{600}}$$

where L is the route length (km), Δh is positive elevation gain (m), $v_0 = 5$ km/h and 600 m/h is the estimated walking time per 600 m ascent. Satisfaction is updated after each stage considering positive factors (landscape quality, points of interest, path variety) and negative factors (difficulty, limited services).

If no hostel beds are available, walkers are assigned an improvised accommodation, reducing satisfaction (-1) and impacting overall trail reputation and future attractiveness. Only a minimal number abandons due to lack of accommodation (1 in 300). About 10% of walkers use alternative transport to reach subsequent stages, incurring a minor satisfaction penalty (-0.5). Incident-related abandonments remain rare.

During a 30-day simulation with 600 walkers (20/day), 508 walkers completed the full route, with an average final satisfaction of 7.5/10 (Table 5.3). Hostel occupancy ranged between 65% and 85% and maximum congestion per stage did not exceed 20 walkers. This discrete-event approach allows realistic modelling of walker-infrastructure interactions, identification of critical points and supports sustainable management of long-distance walking itineraries.

Table 5.3 - Average walker's satisfaction for each stage.

Stage	Km	Elevation (m)	Effective Speed (km/h)	Estimated Time (h)	Avg. Satisfaction	Notes on Satisfaction
Oviedo - Grado	30	250	4.67	6.42	6.8	Base satisfaction 7; +0.5 landscape, -0.7 difficulty
Grado - Salas	32	300	4.64	6.90	6.7	Minor penalties for difficulty; POI bonus +0.2
Salas - Tineo	35	400	4.57	7.66	6.5	More elevation and unpaved paths reduce satisfaction
Tineo - Pola de Allande	30	450	4.48	6.70	6.3	Slight penalty for steep ascent; 1-2 walkers use improvised accommodation
Pola de Allande - La Mesa	32	500	4.43	7.22	6.2	Highest elevation gain; satisfaction reduced by difficulty
La Mesa - Grandas de Salime	30	550	4.38	6.85	6.3	Improved landscape partially offsets difficulty
Grandas - Fonsagrada	35	400	4.57	7.66	6.5	Easier terrain; small POI bonus
Fonsagrada - Lugo	30	300	4.64	6.47	6.7	Moderate slope; satisfaction stable
Lugo - Melide	26	200	4.80	5.42	6.9	Flatter stage; satisfaction improves
Melide - Santiago	30	150	4.88	6.15	7.1	Last stage, positive landscape and POI boost satisfaction

5.6 Simulation implications for trail management

The simulation's implications for trail management manifest across multiple dimensions and levels, providing analytical and predictive tools useful for planning, operational management and valorisation of itineraries. The implications of the simulation are presented below for stakeholders, trail management phases, Trail Life Cycle stage, Sustainability Dimension, Decision Level, Territorial Scale and Time Horizon (Table 5.4).

5.6.1 Implications for each stakeholder group

Key trail stakeholders include a variety of actors operating at different levels and with different objectives. Decision-makers and policy makers, such as local authorities, municipal administrations, regions and ministries of tourism and culture, play a central role in policy definition, strategic planning and resource allocation necessary for trail management and promotion. Tourism operators, including hostel and hotel managers, restaurants, tour guides and agencies specialized in walking tourism, are directly involved in service provision and in shaping the walker experience, adapting the offer to visitor needs and expected flows. Local communities, composed of residents, cultural associations and local producers, play a key role in cultural and economic valorisation of the trails, actively participating in management and promotion of local heritage. Walkers and tourists, of different age groups and origins, are the main trail users and their needs, preferences and behaviours provide essential data for planning and continuous improvement. Trail-promoting associations, often operating on a voluntary basis, contribute to trail maintenance, signage creation and sustainable mobility promotion, without directly managing infrastructure. Researchers and universities provide scientific support through the study of sustainable mobility, territorial development and tourist flow impacts, contributing to data- and model-driven decision-making. Finally, land management organizations, such as parks, natural reserves and environmental protection agencies, ensure ecosystem conservation along the trails, monitoring and mitigating tourist flow impacts on the natural environment.

Trail simulation offers differentiated analysis and decision support tools according to the stakeholders involved. Decision-makers and policy makers can use simulation to plan long-term strategies, assess the impact of infrastructural interventions, promotional campaigns, or tourism policies, anticipate criticalities related to flows, congestion and walker abandonment and optimize resource allocation. Tourism operators, such as hostel and hotel managers and related service providers, can use simulated data to plan the offer, anticipate peak flows and develop personalized tourism packages, enhancing visitor satisfaction. Local communities benefit from flow and economic benefit analysis, as simulation helps identify opportunities for cultural, commercial and social valorisation, while reducing negative impacts of tourist influx. Walkers and tourists are indirect beneficiaries of simulation, as it enables the design of more balanced itineraries, realistic travel times and adequate service availability, improving overall experience. Trail-promoting associations, often voluntary, can plan maintenance and signage improvement interventions, promote awareness activities and optimize flow management. Researchers and universities use data to develop predictive models, sustainability analyses and scientific decision support. Land management organizations, such as parks and natural reserves, can evaluate tourist flow impacts on ecosystems, prevent environmental damage and implement conservation and trail maintenance strategies.

5.6.2 Implications for trail management phases

Simulation implications can be further articulated according to different trail management phases. During the planning phase, simulation allows testing alternative scenarios, identifying optimal paths, estimating demand and predicting potential criticalities, providing an objective basis for strategic choices and infrastructure design. During operational management, simulation enables real-time monitoring of flows, assessment of congestion per stage, management of accommodation use and identification of problems that may compromise walker satisfaction. In the valorisation phase, simulated data allow optimization of territorial promotion strategies,

planning of cultural and commercial activities along the path and maximization of economic and social benefits, ensuring a balance between tourist attractiveness and sustainability.

5.6.3 Implications along the trail life cycle

Considering the trail life cycle, simulation plays a differentiated role in various phases. During the launch phase, simulation models allow testing route feasibility, estimating initial attendance and predicting potential logistical criticalities. During the in-transit phase, simulation supports real-time flow management, optimizing walker distribution along stages and improving overall accessibility. When the trail becomes fully operational, data analysis enables continuous monitoring of performance and participant satisfaction. In the mature phase, simulation allows assessment of long-term impacts on local communities, economy and environment, while in the saturated phase, it becomes an essential tool for identifying critical congestion thresholds and developing mitigation strategies aimed at preventing degradation of the experience and trail quality.

5.6.4. Implications for the Sustainability Dimension

Simulations allow integrated analysis of different sustainability dimensions. From an economic perspective, it is possible to estimate benefits generated by walkers for local communities, evaluate return on infrastructure investments and optimize service management. Socially, simulation enables monitoring walker satisfaction, safety along the path, equitable access and inclusion of different user types. This dimension also includes cultural and psychological aspects, such as how trail quality and stage use influence perceived well-being, local heritage awareness and consequent valorisation. Environmentally, simulation provides tools to predict and prevent trail erosion, impacts on natural heritage and anthropogenic pressure, enabling targeted conservation interventions.

5.6.5 Implications for decision level

Depending on the decision level, simulation offers targeted tools. At the strategic level, it supports long-term policies and integrated territorial planning, providing data on flows, sustainability and economic and social impacts. At the tactical level, it allows coordination of activities at regional and local scales, optimizing management of services and infrastructure. At the operational level, simulation enables daily intervention on walker distribution, trail maintenance, safety management and peak flow handling.

5.6.6 Implications for territorial scale

Territorial scale affects simulation granularity and tools. At the local level, it allows detailed monitoring of individual stages, accommodations and points of interest. At the regional level, it supports flow planning across multiple municipalities or provinces, while at the national level, simulation can guide integrated tourism promotion and development policies, coordinating interventions on extended and multifunctional trail networks.

5.6.7 Implications for time horizon

The time horizon distinguishes between short-, medium- and long-term effects. Immediate effects include congestion management, facility use and walker satisfaction during the experience. Medium-term effects relate to tourism promotion, service planning and recurrent flow management. Long-term effects concern economic, social and environmental trail sustainability, integrated territorial development and the resilience of the tourism system.

Table 5.4 - Simulation Implications.

Classification	Dimension/Stakeholder	Main Implications
Stakeholders	Decision makers / policy makers	Support for strategic planning, resource allocation, assessment of environmental, social and economic impacts, "what-if" scenario simulation
	Tourism operators	Optimization of accommodation capacity, service management, development of tourist packages, monitoring walkers' satisfaction
	Local communities	Cultural and commercial enhancement, participation in trail management, monitoring social and economic impacts
	Walkers / tourists	Improvement of user experience, realistic travel times, availability of services and comfort
	Promoting associations	Planning voluntary interventions, maintenance and signage, promotion of sustainable mobility, assessment of impact of activities on the trail
	Researchers / universities	Calibration of predictive models, data analysis, scientific support for decision-making
	Land management organizations	Assessment of environmental impact, ecosystem conservation, trail maintenance
Management Phases	Planning	Scenario testing, definition of optimal routes, demand estimation, prevention of criticalities
	Operational management	Flow monitoring, congestion, use of facilities, walkers' satisfaction
	Promotion	Territory promotion, development of cultural and commercial activities, maximization of economic and social benefits
Life Cycle	Launch	Feasibility testing, estimation of initial influx, prediction of logistical criticalities
	In progress	Real-time flow management, optimization of walkers' distribution
	Usable	Continuous monitoring of performance and satisfaction
	Mature	Assessment of long-term impact on communities, economy and environment
	Saturated	Identification of critical congestion thresholds, mitigation strategies
Sustainability Dimension	Economic	Estimation of local benefits, return on investment, optimization of service management
	Social	Monitoring satisfaction, safety, equity of access, user inclusion
	Environmental	Prevention of erosion and degradation, management of anthropic pressure, ecosystem conservation
	Cultural / Psychological	Enhancement of cultural heritage, perceived wellbeing of walkers
Decision Level	Strategic	Long-term planning, integrated policies, resource allocation
	Tactical	Coordination of activities at regional or local scale, optimization of service management
	Operational	Daily interventions on flows, maintenance and infrastructure management
Territorial Scale	Local	Detailed monitoring of stages, infrastructure, points of interest
	Regional	Flow planning between municipalities/provinces, coordination of services
	National	Integrated policies on extended trail networks, strategic tourism development
Time Horizon	Short term	Management of congestion, facility usage, walkers' satisfaction
	Medium term	Tourism promotion, service planning, management of recurring flows
	Long term	Economic, social and environmental sustainability, territorial development, system resilience

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Chapter 6

Evaluation of services and performance for pedestrian mobility

6.1 Performance, PLoS, QoS, Satisfaction and Walkability

The evaluation of pedestrian mobility has evolved over time through a progressive expansion of the considered dimensions, moving from purely technical and infrastructural measures to tools capable of including qualitative and perceptual aspects (Table 6.1). As seen previously, in an initial phase, the literature focused on the performance of the pedestrian system, understood as objective and quantitative parameters useful to describe the functioning of infrastructure (e.g., sidewalk width, pedestrian density and flows, waiting times at crossings and average travel speed). These are fundamental for evaluating the efficiency, capacity and safety of the infrastructure, but they do not adequately capture the experiential dimension of the users.

Table 6.1 - Summary framework of walkability measures.

Measure	Object of Evaluation	Nature of Measure	Main Focus	Example
Performance	Technical parameters (width, flows, times)	Objective, quantitative	Efficiency and system capacity	Sidewalk 1.5 m wide, average speed 4 km/h
PLoS	Perceived quality of the route	Semi-objective (indicators + perceptions)	Comfort, continuity, safety	Wide, well-lit sidewalk with low traffic → PLoS A
QoS	Overall quality of the service offered	Objective + subjective	Infrastructure and related services	Presence of benches, signage, and fountains → high QoS
Satisfaction	Individual experience and expectations	Subjective	Personal well-being and fulfillment	Pedestrian feels safe and satisfied with the experience
Walkability	Overall territorial context	Multidimensional	Intrinsic ability to promote pedestrian mobility	Neighborhood with lots of greenery and low traffic → high walkability

To address this limitation, the concept of **Pedestrian Level of Service (PLoS)** was introduced, borrowed from the level of service used for vehicular traffic, integrating infrastructural and environmental variables (sidewalk width, presence of barriers, vehicle flows, path continuity) and translating them into a synthetic measure reflecting the quality perceived by pedestrians. For example, a wide, continuous, well-lit sidewalk with minimal traffic interference tends to generate a high PLoS (A or B), as the pedestrian perceives the path as safe and comfortable.

In parallel, research has introduced the notion of **Quality of Service (QoS)**, particularly developed in Transportation Research Board reports and adopted in numerous applied studies. QoS does not concern only the pedestrian infrastructure strictly speaking but extends to the entire set of services contributing to the overall quality of the walking experience. These include, for instance, the availability of signage and information, lighting, presence of resting areas and toilets, universal accessibility and both actual and perceived safety. This means that even if a path has a good PLoS, the QoS can be low if essential supplementary services for pedestrians, such as resting points, drinking fountains, or clear orientation signage, are missing.

Alongside these analytical dimensions, the literature has progressively considered **walker satisfaction**, understood as the subjective outcome of the individual experience. It represents the degree to which the characteristics of the path and services meet or exceed personal expectations, generating wellbeing, a sense of safety and aesthetic pleasure. Unlike QoS, which focuses on the quality of the provided service, satisfaction describes the user's response in terms of overall perception and is influenced by individual, cultural and motivational factors.

An example clarifies the difference between QoS and walkability. Imagine a network of well-maintained pedestrian paths, with clear signage, benches and widespread lighting: in this case, QoS is high, as the services offered to the pedestrian are numerous and adequate. However, if the surrounding environment has high vehicle traffic, air pollution and scarce urban greenery, overall walkability may be low because the context does not genuinely promote walking. Conversely, a neighborhood with many green areas, quiet local streets and nearby services may have high walkability even in the absence of particularly rich supplementary pedestrian services.

Therefore, the different measures are positioned on distinct but complementary analytical planes: from technical performance to systemic evaluation of walkability, passing through intermediate tools such as PLoS and QoS, up to the individual outcome represented by walker satisfaction (Figure 6.1).

Figure 6.1 - Conceptual framework of measures.



6.2 Set of indicators proposed for the evaluation of trails and paths LoS

Within this research, an integrated system of indicators was developed for evaluating the quality of long-distance trails, based on the concept of **Level of Service (LoS)** from the HCM, originally developed for urban pedestrian mobility. The objective is to measure the overall quality of the segments and stages of the trail, considering physical factors, safety, accessibility, continuity and the availability of supporting services and infrastructure, in order to promote equitable, safe and sustainable mobility.

A **segment** represents a subsection of a stage with homogeneous characteristics in terms of surface, width, obstacles, safety, accessibility and availability of services. The recommended length of a segment is 1-3 km, up to 5 km on uniform paths, to ensure consistency in evaluation without excessively fragmenting the route.

A **stage** represents a larger segment of the trail, typically completed in one day or defined by main resting points (shelters, parking, inhabited centres) and may consist of one or more segments.

Each segment is evaluated according to 10 quantitative criteria, chosen for their relevance in long-distance trails (Table 6.2): pedestrian traffic density, width and type of surface, obstacles, safety, accessibility and path continuity, resting points and shelters, essential services (water, toilets), trail signage and integrated transport/connections. All criteria are quantifiable, with numerical values or measurable densities and translated into numeric scores from 1 to 6 according to the LoS scale (A=6, F=1).

Table 6.2 - Integrated Evaluation Criteria of Trails (LoS for Segment).

Criterion	Measure	LoS A	LoS B	LoS C	LoS D	LoS E	LoS F
Pedestrian traffic density	Pedestrians/m ²	< 0.5	0.5-1	1-2	2-3	3-4	> 4
Trail width	Meters	> 3	2-3	1.5-2	1-1.5	0.75-1	< 0.75
Obstacles	No. obstacles/km	0	1-2	3-4	5-6	7-8	> 8
Surface type	Ground quality	Smooth and even	Slightly uneven	Moderately uneven	Deteriorated	Severely deteriorated	Unpassable
Accessibility and continuity	Barriers/connections	Full accessibility and continuity	Limited but passable access	Partial access, some interruptions	Difficult access	Problematic access	Inadequate access
Safety	Separation from traffic/natural hazards	Safe, separated and controlled	Minimal risk	Moderate risk	High risk	Very dangerous	Highly dangerous
Rest points and shelters	No. points/km	> 1.5	1-1.5	0.75-1	0.5-0.75	0.25-0.5	< 0.25
Essential services (water, toilets)	No. services/km	> 1.5	1-1.5	0.75-1	0.5-0.75	0.25-0.5	0
Trail signage	Signs/km	> 3	2-3	1-2	0.5-1	0.25-0.5	0
Complementary transport / connections	% of key points served	100%	≥ 75%	≥ 50%	≥ 25%	10-25%	0%

The LoS of the segment is calculated as the arithmetic mean of the scores of the individual criteria:

$$LoS_{segm} = \frac{\sum_{i=1}^n P_i}{n} \quad (1)$$

or, if some criteria are considered more important (e.g., safety or accessibility), with a weighted mean:

$$LoS_{segm} = \frac{\sum_{i=1}^n P_i * w_i}{\sum_{i=1}^n w_i} \quad (2)$$

where P_i is the score of criterion i , w_i the weight of the criterion and n the total number of criteria. The LoS of the stage is obtained by aggregating the LoS of the segments composing it, using a weighted mean based on segment length:

$$LoS_{stage} = \frac{\sum_{k=1}^m LoS_{segm_k} * L_k}{\sum_{k=1}^m L_k} \quad (3)$$

L_k is the length of segment k and m is the number of segments in the stage.

The overall LoS of the trail is calculated by aggregating the LoS of the stages, optionally weighting by stage length or strategic importance. Conversion into LoS class A-F is carried out according to the overall numeric mean:

$$LOS_{Total} = \begin{cases} A & 5,5 \leq LoS_{Total} \leq 6 \\ B & 4,5 \leq LoS_{Total} < 5,5 \\ C & 3,5 \leq LoS_{Total} < 4,5 \\ D & 2,5 \leq LoS_{Total} < 3,5 \\ E & 1,5 \leq LoS_{Total} < 2,5 \\ F & LoS_{Total} < 1,5 \end{cases} \quad (4)$$

6.3. Evaluation of existing paths and their quality using a network approach

To support strategic planning of long-distance trails at regional, national, or supranational scales, it is necessary to consider existing paths as an integrated pedestrian mobility network. In this perspective, individual segments and stages are not evaluated in isolation but as components of a territorial network composed of multiple interconnected trails. The network approach allows the identification of deficient areas, strategic nodes and critical connections, supporting targeted decisions to improve accessibility, continuity, safety and usability of the entire trail system.

The proposed methodology includes the following operational steps:

- **collection and definition of trail data:** identify existing routes, main stages and segments between nodes (shelters, inhabited centres, parking);
- **trail decomposition:** subdivide each trail into segments and nodes, clearly defining the units on which to calculate service levels;
- **LoS calculation:** evaluate the quality of segments in terms of safety, comfort, walkability, signage and availability of services (water, toilets, shelters);
- **construction of the pedestrian network:** represent trails as nodes (key points) and arcs (segments), generating a multi-level network integrating all routes in the area;
- **application of Network Analysis (NA):** calculate main measures (degree of connection, network density, average path length, betweenness and closeness centrality, accessibility to services, reliability and overall efficiency) to assess connectivity, accessibility and criticality of the network;
- **identification of priority nodes and segments:** combine NA measures with local LoS to identify strategic points, deficient areas and critical connections;
- **construction of the Connectivity/Quality (CQ) matrix:** classify nodes according to network importance (NA) and level of service (LoS), generating four categories guiding intervention priorities;
- **definition and planning of interventions:** assign operational priorities based on CQ category, focusing on maintenance, safety, services and improvement of usability of critical segments;
- **visualization and decision support:** represent the network and CQ matrix with maps and colour codes to facilitate reading, communication and strategic planning at regional, national, or supranational scale.

The main steps are detailed as follows. Each trail is decomposed into segments and stages according to the methodology already described, with calculation of local LoS. Subsequently, all trails in the area are represented as nodes (key points: shelters, inhabited centres, parking) and arcs (segments between nodes), generating a multi-level network. NA measures allow evaluation of overall network efficiency and identification of priority nodes and segments for interventions (Table 6.3):

- **degree centrality:** indicates how many segments or trails are connected to each node, highlighting strategic access points or network junctions;
- **network density:** ratio between existing and maximum possible connections, useful for evaluating continuity and integration of trails in the territory;
- **average path length:** average distance between nodes, in km or travel time, measuring overall network efficiency;
- **betweenness and closeness centrality:** identify the most critical nodes for connectivity and accessibility, allowing prioritization of interventions on strategic segments or nodes;
- **accessibility to services:** percentage of nodes with availability of essential services along trails (water, toilets, shelters);
- **network reliability:** proportion of walkable segments relative to the total expected;
- **overall network efficiency:** ratio between the sum of LoS of segments and total network length, integrating local segment quality with global territorial performance.

This approach provides quantitative indicators useful for regional or national planning, management of tourist flows, promotion of safety and equitable distribution of services, ensuring sustainable and integrated mobility on a large scale. The interpretation of NA measures allows guiding the planning of interventions on walking trails (Table 6.3).

Table 6.3 - Criteria for Network Analysis, interpretation and suggested interventions.

Network Measure	Definition	Unit of Measure	Interpretation	Suggested measures
Connection Degree	Number of trails or segments connected to each node	edges number	Identifies nodes with the most connections, strategic access points, or network junctions	Priority for maintenance, clear signage, information points and services at the most connected nodes
Network Density	Ratio between existing connections and maximum possible	%	Indicates continuity and integration of the network	Creation of new connections between isolated segments, strengthening secondary paths to increase resilience and flexibility
Average Path Length	Average distance between all nodes	km	Measures overall efficiency and distance between nodes	More direct connections between distant nodes, alternative paths to reduce travel times
Betweenness Centrality	Frequency with which a node lies on shortest paths between other nodes	number	Identifies critical nodes as mandatory passages	Priority interventions on maintenance, safety, services, management of potential congestion or critical issues
Closeness Centrality	Reciprocal of the sum of distances from a node to all others	number	Highlights nodes easily accessible to the entire network	Enhancement of these nodes with support services, rest areas, tourist information
Accessibility to Services	Percentage of nodes with essential services	%	Percentage of nodes with essential services	Installation of water, toilets, shelters, refreshment or emergency points along less-served segments
Network Reliability	Proportion of traversable segments compared to the total planned	%	Proportion of traversable segments	Maintenance, securing inadequate or interrupted segments, updated signage
Overall Network Efficiency	Sum of LoS of segments divided by total network length	LoS/km	Integrates local quality of segments and territorial performance	Improvement of critical segments, revision of inefficient paths, harmonization between local quality and overall continuity

Degree of connection allows identification of strategic nodes of the network, i.e., points where multiple trails or segments converge. In planning, these nodes should be prioritized for maintenance, signage and services, as their functionality influences a significant portion of the network.

Network density provides an indication of trail continuity and integration: a high-density network suggests well-connected itineraries allowing alternative routes, while a sparse network indicates isolated areas. Interventions should aim to improve connection between isolated segments to increase network resilience and user experience.

Average path length represents overall network efficiency. High values may indicate indirect routes or distant nodes, suggesting the need to create shorter connections or alternative paths to optimize travel times and accessibility.

Betweenness and closeness centrality measures identify critical nodes: those with high betweenness serve as bottlenecks and may become congestion points or vulnerable in case of interruption, while those with high closeness guarantee quick access to the entire network. Interventions should prioritize maintenance, safety and services at these nodal points.

Accessibility to services evaluates the usability of the network: areas with limited availability of water, shelters, or toilets require targeted interventions to provide supporting infrastructure, improving comfort and safety for walkers.

Network reliability, i.e., the proportion of segments actually walkable, indicates overall resilience: non-walkable or inadequate segments reduce network attractiveness. Maintenance, signage and safety interventions should focus on the less reliable stretches to ensure continuity.

Overall network efficiency, calculated as the ratio between the sum of segment LoS and total length, integrates local quality and global performance. Low efficiency suggests the need for targeted interventions both to improve individual segments (signage, safety, maintenance) and to reconsider overall network configuration to create a more harmonious and usable walking experience.

These measures allow identification of critical areas, strategic nodes and priority paths, supporting targeted planning of interventions that increase connectivity, safety, accessibility and overall network quality.

To support planning of actions on walking trails, a **two-dimensional matrix** can be used, combining node importance measured through NA indicators and LoS of segments or nodes. This matrix allows categorization of network nodes and strategic and efficient prioritization of interventions.

- the vertical axis represents the importance of the node in the network: high-importance nodes play a crucial role in connectivity and overall network accessibility, acting as main hubs or bottlenecks, while low-importance nodes have a more marginal role with less impact on network usability;
- the horizontal axis represents LoS of nodes or segments, measuring the actual quality of paths in terms of safety, comfort, walkability, signage and service presence. High LoS indicates a well-equipped and easily walkable path, while low LoS signals critical issues or deficiencies in path quality.

Combining these two dimensions yields four main categories (Table 6.4):

1. **high importance and low LoS**: represents critical strategic nodes. These points are essential for network connectivity but present quality, safety, or usability issues. Interventions on these nodes should be prioritized, including urgent maintenance, service improvement and signage optimization, to ensure continuity and safety of the entire network;

2. **high importance and high LoS:** strategic nodes of good quality. Although quality is already satisfactory, these nodes remain crucial for the network. Interventions may include preventive maintenance, additional service improvements, or usability upgrades to consolidate and enhance the network;
3. **low importance and low LoS:** less strategic nodes with quality issues. Interventions on these points are secondary, to be scheduled only if resources allow, aiming at local improvements without significant impact on overall connectivity;
4. **low importance and high LoS:** less strategic nodes already of good quality. In this category, interventions are not necessary except for periodic monitoring, as these nodes do not significantly influence overall network performance.

Table 6.4 - Connectivity/Quality (CQ) Matrix.

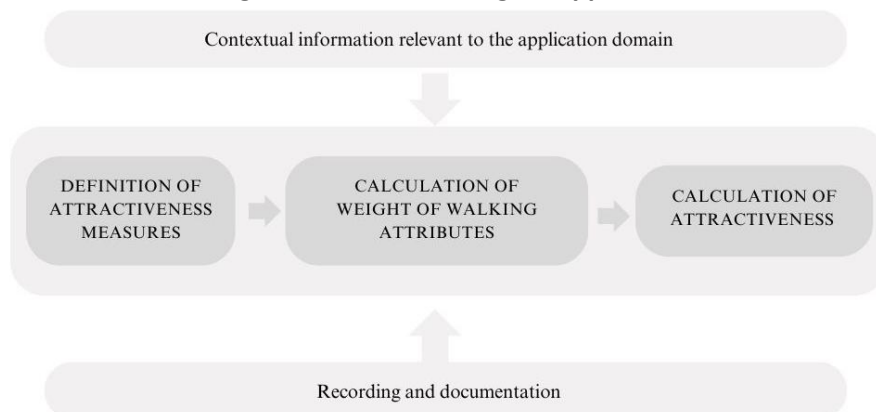
Node Importance	High LoS	Low LoS
High	Well-served strategic node. Non-urgent interventions; possible qualitative improvements	Critical strategic node. Priority interventions for maintenance, safety and services
Low	Less strategic but good-quality node. Optional actions, monitoring	Less strategic and low-quality node. Secondary measures, improvements if resources are available

The adoption of this matrix allows optimizing resource allocation, focusing on the nodes that provide the maximum benefit to the network in terms of accessibility, safety and overall usability. Furthermore, the matrix can be graphically represented with colour codes, making it immediately readable and facilitating the planning of actions.

6.4 An application case for the evaluation of existing paths and their quality according to the attractiveness indicator

In order to evaluate the attractiveness of walking tourist itineraries, a methodological approach was defined aimed at identifying and analysing the factors that influence walkers' satisfaction. The main objective is to understand the components that most contribute to the overall experience and provide useful guidance for the design and management of trails. The methodological process is structured in three main phases (Figure 6.2).

Figure 6.2 - Methodological approach.



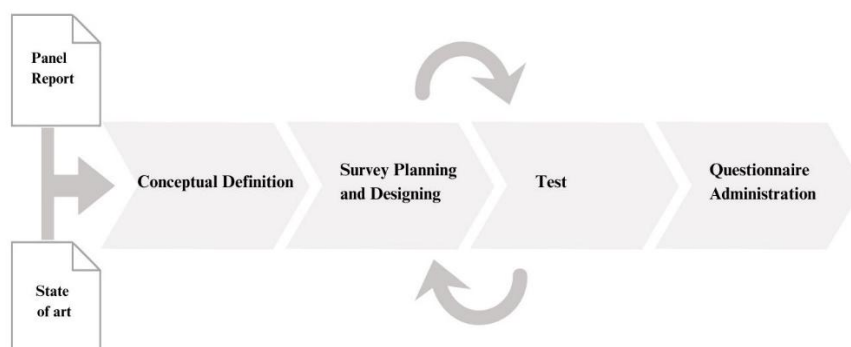
The first phase concerns the definition of the attractiveness measure, which consists of identifying relevant variables for pedestrian mobility along the itineraries. These variables include physical characteristics of the paths, landscape quality, availability of services and users' subjective perceptions. The identified variables are organized into a conceptual framework, aimed at constructing a global attractiveness indicator, calculated as a weighted average of the different attributes.

The second phase concerns the calculation of attribute weights, through the assignment of values to the identified parameters. For this purpose, field surveys were conducted via sample interviews, integrated with statistical analysis of the collected data, to estimate the relative importance of each attribute.

The third phase consists of determining the overall attractiveness of the itineraries, by integrating the weighted values of the variables into a synthetic index. This index allows representing quantitatively both the objective aspects of the paths and the subjective perceptions of the users, including factors such as physical characteristics, aesthetic quality, cultural relevance and overall satisfaction.

To better define the approach, the process was preceded by a review of the state of the art and meetings with sector experts, followed by the definition of attractiveness criteria and the design of the questionnaire. A pilot test in an application context allowed verification of the comprehensibility and coherence of the questions before the final administration (Figure 6.3).

Figure 6.3 - Survey management process.



Data collection was carried out in two main stages: a qualitative phase, through focus groups with experts and a quantitative phase, through a survey addressed to users. The focus groups, conducted between January and September 2023, involved four groups of fifteen participants with experience in the management, organization and promotion of trails. Through brainstorming, ranking, group discussions and SWOT analysis, 25 key variables were identified, organized into six classes: **Path, Itinerary, Orientation, Services and Infrastructure, Communication and Accessibility** (Table 6.5).

