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Integrating Artificial Intelligence and Computational Algorithms to Optimize the 15-Minute City Model

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Abstract: The 15-minute city concept, designed to ensure that all essential services and amenities are accessible within a 15 min walk or bike ride from home, presents a transformative vision for urban living. This paper explores the concept of a 15-minute city and its implications, along with its main features and pillars. Furthermore, it elaborates on how the integration of artificial intelligence (AI) and computational tools can be utilized in optimizing the 15-minute city model. We reveal how AI-driven algorithms, machine learning techniques, and advanced data analytics can enhance urban planning, improve accessibility, and foster social integration. Our paper focuses on the practical applications of these technologies in creating pedestrian-friendly neighborhoods, optimizing public transport coordination, and enhancing the quality of life for urban residents. By executing some of these computational models, we demonstrate the potential of AI and computational tools to realize the vision of the 15-minute city, making urban spaces more inclusive, resilient, and adaptive to the evolving needs of their inhabitants.

Keywords: 15-minute city; AI-driven algorithms; urban development; computational tools

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1. Introduction

In recent years, a large segment of the global populace has engaged in remote work, social distancing, and home confinement. The COVID-19 pandemic prompted a rearrangement of daily routines for non-essential workers. The swift evolution of digital technologies and community-focused living has curtailed social interactions and helped control virus transmission. This shift has sparked renewed discourse on urban service access and the importance of resilient local communities. Scholars assert that the pandemic will reshape our understanding of urban environments [1]. In 2016, Carlos Moreno proposed a planning strategy that emphasizes local accessibility. The concept advocates "15-minute cities", where essential services are reachable within a 15-minute walk or bike ride [2]. The pandemic highlighted the merits of localized urban planning. Moreno champions the reconfiguration of Paris into self-sufficient neighborhoods accessible within 15 min. Essential services should be reachable in a timeframe comparable to commuter waiting periods [3]. The "15-minute city" enables access to all necessary amenities within a short distance, fostering sustainable, resilient communities [4]. This planning paradigm seeks to improve quality of life by minimizing car reliance, enhancing social diversity, and promoting environmental sustainability. The idea of creating healthy, integrated, self-sustaining neighborhoods has historical roots. It can be traced back to Ebenezer Howard's Garden City model from 1898 and Clarence Perry's neighborhood unit concept from 1929. However, the 15-minute city concept faces critiques, particularly around its potential to spur gentrification and doubts regarding feasibility due to the extensive investments and spatial restructuring required [5,6]. In this stance, AI is leading a transformation that is reshaping important industries, like urban planning and development, with new answers to enduring problems. In the goal of attaining the 15-minute city, computational tools emerge as indispensable assets for urban planners and policymakers [7]. These include geographic information systems, simulation models, and urban analytics platforms for microscopic urban analysis and visualization. Machine learning algorithms can identify mobility, resource, and demographic trends in datasets, informing strategic planning. Predictive analytics can predict which infrastructural improvements are required to guarantee that new constructions meet 15-minute city standards. AI-powered technologies can plan city layouts, identify service shortages, and recommend demographic and space-based sites for new amenities [8]. Simulation models predict how new bike lanes and public parks would affect travel times and the environment [9]. AI-powered urban analytics solutions analyze real-time data from sensors and IoT devices tracking traffic flow, air quality, and energy usage to comprehend urban processes, in order to design responsive, data-driven plans that ensure all city residents can reach services within 15 min [8].

Despite growing interest in the concept of the 15-minute city, there is a considerable deficiency in the literature regarding the integration of computational tools and artificial intelligence within the 15-minute city framework. Although many studies explore the theoretical foundations and design principles of the 15-minute city, insufficient attention is given to the practical implementation of AI and computational methods in achieving these objectives. This paper discusses in depth the background to the 15-minute city, including its principles, historical context, and a variety of urban problems to which it is a response. It explains how this paradigm in urban planning could solve such urban problems as traffic congestion, environmental degradation, and social inequities. This paper also utilizes computational tools and platforms, showing how AI and state-of-the-art computational methodologies can be used to optimize processes of urban planning, enhancing the accessibility and efficiency of city services and making decisions based on facts. This paper ultimately contributes to the body of knowledge on smart urban planning and aims to inspire future innovations in the development of 15-minute cities.

2. Historical Context of the 15-Minute City

Most planning approaches for neighborhood movements have developed since the late 19th century [10]. The 15-minute city concept arose from these movements, including various planning paradigms. These movements are categorized into two types: proximity-centric and mobility-centric. The proximity-centric approach enhances urban service distribution, while the mobility-centric approach prioritizes centralization and motorized transport. Figure 1 shows the timeline of neighborhood planning movements stemming from the garden city and ending with the formulation of the 15-minute city movement [11]. To maximize efficiency, urban planners of the Industrial Revolution aimed to integrate all urban amenities, services, and actions within the centers of cities [12].

However, this concentrated urban form resulted in many issues, including ecological deterioration, architectural abnormalities, and medical crises. In response to these challenges, a wave of utopian idealism emerged to find an alternative to the traditional metropolitan areas. Ebenezer Howard presented the concept of the garden city in 1898, envisioning a network of interdependent and self-reliant satellite towns that surround a central metropolis, which are all ringed by a greenbelt. Howard's innovative concept included the garden city being divided into several districts, locating commercial operations and job centers along major highways, and addressing social and health issues through conscientious architectural design [12].

Subsequently, in 1923, Clarence Perry proposed the neighborhood unit concept as a solution to urban challenges in early 20th-century America. He envisioned the neighborhood as a fundamental design unit, promoting proximity to essential services such as schools, parks, and shopping areas. His model targeted a population of 5000 to 9000 on 160 acres, with a density of 10 people per acre. Roads were designed to minimize traffic, ensuring a safe, pedestrian-centric environment with urban amenities accessible within a 400 m radius [11].

