SmartPath: multi-criteria approach for optimal pedestrian routes for well-being and inclusion

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***Abstract*— We present a multi-criteria pedestrian routing system, SmartPath, which combines accessibility, environmental comfort, and urban service availability within a graph-based model. Based on the Urban Intelligence paradigm and the 4C model, the approach goes beyond distance minimization to incorporate the qualitative dimensions of the urban experience.**

Keywords—Urban Intelligence, Pedestrian Paths, Optimization, Mobility

I. Introduction

Contemporary cities are complex adaptive systems in which mobility, environmental quality, social cohesion, and accessibility intertwine in nonlinear ways that are difficult to govern through traditional planning approaches [1] (Batty, 2013; Portugali, 2011). In this context, major urban events represent both a challenge and an opportunity: they demand solutions capable of managing exceptional flows of people while offering privileged laboratories for experimenting with models of urban governance oriented towards collective well-being and inclusion.

The Milan-Cortina 2026 Winter Olympics and Paralympics provided the occasion to develop a methodology for calculating optimal accessible pedestrian routes, carried out by CNR-CISC (IASI, ITC, DIITET) in collaboration with the Municipality of Milan. The central objective was not merely to optimize pedestrian journeys between points of interest in the city, including the five Olympic venues — Stadio Meazza, Forum di Assago, Forum Santa Giulia, Rho Fiera, and the Duomo — but to shift the focus towards the relationship between pedestrian mobility, accessibility, and the quality of public space, with greater attention to the qualitative dimension of urban experience.

II. Methodology

The theoretical framework is that of Urban Intelligence [2], a paradigm for adaptive urban governance that interprets the city as a cognitive system in which data, institutions, and citizens continuously interact to produce collective knowledge and support public decision-making [3]. Unlike conventional Smart City approaches, which prioritize technological optimization and infrastructural efficiency, Urban Intelligence emphasizes the cognitive dimension of urban systems and the need to integrate technical knowledge with experiential understanding, avoiding the reduction of citizens to mere data sources. Within this framework, the 4C model — Cognizant, Commonality, Constructing, Caring — provides the epistemological and operational structure of the entire project. The Cognizant dimension concerns the capacity to produce multidimensional urban knowledge by integrating heterogeneous datasets: not only infrastructural data, but also information on environmental quality, the distribution of welfare services, and the experiential perception of spaces. Commonality transforms this knowledge into a shared resource, accessible to institutions, researchers, and citizens through open interfaces and interoperability platforms. Constructing involves the co-creation of urban scenarios through simulation, optimization, and participatory design. Caring, finally, introduces a logic of continuous monitoring and adaptive management: governance conceived not as a sequence of isolated decisions, but as a recursive process of observation, evaluation, and recalibration. From this perspective, the urban digital twin is not a technical replica of the city [4], but a cognitive infrastructure capable of connecting representation, simulation, participation, and the production of knowledge oriented towards citizens' well-being.

III. Case study

From a methodological perspective, the project is based on a graph representation of Milan's pedestrian network provided by the Municipality of Milan. In this model, intersections are represented as nodes, while street segments are represented as edges. This approach draws on network-based analyses of urban space [5;6], while applying them to a pedestrian routing problem that combines accessibility, environmental comfort, and the availability of urban services. The municipal dataset already includes a number of annotations related to the physical characteristics of the network, such as the length of street segments and the presence of architectural barriers. These data were integrated with information on urban services available along the routes, including pharmacies, benches, drinking fountains, and other facilities that may support users' practical needs during the journey.

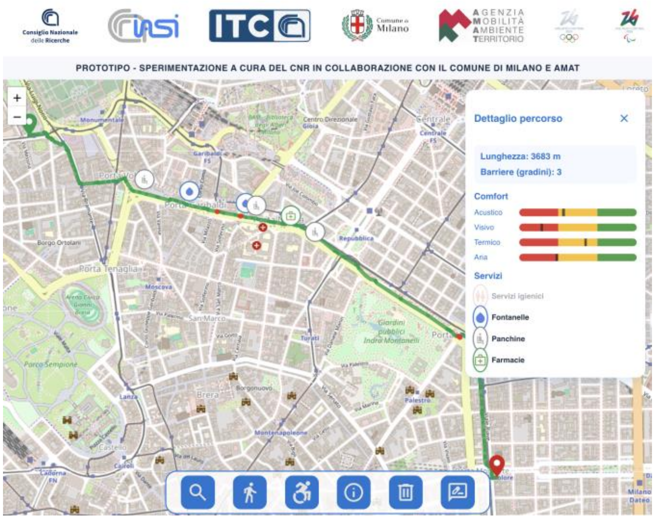

Fig 1. Smart path example with architectural barriers and environmental comfort

A second layer focused on environmental comfort. Indicators for thermal, visual, acoustic, and air-quality conditions were defined and associated with the pedestrian network where data were available. This made it possible to describe route characteristics that are not captured by distance alone but may affect the experience of walking. Selected points of interest, such as metro stations, public squares, meeting places, and other relevant urban destinations, were also associated with the network.

On this basis, a routing algorithm was developed that compares alternative pedestrian paths between two selected points using multiple attributes associated with the network. In its current version, the algorithm identifies either the shortest path or the path with the fewest architectural barriers. The prototype therefore introduces a first multi-attribute routing logic, in which distance is assessed together with accessibility constraints. For each proposed route, the prototype reports the services located along the path and the available information on environmental comfort for the selected segments. Users can therefore see not only the geometry of the route, but also the conditions and facilities that characterize it. This is useful for comparing alternatives that may be similar in length but different in terms of accessibility, comfort, or support services.

In a more advanced version, the system could support multi-objective routing, with distance, architectural barriers, environmental comfort, and service availability weighted according to user needs or predefined profiles. This would make route selection less dependent on distance alone and more sensitive to the conditions of walking. The approach is consistent with public-space assessment methods that consider both physical and experiential aspects of urban space [7] as well as with studies showing that pedestrians may accept slightly longer routes when these are more pleasant or stimulating [8].

In this sense, the prototype is not intended only as a navigation tool. It also functions as an exploratory interface for reading the pedestrian network through a set of urban qualities that are often absent from standard routing systems. The contribution of the project lies in making these qualities explicit and operational: architectural barriers, comfort indicators, and service availability are translated into attributes that can be visualised, compared, and potentially used in routing decisions. This provides a first step towards a pedestrian routing framework that combines network optimisation with information on the actual conditions of walking in the city.

The SmartPath web app prototype allows users to explore optimal pedestrian routes considering not only distance but also accessibility, environmental comfort, and the availability of services along the route. The tool was developed with the primary aim of collecting qualitative feedback on the relevance of the proposed routes and the clarity of the information provided, feeding an iterative cycle of algorithm improvement.

The project demonstrates how the integration of advanced ICT technologies — graph optimization, interoperability platforms, environmental comfort models, multi-source geospatial data — can be oriented towards a vision of the city that goes beyond technical efficiency, aspiring instead to the care of citizens and the quality of their everyday urban experience, as an operational realization of the 4C model. The value of the work lies not only in the technical quality of the models developed, but in their capacity to incorporate public objectives, deliberative practices, and situated readings of urban territories.

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