Table 6.5 - Walking variables and related aggregation in 6 classes.

Walking variables	Class
Presence of high percentage of unpaved trails, Altitude difference, Length of each stage, Overall length	Track
Landscape, Quality of the way in urban areas, Points of interest, Path variety	Itinerary
Presence of signs, Printed guides/maps, Availability of GNSS-tracks	Orientation
Quality of meals, Value for money meals, Quality of accommodation, Value for money accommodation, Support services, Guide, Presence of resting place, Presence of drinking water sources	Services and infrastructures
Starting certification, Final certification, App, Web Site, Direct interaction	Communication
Starting point accessibility by PT	Accessibility

The online survey, conducted between September and December 2023, involved walkers with previous experience on international or Calabrian itineraries. The main objectives were to evaluate satisfaction relative to the different attributes, identify the requirements of an “ideal itinerary,” and provide a basis for the development of decision support systems. The questionnaire, divided into seven main sections, collected information on sociodemographic data, travel behaviours, importance of walking factors, satisfaction level, expenses and preferences, perception of walking and rest times and attractiveness of the walking area. The administration was carried out through online platforms, in collaboration with associations and networks of walkers, both local and international, ensuring access to a broad and diverse sample.

For each walking variable, participants were asked to assign a level of importance (from 1 to 5), allowing the calculation of the mean importance value (x_i) and, consequently, the overall attractiveness of each itinerary (W_k) according to the formula:

$$W_k = \frac{\sum_{i=1}^n x_i w_i}{\sum_{i=1}^n x_i} \quad (5)$$

where x_i represents the mean interest level for walking attribute i and w_i represents the mean satisfaction level for walking attribute i .

The score can also be calculated for the different classes (Path, Itinerary, Orientation, Services and Infrastructure, Communication, Accessibility) according to formula (6):

$$W_{dk} = \frac{\sum_{d=1}^n x_d w_{dk}}{\sum_{d=1}^n x_d} \quad (6)$$

where W_{dk} is the score of class d for itinerary k ; n is the number of walking attributes belonging to class d ; x_d is the total importance of attribute d ; w_{dk} is the satisfaction level for attribute d in itinerary k .

To calculate the attractiveness of the itineraries, a specific question was included; participants were asked to evaluate the importance of the 25 walking attributes listed in Table 6.5. The question was addressed to all respondents, collecting a total of 125 responses. These responses were used to weight the importance of the various factors in determining the attractiveness of the itineraries. The 25 factors considered were evaluated on a 5-point Likert scale (“Not important at all” to “Very important”). For statistical analysis, the means for each attribute were calculated to identify those considered most relevant by walkers. This approach allowed quantification of the relative importance of each factor, highlighting walkers’ preferences and priorities. The results obtained were used to weight the factors in determining the overall attractiveness of the walking itineraries.

The importance levels assigned by walkers to the different attributes provide valuable insights into their preferences and priorities in planning and enjoying the trail. It is important to note that the importance value does not vary for each itinerary, as it refers to the overall weight assigned by respondents to the single walking variable (Table 6.6, relative to all 125 interviews).

Among the most appreciated attributes are the landscape, with a mean importance level of 4.47, highlighting the importance of natural beauty and panoramic views along the itinerary. The presence of signage obtains an importance level of 4.36, emphasizing how well-marked paths are fundamental for orientation and safety. Points of interest, rated 4.19, include historical, cultural, or natural attractions that enrich the walking experience. Access to water sources, with an importance of 4.18, is crucial for long or remote trails. Accommodation and meals with good quality/price ratio register importance levels of 4.17 and 4.08, highlighting the priority given by walkers to convenience without compromising comfort or quality. Other relevant attributes include accessibility of the starting point via public transport, accommodation quality and the presence of rest areas. In contrast, support services (e.g., luggage transport) and guides are rated lower, indicating that while appreciated by some, they are not considered essential by the majority.

Women attribute higher importance to almost all variables compared to men, except in some cases where the male judgment prevails (Meal quality, Meal value for money, Accommodation quality, Guide service, Certification, App). Overall, gender differences are minimal, suggesting more similarities than disparities in preferences. Elderly walkers show particular interest in water and landscape, while middle-aged participants value signage and starting point accessibility. Young people focus on landscape and accommodation value for money, neglecting certifications. All participants assign lower importance to support services and guided assistance, prioritizing landscape and signage.

**Table 6.6 - Average level of importance for walking attributes.
Scale from "Not important" (1) to "Very important" (5)**

Walking attribute	Mean	Median	Class
Landscape	4.47	5	Itinerary
Presence of signs	4.36	5	Orientation
Points of interest	4.19	4	Itinerary
Presence of drinking water sources	4.18	4	Services and infrastructures
Value for money accommodation	4.17	4	Services and infrastructures
Starting point accessibility by PT	4.10	4	Accessibility
Value for money meals	4.08	4	Services and infrastructures
Direct interaction with a contact person	4.01	5	Communication
Quality of accommodation	3.97	4	Services and infrastructures
Availability of GNSS-tracks	3.93	5	Orientation
Web Site	3.87	4	Communication
Quality of meals	3.84	4	Services and infrastructures
Length of each stage	3.84	4	Track
Path variety (urban, rural, etc.)	3.79	4	Itinerary
Presence of high % of path on dirt trail	3.79	4	Track
Overall length	3.79	4	Track
Quality of the way in urban areas	3.75	4	Itinerary
Printed guides/maps	3.73	4	Orientation
Credential (Starting certification)	3.47	4	Communication
Testimonium (Final certification)	3.43	4	Communication
Altitude difference	3.42	3	Track
Presence of resting place	3.39	3	Services and infrastructures
App	3.38	3.5	Communication
Guide service	3.06	3	Services and infrastructures
Support services	2.78	3	Services and infrastructures

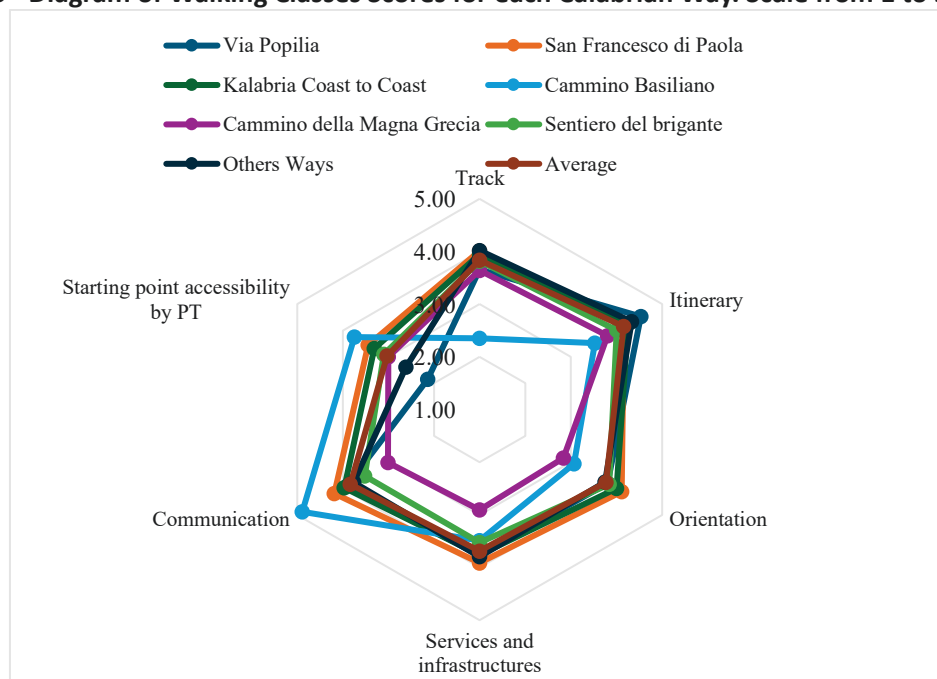
Based on the previous formulation, an application case was developed, considering 79 responses from Italian and foreign participants who had walked at least one stage of Calabrian itineraries. The analysis concerns nine tourist itineraries of the Network of Trails and Paths of Calabria (Figure 6.4). Only six itineraries collected a significant number of responses (Via Popilia, Cammino of S. Francesco di Paola, Calabria Coast to Coast, Cammino Basiliano, Cammino della Magna Grecia, Sentiero del Brigante), while the remaining three were aggregated into the “Other itineraries” category.

Figure 6.4 - The 9 itineraries in the Network of Paths and Ways of Calabria (Italy).



The scores for each class and the overall score were calculated applying formulas (5) and (6) and using attribute weights based on satisfaction levels expressed by walkers for the 25 attributes (Table 6.6). Overall scores range from 3.19 to 4.03, capturing the global attractiveness of each itinerary. Figures 6.5 and 6.6 show the detailed positioning of the individual itineraries with respect to the various attributes.

Figure 6.5 - Diagram of Walking Classes Scores for each Calabrian Way. Scale from 1 to 5 (n=79).

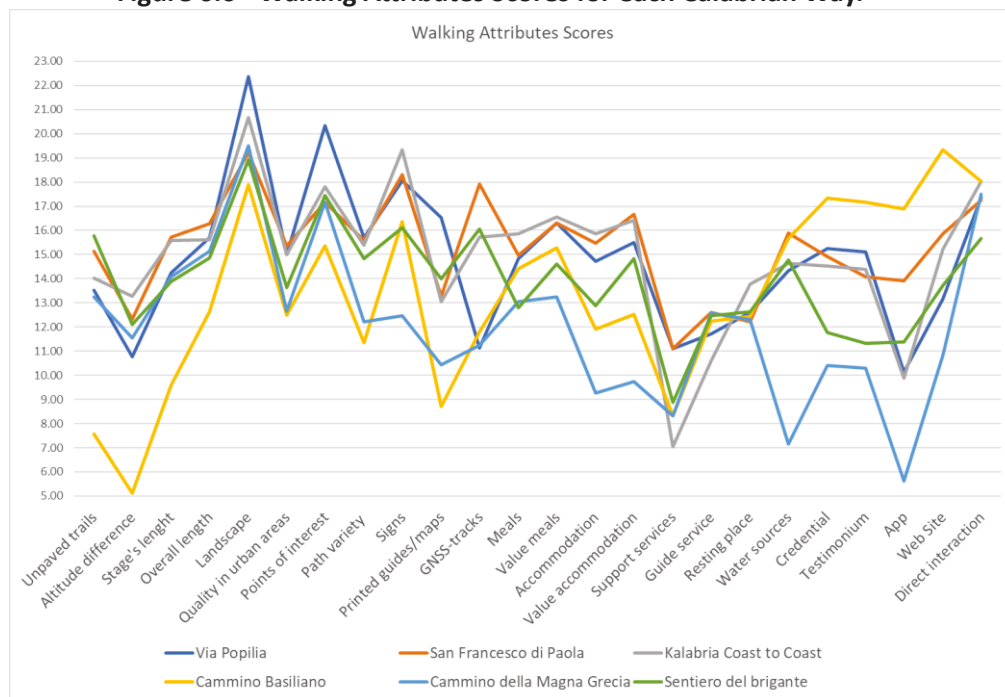


The Cammino di S. Francesco di Paola achieves the highest score (4.03), with consistent results across all classes, especially Itinerary and Communication and a good score also for Orientation. Calabria Coast to Coast ranks second (3.92), with strengths in Itinerary and Orientation. Via Popilia obtains 3.84, balanced across all classes, with critical issues in public transport accessibility. Sentiero del Brigante records 3.67, balanced on Itinerary and Orientation. Cammino Basiliano scores 3.54, with lower scores on Path and Orientation but excellent Communication. Finally, Cammino della Magna Grecia ranks last (3.19), with critical issues in Orientation and Services/Infrastructure, but strengths in Path and Communication.

Analysis of scores for the six attribute classes highlights:

1. Path: average scores 2.35-4.02, reflecting perceived quality of the trails.
2. Itinerary: scores 3.53-4.53, indicating variety and completeness of the experience.
3. Orientation: scores 2.84-4.11, showing effectiveness of signage and navigation tools.
4. Services and Infrastructure: scores 2.91-3.91, highlighting availability and quality of services.
5. Communication: scores 3.01-4.89, representing effectiveness of promotion and available information.
6. Accessibility of the starting point via public transport: scores 2.14-3.75, evaluating ease of reaching the itinerary's start.

Figure 6.6 - Walking Attributes Scores for each Calabrian Way.

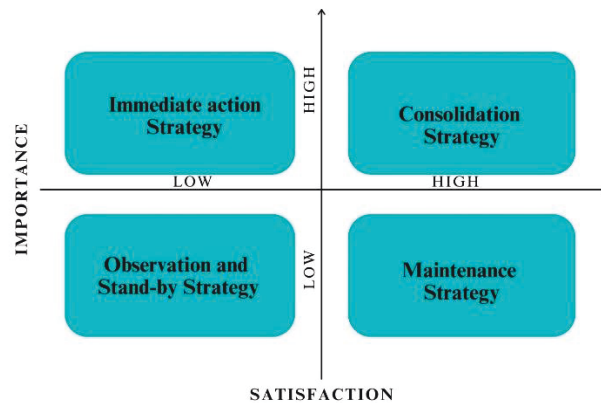


Attractiveness analysis is supported by a matrix representing walkers' satisfaction on the x-axis and the importance of each factor on the y-axis (Figure 6.7). The four-quadrant matrix constitutes a strategic tool to identify areas for intervention and improvement:

1. top-right quadrant: highly rated factors considered important. Interventions aimed at consolidating these strengths;
2. top-left quadrant: important factors with low satisfaction. Necessity to improve walkers' perception, possibly with institutional resources;

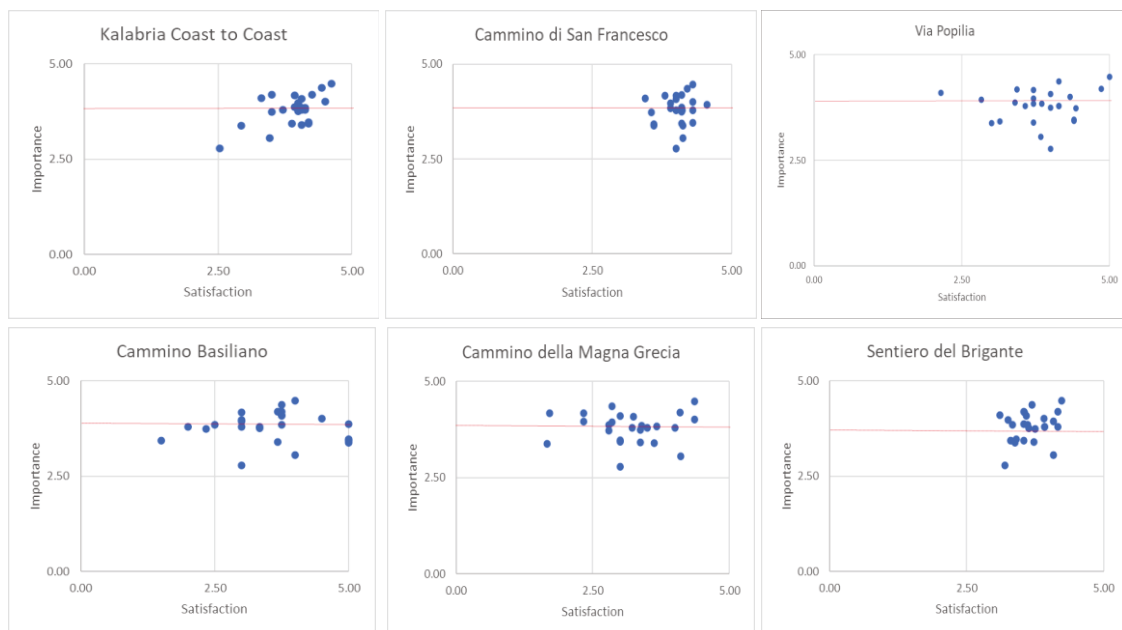
3. bottom-right quadrant: positively rated factors but less relevant. Maintain quality, allocating resources to more critical aspects;
4. bottom-left quadrant: factors of low importance and negatively rated. Monitoring and reduction of investments if not strategic.

Figure 6.7 - Satisfaction/Importance Matrix with corresponding suggested strategies.



Applying the matrix to Calabrian itineraries, currently none fall into the lower quadrants, as all importance values exceed 2.50 (Figure 6.8). Considering the median of scores (3.84), contingent strategies can be identified, such as focusing investments on Cammino della Magna Grecia to improve signage, water sources and accommodation, while consolidating positive aspects such as landscape and direct contact with organizers.

Figure 6.8 - Satisfaction/Importance Matrices for each itinerary, with central value of satisfaction
X Axis scale from "Dissatisfied" to "Extremely Satisfied",
Y Axis scale from "Not at all important" to "Very important" (n=125).



The transition from “walkability” to “attractiveness” represents a significant evolution in the design and management of pedestrian spaces, including long-distance walking itineraries. While walkability focuses on safety and ease of movement, attractiveness integrates emotional and

aesthetic elements, enhancing natural landscapes, architecture, public art and cultural points of interest along the route. The walking experience thus becomes more engaging, with challenges and roughness enriching the path and creating positive emotions and lasting memories.

Enhancing path attributes emerges as crucial for pedestrian satisfaction, with particular attention to landscape beauty and overall experience quality. The integration of digital tools and connection with intermodal nodes improves accessibility and engagement, promoting slow and sustainable mobility. Walking itineraries support more conscious tourism, distributing tourist flows, preserving high-demand areas and enhancing marginal regions, supporting local economies and active mobility practices. The proposed methodology allows evaluation of path attractiveness and correlates the most relevant factors with satisfaction level, providing strategic guidance for the design, management and promotion of walking itineraries in national and international contexts, contributing to the development of sustainable and memorable tourist experiences.

6.5 Risk assessment of walking itineraries according to the Impact/Likelihood Matrix and identification of preventive and subsequent measures

Pedestrian safety today represents one of the most urgent challenges in the field of road safety. According to the WHO Global Status Report on Road Safety 2023 [1], in 2021 about 1.19 million people lost their lives in road accidents, of which about 21% were pedestrians. The percentage varies considerably between regions, reaching 40% in Africa and dropping to 14% in South-East Asia, testifying to infrastructural and systemic differences, especially in low-income countries. The WHO pedestrian safety manual [2] highlights that pedestrian deaths increase almost twice compared to other road users, with a per km risk nine times higher than that of vehicle occupants. Road accidents also have a strong economic impact, ranging between 1% and 3% of national GDP and, in some cases, up to 6%, contributing to the perpetuation of poverty and affecting the most vulnerable. In response to this issue, the United Nations launched the Decade of Action for Road Safety 2021-2030 [3] and subsequently reaffirmed the commitment of Member States with resolution [4], promoting integrated strategies that combine safe infrastructures, regulations, data collection and awareness campaigns, with particular attention to children, young people and the elderly.

The research of Shrinivas et al. [5] indicates that pedestrians represent about 26% of global victims and identifies key factors that influence the severity of accidents, including impact speed, age and even dark clothing [6]. These studies highlight the need for a multidimensional approach that integrates behavioural, infrastructural and vehicular factors to mitigate pedestrian risks.

In addition to road safety, safety from intentional risks such as thefts, assaults or harassment is also increasingly important, influenced by lighting, urban design and surveillance. For this reason, in the present work the term “accidents” includes both accidental events and intentionally harmful events.

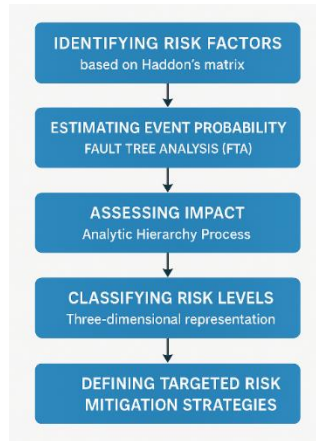
Pedestrian safety, both urban and extra-urban, requires adequate infrastructures, traffic calming, flow separation and attention to environmental conditions. International examples such as the Camino de Santiago highlight how long-distance walking itineraries require detailed risk analysis, taking into account user volume, vehicle speed, traffic, visibility and the vulnerability of the most fragile groups, such as the elderly and women [7], [8].

Within the present research work, an integrated methodological approach is proposed for the assessment and management of pedestrian risks, with practical implications for infrastructural design and sustainable mobility policies.

6.5.1 Methodology for risk analysis and classification

To systematically assess and classify risks, the proposed methodology (Figure 6.9) integrates a multidimensional framework based on qualitative and quantitative approaches, structured into five main phases: identification of risk factors according to Haddon's matrix [9], estimation of event likelihood, impact assessment, classification of risk levels and definition of targeted mitigation strategies.

Figure 6.9 - Proposed methodology for risk analysis.



Identification of risk factors based on Haddon's matrix (USE factors)

Haddon's matrix analyses factors related to personal characteristics (pedestrian), to the vector or agent (vehicles, infrastructures) and to the environment, dividing the observation into three phases: before, during and after the event. For pedestrian mobility, urban and extra-urban itineraries present different risks, due to traffic, crime, isolation or natural factors. The factors are categorized as:

- **user factors (U):** age, gender, walking alone or in a group, physical condition, level of awareness;
- **system factors (S):** surface quality, crossings, signage, lighting, rest areas;
- **environmental factors (E):** weather conditions, traffic density, presence of animals, crime rates.

Each factor receives a score based on expert evaluation and is subsequently weighted through techniques such as the Likert scale or AHP (Analytic Hierarchy Process). The final weighted score for each factor is calculated by multiplying the objective score and the assigned weight:

$$U_i = \sum_{j \in U} w_j * U_{j,i} \quad (7)$$

$$S_i = \sum_{k \in P} w_k * S_{k,i} \quad (8)$$

$$E_i = \sum_{l \in E} w_l * E_{l,i} \quad (9)$$

where:

$U_{j,i}$ is the score of the j -th User factor for risk i ;

$S_{k,i}$ is the score of the k -th infrastructural System factor for risk i ;

$E_{l,i}$ is the score of the l -th Environmental factor for risk i ;

w_j, w_k, w_l are the weights of the respective factors.

Estimation of event likelihood

The probability of an accident occurring is estimated using Fault Tree Analysis (FTA), which models the logical relationships between contributing factors. If multiple independent causes $P_{j,k,l}$ contribute to risk i through an “OR” logic, the probability is:

$$P_i = 1 - \prod_{(j,k,l)} (1 - P_{j,k,l}) \quad (10)$$

If multiple independent causes $P_{j,k,l}$ contributes to risk i through an “AND” logic, the probability is:

$$P_i = \prod_{(j,k,l)} P_{j,k,l} \quad (11)$$

where $P_{j,k,l}$ is the probability of each contributing factor leading to the event.

Impact assessment

The impact of an accident is evaluated using scoring methods similar to step 1. Alternatively, AHP can be employed to weigh different impact factors according to their relative importance.

Risk classification and graphical representation

Once likelihoods, impacts and USE factor scores are determined, the overall risk level must be calculated (12). The proposed risk analysis starts from the calculation of a score assigned to individual risk factors as indicated by international standards (ISO 31000), which means that the risk R_i is calculated as the product of the likelihood that the hazardous event i -th will occur P_i and the impact that would result I_i , followed by the introduction of risk modulation coefficients based on personal factors U_j , infrastructural factors S_k and environmental factors E_l .

The risk R_i associated with each type of risk i occurring along the itineraries is therefore expressed by the following formula:

$$R_i = P_i * I_i * (\sum_{j \in U} U_{j,i}) * (\sum_{k \in S} S_{k,i}) * (\sum_{l \in E} E_{l,i}) \quad (12)$$

where: P_i represents the likelihood that risk i occurs; I_i indicates the impact in terms of consequences caused by risk i ; U_j are the personal factors related to risk i ; S_k are the infrastructural system factors related to risk i ; E_l are the environmental factors related to risk i .

Based on P_i , risks are classified into three levels:

- **low risk level**, represented as green zone, indicates situations in which both the likelihood of an accident and the potential consequences are minimal, together with favourable conditions in terms of user characteristics, infrastructure and environmental factors;
- **medium risk level**, represented as yellow zone, corresponds to scenarios in which the likelihood of an accident or its impact is moderate, or where some USE factors contribute to increasing vulnerability, requiring attention and possible preventive measures;
- **high risk level**, designated as red zone, highlights critical conditions in which likelihood, impact or contributing factors present significant threats to pedestrian safety; this suggests an urgent need for mitigation strategies to effectively reduce risks.

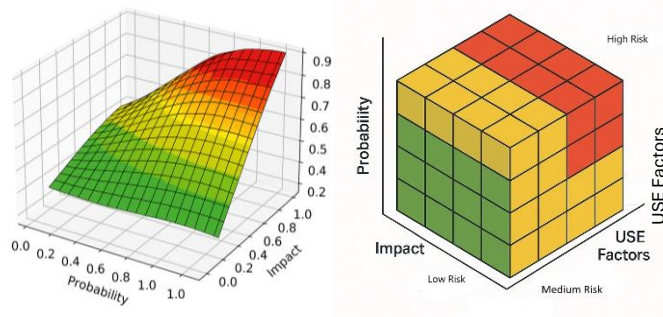
In the proposed risk assessment methodology, two different three-dimensional visualization approaches can be adopted to classify and interpret pedestrian risk levels: **Isorisk Surface** and **Risk Cube**:

- **Isorisk Surface**: risk is seen as a continuous surface, where contour lines connect points with the same risk level; it allows for a gradual transition between risk categories, being particularly suitable for identifying critical thresholds and progressive variations of risk.

This approach is advantageous in large-scale analyses, where risk factors gradually change in space;

- **Risk Cube (3D Grid Representation):** risks are classified into discrete levels within a three-dimensional grid, where each cube represents a specific combination of likelihood, impact and USE factors. Risk cubes facilitate direct classification into low, medium or high risk zones, offering an intuitive and structured representation that supports decision-making. While Isorisk Surfaces are more effective in identifying trends and transitions, Risk Cubes provide a clear classification framework, making them useful for structured risk mitigation strategies.

Fig. 6.10 - Examples of the three-dimensional representation of the Isorisk surfaces and of the Risk Cube.



6.5.2 Definition of strategies aimed at risk mitigation

In the last step, mitigation strategies are developed to reduce risk by acting on: reduction of likelihood (e.g., improving path conditions, increasing awareness campaigns); minimization of impact (e.g., installing protective barriers, applying speed limits); enhancement of USE factors (e.g., better urban planning, increased surveillance). Each strategy is prioritized according to feasibility and effectiveness, ensuring targeted interventions for pedestrian safety. Table 6.7 provides a structured overview of the actions designed to address the main safety risks along pedestrian itineraries in urban and rural contexts. According to Haddon's framework, risks are categorized based on the time phase of the accident, Pre-event (P), Event (E), Post-event (PE), allowing for a comprehensive approach to risk management. For each category, targeted strategies are proposed, ranging from preventive and infrastructural planning (e.g., regular maintenance of paths, vegetation management, public lighting) to real-time systems for monitoring, alarms and emergency response.

It is important to note that in urban areas technological integration tends to be emphasized (e.g., smart lighting, pedestrian monitoring systems, public Wi-Fi), while in rural areas priority is given to infrastructural strengthening and improvement of mobile connectivity, reflecting different spatial limitations and service availability. This temporal and spatial differentiation supports the development of tailored pedestrian safety strategies, sensitive to specific contextual vulnerabilities and resource availability.

The application of the methodology varies depending on whether the routes are urban or extra-urban, due to differences in incident likelihood, potential impact, infrastructure, environmental factors and pedestrian conditions. In urban routes, it is essential to improve pedestrian safety through adequate infrastructure, signage, visibility and protection from criminal threats, ensuring

rapid access to emergency services. In extra-urban routes, the design should include protective natural barriers (shelters or resting points), improved signage and reduced risk of encounters with wild animals, ensuring access for rescuers.

The distinction between urban and extra-urban routes is crucial: in urban areas, high traffic density and the presence of obstacles increase the risk of incidents, whereas in extra-urban routes, risk factors include poorly maintained pedestrian infrastructure, roaming animals and reduced visibility.

To support risk management, the methodology uses a three-dimensional graphical representation based on incident likelihood, consequent impact and USE factors, allowing the identification of critical risks, visualization of their distribution, assessment of their impact and guidance for targeted strategies. Decisions regarding infrastructure modifications, installation of shelters, protection from wild animals and urban traffic management can thus be based on concrete and up-to-date data.

In extra-urban routes, it is particularly important to implement emergency infrastructures, monitoring and alert systems, promoting safe and sustainable pedestrian mobility. Educational and awareness-raising actions aimed at vulnerable pedestrians complete the interventions, encouraging safer behaviours.

Table 6.7 - Context-Specific Risk Management Strategies for Pedestrian Safety in Walking Routes.

Risk/Time		Urban	Rural
Physical obstacles	P	Regular path maintenance and planning	
	E	Routing towards alternative paths	
	PE	Real-time obstacle reporting system	
Illness, injury or similar	P	Difficulty maps based on user type	Difficulty maps based on user type; training
	E	Emergency medical call systems; emergency response stations	
	PE	Preventive analysis of healthcare center locations and emergency response times	
Difficulty of the route/Length	P	Design of routes with varying levels of difficulty and intermediate access points to easier paths	
	E	Real-time monitoring alerts	
	PE	Real time re-routing system	
Lack of resting area/accommodation	P	Planning the placement of benches and rest areas	Plan accommodation and emergency shelters; pre-book system
	E	Real-time monitoring system with indications of resting points	
	PE	On-demand shuttle system	
Lack of food or shopping points/water sources	P	Plan and map shopping or delivery points/water sources	
	E	Real-time monitoring system with indications of shopping points/water sources	
	PE	On-demand delivery system	
Isolation/Lack of mobile connection	P	Installation of surveillance cameras; create public Wi-Fi coverage areas	Installation of surveillance cameras and preventive departure notification system; improve infrastructure and mobile network access in rural areas; installation of signal repeaters
	E	Real-time presence monitoring or notification systems; emergency systems on autonomous telecommunication networks	
	PE	On-demand shuttle system	
Fires/Natural disasters/Sudden weather events	P	Vegetation management; installation of automatic irrigation systems; adoption of fire-resistant materials for buildings and pavements	Fire barriers and path warnings in rural areas; preventive analysis of fire brigades locations and emergency response times
	E	Alert systems; escape routes; real-time monitoring and alerting systems	
	PE	Install emergency kiosks or visible alert systems along the path	
Lack of signage/Getting lost	P	Design, install and maintain visible signs; provide maps	
	E	Real-time pedestrian monitoring system	
	PE	System for directing and recovering lost pedestrians	
Bedbug/insect/snake/tick bites	P	Maintenance of green areas	Maintenance of green areas; checks on accommodation facilities
	E	First aid kit	
	PE	Contact system for reporting and requesting intervention	
Insufficient illumination	P	Ensure urban lighting along pathways	Self-sustaining lighting
	E	Smart lighting	
	PE	Implement a contact system for pedestrian assistance	
Criminals, attacks, sexual violence	P	Urban surveillance, neighborhood watch programs	Surveillance
	E/PE	Contact system for reporting and requesting intervention	
Hunters	P	//	Create awareness about hunting seasons and restricted zones
	E/PE	Contact system for reporting and requesting intervention	
Aggressive animals	P	Urban animal control and public awareness	Avoid paths with known animal activity
	E/PE	Contact system for reporting and requesting intervention	
Being run over	P	Implement pedestrian safety infrastructure, signs	Plan designated pedestrian paths
	E/PE	Contact system for reporting and requesting intervention	

6.6 Framework for the evaluation of walking itineraries according to Doughnut Economics

To integrate the evaluation of services and performance along walking itineraries, the conceptual model of Doughnut Economics [10] provides a useful framework to analyze mobility not only in terms of functionality and safety, but also considering social and environmental sustainability (Figure 6.11). This approach allows assessing whether the infrastructures and services offered respect the ecological limits of the territory and ensure conditions of accessibility, inclusion and well-being for all users, fostering a more responsible, balanced and resilient management of long-distance walking routes.