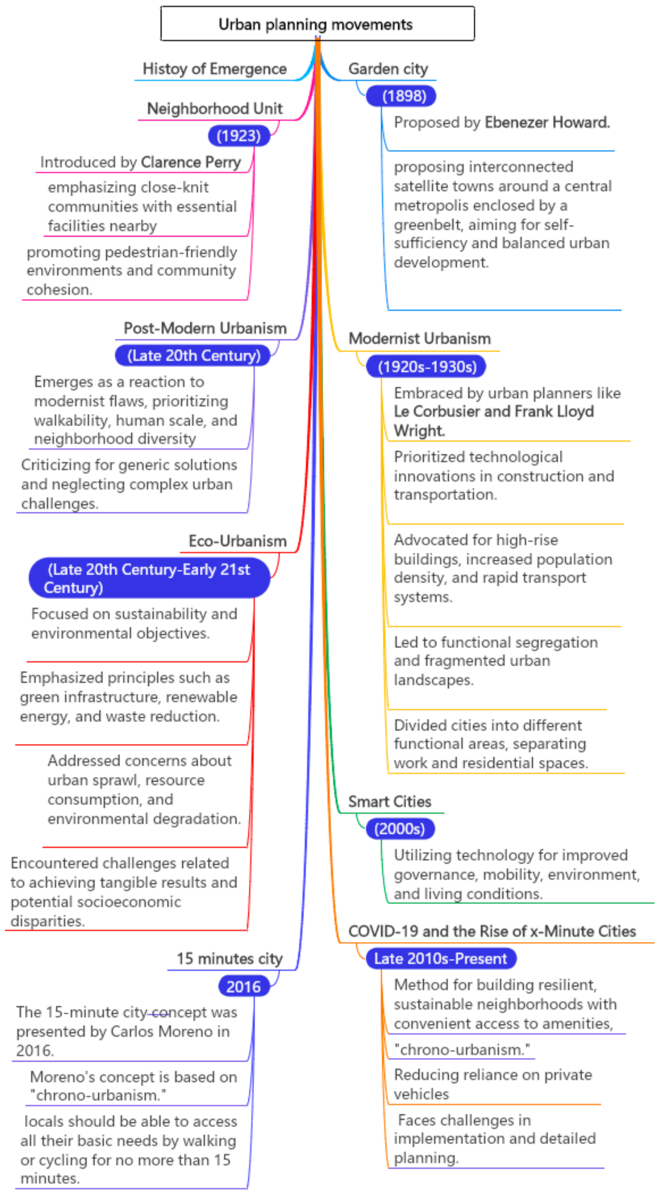


Figure 1. Urban planning movement. Source: Author.

Nonetheless, garden city and neighborhood unit models were criticized. Poor integration of productive tasks, lack of self-sufficiency, sprawl promotion, and unsustainable environmental practices plagued the garden city. Land limits compromised green belts, and the garden city failed to meet social goals. Functional segregation, strict land-use zoning, inadequate pedestrian infrastructure, restricted social contact, car dependency, and excessive greenhouse gas emissions plagued Perry's community unit [12]. These critiques challenged Jane Jacobs' urbanist principles. They underscored the deficiencies in early 20th-century urban planning and stimulated discourse on sustainable urban development.

During the 1920s and 1930s, Modernist urban planners, like Le Corbusier and Frank Lloyd Wright, also became strong advocates of technological innovations in construction and transportation. They developed high-rise buildings, increased population density, and fast transportation systems [13]. However, this meant that cities became functional areas, resulting in fragmented urban settings. All the differentiation between work and residential space had negative influences on the quality of life of residents and the general sustainability of cities [14]. So, in the latter part of the 20th century, post-modern urbanism arose as a response to these challenges. It focuses on walkability, human scale, and neighborhood diversity. However, among the criticisms of post-modern urbanism is its reliance on generic physical solutions and its failure to take up the complex, highly relativistic urban challenge.

In the late 20th century and early 21st century, the eco-urbanist era began, focused on adopting sustainability principles and environmental goals. However, critics have questioned eco-urbanism efforts due to their lack of success and tendency to worsen social gaps [15]. The practicality of eco-urbanism has also been questioned. Critics argue most eco-urban projects prioritize aesthetic and technological solutions over social and environmental transformation. While green structures and renewable energy are offered, low-cost housing and poor populations are neglected [16].

In this context, the concept of the smart city arose in the 2000s. It is a governance-oriented approach that utilizes technology to enhance urban living, address marginalized needs, and consider socioeconomic factors. It encompasses aspects of people, mobility, living, the environment, the economy, and governance [17]. The COVID-19 pandemic highlighted the vulnerabilities of car-dependent communities within modernist frameworks during health crises [18]. Mobility restrictions led to reduced motorized transport, underscoring the necessity for sustainable urban design [19]. This context catalyzed the development of the x-minute city concept as a strategy for post-COVID recovery.

The x-minute city prioritizes accessibility to urban services and highlights the resilience of comprehensive neighborhoods in health emergencies. Grounded in Chrono-urbanism, it conceptualizes cities through the lenses of time and space, aiming for optimal time utilization in neighborhood design [20]. It aims to reduce car dependency by ensuring residents can access essential services within a designated walking or cycling distance [6]. In this stance, Melbourne's Plan Melbourne 2017–2050 aims to establish "20-minute neighborhoods" where residents can fulfill daily non-work needs without motorized transport [21]. Similarly, Portland, USA advocates for a 20-minute community, defined by secure pedestrian access to essential locations. Likewise, the Greater Sydney Commission promotes the "30-Minute City" concept, focusing on improving transportation links to major urban centers within a 30-minute commute via walking, cycling, or public transport [22]. This 30-minute city model proposed for Sydney by Levinson, 2019, emphasizes enhanced public transport and intermodal connections. Barcelona's superblocks, meanwhile, represent a polycentric urban design aimed at fostering active transportation and prioritizing pedestrian spaces, thereby promoting green and healthy neighborhoods [23]. Mueller, 2020, highlighted their potential to enhance social capital. Carlos Moreno coined the "15-minute city" in 2016. Moreno's concept of the 15-minute metropolis is based on the term "chrono-urbanism" and is in line with the concept that the quality of urban life decreases with the increase in time spent on transportation [20].

3. Emerged Concept of the 15-Minute City: Definitions and Key Features

The 15-minute city concept is influenced by many ideas and theories that have emerged over time, including urban planning movements. Thus, the "15-minute city" concept is unique but not novel in its core. The compact city concept influenced the FMC concept and many other ideas. This idea promotes high-density mixed-use urban districts with residential, commercial, and leisure activity [24]. From Cerda's urbanism to Rob Krier's public space typology studies and Jane Jacobs' publications, urban planners and architects have promoted this idea for years [25]. FMC aims to improve quality of life, environmental responsibility, and the social mix [26].

3.1. The 15-Minute City Definition

A 15-minute city advocates for a decentralized urban model providing equitable access to essential services within proximate neighborhoods, to mitigate various urban challenges [27]. It seeks to "repair" urban divisions, fostering a polycentric metropolis with comprehensive amenities. This vision emphasizes a human-centered and sustainable urban future. It envisions cities structured to ensure that all individuals can access their fundamental needs within a 15-minute walk or bike ride [28]. This approach promotes decentralization and a shift from private vehicles, thereby reducing fossil fuel dependency and enhancing quality of life [29]. Decentralized, polycentric frameworks that prioritize the communal good thwart gentrification and cultivate inclusive urban environments.

3.2. The 15-Minute City's Main Pillars

In refs. [1,2] 15-minute city is driven by four major components: proximity, diversity, density, and ubiquity, as shown in Figure 2.