The Doughnut Economics approach, developed by Kate Raworth, constitutes a theoretical framework particularly suitable for integrating principles of environmental sustainability, social equity and the management of long-distance walking itineraries. The model defines a social minimum threshold, necessary to guarantee human well-being and an ecological maximum threshold, aimed at avoiding the exceedance of ecosystem carrying capacities. Applied to long-distance itineraries, this paradigm allows the design and management of routes that promote positive and accessible user experiences while preserving the environmental integrity of the traversed territories.

From a social perspective, the approach suggests that itineraries should ensure safety, accessibility, adequate services and cultural opportunities, promoting inclusion and social cohesion. From an ecological perspective, route management must prevent trail erosion, protect biodiversity and minimize impacts deriving from infrastructures and activities related to tourist mobility. The integration of digital tools, such as route planning applications, environmental sensors and GIS systems, allows real-time monitoring of compliance with ecological and social limits, facilitating targeted and timely interventions.

Finally, adopting Doughnut Economics in the design of long-distance itineraries supports the resilience of local communities, promoting sustainable and distributed tourism that reduces pressure on high-traffic areas and enhances local economies. In this way, walking routes become concrete tools for sustainable development, integrating tourism use, environmental protection and social equity, in line with the objectives of the 2030 Agenda for Sustainable Development.

To evaluate long-distance walking itineraries in terms of social, environmental and economic sustainability, a multi-phase methodological procedure in 8 steps is here proposed, scalable from the local to the transnational level, integrating stakeholder engagement, the definition of measurable KPIs and continuous monitoring.

A. Definition of the context and objectives of the itinerary

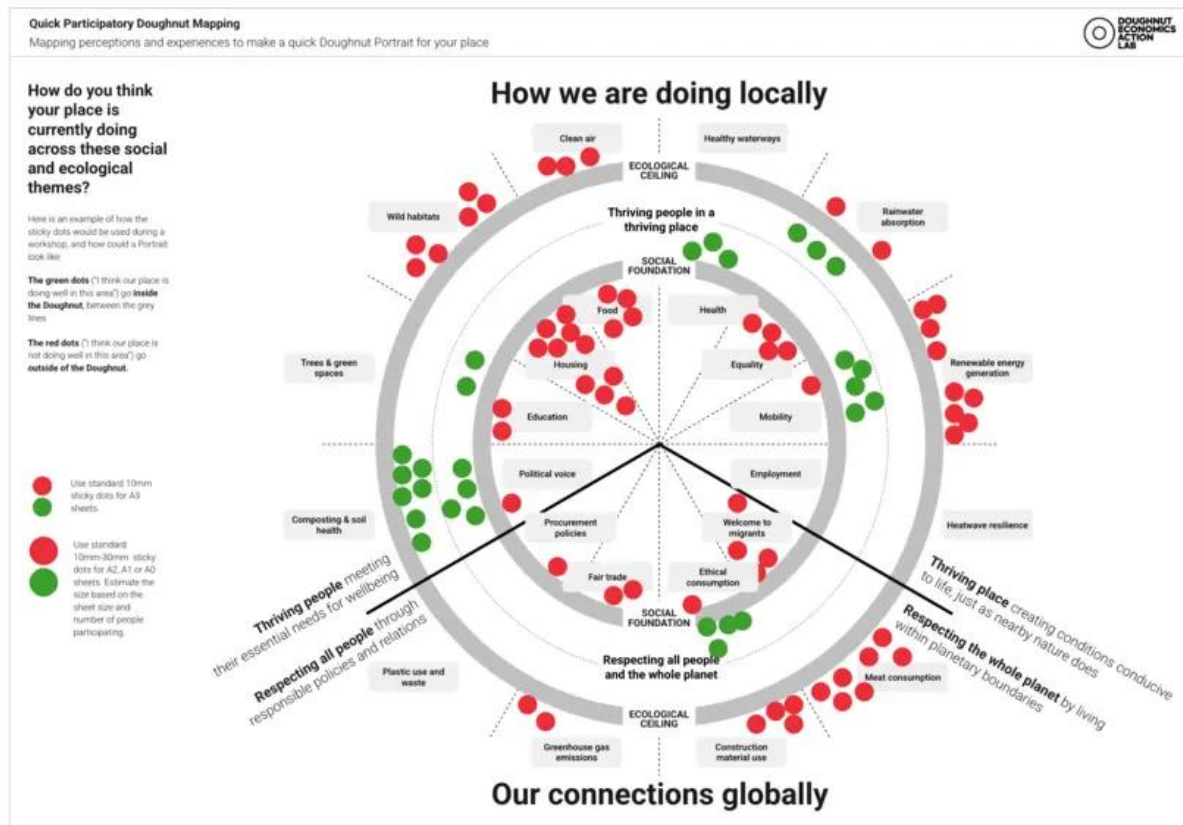
The process begins with defining the context and main objectives of the walking route, such as inclusive mobility, safety, access to services, slow tourism and cultural enhancement. Simultaneously, reference thresholds are established according to the principles of Doughnut Economics: the social foundation (right to mobility, safety, inclusion) and the ecological ceiling (emission reduction, biodiversity protection, territorial impact).

B. Participatory stakeholder engagement

Participatory workshops inspired by the Quick Participatory Doughnut Mapping of DEAL [11] are organized, with local and regional representation, including residents, administrators, tourism operators and urban planners. During the meetings, participants jointly define:

- foundational social indicators (accessibility, perceived safety, inclusion, benefits for communities);
- ecological indicators (avoided emissions, land use, environmental quality).

Figure 6.11 - The workshop sheet and how a Quick Doughnut Portrait could look like.



Source: doughnuteconomics.org [11]

C. Structuring the thematic “Doughnut” for itineraries

A wheel with two concentric circles is built: the inner ring represents the social foundation, while the outer ring represents the ecological limits. This visual tool allows verifying whether the itinerary falls within the “safe and just space.”

D. Definition of evaluation criteria and KPIs

The next step is the identification of evaluation criteria and the corresponding KPIs (Table 6.8).

Table 6.8 - Dimensions, criteria, KPIs and data collection methods.

Dimension	Criterion	KPI	Score Scale (0-4)	Data Collection Method
Social Foundation	Accessibility	% of population with access to entry points within 5 km	0 = 0% ... 4 = 100%	GIS, local demographic data
	Safety	Pedestrian accident rate per 100,000 passages; qualitative PERS audit	0 = >50 accidents ... 4 = <5 accidents	Accident data, site inspections, checklists
	Social Inclusion	Distribution of users by gender, age, disability; average access cost/income	0 = low inclusion ... 4 = high inclusion	Surveys, questionnaires, socio-economic data
	Local Community Benefits	Number of micro-enterprises/services per km; € generated per km	0 = <1 enterprise/km ... 4 = >10 enterprises/km	Local economic data, business registers
	Cultural Enhancement	Number of accessible cultural sites per 10 km; informational signage index	0 = no sites, signage absent ... 4 = well-accessible sites, complete signage	Site inspections, GIS, cultural catalogs
Ecological Ceiling	Emission Reduction	t CO ₂ avoided thanks to pedestrian mobility	0 = <10 t ... 4 = >1000 t	Calculation of emissions from motorized transport substitution
	Land Use and Territorial Impact	Additional impervious area per km; % of route with permeable materials	0 = high consumption ... 4 = minimal consumption	GIS, field surveys
	Biodiversity Protection	Habitat Connectivity Index; number of protected species recorded	0 = low connectivity ... 4 = high connectivity	Ecological monitoring, biological data
	Waste and Resource Management	Number of recycling bins every 5 km; % of sustainable water	0 = absent ... 4 = fully available	Site inspections, local manager data
	Perceived Environmental Quality	Average sound level (dB); microclimatic comfort index	0 = >80 dB, <20% comfortable days ... 4 = <60 dB, >80% comfortable days	Environmental sensors, climatic measurements

E. KPI Scoring Scale

Each KPI is evaluated on a scale from 0 to 4, where 0 indicates a critical deficit and 4 an optimal practice:

- 0 = Critical, minimum threshold not met;
- 1 = Low, partial compliance;
- 2 = Sufficient, basic standard met;
- 3 = Good, criteria consistently satisfied;
- 4 = Excellent, benchmark model.

F. Multilevel Application and Supra-local Adaptability

The approach is multi-scale, allowing local, regional and supranational aggregations and supports decisions on infrastructural, environmental, or managerial improvements:

- local level: assessment of accessibility, safety and specific ecological impacts for each municipality crossed;

- regional level: analysis of connectivity among communities, tourist flows and coordinated governance of natural resources;
- national and international level: monitoring of avoided emissions, integration with public transport, shared cultural promotion and sustainable development policies.

G. Implementation, Monitoring and Visualization

Data are collected through GIS, environmental sensors, pedestrian counters and surveys. Monitoring is continuous or periodic (annual or biennial) and results are represented with radar charts or Doughnut diagrams to visualize strengths and criticalities along the route. Aggregated analysis allows comparison of segments, regions, or national routes and the definition of intervention priorities.

H. Iteration and Updating

The assessment is iterative: initial evaluations identify criticalities and strengths, while periodic updates verify the effectiveness of corrective actions, such as infrastructural improvements, environmental rehabilitation and awareness campaigns.

Therefore, in long-distance walking routes, Doughnut Economics is not applied as a “single static portrait,” but as a network of interconnected local and regional portraits. This multi-scale approach allows the evaluation of social, environmental and economic sustainability in a consistent and comparable manner, supporting the planning, management and continuous improvement of pedestrian routes.

6.7 Evaluation according to equity criteria

The evaluation of long-distance walking itineraries can be effectively approached through the lens of equity, considering the route not as an end in itself but as a tool to ensure access, participation and opportunities for all potential users. As in transport systems, a perspective focused exclusively on infrastructure or route duration tends to favor specific user groups, such as experienced walkers, adult men, or individuals with greater physical ability and leisure time, while other categories (women, people with reduced mobility, elderly, families with children, or occasional tourists) risk being excluded from the benefits of the route or facing significant difficulties [12], [13], [14].

Considering the itinerary as a means implies adopting a strategic vision that goes beyond mere route use, aiming to transform it into a tool for equitable and sustainable territorial development. In this context, equity does not only ensure physical access to the route but extends to promoting growth opportunities for local communities, respecting social, cultural and economic diversity.

Long-distance itineraries can act as catalysts for local development, stimulating the economy through sustainable tourism, enhancement of cultural heritage and promotion of natural resources. However, for these benefits to be equitably distributed, inclusive practices in route design and management are essential, actively involving local communities in decision-making and recognizing their needs and aspirations. A notable example of this approach includes the “Reconnecting Communities” and “Rails to Trails Conservancy” initiatives in the United States, which promote trail networks in historically disadvantaged areas, ensuring local communities can define how the routes are conceived, designed and constructed, guaranteeing that residents directly benefit from their use and impact.

Equity in this context also implies recognition of the cultural and historical diversity of the territories crossed. For instance, the “Native Lands, National Trails” project in the United States

aims to highlight how modern hiking trails interact with ancestral indigenous lands, promoting greater awareness and collaboration with native communities. In Italy, a notable case is represented by the “Sentieri Metropolitani” in Milan, which connect urban and peri-urban areas through hiking routes, encouraging the discovery and enhancement of often overlooked territories and promoting social and cultural inclusion of diverse local communities.

The evaluation of itineraries according to equity criteria therefore requires adopting indicators capable of measuring the distribution of benefits and costs among users with different characteristics and needs. These include physical and economic accessibility of the route, perceived safety, availability of essential services, compatibility with different physical capacities, quality of support infrastructure (accommodation, refreshment points, supplementary transport) and participation of vulnerable groups in planning decisions. Applying these criteria enables the design of inclusive, sustainable and environmentally respectful routes, promoting socialization, territorial enhancement and equitable tourist experiences for all [15], [16], [17], [18].

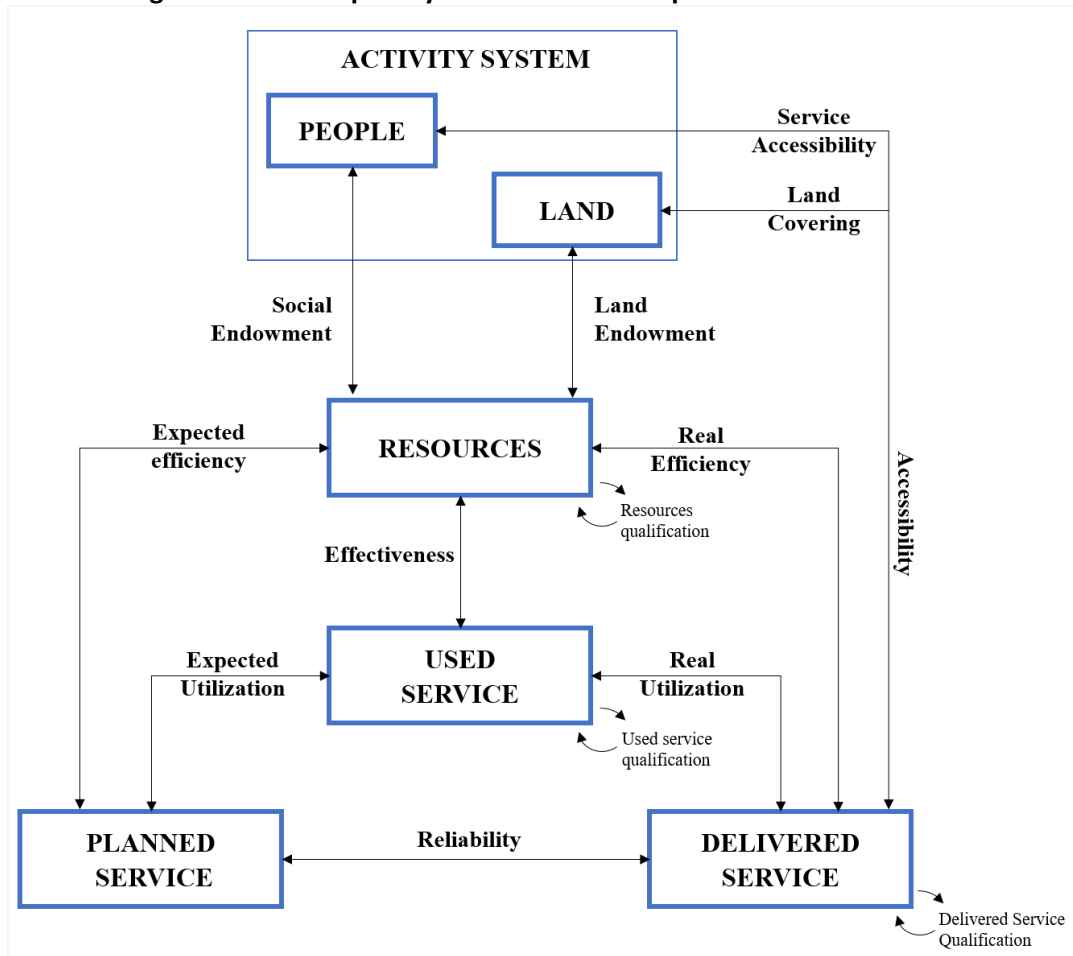
Therefore, considering long-distance walking itineraries as a means for equitable territorial development implies recognizing the route not only as a physical path but as an opportunity to promote social inclusion, cultural enhancement and economic sustainability. Through participatory design and respect for diversity, it is possible to transform these itineraries into development tools that equally benefit all involved communities.

In the context of long-distance routes, the concept of “equity” refers to the fair distribution of resources and services, aiming to support the most vulnerable user groups and less-equipped territories in fostering sustainable mobility. To operationalize this concept, a structured framework inspired by public transport performance assessment studies can be adopted (Figure 6.12), adapted to pedestrian routes and slow tourism [19].

The framework organizes variables into five main clusters:

- Activity System, grouping data on the physical and socio-economic context of the routes, including population density, land use, territory morphology, accessibility to transport nodes, presence of points of interest and natural obstacles along the route;
- Resources, including both tangible and intangible assets required for route management and maintenance, such as the number of hostels, refuges, rest points, maps, signage, support tools (e.g., shuttles or backpacks), personnel and the overall length and connectivity of the route;
- Service Delivered, which measures the service actually made available to users, including the maintained and accessible route length, number of equipped rest points, functioning signage, availability of supplementary transport and overall route safety;
- Planned Service, describing the service as originally intended, including the planned availability of routes, rest points, signage, maps, supplementary transport and safety standards established at the start of the management period;
- Service Utilized, representing the demand dimension, recording actual use by walkers, such as number of users per segment, frequency of facility usage, average route duration and user satisfaction with available services.

Figure 6.12 - Transport System variables and performance indicators.



From the diagram, the following performance indicators can be derived:

- Efficiency (actual or expected) expresses the ratio between delivered or planned service and resources employed. For example, actual efficiency (E_r) measures kilometers of walkable route per resource converted into euros (sum of personnel costs and maintenance budget), while expected efficiency (E_a) evaluates planned kilometers per allocated resources. These indicators allow comparison of how effectively economic and human resources are used.
- Effectiveness measures the extent to which the delivered service is actually used by users. For example, user effectiveness (E_u) considers the number of walkers relative to resources and active route segments, while economic-service effectiveness (E_e) evaluates revenue generated by walkers (credentials, food, accommodation) relative to total revenue. These indicators help assess whether the service is effectively utilized.
- Degree of Utilization (actual or expected) indicates how much of the delivered or planned service is actually consumed. The Gur indicator measures the number of walkers per kilometre of walkable route, while the Gua indicator considers the number of planned credentials per kilometre. These values reflect the average load of routes in terms of users per kilometre or per rest point.
- Reliability measures the correspondence between the service actually delivered and the planned service. Indicators such as Af (reliability), Cs (signage coverage) and Pa (% accessible route) assess maintenance, safety and signage quality, comparing walkable lengths, safety standards and accessible points with project specifications.

- Endowment links resources to territorial or demographic characteristics. Indicators such as Dpu (endowment per user), Dr (route network density), Ra (network per inhabitant) and PIKm (beds per km of route) quantify resource distribution (route, rest points, accommodation) relative to population, area served, or number of users, allowing evaluation of infrastructural adequacy.
- Accessibility, broadly defined, reflects the interaction between service provision and the territorial system. Indicators such as Ct (territorial coverage) and CsR (delivered service coverage) measure the area actually served by the route relative to territory and population involved, while Pa (% accessible route) and Cac (annual walker coverage) evaluate the ease of reaching points of interest and the distribution of route use throughout the year.

From these indicators, equity assessments of routes are derived: territorial equity, evaluated as the fair distribution of infrastructure and services across the territory; and social equity, assessing accessibility of delivered services to different user groups, considering physical or demographic vulnerabilities. Differences between actual and expected efficiency or between actual and expected degree of utilization provide valuable insights into gaps between planned outcomes and results actually achieved.

Finally, qualification indicators can be defined, expressed as percentages, representing the proportion of quality resources or services relative to the total available, such as the ratio between accessible refuges and total refuges, functioning signage versus total signage, or certified segments versus total segments. These indicators are fundamental for monitoring equitable and sustainable mobility along long-distance routes, ensuring access for all users and maintaining environmental, social and economic sustainability values (Table 6.9-6.14).

Table 6.9 - Territorial Characteristics Metrics.

Metric	Symbol	Measure Unit	Explanation
Territory Area	At	km ²	Total area of the territory crossed by the walking route
Resident Population	Pt	inhabitants	Number of residents in the territory affected by the walking route
Population Density	Dt	inhabitants/km ²	Population per unit area
Walkable Area	Sp	km ²	Area of influence of the route, e.g., 5 km extension to the right and left of the linear path
Number of Accommodation Facilities	Sr	n	Lodgings, hostels and hotels available along the route
Total Beds	Pl	n	Total beds available along the route
Route Network Length	Rc	km	Total length of the route available

Table 6.10 - Resources Metrics.

Metric	Symbol	Measure Unit	Explanation
Total route length	L	km	Sum of walkable segments
Number of stages	Nt	n	Count of stages along the route
Number of rest areas	Ns	n	Shelters or rest areas available
Signage provision	Ds	n	Total number of signs and indicators present
Human resources	Rh	n persons	Guides, maintenance staff, volunteers and operators
Supplementary transport	Ti	n	Support vehicles for the route (shuttles, transfers)
Available water sources	Fd	n	Number of water sources along the route
Involved business facilities	Si	n	Lodgings, restaurants, partner commercial establishments
Activated collaborations in	Ct	n	Entities, associations and stakeholders involved in

the territory			management
Maintenance budget	Bm	€	Economic resources dedicated to maintenance
Points of interest (Poi)	Poi	n	Number of points of interest (natural, historical, cultural, etc.)

Table 6.11 - Planned service Metrics.

Metric	Symbol	Measure Unit	Explanation
Planned length	Lp	km	Length planned in the project
Number of planned stages	Ntp	n	Stages planned at the beginning of the period
Planned rest areas	Nsp	n	Rest areas scheduled
Planned signage coverage	Csp	%	Percentage of segments with planned signage
Planned supplementary transport	Tip	n	Planned support vehicles
Planned accessibility of key points	App	%	Percentage of planned key points accessible
Planned budget	Bmp	€	Planned economic resources
Planned personnel	Php	n persons	Planned guides and operators
Planned maps and guides	Mpp	n	Number of planned maps or guides
Planned safety standards	Spp	%	Percentage of segments planned to comply with regulations
Planned number of credentials	Ncp	n	Number of credentials planned to be issued
Planned support services	Ssp	n	Backpack transport, insurance, guided accompaniment, etc.

Table 6.12 - Metrics of Delivered Service.

Metric	Symbol	Measure Unit	Explanation
Accessible length	Lr	km	Length actually accessible and safe
Equipped stages	Nta	n	Number of stages provided with services
Actual signage coverage	Csr	%	Percentage of sections with functioning signage
Active refreshment points	Ar	n	Number of refreshment points actually operational
Updated maps	Mu	n	Maps available and up to date
Active supplementary transport	Tf	n	Support vehicles actually operational
Cleaning and maintenance	Mp	%	Percentage of sections in good condition
Staff present	Ph	N persons	Guides and operators available
Actual accessibility of key points	Ap	%	Percentage of key points actually accessible
Actual safety	Sr	%	Percentage of sections compliant with safety standards
Credentials issued	Ncr	n	Actual number of credentials delivered
Final certificates issued	Naf	n	Number of walkers completing the route
Active support services	Ssa	n	Number of additional services actually operational

Table 6.13 - Metrics of used service.

Metric	Symbol	Measure Unit	Explanation
Number of walkers	Nc	n	Actual users of the trail
Frequency per stage	Ft	pers/day	Average number of people per stage per day
Average travel time	Tm	h	Average time to complete the trail
Use of rest points	Us	pers	People using the rest points
Use of supplementary transport	Ut	pers	People using supplementary transport
Resource consumption	Cr	%	Percentage of resources actually consumed
User satisfaction	Su	scale 1-5	Average rating by walkers
Number of overnight stays	Np	n	Total overnight stays recorded
Incidents or problems	I	n	Number of negative events recorded
Credentials used	Ncu	n	Credentials actually collected/used
Additional services used	Ssu	n	Number of additional services actually used

Table 6.14 - Performance Indicators.

Indicator	Formula	Measure Unit	Explanation
Actual efficiency (Er)	$E_r = \frac{L_r}{Rh_{\epsilon} + Bm}$	km/€ equivalent	Service delivered in relation to resources used (human + maintenance budget)
Expected efficiency (Ea)	$E_a = \frac{L_p}{Php_{\epsilon} + Bmp}$	km/€ equivalent	Planned service in relation to allocated resources
Economic-financial effectiveness (Ef)	$E_f = \frac{Ricavi\ totali + Sussidi}{Co}$	%	Service efficiency considering direct revenues and external support
Economic-service effectiveness (Ee)	$E_e = \frac{Ricavi\ cammino}{Ricavi\ totali}$	%	Percentage of revenues directly linked to trail use (credentials, meals, lodging, etc.)
User effectiveness (Eu)	$E_u = \frac{N_c}{Rh + Lr}$	n/resource	Users who have used the service relative to resources and trail actually active
Actual utilization rate (Gur)	$G_{ur} = \frac{Nc}{Lr}$	n/km	Percentage of service actually used by users
Expected utilization rate (Gua)	$G_{ua} = \frac{Ncp}{Lp}$	n/km	Planned usage (planned credentials) relative to planned length
Reliability (Af)	$A_f = \frac{L_r}{L_p} * 100$	%	Ratio between actually accessible length and planned length
Signage coverage (Cs)	$C_s = \frac{Csr}{Csp} * 100$	%	Degree of consistency between actual and planned signage
Credential issuance rate (Trc)	$Trc = \frac{Ncr}{Ncp} * 100$	%	Percentage of credentials actually issued relative to planned credentials
Credential usage rate (Tuc)	$Tuc = \frac{Ncu}{Ncr} * 100$	%	Percentage of credentials actually used by walkers relative to those issued
Completion rate (Tc)	$T_c = \frac{Naf}{Ncr}$	%	Percentage of walkers completing the trail relative to credentials issued
Additional services reliability (Asa)	$A_{sa} = \frac{Ssar}{Ssp}$	%	Ratio between activated support services and those planned
Additional services utilization rate (Gusa)	$G_{usa} = \frac{Ssu}{Ssa}$	%	Percentage of additional services actually used by walkers relative to those provided
Resources per user (Dpu)	$D_{pu} = \frac{Rc}{Nc}$	km/user	Trail length relative to actual number of users
POI allocation (Dpoi)	$D_{poi} = \frac{Poi}{Nt}$	n/stage	POIs available per stage
Territorial coverage (Ct)	$C_t = \frac{Sp}{At} * \frac{Pt}{1000}$	km ² /10 ³ inhabitants	Percentage of area covered by the trail relative to total area and population involved
Trail network density (Dr)	$D_r = \frac{Rc}{At}$	km/km ²	Length of network per unit area
Network per inhabitant (Ra)	$R_a = \frac{Rc}{Pt/1000}$	km/10 ³ inhabitants	Network length relative to population
Resource qualification (CoCt)	$CoCt = \frac{Co}{Ct} * 100$	%	Share of operating costs over total costs
Maintenance cost / total costs (CmCt)	$CmCt = \frac{Cm}{Ct} * 100$	%	Share of maintenance costs over total
Operating cost per inhabitant (CoPa)	$CoPa = \frac{Co}{Pt/1000}$	€/10 ³ inhabitants	Efficiency of operating costs relative to population
Operating cost per involved person (CoPi)	$CoPi = \frac{Co}{Nc}$	€/user	Efficiency of operating costs relative to users
Beds per km of trail (PIKm)	$PIKm = \frac{Pl}{Rc}$	n/km	Accommodation availability along the trail
% unpaved (%Ps)	$P_s = \frac{L_{sterrato}}{L} * 100$	%	Percentage of unpaved trail relative to total length
% salaries over operating costs (PsCo)	$PsCo = \frac{S}{Co} * 100$	%	Share of salaries in operating costs

% accessible trail (Pa)	$Pa = \frac{Lr}{L} * 100$	%	Percentage of trail actually accessible
Realized service coverage (CsR)	$CsR = \frac{Nc}{Ncpotenziale} * 100$	%	How many users benefited from the service relative to the maximum annual potential

6.8. Gender perspective in the perception and management of safety

The assessment of walking trail performance must include the subjective perception of safety, a dimension that assumes different connotations when observed from a gender perspective. The survey conducted and described in the previous chapters highlighted how men and women assign different weights to safe factors (objective safety, related to the physical conditions of the trail, lighting, maintenance) and security factors (subjective safety, related to perceived vulnerability, isolation, risk of assaults).

In particular, it emerged that women tend to perceive trails as less safe than men, especially on isolated or poorly serviced sections, thereby influencing their propensity to traverse them and the overall evaluation of walkability, PLOS and QoS. Men, on the other hand, tend to give greater importance to infrastructural aspects and route continuity, while for women elements of protection and the presence of support services assume priority significance.

This gender-based approach allows safety to be read not only as a technical requirement but also as a factor that affects satisfaction, perceived quality and actual use of the network. The integration of survey data with performance measures thus enables the identification of criticalities that affect users differently, guiding planning towards interventions aimed at ensuring accessibility, comfort and protection conditions that promote equitable and sustainable trail use.

Concrete measures to address these criticalities can include (Table 6.15) improving lighting along the most isolated sections, installing information panels and clear signage to reduce disorientation, creating safe and supervised rest areas, providing emergency or quick-call points and regular vegetation maintenance to enhance visibility and reduce areas perceived as unsafe. If prioritized at nodes and sections identified as critical by the survey, these interventions contribute to improving overall walkability and ensuring equitable, safe and satisfying use for all users, promoting inclusion and sustainability of long-distance trails.

Table 6.15 - Examples of metrics for managing trail safety from a gender perspective.

Metric	Effect on perceived safety	Priority from a gender perspective
Lighting of isolated segments	Reduces the sense of vulnerability and perceived risk of assaults	Particularly relevant for women
Clear signage and information panels	Decreases disorientation and increases wayfinding	Equally important for men and women
Safe and supervised rest areas	Provide reassuring reference points and protected rest opportunities	More valued by women
Emergency points / quick call	Reinforces sense of control and protection in case of unexpected events	Particularly appreciated by women
Vegetation maintenance and management	Improves visibility, reducing areas perceived as unsafe	Relevant for both genders
Continuity of paths and direct connections	Increases efficiency and reduces travel times	More relevant for men, but also useful for women
Availability of services (bathrooms, shelters, refreshment points)	Increases comfort, safety, and extended usability	More appreciated by women

6.9 Safety and inclusivity: considerations for all walkers

The assessment of walking trail performance must extend the concept of safety beyond the gender perspective, encompassing the full heterogeneity of walkers. Safety and inclusivity thus become complementary dimensions aimed at ensuring that trails are accessible, usable and perceived as reliable by users with different characteristics, abilities and needs.

Objective safety concerns the physical integrity of trails (absence of barriers, stability of sections, regular maintenance, adequate signage), while perceived safety relates to walkers' ability to feel protected and oriented along the trail. Inclusivity, instead, emphasizes the importance of adapting trails to different groups: elderly people who require frequent and well-equipped rest areas, families with children who prefer easily accessible and safe sections, walkers with disabilities who need obstacle-free infrastructure and accessible solutions.

In this sense, evaluation measures such as PLOS and QoS must consider not only the average perceived quality but also disparities in use among user categories. For example, a steep section or one without resting points may be acceptable for experienced walkers but penalizing for elderly people or those with reduced mobility. Similarly, the lack of digital orientation services may limit the experience of foreign tourists or less experienced walkers.

Integrating safety and inclusivity in trail assessment therefore directs planning towards a universal mobility model, capable of combining technical standards with attention to subjective needs. This increases not only objective and perceived safety but also the participation of a broader user base, enhancing the attractiveness and social value of long-distance trails.

In this perspective, the adoption of specific metrics (Table 6.16) allows planning to focus on truly universal pedestrian mobility. Some examples of inclusive indicators are:

- presence of accessible sections: share of the trail free of architectural barriers (stairs, height differences, unstable surfaces);
- frequency and accessibility of rest areas: availability of equipped and easily reachable spaces at regular intervals;
- universal signage: presence of pictograms, simple languages, multilingual translations, Braille information, or audio QR codes;
- access to essential services: percentage of nodes with accessible bathrooms, water points, refreshment stops, shelters;
- digital support tools: availability of applications or information kiosks for orientation and assistance, inclusive for foreigners and inexperienced users;
- widespread and uniform lighting: not only as objective safety but also as an inclusion tool for visually impaired people or those walking in the evening;
- parallelly, the design process must include direct involvement of walkers through participatory tools. This approach allows the collection of differentiated qualitative data by profile and better directs interventions.

Table 6.16 - Examples of inclusive metrics and participatory tools for the evaluation of walking itineraries.

Metric	How to measure	Suggested participatory tools	Objective
Accessible sections	% of route free of barriers	Walking audit with people with disabilities	Identify physical and perceptual criticalities
Accessible rest areas	No. of equipped areas every X km	Focus groups with elderly and families	Improve comfort and continuity of the route
Universal signage	% of panels with pictograms, multilingual, braille	Participatory mapping with tourists and associations	Facilitate orientation for all
Accessible essential services	% of nodes with universally usable services	Questionnaires to walkers during the routes	Extend functional accessibility
Digital tools	No. of applications or totems active along the route	Collaborative online platforms	Support inexperienced or foreign users
Inclusive lighting	% of sections with widespread lighting	Multi-group safety audit	Increase perception of evening safety

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Chapter 7

Management and logistics of services for tourist pedestrian mobility

7.1 Logistic management for walking itineraries: transport, supply and support

7.1.1 Definition of trail logistics

Pedestrian tourism on long-distance trails is gaining increasing attention both for its experiential value and for its potential impact on the territory and local economy; however, the analysis of the logistic dimension is still underestimated. Yet, the use of multi-stage itineraries, often exceeding 50 km and crossing urban and extra-urban areas, presents numerous logistic challenges that can significantly affect the walker's experience. Among the most relevant issues is the management of luggage transport between stages, often characterized by a lack of reliable services, high costs and informal, poorly traceable organizations, which make it difficult to ensure a consistent service for moving backpacks and suitcases between accommodations. Poor accessibility to departure and arrival points represents another issue, with limited connections to public transport (buses, trains) and times or schedules often incompatible with walkers' needs, both regarding public and private services.

The poor coordination between accommodations and services along the itinerary complicates the complete planning of the trail: difficulties in booking in advance along the entire route and the lack of integrated logistic management systems make organization complex. Moreover, inadequacy of food and water supplies at the most isolated stages, combined with difficulties in ensuring the cold chain or transporting fresh products for organized groups, can limit the safety and comfort of the journey.

Managing flows during peak season highlights additional criticalities, such as congestion in the most touristic stages and a lack of scalable services to cope with demand peaks [1]. Equally relevant is the absence of logistic support in case of unforeseen events, where the difficulty in organizing the recovery of injured or withdrawn walkers is exacerbated by the lack of vehicles or support personnel in remote areas. The logistics of technical equipment, such as footwear, trekking poles, or specific clothing, is often poorly developed, with an absence of rental or repair services along the route. Finally, sustainable transport represents an emerging challenge, due to the scarcity of low-emission vehicles and the difficulty of reconciling logistic comfort with low environmental impact.

It is evident that the logistic management of long-distance itineraries requires an integrated and multidimensional approach, capable of combining operational efficiency, environmental sustainability and quality of the walker's experience, opening new perspectives for the development of pedestrian tourism and slow mobility.

Today, the possibility of receiving a product at home with a simple click highlights the complexity and efficiency of modern logistic systems, whose roots can be traced back to the Sumerians who, with the invention of the four-wheeled cart, devised heavy transport. Subsequently, the Romans developed military logistic practices capable of ensuring a constant supply of food, weapons and equipment, even in hostile territories and adverse conditions. The management of material flows and resources ensured mobility, operational efficiency and continuity of activities, anticipating principles still fundamental in logistics [2].

Subsequently, logistics extended to the industrial and service context, dealing with the planning, implementation and control of material, information and resource flows from supply sources to the final consumer. According to Ballou [3], logistics consists of “getting the right goods or services to the right place, at the right time and under the desired conditions, while simultaneously optimizing the overall contribution to the organization”.

Thus, logistics in its classical definition represents the set of activities for planning, organizing, managing and controlling the flows of materials, people and information within a system, with the aim of optimizing resources, reducing time and costs and ensuring operational continuity [4].

Similarly, trail logistics can be defined as the set of activities for planning, coordinating and managing flows of people, materials and information along pedestrian routes of varying length and complexity. Although in a modern context, the organization of walking itineraries presents principles similar to those that governed Roman military logistics: ensuring the availability of essential resources, continuity of the route and participant safety. New digital technologies and robotics now allow optimizing the distribution of food and water, accommodation management, emergency coordination and monitoring walker flows, making the experience efficient, safe and sustainable along the entire route.

Traditionally, logistics is articulated into different definitions and classifications (e.g., business logistics, transport logistics, integrated logistics and urban logistics, the latter with increasing attention to environmental sustainability); building on these concepts, a specific definition of trail logistics, or **light logistics**, is proposed, understood as the set of activities aimed at ensuring that walkers can traverse long-distance itineraries safely, autonomously and comfortably, maximizing satisfaction, minimizing impacts and supporting sustainable use of the territories. Light logistics integrates material and immaterial solutions to respond efficiently to users’ needs, placing the quality of the experience and sustainability at the centre.

Light logistics in walking itineraries therefore includes a set of strategies, tools and services that enable walkers to organize long-distance movements with the minimum possible load, optimizing the transport of essential goods, access to support points along the route and management of time and resources, improving safety, comfort and overall experience quality. It includes aspects such as luggage transport from stage to stage, availability of supply points, planning of stages with essential services, management of meals, water and emergencies and may include innovative solutions such as apps, booking systems and smart supports to reduce the physical and mental burden of the journey.

The components of trail logistics can be divided into two main categories:

Primary light logistics: includes essential services for mobility and physical support of the walker:

- **intermodal transport:** connections between cities, train stations, airports and entry points of the trails, in addition to local shuttles;
- **luggage transport:** dedicated services transferring luggage between stages, allowing walkers to cover long distances with only a light backpack;
- **water and energy supplies:** presence of water points, refreshment and snack points, or vending machines to ensure continuous availability along the route;
- **money management:** access to ATMs, POS in refuges or retail points along the stages, allowing secure payments and withdrawals without interrupting the itinerary;
- **first aid and emergency management:** coordination of first-response points, rapid communication with healthcare facilities, presence of emergency kits and visual signage along the trails.

Supportive light logistics: includes services that enhance the overall walker experience and facilitate route use:

- **information and signage:** clear signs, route maps, information points on stage difficulties;

- **digital and smart services:** mobile applications for bookings, real-time monitoring of trail conditions, availability of accommodation and food services.

The concept of light logistics integrates perfectly with the evolution of WAAS (Walking as a Service) and MaaS (Mobility as a Service) paradigms [5]. These innovative approaches expand the possibilities offered by trail logistics, providing digital tools and integrated services to optimize planning and management of pedestrian routes. WAAS allows walking to be considered as an actual service, offering real-time information on routes, safety, refreshment points and availability of support along the stages, enabling personalized and optimized planning [6]. MaaS [7], [8], instead, integrates the pedestrian component within broader mobility platforms, combining walking, public transport, local shuttles, or sharing services, making access to the trails smoother, more efficient and sustainable. The adoption of these approaches allows improving walker flow management, coordinating transport and supplies, increasing safety and comfort along the route and overall enriching the experience, reinforcing user centrality and the sustainability of the logistic system.

Key elements of light logistics include flexibility, modularity, environmental sustainability and user centrality. The integration of primary and supportive logistics, with the use of digital technologies and smart platforms, WAAS and MaaS, allows effectively responding to walkers' needs, ensuring safety, comfort, autonomy and continuity of the route, while maintaining a low environmental and social impact on the traversed territory.

Light logistics differs from traditional logistics because it prioritizes flexibility, adaptability and sustainability, aiming to reduce both the walker's physical and psychological load and the organizational complexity of the experience. It can only be participatory logistics. Furthermore, light logistics is by excellence an approach aligned with **Logistics 5.0**. Logistics 5.0 focuses on personalization, sustainability, human-machine interaction and intelligent process optimization. Compared to traditional or 4.0 logistics, it adds a strong focus on human well-being, reduction of environmental impact and system resilience.

Light logistics in walking itineraries can be seen as a concrete application of Logistics 5.0, because:

- it **places the individual at the centre**: the walker is the protagonist, with personalized weight, autonomy and comfort needs;
- it **optimizes resources intelligently**: uses digital tools or apps to plan stages, supplies and supports along the route;
- it **reduces environmental impact**: minimizes luggage transport, favors local services, promotes sustainable solutions;
- it **integrates technology and human experience**: apps, booking systems, stage monitoring and innovative logistic supports work together with the physical walking experience.

Light logistics embodies the spirit of Logistics 5.0 adapted to an experiential and human context, focused on sustainability, well-being and personalization of slow mobility.

7.1.2 The role of logistics in the walking experience

Logistics plays a central role in the overall quality of the walking experience, as it enables transforming an individual and physical activity into a safe, accessible and sustainable journey. Logistic organization must be considered as a process articulated in three distinct but interconnected moments: before the walk, during the walk and after the walk (Table 7.1).

Before the walk, logistics supports the planning and preparation phase, ensuring access to reliable information on routes, stages and available services. This includes the availability of digital and paper maps, integrated booking platforms for accommodations and luggage transport, tools for

calculating times and difficulty levels, as well as support services such as equipment rental or advance shipment of materials. Adequate preliminary logistics reduces uncertainty, favours the inclusion of user categories with specific needs (elderly, families, people with disabilities) and improves the perception of safety.

During the walk, logistics becomes an enabling factor for continuity and usability of the route. It includes luggage transport between stages, availability of water and food supply points, real-time signage and information, health and first aid services and management of flows in case of congestion in the most frequented stages. In this phase, logistics must ensure flexibility and resilience, allowing rapid adaptation to adverse weather conditions, accidents, or variations in walker flows. The presence of light support infrastructure, such as rest areas, shaded points and energy charging stations, also contributes to improving comfort and well-being.

After the walk, logistics plays a role in consolidating the experience and generating added value. Activities include the recovery and final transport of luggage, connections with public or private transport nodes for the return, collection of feedback via digital surveys or interviews, as well as processing mobility and satisfaction data to improve future editions of the route. This phase, if well-managed, allows not only to increase walker satisfaction but also to develop strategies for loyalty and territory promotion.

Therefore, Trail logistics is not an ancillary activity but a structural element of the experience, accompanying the walker throughout the entire usage cycle and representing a critical factor for the sustainability, resilience and inclusiveness of the routes.

Table 7.1 - The role of logistics in the walking experience.

Phase	Main logistic functions	Objectives
Before the trail	Information on routes and stages, integrated booking platforms, digital/paper maps, advance luggage transport, equipment rental	Reduce uncertainty, favor accessibility, support planning, ensure inclusion
During the trail	Luggage transport stage by stage, water and food supplies, real-time signage and information, health and emergency services, flow management, light support infrastructure (rest areas, charging stations)	Ensure continuity, safety, resilience and comfort along the route
After the trail	Luggage recovery, connections with public/private transport, feedback collection, analysis of mobility and satisfaction data	Consolidate the experience, improve service quality, promote loyalty and territorial enhancement

7.1.3 Decalogue of trail logistics

The concept of trail logistics can be traced back to an organic set of attributes that, in the form of a decalogue, outline its function and impact on the overall experience of the walker (Table 7.2). Firstly, accessibility ensures that everyone, including people with specific needs, can utilize services and infrastructure equitably. Reliability guarantees continuity in connections and logistic support, reducing the risk of interruptions along the route. Flexibility allows services to be adapted to different types of walkers, seasons and contingent conditions, while resilience represents the ability to maintain functionality even in the event of unforeseen events or emergencies.

Alongside these dimensions, sustainability plays a central role in minimizing environmental impacts, promoting soft mobility practices and responsible resource management within new circular economy models based on decarbonization [9]. Scalability allows efficient management of variable tourist flows, preserving service quality during high and low seasons. Integration promotes coordination between transport, accommodation facilities and local administrations, strengthening

the overall coherence of the offering. Digitalization introduces innovative technologies for safety, information and real-time monitoring, expanding utilization possibilities.

The ninth attribute, user centrality, emphasizes the importance of a design oriented towards the needs and well-being of the walker, enhancing inclusiveness and personalization. Finally, cost-effectiveness ensures a balance between the financial sustainability of services and cost accessibility for walkers. Together, these ten principles define a true decalogue of trail logistics, providing a methodological basis for the analysis, design and evaluation of long-distance walking routes.

Table 7.2 - Decalogue of trail logistics.

Attribute	Description
Accessibility	Ensure usability for all walkers, including people with disabilities, families and the elderly
Reliability	Ensure continuity and regularity of logistic services, reducing interruptions and service failures
Flexibility	Adapt services to seasonality, user types and contingent conditions
Resilience	Maintain functionality even in case of unforeseen, climatic, or emergency events
Sustainability	Minimize environmental impact through soft mobility, waste management, renewable energy
Scalability	Efficiently manage variable tourist flows without compromising service quality
Integration	Coordinate transport, accommodation, local authorities, private operators in a coherent system
Digitalization	Implement 4.0 technologies for safety, information and real-time monitoring
User-Centricity	Design logistic services placing the walker's needs and well-being at the center
Cost-Effectiveness	Ensure balance between economic sustainability of services and affordability for users

7.2 Impacts of logistics on the walker experience

Trail logistics represents a key element in the overall walker experience, influencing safety, comfort, accessibility, subjective perception of well-being. Logistic management concerns not only the availability of resources and infrastructure along the route, but also the coherence, continuity and usability of services, all factors that impact the quality of the experience.

7.2.1 Comfort and usability

Comfort along the Camino is closely linked to the quality of logistics. Reducing the physical and cognitive effort required to traverse the route increases perceived well-being and overall satisfaction. The availability of adequate rest areas, water sources, shelters, updated maps, integrated luggage transport and optional services contributes to creating a smoother and more enjoyable experience. Indicators such as the walkability index, which considers accessibility, safety, service density and route continuity, could be integrated with specific logistics-related indicators.

7.2.2 Perceived safety

As noted, safety represents a determining factor in the utilization of walking routes. Well-marked infrastructure, constant maintenance, lighting in critical areas and secure rest points reduce perceived and actual risks, especially in isolated zones. A well-organized logistics system contributes to reducing the injury rate and limiting route abandonment, increasing continuity and experience quality. Objective indicators, such as the incident rate and subjective safety assessments collected via questionnaires or apps allow measuring logistics effectiveness in protecting walkers. These results, in addition to improving overall satisfaction, strengthen the reputation of the Camino as a safe, accessible and enjoyable destination.

7.2.3 Flexibility and personalization

The possibility of accessing personalized services, such as luggage transport, guided stops, catering, or bookable accommodations, increases satisfaction and promotes modular use of the Camino. Flexible logistics allow the experience to be adapted to individual needs, walking pace and physical conditions, enhancing perceived autonomy and comfort.

7.2.4 Route continuity and coherence

Route continuity is essential to ensure an immersive and smooth experience. Well-planned logistics reduce interruptions, delays and discontinuities, ensuring consistency between what is planned and what is actually available. Indicators such as the percentage of accessible route and territorial coverage quantify the coherence between supply and use, evaluating the experience quality in terms of continuity and accessibility.

7.2.5 Strategies to mitigate negative effects

Logistic planning is fundamental to ensure safety, comfort and accessibility along the Camino, but an overly structured approach can produce paradoxical effects: rather than increasing satisfaction, it may decrease it or alter the very sense of the experience, attracting walkers more oriented toward convenience than the inner or natural dimension of the experience (as is occurring, for example, in mountain tourism or on the Camino de Santiago with the so-called “turigrini,” a neologism referring to how the figure of the pilgrim is increasingly replaced by that of the tourist).

As examined previously, many benefits stem from detailed planning, including:

- increased safety: identification of secure rest points, water sources and shelters, reducing risks and exposure to adverse environmental conditions;
- Efficient resource management: optimization of transport, supplies and medical services along the route;
- Improved accessibility: accessible routes and dedicated services for users with specific needs, such as disabilities or reduced mobility.

Conversely, it is necessary to consider the risks of excessive planning:

- decreased satisfaction and loss of authenticity: a rigidly defined itinerary can transform the experience from an authentic pilgrimage to standardized tourism, reducing immersion and spontaneity;
- Unpredictable effects on attendance: phenomena of overcrowding in certain stages or periods of the year, with possible discomfort and infrastructure overload;
- Information overload: an excess of data, maps and services may generate confusion or anxiety;
- Environmental impact: infrastructure construction and intensive management of tourist flows can cause soil erosion or biodiversity loss.

Therefore, it is essential to find a balance between planning and flexibility, ensuring safety and convenience without altering the spontaneity and authentic sense of the Camino.

To counter the paradoxical effects of excessive logistics, it is crucial to adopt strategies combining intelligent planning and flexibility. Routes can be designed modularly, allowing walkers freedom to choose variants, stops and walking times, preserving autonomy and a sense of adventure. Logistic information can be organized hierarchically and personalized through digital applications or interactive guides, avoiding information overload. Tourist flow management can rely on staggered bookings and incentives for less crowded periods, supported by real-time monitoring to prevent overcrowding. Finally, sustainable strategies to reduce environmental impact include regular trail maintenance, eco-friendly routes, responsible waste management and raising walker awareness on environmental respect.

7.2.6 Metrics for trail logistics

To objectively evaluate the impact of logistics on the walker experience, it is necessary to adopt specific metrics capable of measuring not only service availability and quality but also actual use and subjective user perception. These indicators allow quantifying aspects such as route continuity, territorial coverage of services, actual and perceived safety, comfort, flexibility and overall satisfaction. Metrics provide monitoring and comparison tools between what is planned and what is actually delivered, offering useful data to optimize planning and mitigate potential negative effects. Subsequently, formulas and quantitative indicators will be presented in detail, directly linking observations on the walker experience to elements of planned and delivered logistics.

7.3 Trail logistics management process

Trail logistics is not limited to the mere availability of services along the route, but accompanies the walker throughout the entire experience cycle, effectively representable through the PDCA model (Plan-Do-Check-Act) (Figure 7.1), integrating a participatory logistics approach that values the voice and direct experience of walkers in all phases. The PDCA cycle, or Deming cycle, represents an iterative model of continuous improvement that guides planning, implementation, monitoring and process review, promoting progressive performance optimization and the reduction of inefficiencies [10], [11].

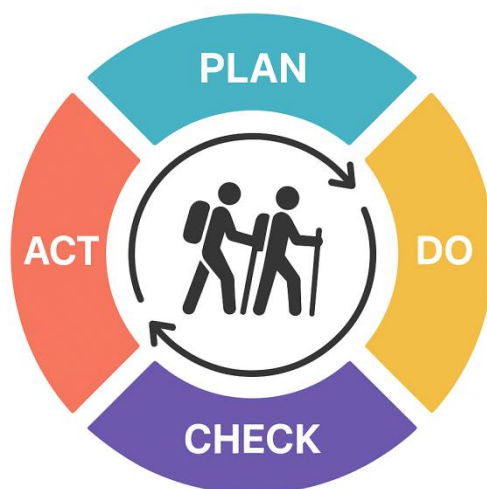
In the planning phase (Plan), participatory logistics allows the collection of walkers' needs, including physical requirements, travel times, desired comfort levels and safety requirements, through questionnaires, interviews, or digital platforms. This information guides route organization, the definition of rest points, the planning of optional services, risk management and route optimization, promoting a modular design that considers diverse individual needs.

During the execution phase (Do), logistics ensures the functioning of planned services, from the availability of shelters and water points to the management of luggage transport and digital support, ensuring continuity and route coherence. The participatory approach allows walkers to provide real-time feedback on accessibility, safety and usability, enabling the adaptation of rest points, luggage transport, shelters, or digital supports to emerging needs, improving comfort, perceived safety and experience personalization.

In the verification phase (Check), participatory logistics integrates the collection and analysis of objective and subjective data, such as incident rates, walker feedback and evaluations of service quality and route accessibility. This allows the identification of potential criticalities, such as overcrowding, route discontinuity, or service inefficiencies and measures the overall effectiveness of logistics in promoting a positive and safe experience.

Finally, in the corrective action phase (Act), monitoring results and walker suggestions are used to update, improve and adapt logistics, introducing corrective interventions, innovations and sustainable strategies. Participatory logistics enables the combination of detailed planning and operational flexibility, reducing the paradoxical effects of overly structured logistics and preserving authenticity, autonomy and immersion in the natural and cultural dimension of the Camino. In this way, logistics is configured as a transversal and dynamic element, accompanying the walker before, during and after the Camino, integrating safety, comfort, continuity and sustainability and ensuring balanced management of flows, information and environmental and infrastructural resources, always with a participatory approach that values the direct experience of walkers.

Figure 7.1 - PDCA Cycle Applied to trails.



7.4 Gender perspective in trail logistics

Trail logistics must also be analysed through a gender perspective, as men and women present different needs and behaviours in the utilization of routes. Differences mainly concern perceived safety, service use, management of family responsibilities and route planning. To understand these differences and improve the walker experience, it is useful to divide the analysis into three temporal phases: before departure, during the Camino and after the Camino.

Before departure, the main needs concern access to detailed and understandable route information, the availability of maps, guides and digital tools, as well as preparation of adequate equipment (Table 7.3), such as ergonomic backpacks and communication devices. Women, in particular, tend to request specific information regarding safety along the route, the presence of rest points with sanitary facilities and the availability of logistic support for any family responsibilities. Planning luggage transport or optional services is also perceived differently between men and women, influencing choices on route and travel times.

During the Camino, gender differences mainly manifest regarding risk perception, comfort and service accessibility. Well-marked infrastructure, adequate lighting, availability of integrative transport and safe rest points help reduce women's perceived vulnerability, improving continuity, safety and satisfaction. The management of family responsibilities can influence choices related to breaks, travel times and use of additional services, highlighting the importance of flexible and modular logistics.

Table 7.3 - Examples of trekking equipment with gender-specific ergonomic adaptations.

Category	Equipment	Male / Female Differences	Functional Notes
Clothing	Jackets and soft-shells	Torso length, broader shoulders in male models, shaped pockets	Provide the same wind and rain protection
	Trekking pants	Shaped waist, different hip/leg proportions	Optimized freedom of movement for each body type
	Technical shirts and fleeces	Torso cut, collar length and shape	Identical breathability and thermal insulation
	Technical socks	Size and compression specific to male or female feet	Prevent blisters and ensure comfort during the walk
Footwear	Trekking boots	Foot shape, heel and arch support differ	Same protection, grip and stability
	Light shoes / sandals	Fit and support adapted	Ideal for shorter or summer walking itineraries
Backpacks and bags	Trekking backpacks	Shoulder straps, back panel and hip belt shaped	Capacity and functionality identical
	Waist packs	Adapted to male or female hips	Quick access to small items
Trekking poles	Adjustable poles	Optimized grip and length, sometimes shaped handle	Stability and reduced fatigue
Accessories	Technical gloves	Finger shape and length	Thermal insulation and optimal grip
	Hats / caps	Circumference and crown shape adapted	Same sun or thermal protection
	Harnesses (for technical walks)	Shaping and straps differentiated	Safety and comfort on vertical or equipped sections

After the trail, needs focus on feedback and experience evaluation. Data collection via surveys, interviews, or apps allows measuring satisfaction, safety perception, comfort and service accessibility, differentiating responses by gender. This information is essential to identify areas for improvement and optimize future editions of the route, making logistics more inclusive and suitable for the needs of different users.

To ensure trail logistics effectively meets gender needs, a structured cycle of detection, intervention and monitoring can be adopted, based on the PDCA model (Plan-Do-Check-Act). In the Plan phase, walkers' needs are collected through surveys, interviews, participatory workshops and digital tools, paying attention to differences between men and women. The Do phase involves implementing services and infrastructures targeted at the identified needs, including integrative transport, safe rest points, clear signage and dedicated equipment. During the Check phase, the walker experience is monitored in real-time, collecting data via daily questionnaires, tracking apps, direct observations and feedback on logistic interventions. Finally, in the Act phase, post-Camino data are analysed, evaluating gender differences and received suggestions, to update logistics and plan more targeted interventions in subsequent editions.

7.5 Inclusive logistics: needs of vulnerable groups (PRM, families with children, elderly)

Trail logistics must be analysed through an inclusion perspective, as people with disabilities, families with children, or elderly users present specific needs and behaviours in the use of routes. Differences mainly concern accessibility, perceived safety, service use and the management of difficulties related to reduced mobility, physical needs, or family responsibilities. To understand these differences and improve the walker experience, it is useful to divide the analysis into three temporal phases: before departure, during the Camino and after the Camino.

Before departure, main needs concern access to detailed and understandable route information, availability of adapted maps, guides and digital tools, as well as preparation of adequate equipment such as strollers, mobility aids, or ergonomic supports for the elderly. People with disabilities require ramps, suitable pavements, braille signage, tactile routes and accessible restrooms; families with children need equipped rest areas, refreshment points and spaces for play, with short and safe routes between stages; elderly benefit from frequent benches, luggage transport support and clear information on routes and difficulties. Intangible services such as accessible guides, apps with voice reading and multilingual information help ensure an inclusive experience.

During the Camino, infrastructures must guarantee continuity, safety and comfort for all vulnerable groups. Barrier-free routes, safe rest points, integrative transport, accessible toilets and clear signage reduce vulnerability and difficulties, improving autonomy and satisfaction. Logistics must be flexible and modular, allowing more frequent breaks, alternative routes and personalized support according to physical characteristics and family needs.

After the Camino, needs focus on feedback and experience evaluation. Data collection via surveys, interviews, or apps allows measuring satisfaction, perceived safety, comfort and service accessibility, differentiating responses by type of vulnerable group. Useful evaluation indicators include the percentage of accessible routes, satisfaction of vulnerable groups and the number of inclusive services available. This information is essential to identify areas for improvement and optimize future editions of the route, making logistics more inclusive and suitable for the needs of all users.

To ensure trail logistics effectively meets the needs of vulnerable groups, a structured cycle of detection, intervention and monitoring based on the PDCA model (Plan-Do-Check-Act) can be adopted. In the Plan phase, the needs of vulnerable walkers are collected through surveys, interviews, participatory workshops and digital tools, considering the different characteristics of the groups. The Do phase involves implementing services and infrastructures targeted at identified needs, including accessible routes, integrative transport, equipped rest points, accessible toilets, clear signage and inclusive digital supports. During the Check phase, walkers' experiences are monitored in real-time, collecting data via daily questionnaires, tracking apps, direct observations and feedback on logistic services. Finally, in the Act phase, post-Camino data are analysed, evaluating the needs of vulnerable groups and received suggestions, to update logistics and plan more targeted interventions in subsequent editions.

In this way, logistics is configured as an inclusive, transversal and dynamic tool, accompanying the walker before, during and after the Camino, integrating safety, comfort, continuity and sustainability and ensuring balanced management of flows, information and environmental and infrastructural resources for all users.

7.6 Towards sustainable and resilient trail logistics

Sustainable trail logistics integrates environmental, social and economic dimensions, promoting practices that reduce ecological impact, foster social inclusion and ensure economic sustainability. In particular, environmental sustainability translates into the optimization of support transport, such as electric shuttles or cargo bikes for luggage transport, efficient waste management through collection stations along the route, reduced land consumption through the use of existing paths or natural trails and the use of renewable energy to power services along the Camino, such as water points and refreshment stations powered by solar panels.

7.6.1 Trail assessment: integrated evaluation

To guide policies and actions towards sustainable and resilient trail logistics, it is essential to adopt assessment tools capable of evaluating the different dimensions indicated by the decalogue. Accessibility is measured through indicators of route usability by people with disabilities, families and the elderly, with maps of rest points, signage and dedicated services. Reliability is evaluated by monitoring service continuity, regularity of support transport and availability of facilities along the route. Flexibility can be analysed considering the ability of routes and services to adapt to seasonality, different user types and contingent conditions, including optional variants or alternative paths. Resilience is observed both in infrastructures, designed to withstand extreme weather events or emergencies and in social and territorial solutions, such as alternative paths, alert systems and scheduled maintenance. Environmental sustainability is evaluated through monitoring emissions, energy consumption, waste management and the use of eco-friendly materials along the Camino. Scalability emerges from analysing the capacity of services to manage variable tourist flows without compromising experience quality, supported by dynamic planning tools and cooperation models with local operators. Integration is measured by evaluating coordination among public entities, private operators, transport and accommodation facilities, also through digital platforms for bookings and service management. Digitalization is observed in the use of mobile applications for real-time information, IoT sensors to monitor pedestrian flows and alert systems for weather conditions or temporary trail closures. User centrality is evaluated by collecting feedback, satisfaction indicators and safety perception, used to guide service design. Finally, cost-effectiveness considers the balance between service sustainability and economic accessibility for walkers, supported by circular economy models and territorial cooperation. Visualization tools, such as dashboards or radar charts, allow aggregating these indicators, providing a comprehensive assessment of logistics quality along the Caminos.