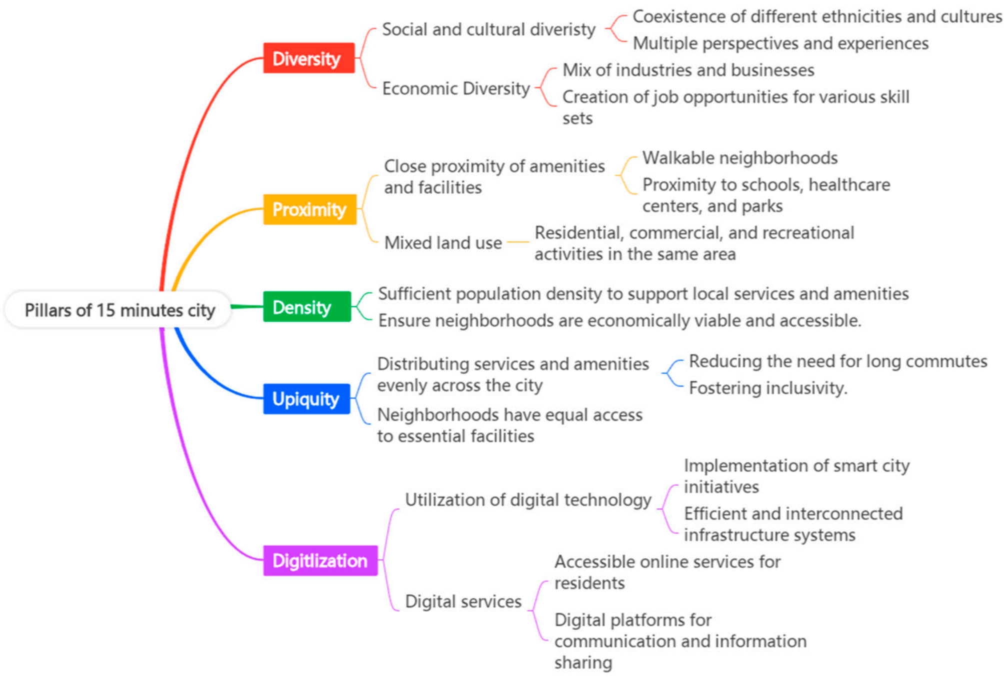


Figure 2. Pillars of the 15-minute city. Source: Author.

A. Density: The 15-minute city model assesses density through capita per square kilometer. An adequate population density is vital for health and longevity. This enables the creation of efficient, car-free transport systems, optimizing time and fuel usage. A sufficient density facilitates tailored solutions for specific areas.
B. Diversity: This plays a dual role in 15-minute cities. Key elements for healthy communities include mixed-use neighborhoods and a varied population and culture, with mixed-use neighborhoods are critical for economic vitality, housing adequacy, and sustainable practices.
C. Proximity: The 15-minute city framework relies on local amenities. It facilitates access to six essential urban functions within a 15-minute distance. These functions include residence, employment, commerce, healthcare, education, and leisure. The model requires both temporal and spatial closeness to ensure essential services are accessible. This methodology redistributes urban services among diverse neighborhoods rather than centralizing them [30].
D. Ubiquity: This underscores equitable access to vital services and amenities within a brief walk or bike ride. This ensures all areas have access to healthcare, education, groceries, recreation, and public transport, fostering a sustainable lifestyle [31].

The 15-minute city model integrates diverse sectors, boosting local economies and urban quality of life. Influenced by Jacobs' urban theory and Ostrom's governance, it addresses climate change, COVID-19, and globalization via human-centered urban strategies. It incorporates electric transport, digitalization, and the sharing economy to respond to changing lifestyles and work dynamics. This holistic approach to sustainable urban development intertwines cultural, social, and environmental aspects. Therefore, ref. [32] proposed a digitalization framework to achieve a fully walkable city.

E. Digitalization: Ref. [32] asserts that digitalization is a crucial pillar for the 15-minute city, supporting the efficacy of the other four pillars. Inspired by the smart city concept, creator Carlos Moreno emphasizes digital platforms for resident engagement, swift delivery, and inclusivity. Additionally, digital tools such as sensors assist planners and stakeholders in evaluating critical factors. A diversity of advanced technologies, including computational ones, is useful in achieving and optimizing the concept of 15-minute city.

4. Reimagining Urban Futures: From Smart Cities to AI-Driven City Planning

As previously mentioned, digitalization as a crucial pillar for the 15-minute city development has paved the way to the integration of AI, city planning, and the concept of urban smartness. This has led to a drive to explain what differentiates related concepts such as urban AI or AI urbanism and smart cities. The capability and potential of those concepts in a wider sense, and more precisely the role they play in supporting the goals of the 15-minute city, is an issue on which scholars have sought to provide a better understanding. These explorations are important in determining how AI can contribute to urban transformation, optimizing access and sustainability with human-centered framework of urban environments.

During the last few years, with their respective processes, rapid evolution in smart technologies and digital governance have totally revamped urban landscapes. Big data analytics, the IoT, sensor systems, and 5G mobile networks are some examples of phenomena that have turned cities around via smart city development [33]. It might be tempting to approach urban AI as a natural heir-apparent in the evolutionary staircase of urbanism. For these reasons, framing like that does not fully hold true to the intricacy. Unlike smart cities, defined by a clear vision directed to optimize and connect fragmented infrastructures [34], we can frame urban AI as different from such preconceived ideas. Research by [35] has shown that while smart urbanism is usually preoccupied with near-real-time data and optimization, urban AI engages in a future-oriented dynamic process, underlining continuous flux and recalibration rather than seamless connectivity.

The emergent and fluid nature of urban AI is one of the important characteristics that differentiate it from the somewhat rigid model of the smart city [34]. It is less about fixed urban AI and more about continual adaptation, comprising small changes over time, iterating and unfolding over longer periods. Organic, emergent metaphors in AI urbanism replace those of the smart city: ideas of predictability, control, and optimization. This shift, from control to autonomy and from optimization to emergence, underlines the active and indeterminate role of AI technologies in shaping urban life [35].

The crucial point in this transformation is the way in which smart and AI technologies operate spatially within the city. While smart city technologies often operate within confined, hidden infrastructures, such as smart grids buried beneath the city or automated transport systems operating in underground spaces [36], urban AI technologies are much more integrated into everyday urban environments. For example, AI technologies, like service robots, drones, and autonomous vehicles, are directly interfacing with the public in real-life open spaces, tearing down traditional barriers between technology and human life [33,36,37] write that spatial diffusion of urban AI reflects its intrinsic relation to human experiences and operates within spaces where unpredictability forms part of daily interactions.

While smart cities are driven by automation, where systems follow repetitive and generally predetermined processes, urban AI introduces a more emphatic turn toward autonomy. In this case, AI systems, such as autonomous vehicles or service robots, act on their own according to real-time data and personal inputs, the latter often controlled by customers/user-citizens themselves [38]. This independence, however, does not mean an absolute dissociation from human influence. AI systems are still shaped by human-generated data, and their decision-making processes can reflect historical biases or pre-existing societal norms [39]. For this reason, though new forms of agency are introduced, urban AI maintains its deeply embedded position in human-made systems, echoing prior decisions even as new paths are created.

This dual character—of autonomy versus influence from humans—further underlines the need to underpin urban AI in particular spatial contexts. However, in its impact-both materially and cognitively on the urban fabric, AI is in sharp contrast with the abstract and cloud-based intelligences of smart city technologies, influencing social, political, and cultural dynamics. When situating spatial and contextual dimensions within concepts of urban AI, one can see the potential of thoroughly exploring what this can mean from shifting public spaces to articulating the dynamics within urban governance and the activation of urban citizenship [40]. That is, from the perspective of cities, these are not passive environments for technology but active sites where AI technologies constantly reshape human interactions and urban life.

In summary, while smart cities strive for optimization and predictability, building a digitally connected urban environment from existing infrastructure, urban AI is marked by autonomy and emergence, where AI systems operate in continuous flux, recalibrating based on feedback loops and driving urban change in an unpredictable and often invisible manner [34,37,38].

This evolution can be described as post-smart, emphasizing the transition from predictable to adaptive and organically developing urban ecosystems that are controlled by machines. As a theoretical framework, post-smart cities contest the end-state vision of smart urbanism [40]. They mark a turn toward an urban environment featuring continuous iteration and an interplay between human and non-human agents. In such cities, AI urban technologies not only enhance the infrastructure but also redefine urban interactions by infusing a host of elements with intelligence—from decision-making to real-time human–AI interactions [41].