7.6.2 Strategies for sustainable and resilient logistics

The development of sustainable and resilient logistics along Caminos requires concrete, integrated strategies aimed at ensuring quality, safety and usability for all users. Integrated planning is based on selecting routes that enhance areas of cultural and natural interest, prioritizing existing trails and minimizing new constructions, creating sustainable thematic routes and providing rest points accessible to families, the elderly and people with disabilities. Adaptive management allows real-time modification of routes and services in response to extreme weather events, emergencies, or peaks in attendance, through alternative paths, digital alert systems and scheduled maintenance, ensuring continuity and safety of the experience.

The use of green and digital technologies facilitates both logistics and sustainability: mobile applications integrate accommodation and luggage transport bookings, IoT sensors monitor pedestrian flows and environmental conditions and electric vehicles or cargo bikes support material management along the Camino, reducing emissions and environmental impact. Education and awareness represent a key lever to promote responsible behaviour: informative signage, campaigns on flora and fauna protection, waste and water consumption reduction and workshops aimed at both walkers and local communities strengthen environmental and social awareness. Inter-institutional collaboration ensures coherence and service integration, with public-private partnerships among local associations, public entities, tourist operators and accommodation facilities, promoting user centrality and cost-effectiveness.

Furthermore, monitoring and continuous evaluation strategies via dashboards and indicators allow verifying the effectiveness of implemented actions, measuring safety, accessibility, walker

satisfaction, infrastructure resilience and environmental impact, creating a virtuous cycle of continuous improvement.

7.6.3 Continuous monitoring and adaptation

Continuous monitoring is a central element to ensure resilience, sustainability and quality of the Camino experience, allowing anticipation of criticalities and timely response to walkers' needs. Technological tools play a key role: IoT sensors allow real-time detection of crowding, pedestrian flows and environmental conditions, while mobile applications allow users to report incidents, route criticalities, service shortages, or safety issues. Collected information is centralized in integrated dashboards, displaying key environmental, social and economic indicators (KPI), allowing immediate evaluation of accessibility, safety, walker satisfaction and environmental impact.

The monitoring system is closely linked to continuous adaptation strategies, which include immediate interventions to maintain service continuity and route usability. This includes temporary opening of refreshment or assistance points, detours signalled in case of obstacles or unforeseen events and resource reallocation based on detected pedestrian flows. Monitoring also allows evaluating the effectiveness of education and awareness actions, such as environmental campaigns or responsible walker behaviour, providing useful data for corrective interventions.

Collected data integration also supports medium- and long-term strategic decisions, such as planning new routes, optimizing logistic services, or managing variable tourist flows, contributing to a truly resilient, flexible and user-centred trail logistics system. In this way, monitoring is not limited to recording route status but becomes a dynamic tool for continuous improvement, service disruption prevention and promotion of sustainable mobility.

7.6.4 Community involvement and participatory governance

Direct involvement of walkers and local communities is fundamental for participatory and inclusive governance. This can be realized through:

- participatory workshops with walkers and residents, aimed at collecting feedback on safety, comfort and services;
- public consultations to define maintenance priorities, technological innovations and inclusive services;
- partnerships with local businesses to provide luggage transport, catering and cultural activities along the route, enhancing the territory and creating local economic opportunities.

The perspective of sustainable and resilient trail logistics highlights the importance of integrated strategies to reduce environmental impact, ensure accessibility and strengthen infrastructural and social resilience. However, merely adopting principles and strategies is not sufficient to guarantee systemic improvement: evaluation tools and methodological models are necessary to measure and compare different levels of Camino maturity, identifying areas for improvement and intervention priorities.

In this regard, the introduction of innovative technologies represents a decisive enabling factor. Digitalization and the application of 4.0 and 5.0 logistics paradigms allow transforming Caminos from static infrastructures into truly intelligent and adaptive ecosystems, capable of integrating safety, comfort and sustainability. To systematize these possibilities, the SmartTrail Framework is proposed, a tool that combines assessment criteria, technology classification and a maturity level

system, offering a comparative and scalable approach for the management and logistic innovation of Caminos.

7.7 Trail logistics and SmartTrail Framework

A smart trail is defined as a walking itinerary that integrates principles of sustainability, inclusion and resilience with the adoption of advanced technological solutions and with adaptive and participatory logistics. The objective is to enhance the overall experience of the walker, ensuring safety, accessibility, comfort and quality of services, while optimizing resource management and territorial enhancement, simultaneously guaranteeing environmental sustainability and service resilience.

In this context, trail logistics is not limited to operational support (luggage transport, management of rest points, information), but becomes an enabling platform that integrates physical infrastructure, digital platforms and local communities. Logistics serves as a link between demand (walkers with diversified needs) and supply (services, accommodations, support transport), coordinating activities through 4.0 solutions [12].

Through tools such as IoT sensors, navigation apps, integrated booking systems and digital governance platforms, logistics enables flow monitoring, capacity management, environmental impact reduction and real-time service adaptation.

In this way, the trail is configured as a true intelligent logistical infrastructure supporting slow mobility and sustainable tourism, capable of guaranteeing continuity, safety and quality even under adverse conditions.

This definition provides the conceptual reference for building an assessment framework based on measurable indicators and a systematic classification of implemented technologies.

7.7.1 Assessment dimensions

The assessment of smart trails is developed along four complementary dimensions:

a) Identification of walker functional requirements. The analysis of functional requirements highlights the primary needs that must be satisfied by the integrated logistical system of the trail. These needs can be grouped into five main categories:

- **navigation and orientation:** ability to orient along the trail even offline, supported by maps, GPS and AR;
- **safety and emergency management:** risk monitoring, incident management and rescue operations;
- **comfort and physical well-being:** support for fatigue, hydration, nutrition and physiological monitoring;
- **information and detailed planning:** access to updated data on services, accommodations and trail conditions;
- **operational logistics and on-field services:** management of luggage transport, availability of refreshment points, automatic check-in and digital payment systems.

b) Mapping and classification of logistical and technological solutions based on functional requirements. The core of the SmartTrail Framework is a classification of innovative technologies based on the five fundamental walker needs, serving as a methodology to identify and integrate 4.0 solutions in a logistics and safety improvement perspective.

1. **navigation and orientation:** to ensure the walker knows their location and can stay on track even offline, the framework proposes next-generation mobile applications (offline maps, AR, 3D models) and advanced GPS and satellite devices, capable of improving planning and mitigating accessibility issues at trailheads and endpoints;
2. **safety and emergency management:** this need is addressed with personal wearables and IoT, satellite communication devices, fixed environmental sensors, artificial intelligence for forecasting and mobile safety apps, ensuring rapid monitoring and alerts in case of contingencies;
3. **comfort and physical well-being:** the framework includes integrated clothing sensors and AI systems for personalization, suggesting pace, breaks, hydration and nutrition, also helping prevent water supply shortages;
4. **information and detailed planning:** cloud platforms and big data analytics aggregate real-time data on accommodations and services, improving coordination among operators and facilitating bookings, while AI virtual assistants provide precise information on refreshment and support points;
5. **Operational logistics and on-field services:** blockchain for luggage transport traceability, IoT for infrastructure monitoring and digital payment systems ensure more reliable, scalable and accessible services.

c) Assessment of technological maturity level

For each walker need, the adoption level of 4.0 solutions is evaluated through a technological maturity level, called the **SmartTrail Readiness Level**, according to the scale:

- 0: no technological implementation;
- 1: basic/traditional implementation;
- 2: advanced implementation with specific 4.0 technologies;
- 3: complete and integrated implementation with cutting-edge solutions.

d) Analysis of logistical sustainability and resilience

This dimension integrates two aspects:

- **environmental and economic sustainability:** optimization of support transport (e.g., electric shuttles or cargo-bikes), waste management, use of renewable energy and support for local economies;
- **infrastructural and social resilience:** ability of the trail to maintain operational continuity in case of extreme weather events or logistical issues, adaptive flow management and preventive maintenance.

7.7.3 Methodological Procedure

The assessment methodology is structured in the following steps:

1. **data collection on the trail.** Analysis of infrastructural characteristics, available services, walker flows and technologies implemented along the trail;
2. **technology classification.** For each walker need, the implemented technologies (e.g., mobile apps, IoT, AI, wearables, blockchain) are identified and their integration evaluated;
3. **assignment of maturity levels.** Each need is assessed through the SmartTrail Readiness Level (0-3), quantifying the trail's degree of "smartness";

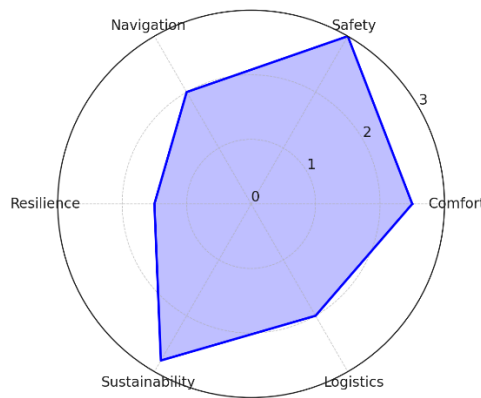
4. **assessment of logistical sustainability and resilience.** Environmental, economic and infrastructural resilience indicators are measured and converted into scores (e.g., scale 0-5), integrated with functional scores to obtain a complete profile;
5. **calculation of the overall score - SmartTrail Index (STI = F + S + R)** which can range from a minimum score of 0 to a maximum score of 21, where:
 - F = walker functionality (average of levels 0-3 for the 5 needs);
 - S = sustainability (average of environmental and economic scores, scale 0-5);
 - R = resilience (average of infrastructural and social scores, scale 0-5).

The total or normalized score constitutes the **SmartTrail Index**, representing the overall level of innovation, sustainability and resilience of the trail (Table 7.4);
6. **visualization and comparison:** results are represented through radar charts or integrated dashboards, facilitating comparison between different trails and definition of priorities for improvement interventions (Figure 7.2);
7. **improvement strategies:** based on SmartTrail assessment results, the most appropriate solutions can be identified for each dimension of trail logistics. The analysis of technological maturity levels, sustainability and resilience allows identifying priority interventions and proposing targeted actions to improve safety, accessibility, comfort, flow management and environmental and economic sustainability, guiding the development of increasingly efficient, inclusive and adaptive trails .

Table 7.4 - SmartTrail Readiness Level Evaluation Grid.

Walker Needs	Level 0	Level 1	Level 2	Level 3
Navigation and Orientation	Only traditional physical signage	Paper maps, generic apps, basic GPS	Official app with detailed offline maps, georeferenced points of interest	Advanced app with offline maps, AR, AI algorithms for dynamic routing, BLE beacon integration
Safety and Emergency Management	No specific system beyond mobile phone	Emergency contact points, basic SOS app, generic weather forecasts	Environmental IoT sensors at critical points, wearable with manual alerts, AI weather forecasts	Dense IoT sensor network, wearable with automatic alerts, two-way satellite communication, AI operations center for rescues
Comfort and Physical Wellbeing	No technological support	General information on equipment and physical preparation	App with basic hydration/nutrition suggestions, wearable for step/elevation tracking	AI assistant personalized on biometric data, recommendations for pace/pause/hydration, smart charging points along the trail
Information and Detailed Planning	Fragmented information, self-sourced	Generic website listing services, manual updates	Online platform with near real-time availability, user feedback	Cloud-integrated platform with providers, AI chatbot, management dashboard, review system, real-time alerts
Operational Logistics and Field Services	No digitized service	Manual luggage transport, cash payments	Luggage transport bookable online with tracking, digital payments	Luggage transport traceable via blockchain, smart contracts, IoT for check-in/out and consumption monitoring in shelters
Environmental and Economic Sustainability	No sustainability measures	Basic good practices: waste separation, traditional transport	Low-emission transport, use of renewable energy, cooperation with local businesses	Full integration with smart waste management, electric transport, optimized energy use, support for local economy
Infrastructure and Social Resilience	No consideration	Minimal maintenance, rudimentary emergency plans	Scheduled maintenance plans, alternative routes	IoT monitoring, adaptive flow management, advanced emergency plans, real-time alternative routes

Figure 7.2 - Example of Radar Diagram.



7.8 Modular logistics element for trails and PATHS module (Pedestrian Advanced Trail Hub for Sustainability)

To ensure support, safety and comfort for hikers along long-distance trails, while at the same time collecting useful data for trail management, the implementation of a modular logistics element is proposed, placed on average every 5 km along the trail, with distances varying according to the context: in isolated or particularly challenging sections, the modules will be installed every 3-4 km to guarantee constant supplies and assistance, while in urban or already serviced sections the distance between modules may increase up to 6-7 km, integrating the services already available in the area. The objective is to create a network of modular support points along the trail that provide essential and additional services to hikers (safety, refreshment, information, device charging) in a flexible and sustainable manner, maintaining freedom of choice and the quality of the experience.

The module integrates primary logistics, including water and energy supplies through low-impact dispensers and long-life food, temporary luggage storage with the possibility of transfer between modules, money management via secure digital solutions (e.g., wallet or prepaid card specific for the trail), first aid kit and defibrillator, accessible compostable toilets and charging stations for devices and electric bicycles powered by solar panels. A system for collecting and reusing rainwater or greywater to supply toilets and irrigate green areas is also planned. Support logistics include information panels and QR codes for digital access to maps and data, Wi-Fi hotspots, equipped resting areas and sensors for monitoring hiker flows and environmental conditions.

The design of the element follows principles of modularity, flexibility, sustainability and accessibility, with surfaces ranging from 20 to 30 m² and a height of 2.5-3 m, divided into functional areas dedicated to supplies, toilets, first aid, luggage storage, charging and informational support. The structure is rectangular or square (Figure 7.3), easily extendable or combinable with other modules and made of lightweight, recyclable and low-impact materials. The use of renewable energy and intelligent management of water and environmental data makes the module sustainable and monitored.

The project ideally aligns with the potential of prefabricated and modular 3D printing. The module components can be produced in a controlled environment using sustainable materials and optimizing resource use. The pieces, designed to be lightweight, manageable and easily assembled, would be transported along the trail and assembled on-site. This approach reduces environmental impact and logistics costs, ensures structural precision and quality and transforms construction into a fast and clean process, harmoniously integrating with the natural environment.

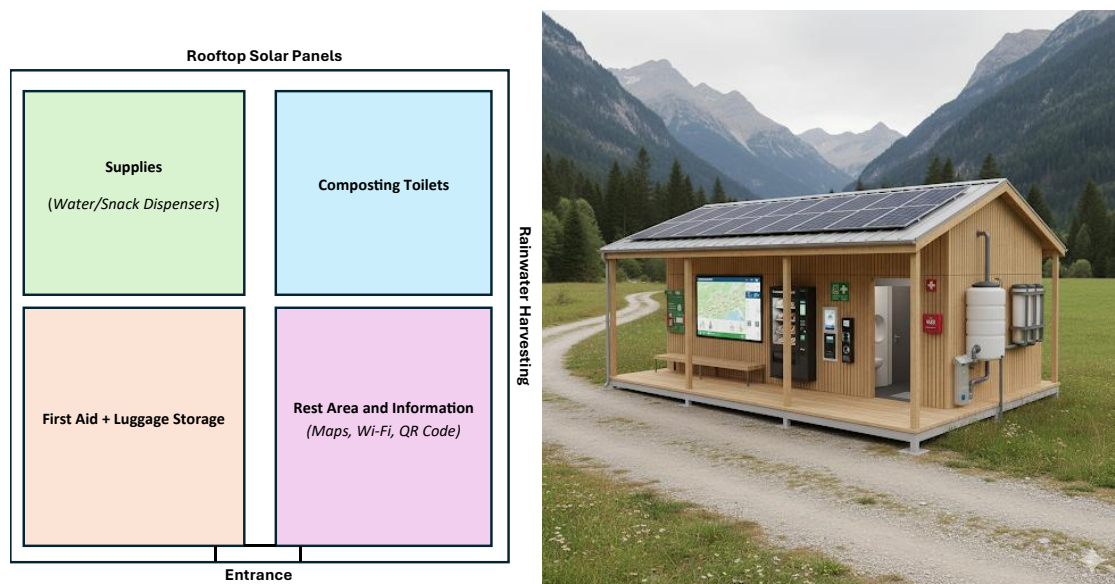
Inspiration comes from high-altitude bivouac architecture, minimal and spartan structures providing shelter and support in extreme mountain environments. As with bivouacs, the design of the logistics modules emphasizes reversibility, modularity, dry assembly and the use of lightweight and durable materials, with attention to protection from weather and internal comfort. The experience of refuges such as Bivacco Skuta or Bivacco Fratelli Fanton demonstrates the effectiveness of approaches based on prefabrication, transport of disassembled components and on-site assembly, ensuring safety, sustainability and minimal landscape alteration. This model allows combining the freedom and adventure of the trail with service quality and environmental protection, offering hikers a safe, customizable and sustainable experience.

The module is designed to provide services falling within primary logistics and support logistics.

With reference to **primary logistics**, the following are highlighted:

- **water and energy supplies:** drinking water and low-impact snack dispensers, long-life food, or vending machines;
- **luggage transport:** temporary storage with the possibility of transfer between modules via a booking app and service acquisition;
- **money management:** secure digital solutions, such as payments via app or QR codes linked to smart tourism systems, or prepaid cards to use along the trail, reducing the need for vulnerable physical devices;
- **first aid:** first aid kits, possible defibrillator and rapid emergency call system;
- **compostable toilets:** ecological toilets, with sustainable waste management and accessibility for people with impairments;
- **electric charging point:** charging stations for personal devices and electric bicycles, integrated with solar panels;
- **water collection and reuse system:** rainwater or greywater collection to supply toilets and irrigate green areas.

Figure 7.3 - Simplified plan view of the PATHS Module and example of rendering.



With reference to **support logistics** (additional services), the following are included:

- **information and signage:** maps, information panels and QR codes for digital access;
- **digital and smart services:** Wi-Fi columns or hotspots, apps for reservations, real-time information on trails, accommodations, weather conditions and environmental parameters;

- **rest areas:** benches, shelters, shaded areas for rest and refreshment;
- **passage detection and environmental monitoring:** sensors to record the number of hikers, weather station for temperature, humidity, wind and other environmental parameters, useful for safety and flow management.

The advantages of the modular solution consist of distributed support along the trail without saturating the landscape, customizable experience, increased safety and comfort, reduced environmental impact, integration with the local economy, possibility to adapt modules to seasonal needs or hiker flow and smart management of environmental data and visitor flows. For further details, refer to the technical sheet in **Table 7.5**.

The efficiency and effectiveness of the PATHS Modular Element placement depend on the intelligent distribution of individual modules along the trail. Modular and strategic planning allows optimizing resource accessibility, reducing idle times and ensuring safe and comfortable enjoyment of the entire trail. Simultaneously, at the central level, the collection and integration of data generated by each module, related to presence, consumption, environmental conditions, or maintenance status, allows creating a unified control point. The use of a centralized dashboard enables real-time monitoring of the entire itinerary, supports immediate operational decisions, identifies critical issues and optimizes resource management, ensuring continuity, safety and quality of the hiker experience along the entire trail.

Table 7.5 - PATHS Module technical sheet.

Section	Content
General Description	Modular, sustainable and flexible logistics unit for support, safety and comfort of hikers along long-distance trails. Placed approximately every 5 km (3-7 km depending on context). Integrates primary and support services, monitoring and data collection for intelligent trail management.
Placement	Modules placed on average every 5 km along the trail, with distances varying according to context: - Isolated or challenging sections: modules every 3-4 km to ensure constant safety and supplies. - Urban or already serviced sections: modules every 6-7 km, integrating services available in the area.
Key Features	- Modularity and scalability: 20-30 m², extendable and combinable - Sustainability: recyclable materials, solar energy, rainwater collection, compost toilets - Accessibility and inclusion: universal design for people with disabilities, families, elderly - Flexibility: adaptable to urban, rural and mountain contexts - Intelligent monitoring: sensors for pedestrian flows and environmental conditions
Services - Primary Logistics	- Eco-friendly water and energy supplies - Luggage transport and storage with digital management - Smart payments (apps, QR codes, prepaid cards) - First aid kit, defibrillator, SOS stations - Compostable and accessible toilets - Charging stations for devices and e-bikes
Services - Support Logistics	- Equipped resting areas (benches, shelters) - Information panels, maps, QR codes - Wi-Fi hotspots, smart tourism apps - IoT sensors for weather monitoring and air quality - Spaces for promoting local products and services
Indicative Dimensions	- Surface: 20-30 m² - Height: 2.5-3 m - Supplies area: 5-8 m² - Toilets: 6-8 m² - First aid/luggage/charging: 4-6 m² - Rest and information: 5-8 m²
Technology and Innovation	- Prefabricated structure, lightweight and recyclable materials - On-site dry assembly- Solar panel energy supply - Rainwater collection and filtration - Centralized dashboard for real-time monitoring (flows, consumption, critical issues)
Advantages	- Continuous support for hikers without landscape impact - Reduction of costs and environmental impact - Increased trail safety and resilience - Integration with the local economy - Customizable, inclusive and sustainable experience

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Chapter 8

New Standards for the design of pedestrian mobility infrastructure

8.1 Standards and guidelines for the design of pedestrian routes

The definition of standards and guidelines represents a fundamental step to ensure that pedestrian routes and in particular long-distance walking itineraries, meet criteria of safety, accessibility, quality and sustainability. In this context, it is useful to distinguish between general pedestrian infrastructures and dedicated pedestrian routes: the former include all spaces designed for pedestrian mobility, such as sidewalks, pedestrian areas, walkways, or shared paths, while the latter are spaces physically separated from vehicular traffic, designed exclusively for pedestrians, thus ensuring greater safety and comfort. This distinction is similar to that adopted for cycling infrastructures and bike lanes and makes it possible to define more precise and standardized design criteria [1]. In the following, the main regulatory and technical references will be analyzed, with particular attention to the aspects related to the design, management and maintenance of pedestrian infrastructures, leading to the formulation of specific strategic recommendations (Sect. 8.6) aimed at guiding future choices in an integrated and systemic way.

8.1.1 The regulatory and institutional framework: a mosaic of rules

The design of long-distance walking itineraries in Italy represents a significant evolution compared to the simple creation of hiking trails. These routes are conceived not only as transit routes for physical activity, but as complex infrastructures that connect elements of history, culture, nature and services, acting as catalysts for territorial development.

As discussed in the second chapter, the terminology itself reflects this distinction. While a "trail" is typically a transit path, classified by technical difficulty (hiking, mountain, alpine), a "walking itinerary" is a long-distance route with a strong cultural, historical, or religious connotation, such as the Via Francigena, which retains its historical function as a place of pilgrimage and cultural exchange. Yet in our country, the regulatory discipline concerning the construction and maintenance of hiking trails is not defined by a specific national framework law, except for provisions regarding easements [2]. In the absence of centralized regulation, the system relies on a model in which directives and standards are defined by private associations and then adopted at local and regional levels. Regional laws, such as that of Liguria, establish "regional guidelines for the construction and placement of trail markers" explicitly referencing the directives of the Italian Alpine Club (CAI) and the European Hiking Federation (FEE)[3]. The case of Calabria is particularly emblematic: Regional Law N.12 of 2023 on "Cammini di Calabria" requires that signage be unified and functional, in compliance with the "current CAI regulations," thereby legitimizing the role of the association as the de facto standardization body for recognized walking itineraries [4]. This "bottom-up" flow, where practices and standards emerge from the bottom and laterally (from associations and the European level) to be subsequently adopted and formalized by individual regions, has both advantages and disadvantages. The flexibility of the system allows rapid adaptation to local specificities and the exploitation of organized volunteer expertise. However, this regulatory fragmentation can lead to non-homogeneity and a potential lack of consistency among different regional trail networks, as well as paradoxical situations where overlapping signage of various kinds accumulates in the same places. Although, with reference to hiking trails, the role of the Italian Alpine Club (CAI) and the Italian Hiking Federation (FIE) is central and formally recognized even at legislative and financial levels in relation

to ordinary trail maintenance, the situation of long-distance walking itineraries is quite different. These often arise along already existing trails and become a "tourism product" thanks to the systematic enhancement of points of interest connected by common historical, cultural, or religious roots. Therefore, the Italian landscape of walking itineraries is animated by a wide network of associations and entities that contribute to their promotion and, sometimes in an improvised manner, to their management.

8.1.2 Technical criteria for trail identification, design and signage

The selection and layout of new pedestrian routes must be guided by strategic principles that ensure functionality, value and long-term sustainability. The most effective approach prioritizes the recovery and enhancement of the existing trail network, limiting the creation of new routes to exceptional cases [5].

A trail acquires value when it is integrated into a coherent mobility network. The priority selection criteria include the ability to connect valleys, settlements and valley bottoms through already used routes. It is essential that trails provide access to accommodation facilities such as refuges and mountain huts, acting as essential communication routes for visitors. Integration with other pedestrian networks, cycling networks, or public transport hubs is a key factor in creating a multimodal and interconnected mobility system.

The choice of routes is not limited to mere functionality but also embraces their historical and natural significance. Trails should be identified based on their ability to represent the history and evolution of the landscape, offering an experience that goes beyond simple walking. This approach contributes to preserving the memory of places and their cultural and natural heritage.

Sustainability is a fundamental pillar in planning. It is crucial to assess the environmental impact of building and using trails, considering that even an apparently "light" infrastructure can disturb ecological balances. The carrying capacity of the environment must be calculated to avoid damaging fragile ecosystems and compromising the habitats of local wildlife. Likewise, the ability to ensure regular maintenance over time is an essential requirement to guarantee walkability and durability of the trail.

The approach to trail design must overcome the traditional limitation to mountain or hilly areas. Plains offer great potential for the development of slow tourism and must be considered in planning. Recognizing the value of these territories makes it possible to expand the offer of itineraries and promote pedestrian mobility on a wider scale.

The design of long-distance walking itineraries must balance safety and usability with landscape integration and sustainability [6].

The general principles suggest the choice of a well-recognizable, as direct and varied as possible route, preferably away from motor traffic roads. A reference model, such as the Swiss manual, classifies trails according to difficulty:

- **hiking trails (yellow signage):** Do not require specific knowledge or skills. The surface must be free of asphalt or concrete paving to preserve recreational value and reduce fatigue. The most suitable materials for the foundation are gravelly sands and crushed stones;
- **mountain trails (white-red-white signage):** May include difficult-to-traverse, steep and narrow sections. They require sturdy shoes and appropriate equipment;
- **alpine trails (blue-white-blue signage):** Require sure-footedness, absence of vertigo, excellent physical condition and the ability to use mountaineering equipment such as ropes and ice axes. They are often without evident tracks.

The choice of trail type is a crucial aspect in the design of pedestrian routes, as it determines the safety, durability and environmental impact of the infrastructure. This section describes the four main types of trails, focusing on technical aspects and specific construction activities [7].

Figure 8.1 - Types of trails.



Source: Swiss Confederation [7]

A) Trails on natural ground (dirt)

This category refers to routes built on stable soils, with low slopes and adequate load-bearing capacity (Figure 8.1). The design approach aims to minimize artificial interventions, avoiding the construction of a track and a foundation layer. This not only significantly reduces costs and environmental impact but also preserves the original landscape features (Figure 8.1.a). Technical interventions are aimed at:

- **accurate drainage:** channels are created or the natural slope is used to divert water and prevent erosion;
- **selective consolidation:** in critical points such as tight curves or steep passages, soil consolidation may be carried out to improve stability;
- **soil preservation:** it is essential to avoid removing humus and turf in areas sensitive to erosion.

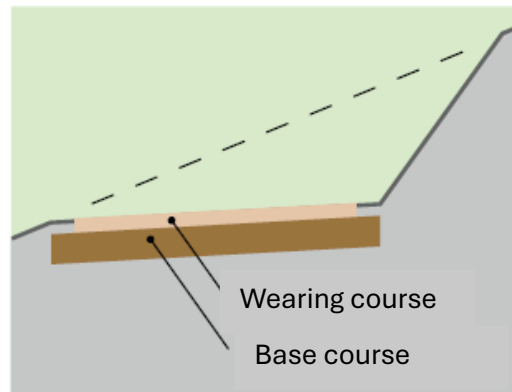
B) Tracks with foundation layer

This type is used in contexts where the soil has poor load-bearing capacity, is waterlogged, or the route is subject to high frequency of use. The main intervention consists of creating a compacted gravel layer that provides the necessary stability (Figure 1.b).

Technical interventions include:

- **foundation construction:** creation of a compacted gravel layer, with thicknesses ranging from 10-15 cm for hiking trails to about 30 cm for heavily used ones, such as cattle tracks (Figure 8.2);
- **choice of materials:** gravelly sands and crushed stones with assorted grain sizes (0-32 mm) are used for optimal compaction. For a possible wearing course, crushed stone up to 45 mm is employed, while the surface layer is made of gravelly sand (grain size up to 16 mm) with a thickness of about 5 cm;
- **prohibited materials:** the use of bitumen, tar and cement is strictly forbidden. Water protection legislation also prohibits the use of asphalt or cement aggregates in unbound form.

Figure 8.2 -Typical section of a trail with foundation layer.



Source: Swiss Confederation [7]

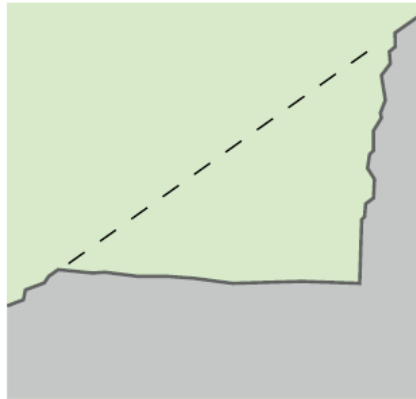
c) Rock trails

Trails in rocky environments exploit the solidity of the soil, often making a foundation layer unnecessary. The design focuses on walker safety and on the management of the rocky surface (Figure 1.d).

The technical solutions provided can be summarized as follows:

- **modification of the trail:** in exposed points, a sufficient width for body passage is ensured, widening the trail at shoulder height compared to the tread surface (Figure 8.3);
- **slippage prevention:** to counter smooth and slippery surfaces, the tread can be constructed with a slight slope towards the mountain. On steeper sections, steps can be carved into the rock to improve traction;
- **drainage:** interventions for the transversal drainage of water may be required.

Figure 8.3 - Typical rock section. Tread surface with slight slope towards the mountain.