5. Leveraging Advanced Computational Technologies to Optimize 15-Minute City Planning and Implementation

With the development of urban analytics and computational design tools, both the quantity and variety of urban data have expanded massively, giving rise to a whole set of new urban design possibilities. Technological developments related to GIS, big data, urban analytics, and the Internet of Things have been combined with newly developed abilities to collect diverse sets of data, such as authoritative, crowdsourced, and remotely sensed data, providing a basis for data-driven urban design practices going forward [3]. Data generated by individuals through sensors, mobile devices, social media activity, online interactions, and volunteered geographic information now create unprecedented opportunities to understand urban dynamics. Moreover, the evolution of resident behaviors and movement patterns in contemporary urban environments has placed additional demands on urban design to meet complex objectives related to industrial, public, and environmental concerns. These changes highlight the growing requirement to reimagine urban design considering the digital era. This juxtaposes “traditional urban design”, defined as a heuristic, designer-oriented, and largely non-discursive process dependent on drafting-based techniques, with “technology-driven urban design”. The latter embeds designers’ creativity in digital computational methods, using rule-based systems that incorporate measurable constraints, parameters, and relational frameworks to drive design processes.

Computational techniques have transformed the study, visualization, and optimization of urban landscapes. These tools enhance planning and design through modern technologies. They facilitate urban design decision-making and augment efficiency [41]. Computational technologies significantly influence data analysis and modeling. Urban designers possess extensive demographic, transit, and environmental datasets. The integration and analysis of these datasets via computational methods elucidate complex urban system dynamics. Furthermore, computational tools have progressed parametric design and generative modeling methodologies [8]. This approach enables designers to experiment, iterate rapidly, and refine designs based on established criteria. Moreover, generative design employs algorithms to create design options contingent on defined factors. It allows designers to discover innovative and effective designs within specified constraints and objectives [3]. The recent literature has introduced parametric tools that align with the principles and metrics of FMC. Nonetheless, these methodologies do not fully encapsulate the principle. Urban network analysis, conceptualized by Sevtsuk and Mekonnen, models pedestrian and bicycle mobility. Initially developed for ArcGIS, it was later refined for use with parametric Rhinoceros3D. The Configurbanist Grasshopper tools by Nourian et al. offer a methodology for urban network analysis. This approach examines the cognitive and physical dimensions of walking and cycling, focusing on geometric and topological spatial configurations [9]. In this stance, Dogan et al. developed Urbano, a tool that simulates active mobility in urban design [42]. Recently, Lima et al. integrated shape grammar with multi-objective optimization to enhance urban fabric layouts and amenity placements. The aim was to establish 15-minute neighborhood configurations that minimize infrastructural costs while maximizing pedestrian access to urban services. In the following section, we elaborate various platforms that utilize computational algorithms, artificial intelligence, and machine learning tools to assess and analyze urban environments through the lens of the 15-minute city concept.

At the very core of computational design processes, the role of a designer shifts from directly modeling design objects to developing scripts or algorithms that generate design output. The script, represented very often as graphs or procedural workflows, dictates the process of design and allows a high degree of modification of the output with minimal alteration to the script [43]. Thus, there is an unprecedented ability to explore the full spectrum of design alternatives [44]. For example, instead of drawing a line manually, the process of parametric design means defining parameters and relationships that create the geometry in question. In this regard, the role of an urban designer involves two important tasks: "(1) setting up the base of generative algorithms through the rules and parameters of a design, and (2) evaluating the outcomes of the generated designs with respect to contextual constraints and initial design intentions" [45].

In the context of developing the design models of the "15-minute city" concept, computational design techniques were adopted to parallelize design operations, efficiently manage extensive data, and respond quickly and flexibly to changes, automating feedback, such as visualizing simulation results. Such an approach was supported with the following tools [46]:

- Generative modeling interfaces: Grasshopper 3D, Dynamo;
- Parametric urban design software: CityCad, CityEngine;
- Optimization plugins: Tools for single-objective optimization include Galapagos, Silvereye, Radical, Opossum, and Goat; tools for multi-objective optimization include Wallacei [47];
- Analysis and simulation plugins: EnergyPlus for energy simulations, Ecotect for daylight analysis, Ladybug to analyze weather data, Radiance for lighting, and Butterfly for fluid dynamics;
- Agent-Based Modeling: Models like 'D-FMCities' simulate community dynamics and help define the spatial extent of 15-minute cities, accommodating diverse urban morphologies [48].

These tools and techniques have been used to illustrate how computational design can solve complex urban issues and, in the process, smooth design processes through algorithmic procedures.

5.1. Proximity and Accessibility as Computational Metrics for the 15-Minute City

Proximity and accessibility lie at the heart of computational design in 15-minute cities, with quantifiable frameworks that ensure urban space is optimized to make essential services and amenities accessible within a walking or biking radius [49]. Proximity indices measure the average distance to key amenities or the density of amenities within a particular area. These metrics rely on variables such as distance thresholds (e.g., 800 m for walking), modes of transportation (e.g., walking or cycling), types of services considered (e.g., education, health, retail), number of amenities within a defined radius, average travel time, and spatial clustering [50]. Quantitative measurement methods involve mapping and analyzing distances using GIS tools, calculating average distances from residential areas to amenities, and creating proximity scores using formulas like dividing the sum of accessibility scores of amenities by the total number of amenities [51]. Tools such as QGIS, ArcGIS, and Python libraries, alongside data from OpenStreetMap or government census datasets, are essential for these analyses.

Accessibility metrics, on the other hand, refer to the percentage of residents who can access essential services, such as schools, healthcare facilities, grocery stores, and parks, within a specified 15-minute walking or cycling radius [43].

To reveal how to assess accessibility, we examined a study conducted within the urban confines of Seville. Within this investigation, an analysis of accessibility was performed, wherein the researchers concentrated on pedestrian and cycling modalities as active transport methods that ought to be prioritized within the x-minute city framework to evaluate the accessibility of the specified destination types. They implemented three distinct temporal thresholds—5, 10, and 15 min—throughout the research area. A travel shed, or isodistance polygon emanating from the origin point (analogous to an isochrone), delineates the region that can be reached within the designated timeframe. The maximum diameter of a hexagonal grid cell utilized in the raster corresponds to the distance of a two-minute walk, equating to 160.8 m [52].

The following gives a visual representation of the calculation for a better understanding:

$$A_i^{d,t,m} = \sum_{i,d,t} D\binom{d}{j} f\left(c_{ij}^{t}\right)$$

where

$A_i^{d,t,m}$ is the number of destinations accessible from grid cell ij for destination type d, within time threshold t, using mode m;

$D\binom{d}{j}$ represents the destinations for destination type d at location j (defined by the travel sheds);

$f\left(c_{ij}^{t}\right)$ is the impedance function between locations i and j with a value of 1 if $f(cij) \leq t$ (for destinations within the travel shed for time threshold t and 0 otherwise;

$m \in [walking, cycling]$; $t \in [5, 10, 15]$; and $d \in$ list of destinations. See Figure 3 for a visual representation of the accessibility analysis after conducting the previous calculations.