Source: Swiss Confederation[7]

d) Boardwalks

This construction solution is ideal for crossing wetlands, marshes, or bogs, where the poor load-bearing capacity and the risk of nutrient input discourage the use of foundation layers. Boardwalks are elevated structures that protect the underlying environment and facilitate passage (Figure 1.d). The technical interventions are as follows:

- **structure:** composed of hardwood planks or logs, arranged perpendicularly to the trail axis, fixed on longitudinal stringers. On unstable soils, the stringers may be supported by transverse elements (Figure 8.4);
- **materials:** durable wood species not chemically treated are preferred;
- **surface treatments:** to prevent the risk of slipping, wooden surfaces may be roughened (for example, using a chainsaw) or covered with a wire mesh. Gravel is a common solution, but it is not permitted in marshes and bogs due to the potential mineral input;
- **improvement of durability:** to increase the service life of the boardwalk, infiltration and oxygen inclusion are minimized by covering the sides of the structure with spoil material and the tread with crushed stone.

On all types of trails, it is possible to provide wooden and stone steps to overcome steep sections. They can be built in harmony with the environment, for example with wooden logs as risers and gravel as treads. Stone steps are also a constructive solution for steep sections.

Figure 8.4 - Boardwalk covering with soil and crushed stone.



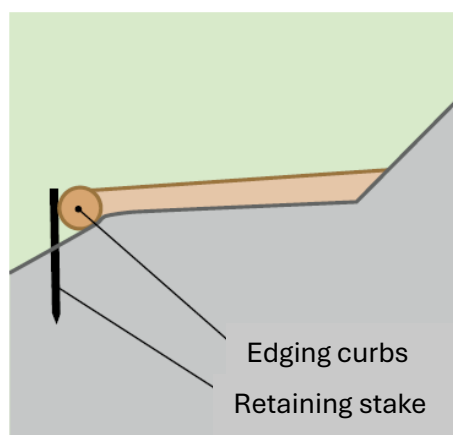
Source: Swiss Confederation [7]

The construction of a hiking trail follows a structured sequence of technical and organizational steps. Initially, clearing works are carried out to prepare the ground, reusing natural materials such as branches and boulders to delimit the trail and reduce environmental impact. Subsequently, excavation works vary depending on the terrain: on flat ground, foundations are dug, while on slopes, humus is removed to stabilize embankments. In rocky contexts, interventions require specialized equipment and may include the creation of steps or walkways. The laying of the foundation layer, when necessary, involves the use of gravel or compacted crushed stone, raising the trail about 5 cm above the ground for effective drainage. Finally, edging curbs may be installed to prevent the collapse of the margins and maintain the shape of the trail over time (Figure 8.5). Water management is a fundamental aspect of design to prevent erosion. Drainage solutions are divided into two main categories:

- **transversal drainage:** intended to channel surface water flowing along the trail towards the sides. This is achieved through the transversal slope of the path (3-5% towards the valley or mountain) and the use of wooden, stone, or rubber channels, positioned at an angle of 30-45 degrees relative to the trail axis. Alternatively, semicircular depressions or U-shaped ditches can be created to redirect water, reducing erosion and maintenance;
- **longitudinal drainage:** used to evacuate water flowing along the trail or coming from the surrounding slope. The most common systems include open ditches with a constant slope of 3-5%, channelling water to lateral discharge points, such as transversal channels. Drain trenches with pipes are a more complex option, used only in specific cases of high water flow.

Finally, slope drainage is also essential for trail stability. Solutions of bioengineering can be employed, such as planting shrubs to absorb water deeply, or creating drainage channels filled with crushed stone in areas with significant water outflow.

Figure 8.5 - Curb on one side.



Source: Swiss Confederation[7]

Structures are essential elements to ensure the safety, stability and comfort of hiking trails, especially in complex contexts such as the crossing of watercourses or steep slopes. Their construction and maintenance are costly, which makes it essential to limit their number and adjust the construction standard to the trail category. All structures must be subjected to periodic inspections to ensure their integrity.

a) Crossing Watercourses

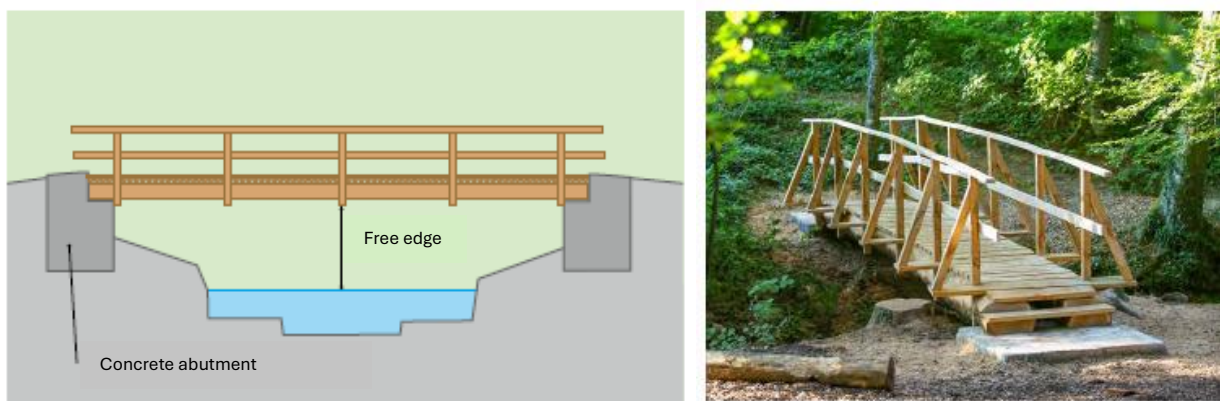
The crossing of rivers and streams must be safe and, if possible, dry. The choice of solution depends on the flow rate of the watercourse and the trail category:

- Stepping stones: a simple solution for small watercourses with minimal and stable flow. Stones, placed at a distance of 0.6-0.8 m, are ideal for hiking trails of low difficulty;
- ford crossings: shallow crossing points, either natural or man-made. Suitable for watercourses with a flow depth of less than 10 cm. They are often paved with local stones, avoiding the use of cement to preserve the aquatic ecosystem;
- drainage pipes: underground pipes laid transversely to the trail, useful for small watercourses with minimal flow variations. They require regular maintenance to prevent clogging;
- footbridges: various types of footbridges exist for crossing watercourses or wetlands. They can be built with wooden beams, especially in marshy areas to avoid soil contamination, or with steel beams, allowing for more complex and suspended structures. Removable footbridges consist of roll-up walkways in fir wood, connected by iron wires, ideal for temporary terrains such as beaches; suspension footbridges are an engineering solution for crossing large differences in height or rivers, with stabilizing steel cables counteracting gravitational loads and wind forces;
- pedestrian bridges: bridges require careful planning, formal authorization and constant maintenance. They must be dimensioned according to the minimum width of the trail and designed to guarantee safety. The choice of location is crucial: the bridge must be positioned at the narrowest point of the watercourse and on a straight stretch to prevent erosion of the foundations (Figure 8.6).

Furthermore, it must be located in an area protected from natural hazards such as landslides or avalanches. As for safety standards, the installation of railings is recommended depending on the degree of exposure of the path:

- no railing: on less exposed trails and if the height from the bottom does not exceed 1 m;
- railing on one side only: on moderately exposed trails;
- railing on both sides: in case of exposed crossings over gorges, streams, or hazardous areas.

Figure 8.6 - Longitudinal section and image of a wooden bridge with handrail.



Source: Swiss Confederation [7]

b) Stairs and fall protection

These structures are built to overcome gradients with high slopes.

- Stairs: used on sections with slopes greater than 25% to facilitate ascent and descent and to prevent erosion. It is recommended to alternate stair ramps with less steep trail sections and to insert intermediate landings in the case of long stairways; they can be made of wood or

stone and must have a tread of at least 25 cm and a riser of 10-15 cm. Suspended stairs, in wood or metal, are an alternative that reduces ground contact;

- ladder steps: used to overcome very steep sections, generally no longer than 5 meters and built in steel for greater safety;
- fall protection: railings, at least 1 m high, are installed in areas with a risk of falling. Fences and guardrails are used to signal hazards and guide users. On mountain trails, handrails in chains or ropes are used for the most difficult passages.

The types of interventions for securing the terrain and stabilizing slopes to prevent erosion may include bioengineering works (methods such as turfing with sods, sowing native species, or creating live terraces and wickerwork are effective and sustainable, as plant roots consolidate the soil) or wooden and stone structures (on steeper slopes, with gradients greater than 60%, structural works such as crib walls and wooden retaining grids are used; on slopes greater than 175%, dry stone walls or gabions, made with local materials, are used). In detail:

- construction of dry-stone walls and gabions: bioengineering works consisting of the construction of retaining walls through the superimposition of selected stones, without the use of binders. The dry technique allows excellent drainage and perfect landscape integration, stabilizing embankments and slopes. Stone and mortar masonry, although a more modern alternative, is considered harmful to the environment and to the typical draining functionality of dry-stone walls. Gabions consist of metal cages filled with compact stones. These are structural works that require static calculations but are permeable to water and allow vegetation to develop;
- construction of crib walls and palisades: soil retaining structures made with wooden poles driven vertically into the ground. Depending on the context, palisades may be simple or reinforced with micropiles to increase stability and prevent landslides or slips on non-cohesive soils. Live crib walls may be single- or double-faced, made with wooden poles forming a sort of box filled with inert material and live vegetation for soil consolidation. These are gravity structures that generally do not exceed 1.5 m in height;
- installation of hand ropes and chains: safety elements installed on rocky, exposed, or extremely steep sections. Chains, securely fixed to the rock, act as handrails, providing essential support to hikers and reducing the risk of falling.

Another important aspect to be considered in the trail design phase is the positioning of signage, which consists of installing visual supports (poles, panels, trail markers) to provide directional indications and route information. The effectiveness of signage depends on strategic placement, visibility and compliance with predefined standards.

The standards defined by CAI and FIE provide for an integrated system of vertical and horizontal signage, often supplemented by other forms of more or less spontaneous and consolidated signage. Although the standards are very precise, the autonomy of individual projects or regional regulations may lead to the introduction of unique elements, such as specific trail logos, which, while innovative, must maintain consistency with the basic system to avoid confusing hikers.

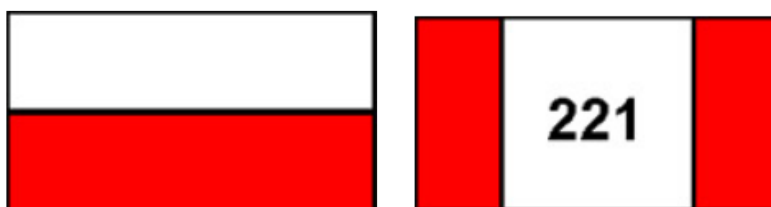
- Horizontal signage (Figure 8.7) consists of the classic white-red stripes (15x8 cm), to be placed every 50-100 m depending on visibility conditions and may or may not include the trail number.
- Vertical signage (Figure 8.8), generally made of wood and less frequently of metal or forex, includes different types of panels [8]:

- Overview board or panel (140x110 cm): positioned at the beginning of the trail, provides a schematic map of the trail network, the list of itineraries, difficulty levels and walking times and historical-environmental notes (Figure 8.8a);
- Trail marker board (55x15 cm): indicates direction, destination and walking times. It is usually an arrow with a red tip and a white-red tail (Figure 8.8b);
- Locality board (25x15 cm): shows the name of the place and the elevation, useful for altimeter calibration (Figure 8.8c).

Other types include:

- trail marker stakes: parallelepipeds or cylinders of wood, with a side or diameter of 6-8 cm and a height of 100-200 cm, with the top painted white and red, driven into the ground along the trail. Generally placed on meadows, pastures, or open terrain where reference points are absent and orientation may be difficult (Figure 8.9a);
- stone cairns (pyramids): stone cairns, or pyramids, indicate the continuity of the trail on open terrain in high mountains, such as scree slopes (Figure 8.9b).

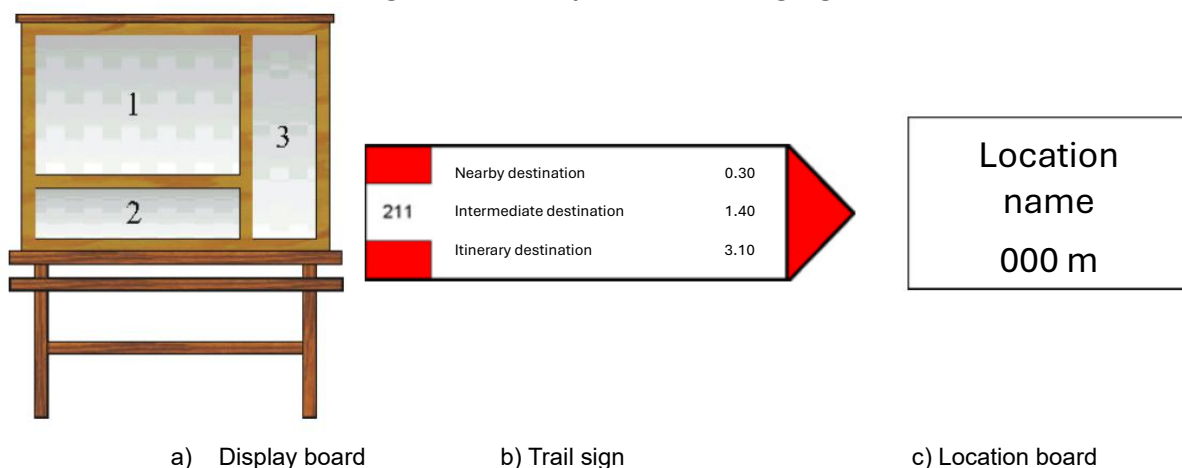
Figure 8.7 - Examples of horizontal signage.



Source: CAI

All vertical signage should be georeferenced to facilitate repositioning in case of removal.

Figure 8.8 - Examples of vertical signage.



a) Display board

b) Trail sign

c) Location board

Source: CAI

The integration of physical signage with the digital network is an increasingly relevant aspect. Regional regulations, such as those of Calabria, oblige managing entities to create and update a dedicated mobile application for each recognized trail, which must display the Region's logo and the option to request the "Hiker's Card" in electronic format. The georeferencing of signs, already

foreseen in the FIE Handbook 11, is the first step in integrating the physical and digital worlds. This evolution shifts the concept of the trail from a simple ground trace to a complete information infrastructure, which supports the user not only with physical indications but also with digital data accessible via smartphone.

Figure 8.9 - Examples of other types of signage.



a) Trail marker stake



b) Stone cairn

Source: CAI

Signage plays a fundamental role in the management of pedestrian flows, crucial for the safety and environmental conservation of trails. However, the most effective measure to keep walkers on the trail is the quality of the infrastructure itself. A well-built and regularly maintained trail, free of damaged, muddy, or overgrown sections, reduces the tendency of users to leave the route and create unauthorized deviations. To prevent unwanted shortcuts and deviations, especially in critical points such as switchbacks or highly frequented areas, physical guiding elements can be used. These include logs, boulders, piles of branches, or shrub planting, strategically placed to block alternative routes. Barriers, such as fences in hazardous areas or near pastures with animals, are also an effective tool to ensure that users remain on the designated trail.

8.1.3 Safety, maintenance and risk management

Safety along walking itineraries is based on a fundamental principle: the self-responsibility of the hiker. Guidelines emphasize that it is the user's duty to carefully plan the excursion, assess their own physical abilities, choose adequate equipment, check weather forecasts and inform friends or family about the route and the return time [2], [9]. This awareness is considered the first line of defence against unforeseen events in an uncontrolled natural environment.

The trail manager has the duty to identify, assess and communicate risks, especially those related to natural hazards such as rockfalls or landslides. The risk management procedure involves technical-structural protection measures (e.g., railings or safety ropes in exposed sections) and organizational measures, such as the provision of specific information and warnings. Trails must be inspected regularly, at least once a year, to ensure that they are in adequate condition and that signage is updated. If a trail is permanently closed, it must be dismantled and removed from official maps. The issue arises in the case of long-distance walking itineraries, which, unlike trails, extend over very long sections under different jurisdictions, so that maintenance is based solely on the commitment of volunteers from associations promoting the itineraries.

Ordinary maintenance is crucial for the safety and durability of routes. In Italy, this activity is largely entrusted to the volunteers of local CAI sections, who periodically carry out vegetation clearing and signage restoration. This model highlights a sort of implicit pact: public investment in ordinary maintenance largely relies on the civic commitment of volunteers. This approach is based on a partnership in which the manager reduces risks and the user assumes responsibility for them. Although not legally binding as in other countries, the model proves economically sustainable and

resilient thanks to the widespread work of associations. The main challenge is to ensure a minimum and constant level of maintenance in a system that depends on local resources and commitment, where the risk of accidents is largely shifted onto the user.

8.1.4 Funding and economic sustainability of walking itineraries

The creation and maintenance of long-distance walking itineraries in Italy are supported by a mix of public and private financial sources. The Ministry of Tourism has established a “Fund for religious walking routes” with an allocation of €4,320,000, intended to finance projects for the enhancement of properties, improvement of usability (safety, accessibility, digitalization) and tourism promotion. Similarly, the Lazio Region has received over €1.6 million from the Ministry of Tourism for a project promoting the Via Francigena. At the European level, funding programs such as the European Regional Development Fund (ERDF), the European Agricultural Fund for Rural Development (EAFRD) and the Interreg program offer opportunities for maintenance and development projects.

The CAI calls for tenders funded by the Ministry of Tourism constitute a practical example of public-private collaboration. This model demonstrates the recognition of the value of volunteer work for the management of the national trail infrastructure.

The vision that is emerging is that of walking itineraries as an integrated territorial development project. The Ministry of Infrastructure and Transport, through the program “Connecting Italy,” has promoted the recovery of existing infrastructures, such as the Case Cantoniere (Maintenance House) , for the creation of services along the routes [10]. This approach, visible in other projects such as the Via Francigena and the Sentiero Calabria, which aims to identify an entire 1,600 km trail network, highlights a gap between initial investment and long-term sustainability. Although the creation and promotion of new itineraries benefit from some funding, ordinary maintenance, which ensures durability and safety over time, is supported by much more modest funds and relies predominantly on volunteering. This disparity could represent a critical point for the future sustainability of the entire network.

8.1.5 Comparison of construction and maintenance costs of pedestrian and transport infrastructures

An aspect often overlooked in literature and transport planning concerns the construction and maintenance costs of pedestrian infrastructures. Indeed, a substantial difference emerges compared to other transport infrastructures, both in terms of initial investment and in terms of management throughout the life cycle. The comparative economic assessment of infrastructures represents a fundamental step for the planning and programming of infrastructural interventions. To make the different types of interventions comparable, the standard unit measure per kilometer (€/km or M€/km) is normally used for construction and annual cost indicators or operating cost indicators are used for maintenance. However, it is necessary to recall two methodological caveats:

- the reported figures are average orders of magnitude or typical ranges, actual costs depend heavily on local factors (orography, environmental constraints, expropriations, etc.);
- the comparison should distinguish between construction/capex costs (civil works, plants, signage) and operating and maintenance/opex costs (ordinary and extraordinary maintenance, service management) (Table 8.1).

The construction costs of 1 km of infrastructure vary enormously depending on the type: while a high-speed railway line involves an investment between €40 and €50 million/km, a subway section

may require €70 to €120 million/km, a four-lane highway ranges between €25 and €40 million/km. Lower, but still significant, are the values for a conventional electrified double-track railway (€10-15 million/km), a tram (€16-30 million/km), or a bus rapid transit system (€3-8 million/km). An ordinary two-lane road may cost around €120,000 per km, but this value increases significantly in the presence of specific works such as viaducts, bridges, soil stabilization, or other structures necessary in complex contexts.

With regard to light infrastructures, such as cycle paths or trails, the values change radically by orders of magnitude. A cycle path ranges from 30,000 to 50,000 €/km, while a pedestrian trail requires on average between €12,000 and 15,000 €/km, values that may increase in the case of new itineraries requiring consolidation works, footbridges, or small bridges. These values derive from technical estimates widely used in infrastructural projects and operational data from civil tenders and they take into account territorial conditions such as topography, hydrogeological risk, distance from service points and climatic conditions. It is evident that pedestrian infrastructures require a much lower economic commitment than heavy infrastructures, placing themselves in a financial accessibility range suitable also for local authorities and territorial communities.

The difference is even more pronounced when considering maintenance costs. In the case of large transport works, the values are very significant: maintenance costs for ordinary roads are generally between 7,000 and 23,000 €/km per year, while for more complex works, such as motorway viaducts, costs can be significantly higher, although specific estimates vary. Operating and maintenance costs of heavy infrastructures include repairs, replacements, technological upgrades and safety measures, which contribute significantly to total life cycle costs.

For walking itineraries, however, the costs are extremely limited. According to estimates by the Italian Alpine Club, the ordinary maintenance of an existing trail requires on average between 10 and 20 €/km per year, mainly covering vegetation clearing and signage restoration. A concrete example comes from the Autonomous Province of Bolzano, which establishes public contributions equal to 30 €/km per year for the ordinary maintenance of trails, with an additional 10 €/km for signage along passable roads. Another significant reference is the 2022 national CAI tender, which distributed approximately €600,000 for the maintenance of over 35,000 km of trails, demonstrating how with relatively modest investments it is possible to ensure the usability of a very extensive infrastructural heritage [11]. The limited costs derive from the fact that pedestrian infrastructures do not require complex systems such as electrical networks, technological installations, or sophisticated signage, significantly reducing operating burdens compared to heavy infrastructures. These data highlight the extraordinary economic convenience of walking itineraries and pedestrian infrastructures, especially if compared with the expenses required for the management of roads, railways, or dedicated collective transport systems. Moreover, pedestrian infrastructures have almost zero service production costs, since their use does not involve motorized vehicles nor significant energy consumption. The only expenditure item that may vary is promotion, which may include the creation of websites, digital applications, printed guides and communication activities. A further element reinforcing the interest in pedestrian infrastructures is their cost-effectiveness understood not only as a reduction in construction and maintenance costs compared to other transport modes, but also as a lever for economic and social development. Walking itineraries are in fact accessible to a much wider audience of users compared to road infrastructures: they do not require ownership of a private vehicle, a driving license, or expenses related to fuel and vehicle maintenance. This makes them intrinsically equitable tools, able to also meet the mobility and usability needs of population groups often excluded from other forms of transport, such as young people, the elderly, or low-income individuals.

From a territorial perspective, walking itineraries also represent an important driver for the revitalization of inland and marginal areas. Several studies have highlighted how slow tourism generates widespread and sustainable economic effects, mainly related to hospitality, catering, local handicrafts and support services. The low costs of construction and maintenance of pedestrian infrastructures translate into low-risk investments for territories, capable of activating new economies without requiring major invasive works.

The economic impact of walking itineraries must also be understood in terms of a multiplier effect: against a limited public investment for the maintenance of the routes (in the order of a few tens €/km per year), the economic return for the territory can be significant. It is sufficient to note that most walkers spend on average between 30 and 50 euros per day, with a considerable share between 50 and 100 euros [12], generating a direct effect on supporting local economies. This confirms that walking itineraries are light infrastructures not only in terms of costs but also in their ability to generate distributed economic value, revitalizing communities and territories often excluded from the major flows of mobility and transport.

From the comparative analysis (Table 8.1) it clearly emerges that walking itineraries represent high-yield light infrastructures, characterized by extremely low construction and maintenance costs when compared with those of large-scale transport works. With limited initial investments, walking itineraries generate widespread economic benefits, thanks to the direct expenditure of walkers that supports accommodation facilities, catering, cultural services and local handicrafts.

Table 8.1 - Summary of costs and benefits of pedestrian infrastructures compared to heavy infrastructures.

Dimension	Walking itineraries (pedestrian infrastructures)	Heavy infrastructures (roads, railways, subways)
Construction costs	€12,000 - €15,000/km (new sections)	Road €120,000/km; Highway €25-40 M/km; Railway €10-15 M/km; Subway €70-120 M/km; High-speed rail up to €50 M/km
Maintenance costs	€10-20/km/year (CAI, 2021); almost zero costs for already existing natural paths	Road: €7,000-23,000/km/year for ordinary sections; higher costs for viaducts and complex infrastructures; Railway: €15-20 M/km/year; High-speed rail up to €61 M/km/year
Management/usage costs	Almost zero: not required fuel, toll, or excise taxes; limited expenses for promotion and signage; service/usage production costs almost zero for itineraries designed to preserve natural areas; variable promotion costs (website, social networks, guide, app)	High: fuel, tolls, excise taxes, vehicle maintenance, service management staff
Social accessibility	High: does not require private vehicles or particular skills; suitable for young people, the elderly, low-income groups	More selective: requires own means or often expensive tickets; excludes less affluent population groups
Territorial impact	Positive: enhances inner areas, activates widespread local economies (hospitality, catering, handicrafts)	Concentrated: investments and benefits focus along major infrastructural axes, marginalizing peripheral areas
Environmental sustainability	High: low ecological impact, promotes slow tourism and landscape conservation	Low-medium: high land consumption, significant emissions, invasive works
Economic benefits	Each walker spends €50-70/day with direct effects on local economies (Symbola, 2020)	Indirect benefits linked to speed and efficiency, but with strong external costs (pollution, congestion, resource consumption)

Their high social accessibility makes them instruments of democratic mobility, capable of involving even segments of the population that would otherwise remain excluded from systems based on the use of private vehicles or the purchase of expensive tickets. Moreover, their environmental impact is minimal, as they promote the enhancement of the landscape and the reduction of land consumption. In this sense, walking itineraries are configured not only as transport infrastructures but also as strategic levers for the revitalization of inland areas and for the promotion of forms of slow, sustainable and inclusive tourism.

8.2 Design of new walking routes and improvements of existing infrastructures

8.2.1 The PATHS methodology: a systemic approach to walking route design

The PATHS methodology, acronym for Place, Accessibility and Inclusion, Technological integration, Harmonization, Sustainability, represents a systemic conceptual framework proposed for the design of walking routes.

This approach is based on the simultaneous consideration of five key dimensions, overcoming traditional design logics and promoting the creation of routes that are not only functional, but also socially, environmentally and economically sustainable.

The five proposed dimensions are:

- **place:** this dimension constitutes the foundation of every project. It includes an in-depth analysis of the geographical, cultural and social context, through tools such as GIS mapping, topographic surveys and the identification of points of interest and connections with existing infrastructures. The goal is to ensure that the walking route is fully integrated into its surrounding environment, preserving and enhancing it;
- **accessibility and inclusion:** inclusiveness is at the core of this dimension. The focus is on making the route accessible to every type of user, including people with impairments, families with strollers and the elderly. This is achieved by defining alternative routes, slope limits, dimensional standards and installing rest areas and appropriate signage, ensuring full social and experiential accessibility;
- **technological integration:** a dimension that values the strategic use of digital tools and IoT sensors. These technologies enable real-time monitoring, management of pedestrian flows, orientation of walkers, enhanced safety and integrated management of ancillary services (e.g., bookings or information). The walking route thus becomes an intelligent and responsive infrastructure;
- **harmonization (participatory):** underlines the importance of participatory design. Through the active involvement of local stakeholders, communities, public authorities and tourism operators via workshops and partnerships, the project is ensured to be consistent with the needs and values of the territory;
- **sustainability:** a cross-cutting dimension that permeates every aspect of the project. It ensures environmental, economic and social sustainability by optimizing ecological impact (e.g., waste management, use of local materials), promoting the use of renewable energy and supporting local economies.

The application of the PATHS methodology unfolds through an operational cycle of four phases, which ensures not only the correct implementation of the design principles but also their continuous verification and adaptive improvement over time: planning, technical design, promotion and management, evaluation and corrective actions. Each of these phases can be articulated into sub-phases based on the five considered dimensions, as described below.

A. Planning

This preliminary phase defines the foundations of the project. In it, potential areas for implementing the route are identified and the feasibility of the project is assessed. If the feasibility analysis proves positive, planning proceeds according to the following five dimensions.

1. Place (territory and context)

- Preliminary study of the territorial, landscape and cultural context;
- Identification of potential routes and connections between main points of interest;
- Assessment of environmental, archaeological and urban constraints;
- Analysis of pedestrian flows and modes of access to the walking routes.

2. Accessibility and inclusion

- Identification of user targets and their specific needs;
- Definition of general criteria for accessibility and social usability;
- Preliminary analysis of physical or logistical barriers that could hinder the use of the route;
- Study of the distribution of rest areas, services and accommodations along the route.

3. Technological integration

- Identification of digital needs and information support systems;
- Preliminary evaluation of digital platforms and tools for data collection;
- General planning for flow tracking and information management.

4. Harmonization (Participatory)

- Strategic involvement of local stakeholders, communities, public authorities and tourism operators;
- Collection of needs, expectations and territorial constraints;
- Definition of participatory guidelines to integrate cultural, social and economic values.

5. Sustainability (Environmental and social sustainability)

- Preliminary analysis of the environmental and social impact of the route;
- Definition of guiding principles for the protection of natural and cultural resources;
- Identification of strategies to enhance local economies and promote sustainable practices.

B. Technical design

In the second phase, the preliminary analyses are transformed into concrete interventions. In this phase, the PATHS dimensions guide the design of the route and infrastructures.

1. Place (territory and context)

- Terrain analysis through topographic surveys, photogrammetry and GIS to assess slopes, soil stability and geomorphological characteristics;
- Identification of cultural, historical and natural points of interest, with assessment of usability and resource protection;
- Study of connections with existing infrastructures (roads, cycle paths, public transport) and safe access to the route;
- Definition of the optimal route in terms of continuity, safety and environmental integration.

2. Accessibility and inclusion

- Calculation of slopes, widths and curvature radii of paths according to accessibility standards for people with reduced mobility or families;
- Planning of ergonomic rest areas and shelters from sun or rain;
- Definition of alternative routes or bypasses in case of natural obstacles or infrastructural issues;

- Specification of signage and orientation devices, considering readability, height, materials and placement.
3. **Technological Integration**
 - Design of IoT sensors and monitoring devices (e.g., people counters, environmental sensors, security cameras);
 - Integration of apps or digital platforms to provide information on the route, weather conditions and available services;
 - Definition of pedestrian flow management systems and automatic alerts in case of critical situations;
 - Provision of digital maps and real-time updates of accessible sections.
 4. **Harmonization (participatory)**
 - Involvement of local stakeholders, communities, public authorities and tourism operators in the definition of the route and services;
 - Shared design of rest areas, interpretative signage and information points;
 - Validation of design criteria through workshops, participatory site visits and field simulations.
 5. **Sustainability**
 - Selection of local, recycled, or low environmental impact materials for signage, furniture and unpaved routes;
 - Optimization of water management, erosion prevention and protection of local flora and fauna;
 - Planning of long-term maintenance and sustainable management of hospitality services;
 - Assessment of social and economic impact, encouraging local economies and responsible use of the walking route.