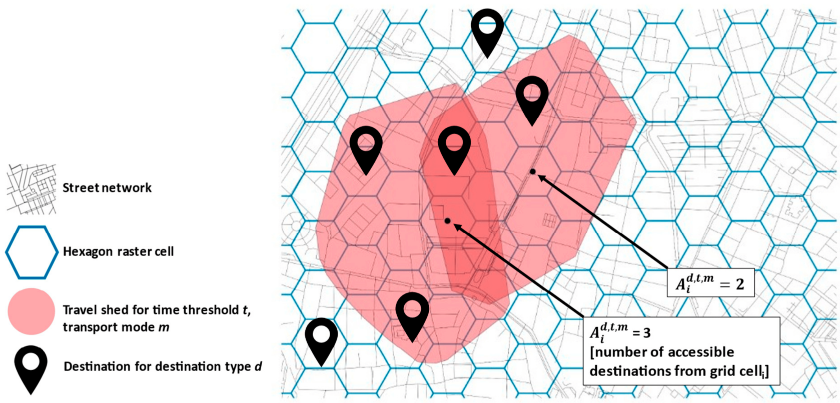


Figure 3. Visual representation of the accessibility analysis. Source: [51].

In [53], to analyze the spatial variations in accessibility, the researchers employed a visual representation of the quantity of destination types associated with each category of destination that are reachable across the urban landscape. This methodological approach facilitates a comparative assessment of the functionality of distinct urban segments and aids in the identification of locales where vital services are deficient. To enhance the comprehension of the spatial discrepancies between pedestrian and cycling modalities, the investigators illustrated the variations in the dimensions of the travel sheds corresponding to the two transportation methods. Figure 4 shows a comparison of walking and cycling travel sheds across the study area whikle numbers in the figure refers to duifefrnt zones across the study area.

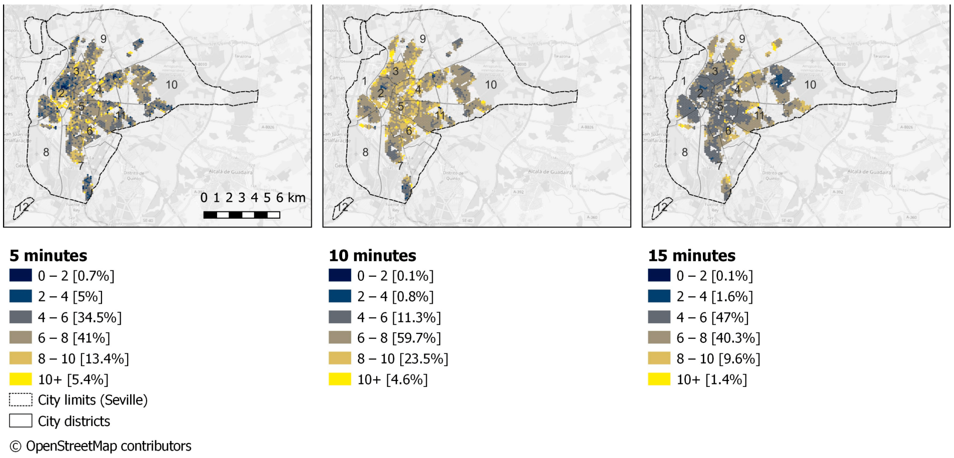


Figure 4. Comparison of the sizes of walking and cycling travel sheds across the study area. Source: [51].

The numerical values indicated in the legend denote the multiplicative factor by which the cycling shed exceeds the walking shed within a specified grid cell.

5.2. NEXT Proximity Index

The NEXI was established in 2021 within the Landscape Metropolis project and further developed in the Air Break project, supported by the UIA program. Its purpose is to assist in achieving project objectives targeting Ferrara, Italy, by identifying areas lacking access to services and requiring urgent intervention. Ferrara, a city located in the Po Valley, is one of Europe's most polluted regions, leading to significant environmental and health challenges, including elevated cancer mortality and acute myocardial infarction rates. The outskirts of Ferrara experience depopulation, resulting in social fragmentation and economic decline, primarily due to inadequate facilities, particularly in transportation. Although approximately 30% of Ferrara's residents utilize bicycles, earning it the title "the city of bikes", private vehicles remain the predominant mode of transport on the outskirts, despite efforts to promote alternative transportation [3]. Thus, the establishment of an index is crucial for enhancing service availability in underserved areas and promoting environmentally favorable transportation modes. This section elucidates NEXI's definition and its application details.

NEXT Index Definition

Since NEXI is designed to assess which areas within the area of interest meet the requirements of the 15-minute model, there should be a well-defined process for determining the adherence to the specified requirements. Hence, the developers of the index created a table (see Table 1) that provides a categorization of various Points of Interest (PoIs) according to the NEXI (Network Expansion Index) categories and maps them to corresponding OpenStreetMap (OSM) categories and features. Each NEXI category encompasses a range of OSM features, which represent different types of services or amenities [3] (see Table 1).

Table 1. Categories and included amenities.

NEXI Category	OSM Category	OSM Features
Education	amenity	college, driving school, kindergarten, language school, music school, school, university
Entertainment	amenity	arts center, brothel, casino, cinema, community center, conference center, events venue, fountain, gambling, love hotel, nightclub, planetarium, public bookcase, social center, strip club, studio, swinger club, theatre
Grocery	shops	alcohol, bakery, beverages, brewing supplies, butcher, cheese, chocolate, coffee, confectionery, convenience, deli, dairy, farm, frozen food, greengrocer, health food, ice-cream, pasta, pastry, seafood, spices, tea, water, supermarket, department store, general, kiosk, mall
Health	amenity	clinic, dentist, doctors, hospital, nursing home, pharmacy, social facility
Posts and banks	amenity	ATM, bank, bureau de change, post office
Parks	amenity	park, dog park
Sustenance	amenity	restaurant, pub, bar, cafe, fast-food, food court, ice-cream, biergarten
Shops	shops	department store, general, kiosk, mall, wholesale, baby goods, bag, boutique, clothes, fabric, fashion accessories, jewelry, leather, watches, wool, charity, ETC

Source: [3].

Nodes of the road network, which are network geometries' junction points, and sites of interest, which represent service locations, are the index computation's smallest elements. For each node, the method determines the time to reach the nearest category-specific PoI. This estimate takes the average walking speed into account and assumes activity on pedestrian-accessible roads. The time needed to reach Points of Interest will be calculated using the formula t = l/s, where l is the length of the shortest path to the PoI that only comprises walkable pathways. The predicted average walking speed is 5 km/h. A "15-minute node\" is accessible within 15 min. At 5 km/h, 15 min can traverse no more than 1250 m. After identifying 15-minute node criteria, the approach might be applied throughout a whole area. The technique averages the closeness levels of nodes in each area to calculate its proximity level. A region is a 15-minute area if the average travel time from its nodes to all categories is 15 min or less. The rating is meant to provide a range of closeness, not just identify 15-minute zones. Personal factors like age and health and environmental factors like weather might affect a person's propensity to walk. Note that some people may walk for longer than 15 min. Two proximity indices are used to measure both the accessibility of each service category and the overall accessibility of the area. In this stance, NEXI-Minutes calculates the average time to reach each category in each location at 5 km/h. NEXI-Global uses the Walk Score methodology to measure the global proximity to all service categories on a scale from 0 to 100, with 0 indicating no category within a 30-minute walk, 100 indicating all categories within a 15-minute walk, and all values in between indicating an intermediate situation. According to the Walk Score, categories are weighted proportionally to their perceived relevance (i.e., food stores are more important than banks). Furthermore, the algorithm implementing the index is designed to be scalable and parallelized and is structured in four main steps, as can be seen in Figure 5.

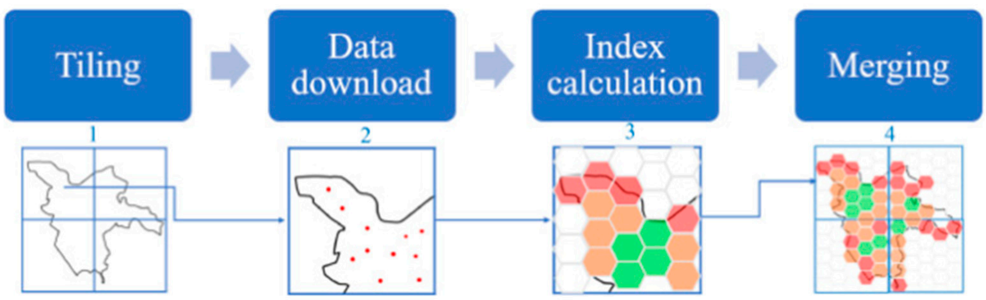
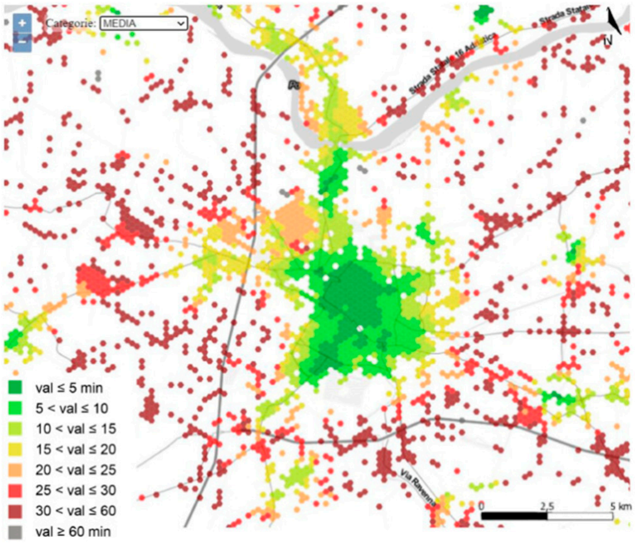


Figure 5. Macro steps of algorithm. Source: [3].

Scheme 1 displays for each cell the average NEXI-Minutes value over all service categories. The missing hexagons correspond to the portion of area where the network has no nodes, meaning it is not possible to compute the algorithm.



Scheme 1. Average NEXI-Minutes value over all service categories—Ferrara. Source: [3].

As an example, Figure 6 shows a comparison of three categories: it is evident that sustenance services are much more homogeneously diffused and dense than the services of the other two categories and that the education category has few service points and is located predominantly in the central areas of the city.

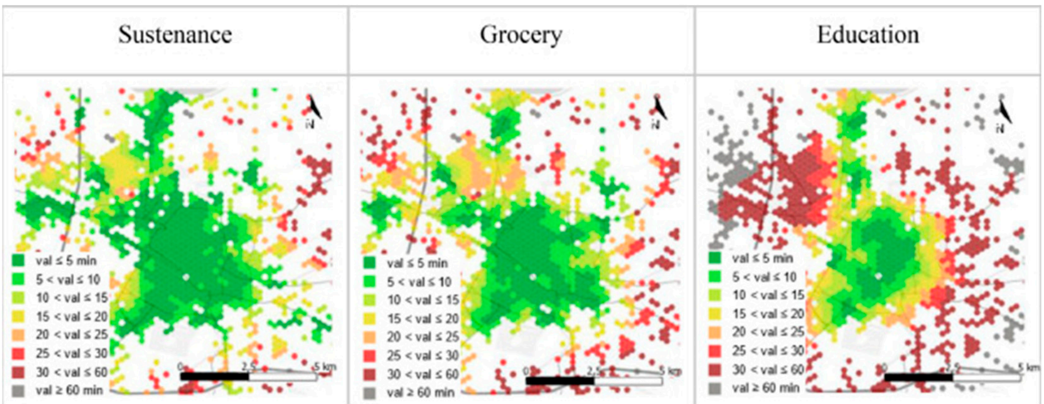


Figure 6. NEXI-Minutes index—Categories' comparison—Ferrara. Source: [3].

5.3. CITYCOMPASS Index

CityCompass was generated by Urbanly with the goal of empowering decision-makers by combining expert domain knowledge with model-based algorithms. It facilitates the real-time evaluation of transportation accessibility metrics through the analysis of both existing and anticipated data. Users can examine current multimodal transportation routes in conjunction with proposed urban infrastructure, enabling the assessment of accessibility indices that could influence demand incentives (Figure 7).

CityCompass enables the depiction of anticipated project impacts by enabling the creation of scenarios centered around these projects, thereby impacting the urban consequences in their surrounding areas. During the simulation, users can finely tune the influence of each project, thereby directly impacting prices and incentives for supply and demand. Moreover, it leverages a powerful simulation engine that reveals complex interactions among agents. Each demand agent represents a particular household type, which will bid for available properties, affecting how prices evolve over time.

Figure 7. CityCompass for transit accessibility metrics. Source: URBANLY | Shaping the future.

The 48 Streets Case Study: Locate Streets to Pedestrianize Using Multiple Selection Criteria

According to Urbanly (2022), the 48 Streets project was launched by the French Development Agency (AFD) to transform Buenos Aires into a sustainable, calm, and dynamic urban environment. Pedestrianization will be carried out in four blocks of each of the 48 neighborhoods, chosen according to an analysis of seven indicators for each street segment: tree density, presence of commerce, crime rate, noise level, compactness, population profile, and the High-Quality Social Life—HQSL—accessibility metric. The HQSL, created by the ETI Chaire at the University of Paris Panthéon-Sorbonne, evaluates housing diversity, commuting methods, shopping behaviors, physical and mental health, access to education and culture, and utilization of public spaces, measured against criteria of well-being, sociability, and sustainability. Anchored in the 15-Minute City paradigm, the program seeks to facilitate urban inhabitants' access to vital services within 15 min and rural inhabitants within 30 min. This study was executed in collaboration with urbaplan.ch and the ETI Chaire, with financial backing from AFD. Figure 8 shows the user-defined criteria for pedestrianization scoring.

According to ref. [4], the project followed certain defined steps.

1. Huge data collection

The biggest challenge in the project was to quantify values for over 25 indicators for each of the 30,000 street segments of Buenos Aires. New technologies were essential to deal with such complexity. These metrics enabled the identification of optimal routes for pedestrianization across the 48 neighborhoods, with community input guiding selections to maximize local benefits.

2. Accessibility evaluation

Calculations of accessibility require knowledge of street networks, transportation infrastructure, and variables such as slope and bicycle lane presence. Those data are tapped by CityCompass™ in calculating travel times across town on foot, by bicycle, or using public transportation.