C. Promotion and management

This phase focuses on the implementation of the project and its use by users based on the five following dimensions.

1. **Place (territory and context)**
 - Clear communication of route sections and cultural, historical and natural points of interest;
 - Publication of maps, guides and multimedia content highlighting the relationship between route and territory;
 - Continuous updating of information on route conditions and available services.
2. **Accessibility and Inclusion**
 - Transparent information on the accessibility of sections and services (paths, rest areas, accommodations);
 - Highlighting of alternative routes for people with reduced mobility or specific needs;
 - Activation of user support tools along the route (e.g., signage, information panels, apps).
3. **Technological Integration**
 - Use of digital platforms, apps and social media for promotion and dissemination of real-time updates;
 - Implementation of pedestrian flow and safety monitoring systems along the route;
 - Data collection on usage, attendance and walker feedback to optimize route management.
4. **Harmonization (participatory)**
 - Involvement of local communities and stakeholders in the management and promotion of the route;

- Creation of partnerships with public authorities, associations and tourism operators to expand visibility and ensure territorial consistency;
 - Organization of events or activities that encourage direct user participation and cultural enhancement of the route.
5. **Sustainability**
- Promotion of sustainable practices among walkers (respect for nature, waste collection, environmental education);
 - Enhancement of local economies and sustainable services along the route;
 - Continuous monitoring of the social and environmental impact of promotional and management activities.

D. Evaluation and corrective actions

This crucial and ongoing phase closes the operational cycle and transforms it into a process of continuous improvement through actions proposed on the five dimensions.

1. **Place (territory and context)**
 - Constant monitoring of territorial and route conditions, detecting environmental or infrastructural changes;
 - Maintenance of paths, bridges, signage and cultural and natural points of interest;
 - Updating maps and routes based on territorial modifications or user needs.
2. **Accessibility and Inclusion**
 - Collection of user feedback on difficulties encountered along the route; Maintenance interventions to restore full usability of infrastructures and rest areas for all types of users, including people with impairments;
 - Identification of sections or services requiring adjustments to ensure safety and accessibility.
3. **Technological Integration**
 - Use of digital systems and IoT sensors to collect real-time data on pedestrian flows and route conditions;
 - Maintenance and updating of digital tools, apps and monitoring platforms;
 - Analysis of quantitative and qualitative data to assess safety, accessibility and service use.
4. **Harmonization (participatory)**
 - Continuous involvement of stakeholders, communities and local operators in evaluating results and defining improvement interventions;
 - Organization of shared participatory maintenance activities, such as volunteering projects or collaboration with local authorities;
 - Sharing of collected data and feedback to ensure transparency and consistency with territorial needs.
5. **Sustainability**
 - Evaluation of the environmental, social and economic impact of activities along the route;
 - Adoption of sustainable maintenance interventions, with eco-friendly materials and reduced environmental impact;
 - Continuous improvement of management strategies to preserve the territory, support local communities and promote responsible practices among walkers.

Table 8.2 presents a summary framework of the PATHS methodology, organized into four operational phases. For each phase, the five key dimensions of the methodology are systematically detailed. The framework highlights the integrated and multi-level approach of the methodology, which connects

territorial, social, technological and environmental aspects throughout the entire life cycle of a walking route.

Table 8.2 - Summary of the PATHS methodology: operational phases and key dimensions.

Operational Phases	Place (Territory and context)	Accessibility and Inclusion	Technological Integration	Harmonization (Participatory)	Sustainability (Environmental and social)
1. Planning	Analysis of territorial, cultural and environmental context; identification of routes and constraints	Identification of target groups and needs, analysis of barriers, planning of accessibility and rest areas	Definition of digital requirements and information support systems	Preliminary involvement of communities and stakeholders to collect needs and expectations	Preliminary assessment of environmental/social impacts; strategies to enhance local economies
2. Technical Design	Topographic and GIS surveys; definition of the optimal route connected to existing infrastructures	Accessibility standards (slopes, widths), alternative routes, inclusive signage	Design of IoT sensors, apps, monitoring systems and flow management	Participatory workshops for validation of routes, rest areas and services	Choice of eco-friendly materials, water management and biodiversity protection
3. Promotion and Management	Communication of sections, maps and points of interest; updating of information	Transparent dissemination of accessibility of sections and alternative routes	Use of digital platforms and social media for promotion, real-time monitoring and feedback collection	Creation of public-private partnerships and involvement of local communities in management	Promotion of sustainable practices among walkers and enhancement of local services
4. Evaluation and Corrective Actions	Monitoring of territory and infrastructure conditions; updating maps and routes	Collection of user feedback; adjustments for universal accessibility	Data collection from sensors; updating and maintenance of digital platforms	Stakeholder involvement for results evaluation and participatory maintenance	Assessment of environmental/social impacts; continuous improvement of sustainable management strategies

8.2.2 Differentiated application of the PATHS Methodology

The presented methodology can be applied with some distinctions both to new itineraries and to pre-existing itineraries.

Regarding the former, as seen previously, the approach starts from a completely new design. In this mode, the five PATHS dimensions guide the definition of all elements of the route: from territory analysis to the choice of the optimal path, from full accessibility for all types of users to the integrated design of technologies and services, from engagement of local stakeholders to the definition of sustainable practices from the beginning (Table 8.3). The priority is to create a coherent and fully integrated route that systematically meets functional, social, environmental and economic objectives.

Table 8.3 - Application of the PATHS methodology to new itineraries.

Operational Phase	Planning (P)	Accessibility and Inclusion (A)	Technological Integration (T)	Harmonization (H)	Sustainability (S)
Planning	Territory analysis (GIS, topographic surveys) to map the route and Pols	Preliminary assessment of inclusion needs and consultation of accessibility regulations	Identification of technological requirements for future monitoring and wayfinding	Initial engagement of communities and stakeholders (e.g., workshops) to define the project vision	Definition of environmental and economic sustainability criteria for the design phase
Technical Design	Detailed design of the route and infrastructures (e.g., bridges, footbridges) with executive plans	Implementation of accessible routes (e.g., ramps, regulation-compliant slopes) and choice of tactile signage	Integration of IoT sensors for flow counting, SOS stations and totems with QR codes	Maintenance of dialogue with the community for the integration of local elements (e.g., craftsmanship)	Selection of low-impact materials (e.g., natural stabilized soil, certified wood) and design of waste management systems
Promotion & Management	Use of updated GIS maps to manage and communicate the route	Promotion of accessibility features and dedicated services	Digital communication (apps, social media) and real-time flow data monitoring	Creation of partnerships (e.g., local authorities, associations) for route management and maintenance	Implementation of environmental management practices (e.g., "Leave No Trace") and support for local economies
Evaluation & Corrective Actions	Analysis of land use data to verify the effectiveness of the route	Collection of accessibility feedback to identify and correct potential barriers	Analysis of data from IoT sensors to optimize services and infrastructures	Evaluation of community engagement and planning of corrective actions based on their feedback	Analysis of environmental data (e.g., waste) to improve management practices

For already existing itineraries, the methodology focuses on targeted improvement of the route. Here, actions are aimed at identifying critical points and strengths already present along the path, updating or adapting infrastructures and services, improving accessibility and social usability, integrating technologies for flow monitoring and management and optimizing the sustainability of activities. The priority is to preserve and enhance the existing itinerary, intervening selectively where necessary, without radically modifying the original path (Table 8.4).

Specifically, the process begins with a Planning phase focused on diagnostics. The Place dimension concentrates on a critical analysis of the route, mapping flows and identifying degraded points or areas at risk. Accessibility and Inclusion performs an access audit, a field survey to detect architectural barriers (e.g., excessive slopes, steps). Harmonization engages the community and hiking associations to collect feedback on critical points and establish intervention priorities. Sustainability evaluates the opportunity to reuse existing materials, while Technological Integration plans the implementation of new tools for data collection.

The process then proceeds with the technical design phase of targeted interventions for the adaptation and optimization of already existing routes (Place). Accessibility and Inclusion guides the redesign of non-accessible sections, with the addition of ramps or alternative routes. Technological Integration foresees the updating of signage with QR codes, the installation of IoT sensors and the implementation of navigation applications. Harmonization ensures that interventions integrate with the identity of the existing route. Sustainability directs the redevelopment of rest points with eco-friendly materials and the implementation of waste management systems.

Table 8.4 - Application of the PATHS methodology to existing Itineraries.

Operational Phase	Place (P)	Accessibility and Inclusion (A)	Technological Integration (T)	Harmonization (H)	Sustainability (S)
Planning	Critical analysis of the existing route to identify degraded points and flows	Execution of an access audit to detect architectural barriers and inclusion needs	Assessment of the opportunity to implement new technologies for data collection and wayfinding	Consultation with stakeholders and the community to establish intervention priorities	Analysis of environmental criticalities and assessment of the potential reuse of existing materials
Technical Design	Redesign of critical sections and development of alternatives to improve usability	Adaptation of non-accessible sections (e.g., installation of ramps) and updating of signage	Enhancement of digital infrastructures with new sensors or informational totems	Integration of interventions with the existing identity of the route, working closely with the community	Implementation of sustainable solutions (e.g., rest points with eco-friendly materials) and waste management systems
Promotion & Management	Updating information (maps, cartography) to communicate the improvements made	Communication of accessibility improvements to attract a broader audience	Use of new technologies to promote the renewed route and monitor its usage	Maintenance of community involvement in maintenance and promotional activities	Promotion of responsible behaviors and support of local economic activities along the route
Evaluation & Corrective Actions	Analysis of usage data to verify the effectiveness of the changes made	Collection of specific feedback on the usability of new interventions	Analysis of real-time data to optimize new technological infrastructures	Evaluation of community involvement and planning of further modifications based on their feedback	Monitoring of the environmental and social impact of changes for continuous improvement

The Promotion and Management phase is dedicated to the revitalization of the route. Place updates cartography and available information. Accessibility and Inclusion highlights the improvements made to attract a broader audience. Technological Integration supports the promotion of the renewed route and the monitoring of new flows. Harmonization continues to ensure community involvement in route maintenance and in communicating the novelties. Sustainability promotes responsible behaviour among walkers. Finally, the Evaluation & Corrective Actions phase becomes crucial. Place analyses usage data to verify the effectiveness of the changes made. Accessibility and Inclusion collects specific feedback on the accessibility of the new sections. Technological Integration provides real-time data to monitor the effectiveness of interventions. Harmonization guides the planning of further corrections based on community feedback. Sustainability evaluates the impact of new management practices to ensure continuous improvement.

Below (Table 8.5) is a summary framework illustrating the application of the methodology according to the type of itinerary.

Table 8.5 - Key differences between the two approaches.

PATHS Dimension	New Itineraries	Existing Itineraries
Place	Definition of the route and points of interest from scratch, complete analysis of the context	Evaluation and adaptation of the existing route, updating points of interest and connections
Accessibility and Inclusion	Comprehensive design of accessibility for all types of users	Improvement of accessibility and adaptation of critical points along the route
Technological Integration	Integration of digital systems and IoT	Updating of digital tools, flow monitoring and technological maintenance
Harmonization	Participatory engagement to define the route, services and rest areas	Consultation and co-design for selective interventions and improvement of existing services
Sustainability	Definition of sustainable practices starting from the design phase	Optimization of existing practices, sustainable maintenance and targeted interventions

8.3 Sustainability as a cross-cutting and integrated dimension

The concept of sustainability applied to the PATHS methodology is a distinctive and fundamental element, transforming it from a simple design approach into an integrated territorial development model. It is not limited to environmental protection but extends to economic and social dimensions, creating lasting value for the communities and territories, operating at three distinct levels:

- **environmental sustainability:** focuses on minimizing the ecological impact of the trail. This includes landscape protection, management of natural resources, use of low-impact materials and pollution reduction;
- **economic sustainability:** concerns the long-term financial feasibility of the project. It is not only about containing construction costs but also generating economic value for local communities, supporting productive activities and sustainable tourism;
- **social sustainability:** focuses on the positive impact of the trail on the community. This includes the inclusion of all citizens, promotion of physical and mental well-being and enhancement of cultural heritage and local traditions.

Below, it is described in detail how sustainability permeates each phase of the trail's life cycle, translating principles into specific actions for each operational phase.

A. Planning phase

In this phase, sustainability is at the centre of the initial assessment.

- **Environmental Scope:** a preliminary environmental impact analysis is carried out to identify risk areas and points of ecological fragility (e.g., protected areas, natural habitats). Routes are selected to minimize alteration of natural habitats or landscape fragmentation. Local materials and their supply chains are studied, favouring zero-kilometre materials to reduce the carbon footprint.
- **Economic Scope:** a feasibility study is conducted to estimate construction and maintenance costs. Potential economic benefits for the territory are analysed, such as the enhancement of local products or the creation of new job opportunities related to tourism.
- **Social Scope:** it is evaluated how the trail can connect local communities, integrating historical-cultural sites and essential services. Communities are consulted to understand their expectations and concerns, ensuring the project respects local traditions. For example, areas may be planned for the sale of local products or for organizing cultural events, integrating the trail into the local social and economic fabric.

B. Technical design phase

Sustainability translates into concrete design choices.

- **Environmental Scope:** naturalistic engineering techniques are favoured to stabilize slopes and control erosion. Pavements are made of draining and natural materials such as stabilized soil or compacted earth, reducing soil impermeabilization. Smart recycling collection systems and LED lighting powered by solar panels are planned at rest points. Infrastructures promoting responsible behaviours are foreseen, such as ecological islands for recycling along the trail or fountains encouraging the use of reusable bottles;
- **Economic Scope:** the choice of materials and technical solutions considers their durability and long-term maintenance costs. Solutions reducing the need for future interventions are preferred, such as the use of FSC-certified wood or the reuse of existing materials. Energy efficiency pursued through the use of solar panels reduces dependence on the electrical grid and operational costs;
- **Social Scope:** the trail is designed to offer services supporting user well-being, such as rest areas with ergonomic benches and refreshment points near local communities. Design elements enhancing the cultural identity of the place are incorporated.

C. Promotion and management phase

In this phase, sustainability becomes part of the walker's experience.

- **Environmental Scope:** operational management actively promotes responsible behaviours through awareness campaigns (e.g., "Leave No Trace") and communication on the importance of waste management. The impact of tourist flows is monitored to prevent overloading of fragile areas.
- **Economic Scope:** a network of partners is created among local tourism operators, farmers and artisans to offer services and products along the trail. Trail management generates direct economic benefits for communities, which see their activities grow thanks to visitors. Commercial activities and local producers are promoted along the route to incentivize a circular economy.
- **Social Scope:** cultural events and volunteer activities for trail maintenance are organized, strengthening the bond between communities and their territory. Maintenance of accessible sections and services is ensured to make them usable by a wide range of users, promoting the trail as a tool for social inclusion and well-being.

D. Evaluation & corrective actions phase

This phase ensures continuous sustainability improvement.

- **Environmental Scope:** data on the trail's impact are collected (e.g., from IoT sensors, walker questionnaires, waste quantities, or energy consumption) to evaluate the effectiveness of adopted measures. The performance of materials and technologies is analyzed to plan possible replacements or improvements. For example, waste volume data are analyzed to optimize collection points or visitor flow is monitored to prevent overcrowding in sensitive areas;
- **Economic Scope:** economic flows generated for local communities are monitored, evaluating the effectiveness of partnerships and the need for new promotion strategies. Feedback from users and residents is collected to understand their perception of the trail's social and economic impact. If a commercial activity does not benefit from the trail, strategies can be studied to better integrate it;

- **Social Scope:** user feedback is analyzed to understand their perception of the social and cultural value of the trail. Periodic consultations with the community are organized to adapt trail management to their evolving needs.

8.4 Technology as an enabling and dynamic tool

In the PATHS methodology, technological integration is not limited to the introduction of devices but represents a strategic tool to enhance the walker's experience and optimize trail management. It operates on three main levels:

- **data collection:** the use of sensors and IoT (Internet of Things) devices allows the collection of real-time quantitative data, such as pedestrian flows, environmental conditions, or infrastructure status;
- **user interaction:** digital platforms and mobile applications create a direct communication channel with the walker, providing information, assistance and personalized services;
- **operational management:** technology automates and optimizes trail management and maintenance processes, making the entire infrastructure more efficient and responsive.

The idea of integrating new technologies into walking trails directly leads to the concept of Smart Trail. This approach transforms a traditional trail into an intelligent and interconnected infrastructure, capable of interacting with users and adapting in real time to their needs. Within the PATHS methodology, the concept of Smart Trail represents the practical and strategic application of the Technological Integration dimension.

A Smart Trail is a system where the physical and digital environments merge. The goal is not simply to add technology to the trail but to use it to improve the walker's experience, optimize management and ensure long-term sustainability. The Smart Trail concept permeates every project phase, ensuring that technology is a valuable tool from the outset.

A. Planning phase

In this phase, technology is employed for preliminary data collection and defining the digital functionalities of the future Smart Trail.

- **Digital analysis and mapping:** advanced tools such as GIS (Geographic Information Systems) are used for detailed and georeferenced mapping of the territory. The use of drones and laser scanners provides a high-precision three-dimensional data base, fundamental for design. The approach is enriched with Participatory GIS (PGIS), integrating local community knowledge into the process. Residents can directly contribute, indicating unofficial trails, points of interest, or specific issues, transforming mapping into a collaborative process.
- **Service planning:** the digital architecture of the user experience is designed. For example, the development of a mobile application as the primary contact point for walkers is defined, with functionalities such as offline maps, multimedia guides, service information and integrated emergency management.

B. Technical design phase

Here, technological planning translates into the physical and digital implementation of the Smart Trail system.

- **IoT infrastructures:** the trail infrastructure is equipped with "intelligence." Sensors are installed along the trail to count pedestrian flows, detecting in real time the number of walkers on specific sections. Environmental sensors monitor parameters such as

temperature and humidity. Security systems are also integrated, such as SOS call stations and, where necessary, video surveillance systems;

- **Interactive wayfinding systems:** traditional signage is enhanced with digital elements. For example, informational totems are equipped with touch screens showing interactive maps and updated information. Classic signs can be accompanied by QR codes linking to multimedia content such as the history of a site or description of a plant species. Extended reality solutions can also be integrated;
- **Software development:** a mobile application for users and a management platform for the managing entity are developed. These platforms act as the system's brain, collecting and analyzing sensor information, enabling centralized management of content and services.

C. Promotion & management phase

In this phase, technology becomes the primary tool for daily management and enhancement of the trail, making the experience seamless.

- **Communication and promotion:** digital channels (mobile app, social media, dedicated websites) are used to promote the trail and communicate in real time with walkers. Push notifications can be sent regarding route changes, adverse weather, or special events. Extended reality solutions can be integrated into the experience;
- **Service management:** technology facilitates interaction between walkers and ancillary services. A user can use the app to book a spot in a refuge, purchase a ticket for local transport, or access discounts at affiliated businesses, creating a fully integrated travel experience;
- **Real-time monitoring:** sensor data are visualized on a management dashboard to monitor flows, identify critical points (e.g., crowding in specific areas) and manage safety proactively, allowing real-time adaptation of trail management.

D. Evaluation & corrective actions phase

In this phase, the Smart Trail concept enables a continuous, data-driven improvement cycle.

- **Data analysis:** collected data (e.g., most frequented routes, travel times, user feedback) are analysed to assess the trail's effectiveness. "Heat maps" can be created to identify areas of higher and lower interest. Feedback collected through the app or PGIS allows identification of specific problems, such as inadequate signage or malfunctioning services;
- **Adaptive improvement:** analysis results guide corrective actions. For example, if a trail section is underutilized, strategies can be developed to make it more attractive with new digital content. Similarly, walker reports via the app allow targeted redesign interventions, ensuring changes meet real needs and local knowledge;
- **Use of extended reality for preventive maintenance:** immersive technologies such as augmented reality (AR) and mixed reality (MR) are applied to assist operators in preventive trail management. Through digital overlays of the real trail, operators can visualize in real time data on sections subject to degradation, humidity, or structural failure, facilitating proactive identification of critical points and timely interventions, reducing downtime and maintenance costs.

8.5 Inclusion and integration of the gender dimension

8.5.1 Application of the methodology for the development of inclusive trails

Accessible tourism is not only an ethical imperative but also a huge market opportunity. According to the Amadeus report “Assessing the value and market attractiveness of the accessible tourism industry in Europe,” the market for travellers with impairments and their companions represents an annual expenditure of over USD 100 billion in the United States. At the European level, the organization Open Doors estimates a value of USD 70 billion in Europe and the United States.

- approximately 50% of people over 60 have a disability and almost two-thirds of people with impairments in developed economies have the means to travel;
- these travellers tend to move with 2-3 companions, multiplying the economic impact;
- yet, 67% find it difficult to obtain reliable information and 36% define trip planning as “frustrating.”

Investing in accessibility meets this unmet demand and generates a positive impact on the local community and individual businesses.

Accessibility and inclusion are central to the PATHS methodology and a complete treatment must go beyond simply removing physical barriers to consider all user dimensions. Below, it is described in detail how the Accessibility and Inclusion dimension applies across the four phases of the project life cycle.

The Accessibility and Inclusion dimension in the PATHS methodology represents a guiding principle ensuring the trail is designed, implemented and managed for a heterogeneous user base. It is articulated as:

- **Physical accessibility:** ensuring a barrier-free trail for people with motor, sensory and cognitive impairments, the elderly and families with strollers;
- **Social inclusion:** creating a space that meets the needs of diverse population groups, considering factors such as age, cultural background and gender, to ensure everyone experiences well-being and safety.

The concreteness of the PATHS methodology manifests in its ability to translate these principles into specific actions in each operational phase.

A. Planning phase

In this phase, inclusion is central to preliminary analyses and strategic decisions.

- **Needs analysis:** a thorough analysis of the requirements of users with motor, sensory and cognitive impairments is carried out, consulting specific regulations (e.g., DM 236/89) and dedicated associations. For example, maximum allowable slopes are mapped and alternative routes for non-passable sections are identified;
- **Assessment of gender needs:** specific needs related to gender and perceived safety are integrated. This includes analysis of safety data in urban and rural areas and organization of focus groups with women and families to understand factors influencing their decision to use a trail, such as visibility, presence of restrooms and lighting.

B. Technical design phase

Here, analyses are translated into engineering and design solutions that make the trail an equitable space.

- **Barrier removal:** trails are designed with moderate slopes (max. 5%), adequate widths (min. 1.5 meters) and stable surfaces. Handrails and tactile pavements for the visually

impaired are installed at critical points. Accessible route alternatives are clearly marked and integrated into the overall design;

- **Safety and visibility:** gender-related safety issues are addressed through design choices that increase the sense of protection. For example, trails with good visibility of the path are favoured, avoiding blind corners. Intelligent solar-powered lighting systems are installed at rest points, intersections and tunnels, increasing intensity as people pass. Signage and rest areas are designed to be clearly visible and recognizable, reducing anxiety related to getting lost;
- **Support infrastructures:** comfortable rest areas are provided and where possible, accessible and well-lit restrooms, a key factor for usability by women, the elderly and families.

C. Promotion & management phase

In this phase, trail management and promotion aim to communicate its inclusive nature.

- **Detailed information:** digital platforms and the trail app provide detailed information on accessibility, clearly indicating sections with steeper slopes or accessible route alternatives. Presence of lighting, rest areas and restrooms is also communicated, reassuring users about trail safety and convenience;
- **Communication campaigns:** trail promotion specifically targets a diverse audience, using images and testimonials depicting people with different abilities, elderly and women walking safely and comfortably, encouraging a sense of belonging.

D. Evaluation & corrective actions phase

This phase is crucial to ensure that the trail maintains its inclusive character over time, adapting to real user needs.

- **Feedback collection:** the methodology relies on collecting specific feedback on accessibility and perceived safety. Online surveys, trail app questionnaires and dedicated discussion forums can be used to gather impressions from all users, with a particular focus on reports from women and people with impairments;
- **Data analysis:** data are analysed to identify critical issues. For example, trail usage data can be cross-referenced with reports of safety problems in certain areas to plan targeted interventions, such as installing new lighting or cameras;
- **Continuous improvement:** corrective actions are planned based on feedback. For example, if analysis reveals that a trail section is avoided by women, interventions can be studied, such as adding informational signage reassuring the proximity of points of interest or creating new lighting to make the trail safer.

8.5.2 Focus on the Gender Dimension

The integration of the gender dimension in the design of walking itineraries is fundamental to creating safer, more accessible and inclusive trails. Supporting an effective approach is the gender-disaggregated risk matrix developed based on the results of the international comparative survey on trail use, which reveals how men and women perceive hazards differently.

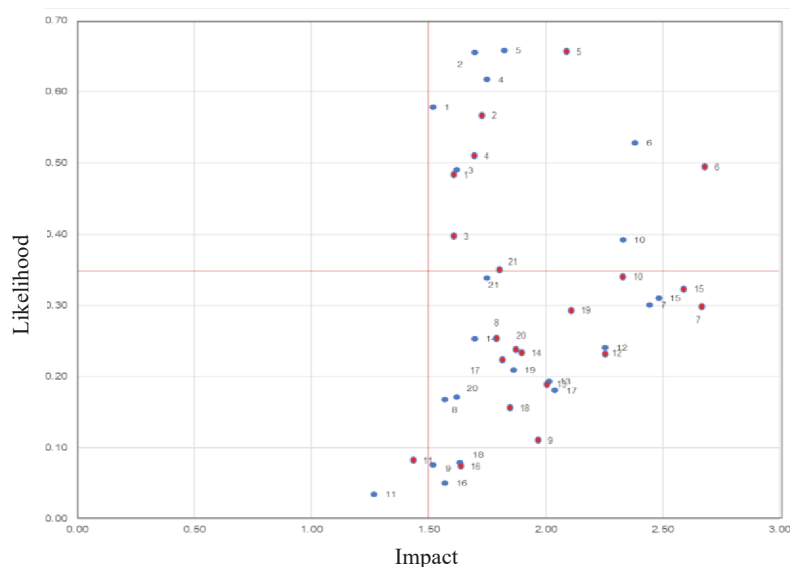
The matrix represents impact on the horizontal axis and the probability of a risk occurring on the vertical axis. This allows four quadrants to be distinguished.

In the top-right quadrant, representing risks with high impact and high probability, significant threats emerge, especially under unfavourable conditions. These require meticulous planning to minimize risk. In the bottom-right quadrant, with risks of high potential impact but low probability, there are elements that could have serious consequences; although unlikely, they still require robust

preventive measures. The top-left quadrant, which includes risks of low impact but high probability, comprises issues that do not directly threaten safety but can significantly influence comfort and the quality of the experience. Finally, the bottom-left quadrant contains risks of low impact and low probability, considered negligible but still requiring monitoring.

The disaggregation of risk perception by gender reveals that women tend to place a greater number of risks in the high-impact quadrants (Figure 8.10), particularly those related to personal safety (e.g., potential presence of aggressors, poor lighting, or lack of connectivity), compared to men, who place greater emphasis on technical or environmental risks. This divergence in perception underlines the need to interpret the matrix not as a simple average of responses but as a differentiated risk landscape, shaped by experiences, vulnerabilities and gender expectations. Recognizing these distinct patterns is essential to designing adaptive safety strategies that address both the psychological and physical dimensions of risk, thus promoting equitable and inclusive access to trails.

Figure 8.10 - Risk matrix by gender (Blue = Men; Red = Women) for each risk factor.



Understanding risk perceptions is crucial for developing effective interventions that improve the safety and security of hiking trails. Table 8.6 presents a detailed list of recommended safety measures and interventions aimed at mitigating identified risks, ensuring that trail design and management strategies address both personal safety concerns and physical hazards.

Women typically express greater concern for risks, especially those related to personal safety such as harassment and theft, while men are more likely to face emergencies requiring technical interventions, such as mountain rescue. This gender difference in risk perception emphasizes the need for safety and security measures that address these distinct concerns. Risk perception also varies based on factors such as the environment, type of trail and level of exposure to potential hazards. Consequently, safety/security measures should be adapted to address women's concerns, reducing their sense of vulnerability, while security interventions should focus on preventing harassment and theft, which women are more likely to experience.

Table 8.6 - Measures for safety and protection along trails to mitigate identified risks.

Category	Measures	Safety	Security
Risk Perception	Tailored safety measures for women (addressing harassment, theft, vulnerability)	x	x
	Gender-specific interventions for personal safety risks (e.g., harassment prevention)	x	x
	Environmental considerations (e.g., safe, visible trail routes)	x	x
Risk Experience	Real-time monitoring systems (e.g., GPS tracking)	x	x
	Enhanced alarm systems and secure rest areas	x	x
	Emergency management response	x	x
	Reporting system for dangerous incidents (during/after trail)	x	x
Personal Preparation	Clear signage indicating trail directions, distance, rest points and potential hazards	x	x
	Information and awareness campaigns to prepare people before departure	x	x
Trail Design	Regular trail inspection and maintenance to remove hazards, with clear signage indicating obstacles and emergency points	x	x
	Trails designed with varying difficulty levels to accommodate all hikers	x	
	Clear Place and trail design with time and distance markers to prevent overexertion	x	
	Installation of emergency call boxes, satellite devices and mobile charging points (solar), with designated safe zones for resting	x	x
	Secure rest areas, transport options (e.g., shuttles) and accessibility for families and vulnerable groups (e.g., on-demand services like luggage transport)	x	
	Strategic placement of emergency centres for quick response times	x	x
	Reliable mobile coverage or satellite communication, with visible emergency numbers	x	x
	Secure storage facilities		x
	Provision of first aid kits (for bites, etc.) and first aid stations along the trail	x	
	Regular patrols and law enforcement in high-risk areas	x	x
	Installation of food kiosks and support for local businesses at trailheads or along route	x	
	Water refill stations or natural water sources clearly marked and accessible	x	
	Fire safety measures with clear emergency instructions	x	
	Early warning systems for natural disasters (e.g., flash floods, landslides) and evacuation routes	x	
	Weather stations and alert systems	x	
	Clear signage indicating hunting areas and specific "no hunting" zones	x	x
	Trail rerouting or barrier placement on dangerous stretches, along with warnings		x
	Wildlife safety education, signage wildlife, emergency procedures for bites or attacks	x	x
	Solar-powered lights along critical sections of the trail to improve visibility	x	x

Data analysis on abandonment of walking plans before departure highlights that a portion of the sample, particularly women, decided to modify or abandon their walking itineraries, often due to fears arising during the planning process or issues related to caregiving responsibilities, a phenomenon similar to urban mobility [13]. Risk perception, although not uniform, is influenced by a series of factors, from fear of dangerous situations (such as crime or aggressive animals) to the physical difficulty of the trail. In this regard, the risk matrix shows a high incidence of concerns related to personal safety/security (impact) compared to actual harmful events recorded (probability).