3. Combining indicators

A flexible approach has been developed to the integration of different urban indicators. This makes it possible for community involvement in decision-making by allowing active weighting through a scoring system for each indicator according to priority. In this way, criteria are used to select compliant streets, whether they be safety, noise levels, or green space coverage, while considering other environmental factors such as flooding. Ultimately, the use of CityCompass contrasts with the ideas of dissatisfied neighbors and allows for listening to everyone's opinions, making pedestrianization a simpler task. As a result of the project, four streets of between three and five segments each were chosen for each of the forty-eight neighborhoods, as can be seen in Figure 9.

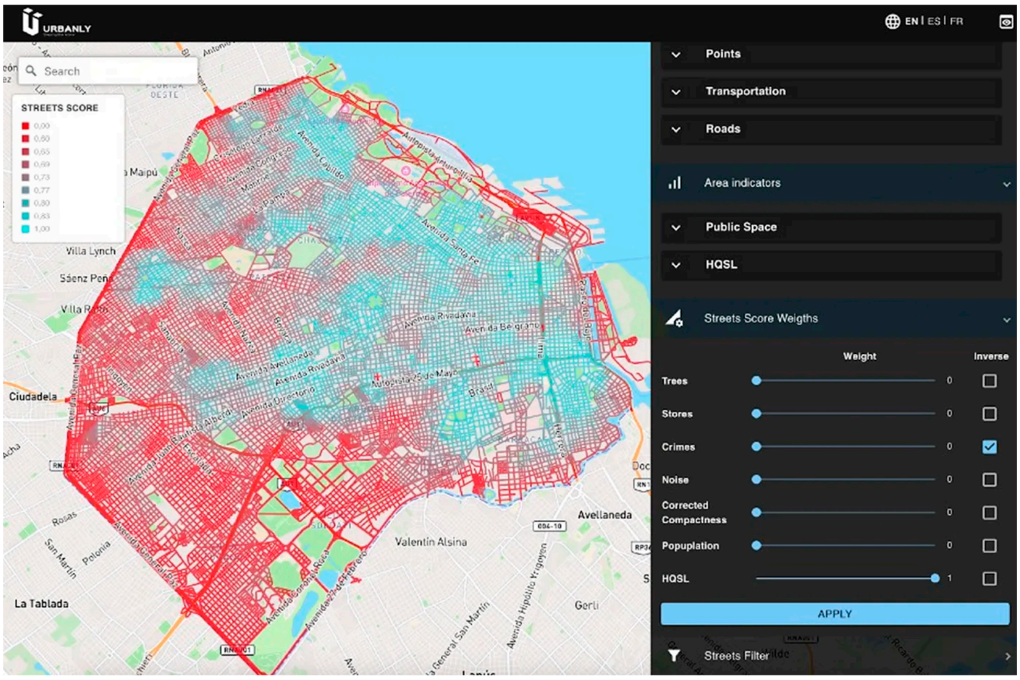


Figure 8. Creation of user-defined criteria for pedestrianization scoring. Source: URBANLY | Shaping the future.

Figure 9. Street segment filters to refine candidates. Source: URBANLY | Shaping the future.

5.4. The 15-Minute City Index Dashboard

As introduced in [7], the 15MinCityIndex is a computing model that measures urban regions' 15-minute city compliance. It provides comprehensive techniques for integrating housing, governance, safety, and service access subindexes. This Florence metropolitan area-validated model will help the municipality and other authorities identify areas for improvement, guide investments, and support civil society and corporate decisions. The Snap4City dashboard visualizes progress toward sustainable and habitable urban areas.

The Snap4City 15MinCityIndex ranked first in the 2020 open data challenge ENEL-X and was co-developed for the Bologna metro area, later extended to Italy. The methodology was presented in [5]; the data gathered a grid of 700 × 700 m cells, which provides evidence for 13 sub-indices covering the urban area. The result then undergoes processing and mapping, which in turn gives heatmaps visualizing performance in urban locations to support planners in assessing the adherence of the neighborhood to the principles of the 15-minute city in support of data-driven decisions on sustainable urban development.

The user manual for the Snap4City dashboard details the functionalities of the 15-Minute City Index, providing comprehensive guidance on its features and use.

The dashboard includes heatmaps that display both the overall 15-Minute City Index and individual sub-indices contributing to the overall index. By selecting a specific area on the map, the tool quickly estimates the profile for all indices and sub-indices, presenting the results on the right side of the dashboard.

The Snap4City 15-Minute City Index dashboard visualizes urban livability using two main methods: a spider diagram and a bar series. This spider diagram extends sub-indexes from the middle of a circle, and arm lengths show the score for every sub-index; similarly, in the case of a bar series, bars will represent scores by their height [6] The dashboard also embeds population density data from select areas and provides very detailed information on the index calculations, the factors considered, and the applied weighting [42]. Moreover, it is comprised of 13 sub-indices that assess different parameters of urban living: environment, economy, housing, health, education, and transportation. These sub-indices, for instance, track air quality, green space, job opportunities, health-care access, and infrastructural conditions that allow non-motorized mobility, and they ensure that all services are within a 15-minute walking distance [9]. Each of the sub-indices has been developed to quantify specific aspects of cities: the Environment Index on sustainability, the Economy Index on job accessibility, and the Education Index on school infrastructure [17].

The methodology was widely validated by experts through comparisons of known service levels in several areas to obtain reliable results. The dashboard therefore allows for comprehensive assessments and delivers actionable insights to enhance urban livability and well-connected sustainable communities. By integrating these sub-indices, the 15-Minute City Index provides a detailed and holistic evaluation of urban areas, aiding urban planners in making data-driven decisions to foster sustainable, walkable communities [52].

In summary, the 15MinCityIndex functions effectively in urban environments but inadequately in rural regions where data are often incalculable. The indicator evaluates adherence to the 15-Minute City model in urban areas. The index's accuracy may be enhanced when more open data are released. A modified version may utilize satellite data to delineate rural, industrial, and urban regions, enabling adjustable parameters and sub-indices. This would enhance the consistency and accuracy of service assessments across various locations, as can be seen in Figure 10.

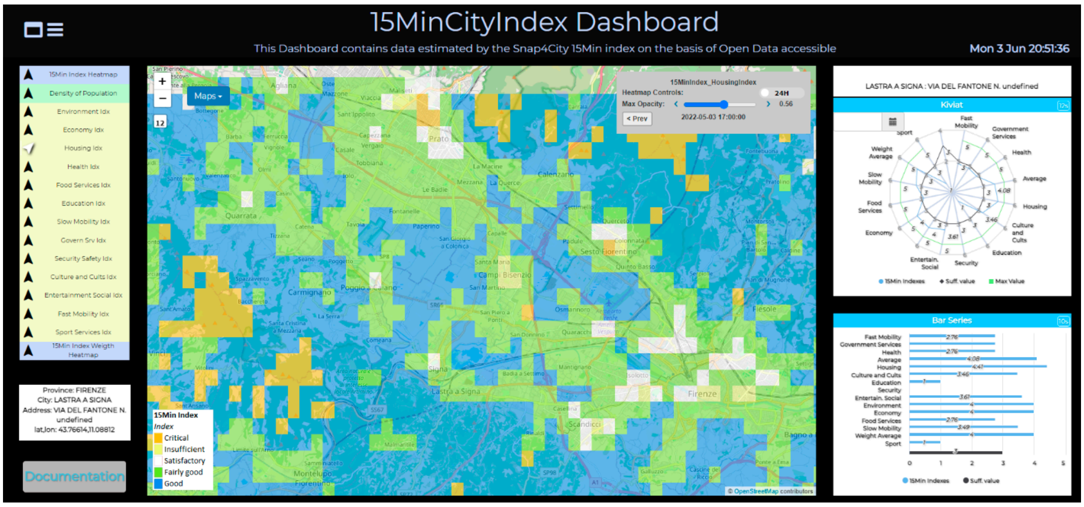


Figure 10. 15MinCityIndex dashboard. Source: [6].