In terms of gender differences, interesting trends are observed: women tend to feel more vulnerable than men. This highlights the need for targeted attention to gender differences in trail design, as women, more than men, appear to perceive higher risks and are more inclined to modify their plans. Other aspects to consider during the design phase, beyond introducing measures to improve safety/security, include solutions addressing the main causes of plan abandonment and enhancing the perception of safety and accessibility for all walkers, particularly women and vulnerable individuals. One of the most urgent measures is improving visibility and safety along the trails, for example, by installing clear signage, a tracking system for walkers, the presence of rest and refuge points and ensuring adequate cellular coverage along the trail. These measures could significantly reduce the sense of isolation and insecurity, making trails more accessible.

Additionally, there are concerns, mainly expressed by women, related to isolation or difficulty reconciling walking with family responsibilities, or the inability to involve other family members in the activity. These data suggest that trail design should also include improving accessibility for family members, such as children, by facilitating trails and reducing distances between rest areas, or introducing and/or enhancing on-demand services such as shuttles and luggage transport.

It is also advisable to create trails with different levels of difficulty, allowing walkers to select routes suited to their physical and psychological capabilities. Institutions should also consider implementing support systems, such as guides or walking groups, which can reassure those who fear walking alone. Finally, promoting a culture of safety/inclusion, through awareness campaigns and adequate information on the benefits of walking, could help change the negative perception associated with trails, especially among women, who are more vulnerable to fear and insecurity. The adoption of these solutions would not only improve trail accessibility but also increase participation, promoting walking tourism in an inclusive and safe way. The integration of the risk matrix in the analysis, together with the calculation of estimated and perceived risks, represents an important step toward safer and more inclusive trail design.

Regarding real risk experiences, significant gender disparities persist. Women report more frequent negative experiences related to personal safety, such as harassment or theft, while men are more often involved in situations requiring physical rescues, such as mountain rescue. This suggests that safety/security measures must be adapted to the specific needs of each gender, incorporating solutions such as enhanced alarm systems, safe rest areas and real-time monitoring to address women's vulnerability. Emergency management should respond quickly to physical danger situations affecting men while ensuring that women feel safe throughout their journey. Additionally, an incident reporting system that tracks dangerous events, both during and after the trail, can help inform ongoing safety improvements and enable design interventions that address newly identified risks.

The preparation process before a long-distance walk also differs by gender. While both men and women prioritize essential equipment such as proper footwear and water, men are more inclined to use advanced technologies such as GPS and navigation apps, while women tend to focus on practical preventive measures, such as thermal blankets. Women are also more likely to inform others about their itinerary, whereas men use advanced technologies primarily for navigation and emergency situations. These differences highlight the importance of considering both technological preferences and practical safety/security measures in trail design. Features such as location monitoring systems, visible emergency numbers, mobile device charging points and adequate cellular coverage will improve both safety and security, allowing rapid communication in case of emergency.

Based on the insights of Roaf et al. [14], effective interventions to improve safety, security and participation in active travel must integrate both structural and behavioral components. In the hiking context, infrastructure includes both natural and artificial elements, such as trails, signage, orientation information, while behavioural aspects include equipment choices, safety precautions and access to orientation or training programs. Promotion and collaboration with female hiking groups emerge as a valuable strategy to address safety issues and foster confidence among female walkers. Encouraging such initiatives, together with structural improvements, ensures a more inclusive and safe trail experience.

Therefore, trail design should consider these diverse experiences and risk perceptions, with particular attention to women's safety and security needs. Essential safety features should include clear signage, safe rest areas and tracking systems for hikers. Increasing visibility through enhanced lighting and strategically placed emergency points can help reduce feelings of isolation, particularly for women. Additionally, ensuring family accessibility through more frequent rest areas and on-demand services such as shuttles and luggage transport will help alleviate both physical and

psychological stress. Trail design should include multiple levels of difficulty, ensuring that all hikers, especially vulnerable groups such as women, can select routes suited to their abilities. Furthermore, ensuring reliable cellular coverage, providing mobile device charging stations and displaying visible emergency contact numbers are vital to improving both safety and security. Strategically positioned emergency centres with rapid response capabilities will significantly enhance trail reliability and overall safety for all hikers.

Beyond physical infrastructure, economic and social measures can play a key role in ensuring equitable access. The ability to walk for free, often with donation-based accommodations, represents an important strength in terms of inclusion and social justice. However, to achieve true equity of access and use, these measures should be consolidated and expanded through forms of public support or agreements with local solidarity networks, ensuring free access to other essential services, such as luggage transport or logistical assistance. For example, the Cammino Minerario di Santa Barbara in Sardinia offers a targeted initiative, “Andiamo in Cammino - Edizione Donne,” which allows female walkers to benefit from free accommodations in affiliated facilities, in exchange for a voluntary donation. This initiative, available to women with credentials during specific periods of the year, promotes safe and inclusive female participation while honouring the historical role of women in Sardinian mining culture. Similar donation-based hospitality models, such as the “albergues donativo” on the Camino de Santiago in Spain, demonstrate how combining institutional support and grassroots solidarity networks can promote accessible, inclusive and sustainable walking tourism throughout Europe.

8.6 Strategic recommendations

As previously noted, the Italian system for the management of walking itineraries is distinguished by its decentralized nature and reliance on collaboration with civil society. In the absence of a national framework law, associations such as the CAI and FIE have assumed a central role in defining standards and maintenance. This approach contrasts with models employed in other countries, including the Swiss model, which is based on well-defined federal legislation and more structured funding at municipal and cantonal levels. Despite the fragmentation, the work carried out by Italian associations ensures signage and safety standards that are recognized and in line with European directives (ERA).

The strengths of the Italian model include a diversified network of trails, a strong tradition of volunteering and increasing attention from public institutions that view walking itineraries as vehicles for tourism and economic development. Areas for improvement include the lack of unified national legislation, which can lead to inconsistencies in management and maintenance and the need for greater integration of accessibility as a mandatory design criterion rather than an optional initiative (Table 8.7).

Table 8.7 - Italian management model vs. Swiss model.

Criterion	Italian Model	Swiss Model
Regulatory Framework	Fragmented; based on regional legislation and adoption of private standards (CAI/FIE)	Based on federal legislation (law and ordinance on trails)
Role of Associations	Central in defining standards and in ordinary maintenance through volunteering. ¹⁵	Collaboration with municipal and cantonal administrations, regulatory role by law. ²¹
Funding Mechanisms	Based on specific calls from the Ministry of Tourism and regional contributions	Primarily municipal and cantonal funding, with contributions from other actors as well
Risk Management	Shared between manager (risk communication) and hiker (self-responsibility)	Legislated, with defined responsibilities and annual control procedures

Research has shown how long-distance walking itineraries are evolving from simple paths to complex slow mobility infrastructures, capable of generating value in terms of territorial development, environmental sustainability and social inclusion. In this context, the PATHS methodology is configured not only as a technical-design approach but as a systemic reference framework for the entire chain of planning, management and promotion of walking itineraries.

The recommendations emerging from the research highlight the need to move from a fragmented approach to an integrated and strategic vision. The establishment of a national framework law would formally recognize walking itineraries as infrastructures of strategic interest, defining uniform rules for their management. Within this regulatory framework, the PATHS methodology provides tools to translate general principles into operational actions, ensuring consistency between planning, design and evaluation.

In particular:

1. the creation of a national registry of walking itineraries, integrated with regional and association data, strengthens the Place dimension, providing a unified knowledge base;
2. the elevation of inclusion and accessibility to binding criteria for the allocation of public funds fully corresponds to the second dimension of the model, Accessibility and Inclusion, which aims to achieve “slow tourism for all”;
3. the development of digital tools and the use of Extended Reality for preventive maintenance support the Technological Integration dimension, transforming walking itineraries into intelligent and resilient infrastructures;
4. the national framework law, together with forms of participatory governance, reinforces Harmonization, overcoming institutional fragmentation and promoting local partnerships;
5. finally, the increase of funds for ordinary and continuous maintenance represents a direct investment in the Sustainability dimension, ensuring the long-term resilience of the network and reducing dependence on volunteering.

The PATHS methodology therefore proposes itself as a bridge between research and policy, capable of guiding strategic choices and transforming walking itineraries into an integrated, inclusive and sustainable infrastructure. The future of the sector indeed requires a multi-level approach, in which technological innovation, participatory governance and public policies converge to consolidate the value of walking itineraries as a collective heritage and a lever for territorial development.

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Chapter 9

Elements of innovation and originality of the research. Further perspectives

9.1 Elements of innovation and originality of the research

The research is situated within the framework of the growing attention to slow mobility, considered today as one of the fundamental directions for sustainable mobility and for achieving the objectives of Agenda 2030. Walking itineraries and long-distance pedestrian routes, in particular, are configured as strategic infrastructures for territorial development, for the enhancement of cultural and natural heritage and for the promotion of fairer and more environmentally respectful forms of tourism. Despite their increasing social and economic relevance, scientific studies on such routes remain limited, fragmented and often lack a unified methodological framework. This research aims to fill this gap by introducing innovative tools and original approaches that lay the foundations for an integrated and systemic vision of walking routes.

In line with the Research Questions (RQ) defined in Chapter 1, the work has produced structured and innovative answers, which can be summarized as follows.

RQ1: Which methodological approach, based on the integration of modelling, simulation and evaluation tools, can be developed to effectively analyze the interactions between demand and supply in long-distance walking routes? (Chaps. 2, 3, 4, 5)

The main element of originality lies in having constructed an integrated methodological framework, capable of treating demand and supply as an interconnected dynamic system. Among the innovative contributions: the definition of a methodology for the classification of walking routes and trails, useful for distinguishing types and levels of infrastructural complexity; the introduction of a new concept of the life cycle of a walking route, conceived as an operational tool for programmed and sustainable management; the development of new methodologies for supply analysis, including an innovative cost function in which travel time is not treated as impedance but as benefit and a network analysis based on specific indicators; the elaboration of a new methodology for demand analysis, with an application-oriented modification of the four-step model, adapted to the specificities of walking routes; the realization of a simulation architecture based on a Causal Loop Diagram (CLD) developed with a System Dynamics (SD) approach, enabling the representation of evolutionary scenarios and complex interdependencies.

RQ2: How can performance, safety, sustainability and inclusiveness of a walking route be defined, measured and integrated into a single set of evaluation indicators? (Chap. 6)

The research has developed an original set of multidimensional indicators for the evaluation of walking routes and trails, with specific contributions that broaden the traditional perspective: proposal of a set of indicators for the Level of Service (LoS) of walking routes; evaluation of the quality of existing routes both according to a network approach and through an innovative Attractiveness indicator; introduction of the Damage/Probability matrix for risk assessment, with identification of preventive and corrective measures; application of the doughnut economics model for integrated sustainability assessment; analysis of walking routes according to equity and social inclusion criteria; study of the gender perspective in the perception and management of safety; definition of guidelines on safety and inclusivity, intended as essential conditions for all walkers.

RQ3: Does a logistics of walking routes exist? How can the introduction of new design standards and innovative technologies address logistical, safety and inclusivity issues, improving the overall walker's experience? (Chaps. 7 and 8)

The originality of the research consists in having introduced and defined the concept of walking route logistics, proposing an innovative definition and translating it into operational solutions. In particular, the PATHS Module (Pedestrian Advanced Trail Hub for Sustainability), a modular and sustainable logistic unit, was developed; the P.A.T.H.S. methodology (Place, Accessibility and Inclusion, Technological Integration, Harmonization, Sustainability) was formulated, proposing a new standard for walking route design; strategic recommendations for the coordinated management of the walking route network at national level were elaborated; the concept of smart trail was introduced, integrating walking routes with digital technologies and the potential of Industry 4.0, such as IoT, Big Data and extended reality for predictive maintenance.

RQ4: What are the implications of gender and inclusion in tourist pedestrian mobility and how can they be integrated into the design, evaluation and management of walking routes? (Chaps. 3, 4, 6 and 7)

The research has made an original contribution to the analysis of gender and inclusion implications in long-distance walking routes, through the elaboration of indicators and tools to include the gender dimension in evaluative and design processes, the integration of these aspects as structuring dimensions on par with sustainability and safety and the highlighting of different risk perceptions and different modes of use by men and women, with concrete implications for planning and management. Within the framework of the international comparative investigation, it emerged that different national contexts present different models of perception and behavior regarding safety and security, with direct effects on the possibility of enjoying the routes and on the overall walking experience. Table 9.1 provides a synthesized overview of the research questions (RQ) alongside the corresponding answers and the main innovative contributions developed within this study, highlighting the methodological, evaluative, logistical and inclusion-related advancements.

Table 9.1 - Summary scheme RQ - Answers and innovative contributions.

RQ	Answers and innovative contributions
RQ1	- Methodology for the classification of trails and paths - New concept of the trail life cycle - New cost function (time as benefit) - Network analysis with specific indicators - Modification of the four-stage model for demand - Simulation architecture based on CLD and SD approach
RQ2	- Set of indicators for the LoS of trails - Path quality assessment (network + Attractiveness) - Damage/Probability matrix for risk assessment - Evaluation according to the doughnut economy - Equity and inclusion criteria - Gender perspective in safety - Safety and inclusiveness as prerequisites
RQ3	- Introduction and definition of "trail logistics" - PATHS Module as a sustainable logistic unit - P.A.T.H.S. Methodology for new design standards - Strategic recommendations at national level - Concept of smart trail and 4.0 technologies
RQ4	- Integration of the gender dimension into design and evaluation processes - Specific indicators of inclusion - Analysis of risk perceptions differentiated by gender - Inclusion treated as a structuring dimension equal to sustainability and safety

9.2 Future research perspectives

Future research perspectives are situated in the view of deepening and expanding the methodological, theoretical and applicative contributions introduced in this work. The growing attention to slow mobility and long-distance walking routes opens various directions of scientific, technological and social development, with a strong rooting in transport engineering.

The study of pedestrian mobility on long-distance walking routes is valuable not only for the management and enhancement of the routes themselves, but also provides tools, data and methodologies useful for urban mobility. Information on walkers' behaviors, route preferences and physiological reactions can be transferred to urban contexts, contributing to the design of safer, more usable and sustainable pedestrian infrastructures. Conversely, research and technologies developed for urban mobility, such as real-time monitoring and flow management systems, can be adapted and integrated into long-distance walking routes.

If the network of trails and walking routes were truly conceived as strategic infrastructure, as proposed in this work, active mobility could become the main mode of transport, with significant benefits in terms of environmental sustainability, public health, territorial development and responsible tourism. Future research perspectives are therefore oriented towards deepening and expanding the methodological, theoretical and applicative contributions already introduced, with a strong grounding in transport engineering and an integrated and multidisciplinary approach.

The development lines can be analysed through the PATHS methodology (Place, Accessibility and Inclusion, Technological Integration, Harmonization, Sustainability), which allows for the coherent organization of future research directions.

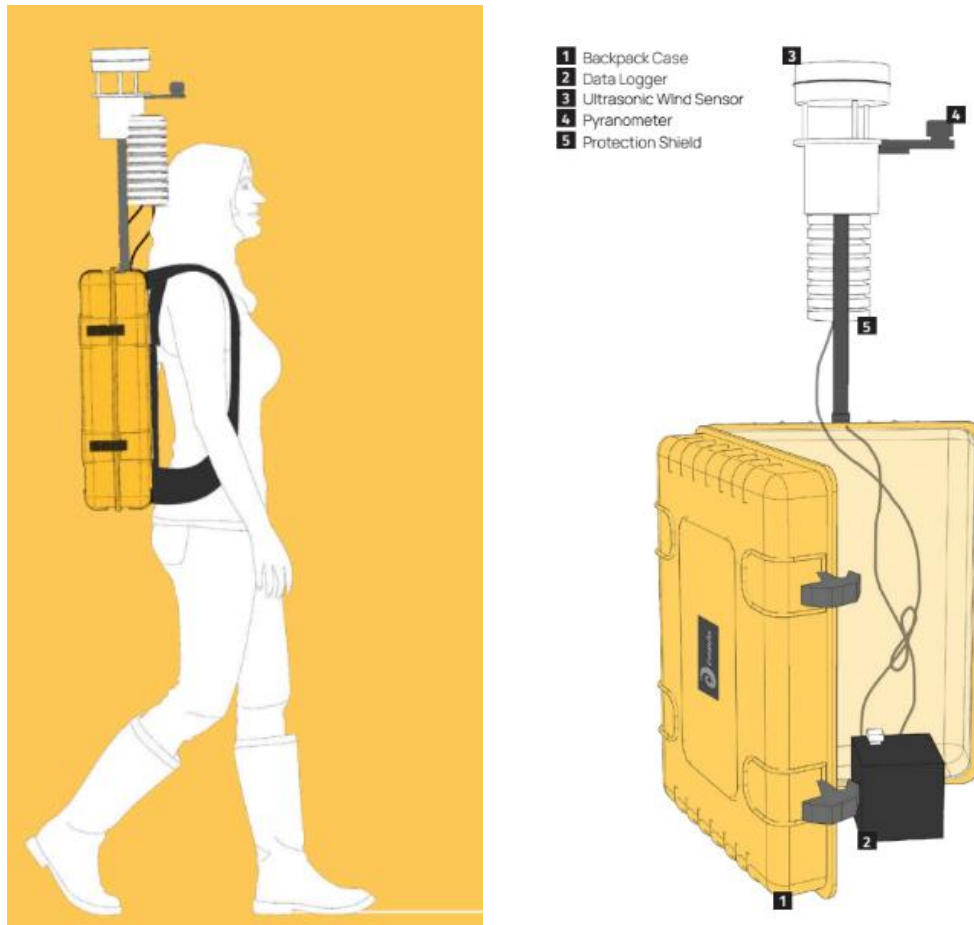
Place: the territory and the enhancement of local contexts

Future research will be able to deepen the analysis of routes in relation to different types of segments (natural, urban, built), integrating tools such as climate walks [1], [2] to study variations in perceptions, physiological reactions and walking strategies of walkers. The Climatewalks Backpack (Figure 9.1) allows high-resolution collection of microclimatic data along walking itineraries, thanks to sensors measuring temperature, humidity, wind (speed, direction, gusts), slope, solar radiation, global temperature and GPS position. Data are also recorded without an internet connection and subsequently uploaded to the cloud, enabling in-depth analyses not only for designing safer and more comfortable pedestrian routes, but also for monitoring the health status of monuments along the routes, supporting assessments of their degradation and conservation over time. These studies make it possible to understand how the characteristics of different segments affect mobility and the overall experience, providing guidance for the design of sustainable itineraries and the enhancement of cultural and natural heritage.

Accessibility and Inclusion: accessibility, equity and gender dimension

Future studies will need to deepen the design of inclusive walking routes, considering the different modes of use and perception of risk by men, women and vulnerable groups. The international comparative investigation suggests the need to develop guidelines and strategies adaptable to different contexts, with particular attention to safety, accessibility and the promotion of truly inclusive pedestrian experiences. The use of standardized and internationally comparable multidimensional indicators will allow for monitoring equity and quality of experience, supporting territorial planning and route governance.

Figure 9.1 - Climatewalks Backpack with the main components and image of use in a real context.



Source: <https://climatewalks.com/> [1]

Technological integration: integration of innovative technologies

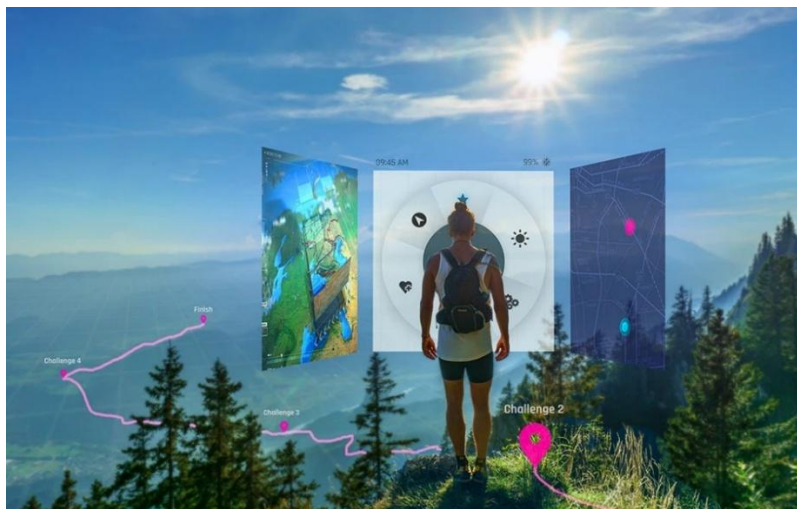
Extended Reality (XR) solutions (Figure 9.2) represent a central element for management, use and research. For walking route management, XR and IoT can support predictive maintenance, infrastructure monitoring and route safety. For use, XR headsets and applications can provide real-

time data on route characteristics, cultural, historical, or archaeological information and the possibility of virtually completing incomplete sites. In research, pedestrian simulators with treadmills connected to XR headsets (Figure 9.3) can be used to study pedestrian mobility in controlled contexts, analyzing routes, behaviors and physiological reactions, also in urban, industrial, or military contexts. The integration of AI and machine learning enables predictive modeling of pedestrian flows, providing advanced tools for dynamic walker management.

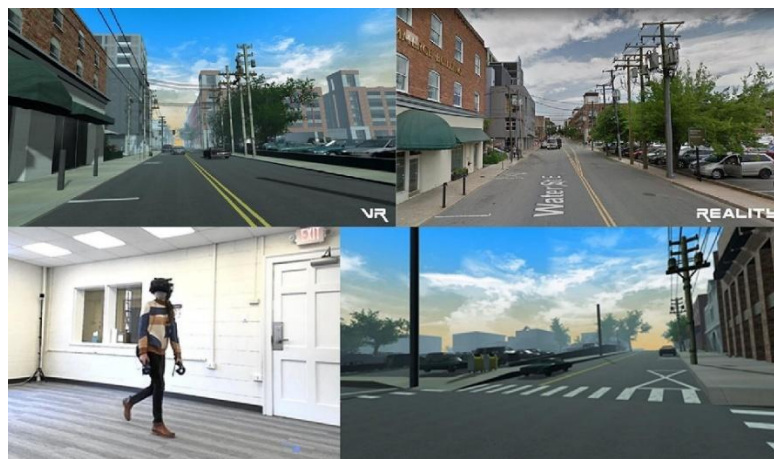
Figure 9.2 - Examples of Extended Reality for pedestrian mobility.



a) Augmented Reality for tourist use. Source: [3]



b) Mixed Reality for trekking (Oolens. Source: [4])



c) Virtual Reality for pedestrian safety analysis. Source: [5]

Figure 9.3 - Example of treadmill with integrated virtual reality.

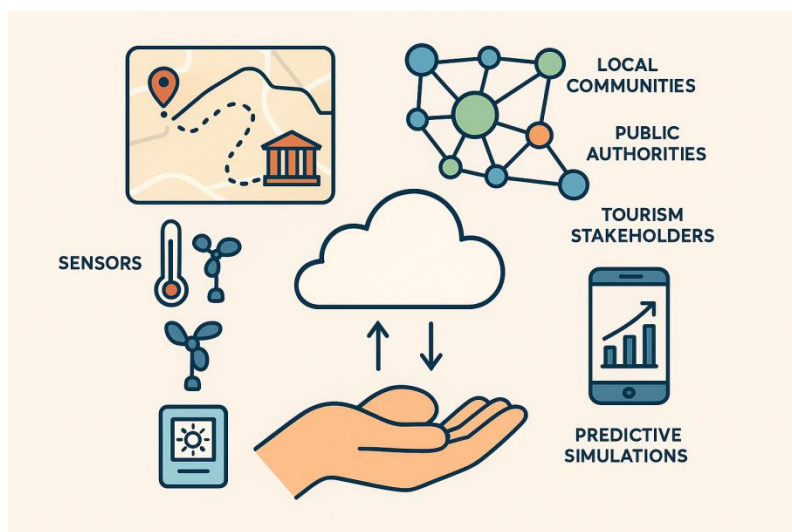


Source: [6]

Harmonization: integration and coordination of systems

It is necessary to develop approaches to harmonize walking route management at local, national and international levels, creating interoperable and shared tools for planning, monitoring and governance (Figure 9.4). The participation of local communities, public authorities and tourism stakeholders becomes central to building integrated governance models, coordinating geolocated data, digital platforms and predictive simulations.

Figure 9.4 - Example of approach based on the concept of harmonization and participation.



Sustainability: environmental, social and economic sustainability

Future research will need to consider sustainability as a guiding principle, developing tools and indicators to assess the impact of walking routes on the environment, society and local economy. The combined use of climate walk, geolocation, pedestrian simulators and XR can support more conscious management of natural resources, improve pedestrian flow planning and promote responsible tourism practices (Figure 9.5).

Figure 9.5 - Integration of the Sustainability perspective into active mobility.



The adoption of the P.A.T.H.S. methodology makes it possible to outline a coherent and multidimensional framework of future research perspectives (Table 9.2), integrating transport engineering, advanced digital technologies, social and inclusion dimensions, systemic coordination and sustainability. This approach promotes the development of safer, more inclusive, smarter and scientifically monitorable walking routes, with applications also in urban, industrial and advanced research contexts, contributing to the consolidation of active mobility as strategic infrastructure.

Table 9.2 - Future research perspectives according to the PATHS framework.

PATHS Dimension	Objective / Focus of Future Research	Tools / Methodologies	Potential Impacts and Expected Results
Place - Territory and valorization of local contexts	Analyze itineraries in relation to natural, urban and built sections; study perceptions, physiological reactions and usage strategies	Climate walks, Climatwalks Backpack, microclimatic sensors, GPS, high-resolution data collection	Design of safer and more comfortable itineraries, enhancement of cultural and natural heritage, monitoring of the conservation status of monuments
Accessibility and Inclusion - Accessibility, equity and gender dimension	Design inclusive trails considering differentiated usage modes and risk perceptions for men, women and vulnerable groups	Standardized multidimensional indicators, international comparative surveys, adaptable guidelines for different contexts	Truly inclusive trails, greater equity, support for territorial planning and governance of paths
Technological Integration - Integration of innovative technologies	Improve management, usage and research of trails; model pedestrian flows	Extended Reality (XR), IoT, XR headsets and applications, pedestrian simulators, treadmills integrated with VR, AI and machine learning	Predictive maintenance, advanced monitoring, trail safety, real-time data for users and planners, predictive modelling of pedestrian flows
Harmonization - Integration and coordination of systems	Coordinate trail management at local, national and international levels; create interoperable tools	Digital platforms, geolocated data, predictive simulations, involvement of local communities and tourism stakeholders	Integrated governance, system interoperability, active citizen participation, greater efficiency in trail management
Sustainability - Environmental, social and economic sustainability	Assess environmental, social and economic impacts of trails; promote responsible tourism	Climate walks, geolocation, pedestrian simulators, XR, sustainability indicators	Better management of natural resources, optimized pedestrian flows, responsible tourism practices, consolidation of active mobility as a strategic infrastructure

The idea of elevating pedestrian infrastructure to a strategic level means recognizing its fundamental role beyond the simple function of passage. It becomes a pillar of territorial and urban planning, comparable to roads, railways, or cycle paths, but with a profound and multifactorial impact on quality of life and territorial resilience.

Transforming pedestrian routes into a strategic network would restore dignity to pedestrians, shifting the focus from the vehicle to the person. This would guarantee equitable mobility for all, offering a central solution for the countless individuals worldwide who do not own a car. This active mobility represents a direct and powerful response to the Sustainable Development Goals, as it reduces emissions, promotes public health and strengthens the social fabric.

This approach is perfectly aligned with the principles of Doughnut Economics, which aims to meet fundamental human needs without exceeding the ecological limits of the planet. In this model, the strategic pedestrian network represents a solution operating within a safe and just space, ensuring both social prosperity (accessibility, safety, health) and environmental sustainability (pollution reduction, climate change mitigation). Active mobility, in this context, is not only a healthy choice but an act of sustainability that contributes to a more balanced and regenerative development model.

A pedestrian infrastructure can be considered strategic when it has the following characteristics:

- connection and continuity: efficiently links key points such as neighbourhoods, shopping centres, schools, offices, stations and parks; it is necessary to create a cohesive network, eliminating interruptions and physical barriers that force pedestrians to take longer or more dangerous routes;
- multifunctionality: goes beyond simple displacement, also serving as a social, recreational and ecological integration space; rest areas, green spaces, artistic elements and infrastructures supporting health and well-being must be included;
- inclusivity: designed to be accessible to all, regardless of age, ability, or gender; this implies removing architectural barriers, using multisensory signage and ensuring a safe environment for all;
- intelligence and resilience: uses advanced technologies (such as IoT sensors and digital platforms) to monitor flows, manage emergencies and provide real-time information; designed to adapt to climatic and social changes, ensuring long-term functionality.

The recognition of pedestrian infrastructure as strategic brings significant benefits for pedestrians, enhancing their experience and role within the mobility system:

- priority in planning: pedestrians are no longer an afterthought, but a starting point for urban planning. Decisions on new building developments, commercial areas, or public transport will give maximum consideration to pedestrian accessibility;
- greater safety: investment in strategic infrastructures translates into better lighting, safer pedestrian crossings, clear signage and reduced conflicts with vehicular traffic, decreasing accident risks;
- better user experience: routes become more pleasant, comfortable and stimulating. The presence of vegetation, services, resting places and points of interest makes walking a preferable choice and a positive experience, encouraging greater and more frequent use;
- health benefits: the promotion of pedestrian mobility as the main mode of transport increases daily physical activity, contributing to disease prevention and improvement of psychophysical well-being;

- local economic development: strategic pedestrian routes revitalize urban centres and rural areas, increasing the flow of people and the economic potential for shops, restaurants and local tourism activities along the routes;
- resilience and national security: elevating pedestrian infrastructure to a strategic level means making it a crucial element for population protection and resilience. In the event of natural disasters or adverse events, routes can function as safe evacuation paths, providing a vital alternative when major road infrastructures are compromised. Constant monitoring, enabled by digital technologies, facilitates rapid interventions in case of illness or danger.

The planning, design and enhancement of long-distance pedestrian routes, as emerged from this research, which lays the foundations for further developments, integrating engineering knowledge, advanced technologies, sustainability and social inclusion, opens the way to a safer, fairer and more responsible active mobility, capable of enriching not only the territory but also the everyday experience of those who walk.

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