6. Challenges and Ethical Considerations in AI-Driven Urban Planning: Addressing Privacy and Bias

The integration of artificial intelligence (AI) into urban planning could serve in the creation of new planning paradigms, but it presents potential ethical challenges, including concerns about bias, transparency, accountability, privacy, and misinformation [53]. As planners rely more on AI for decision-making, the potential for these systems to perpetuate biases, obscure decision-making processes, and infringe on privacy becomes more pronounced, potentially undermining public trust and excluding marginalized communities. These challenges stem from the complexity of AI systems and their multifaceted impact on planning practices. For example, fear of AI often arises from a lack of algorithmic transparency, while the need for new skills aligns with adapting to evolving data types and ensuring ethical use [54]. Recognizing these interrelations is essential for creating comprehensive strategies that address both technical and human dimensions, enabling AI to effectively enhance urban planning outcomes. Furthermore, bias in AI arises from skewed data, missing information, and assumptions embedded in algorithms, leading to unequal outcomes, particularly in urban planning. Implicit human biases—rooted in race, gender, and social class—often infiltrate AI systems, perpetuating discrimination. Addressing this requires robust data scrutiny, continuous monitoring, interdisciplinary collaboration, and transparent fairness criteria [55]. Ethical concerns extend to privacy, with vast data collection in urban planning risking surveillance and misuse. Solutions include de-identification, secure data practices, informed consent, and equitable data ownership. Planners must adopt ethical guidelines and ensure AI-driven decisions benefit communities while safeguarding vulnerable populations [56].

Moreover, accountability and transparency are critical in urban planning, especially when using AI systems, which can obscure decision-making processes and blur lines of responsibility [54]. The opaque nature of AI algorithms, often described as "black boxes", complicates understanding and accountability, particularly when decisions result in unintended consequences. Transparency in AI tools and data is essential to address biases and build public trust, especially in marginalized communities [57]. Ethical guidelines and participatory approaches that involve community input can help ensure inclusive, equitable decision-making [53]. Clear communication and public education about AI methods further foster trust and empower communities to engage in the planning process.

7. Findings

The 15-minute city, a model designed to ensure that all essential services are accessible within a short walk or bike ride, presents a forward-thinking vision of urban planning that prioritizes proximity, accessibility, and sustainability. Historically inspired by urbanist ideas of walkable cities, this concept is built on core pillars such as proximity, diversity, density, and accessibility and aims to create cities that foster social equity, community well-being, and environmental responsibility.

The practical implementation of this concept, however, relies on sophisticated tools that can measure and optimize urban environments for such goals. In this paper, we explored various tools and frameworks that assess and enhance the 15-minute city model, focusing on the Next Proximity Index, the CityCompass case study, and the 15-Minute City Index dashboard. However, the dashboards and indicators used in the present research are commercial products. This means that detailed public documentation on the specific methodologies in training, testing, and validation of the underlying artificial intelligence models is limited. It was difficult to provide systematic paradigms and frameworks for applying these metrics within the scope of the research. Another major problem is that there is a strong demand for more transparency and open access to methodological details, not only for a better understanding but also for facilitating analysis and replication in academic and non-commercial contexts, as readily accessible documentation is lacking.

The Next Proximity Index evaluates urban environments by measuring the proximity of essential services to residents. This tool is particularly effective in identifying gaps in access to healthcare, education, retail, and recreational facilities, making it a useful framework for city planners who seek to improve the spatial distribution of services. It emphasizes the need for an equitable arrangement of amenities, ensuring that no part of a city is underserved and that residents can meet their daily needs within a reasonable travel time.

The CityCompass case study offers a real-world example of how the 15-minute city concept can be applied in practice. CityCompass emphasizes spatial and social integration by creating mixed-use neighborhoods and encouraging community engagement. Through detailed analysis of urban zones, the case study showcases how thoughtful design can foster inclusive, walkable communities where essential services are equitably distributed and accessible. This case study provides valuable insights into how the principles of the 15-minute city can be realized in diverse urban settings, particularly in addressing the challenges of social equity and accessibility.

The 15-Minute City Index dashboard brings the power of artificial intelligence (AI) and computational tools into the assessment of urban environments. By utilizing AI-driven algorithms, machine learning techniques, and real-time data analytics, this dashboard enables urban planners to simulate various development scenarios, identify service provision gaps, and optimize city infrastructures. The dynamic nature of the 15-Minute City Index dashboard allows for a more responsive and adaptable approach to urban planning, ensuring that cities can evolve to meet the changing needs of their populations. It stands as a crucial tool in the quest to make urban spaces more inclusive, resilient, and adaptive.

Through a detailed comparison of these frameworks and tools, this paper has illustrated the practical applications of AI and computational tools in realizing the vision of the 15-minute city. These tools not only help measure and optimize the proximity and accessibility of essential services but also foster social integration and sustainability. In the face of increasing challenges such as climate change, post-pandemic recovery, and urbanization, the 15-minute city offers a flexible and forward-looking model for urban development. By leveraging the insights from these tools, policymakers and urban designers can craft cities that are more livable, equitable, and resilient, ultimately improving the quality of life for all residents.

The Next Proximity Index and 15-Minute City Index dashboard both focus on accessibility, but the former is broader in scope, while the latter is specifically designed around the 15-minute accessibility model. The CityCompass case study provides detailed insights into specific urban projects from the key features, while the Next Proximity Index and 15-Minute City Index dashboard measure accessibility with a focus on proximity. The CityCompass case study provides valuable real-world lessons and practical insights, while the Next Proximity Index may overlook service quality and the CityCompass Case

Study is less generalizable. The 15-Minute City Index dashboard may be limited by its fixed-radius approach.

The Next Proximity Index is useful for optimizing service locations, the CityCompass case study offers insights into specific project implementations, and the 15-Minute City Index dashboard helps in designing more accessible and livable urban spaces.

In summary, while all these tools and case studies offer valuable insights into urban planning and smart city initiatives, they each serve distinct purposes. The Next Proximity Index and 15-Minute City Index dashboard are best for evaluating and improving accessibility. The CityCompass case Study provides practical, project-specific insights. Combining these approaches can lead to a more comprehensive understanding and improvement of urban environments. Table 2 offers a comparison of the three indices.

Table 2. Comparison of Next Proximity Index, CityCompass case study and 15-Minute City Index.

	Next Proximity Index	**CityCompass Case Study**	**15-Minute City Index Dashboard**
Purpose and focus	Measures accessibility and proximity to essential services and amenities within urban areas.	In-depth project analysis. Highlights challenges, solutions, and outcomes. Provides practical lessons and impact assessments.	Evaluates urban areas based on the 15-minute city concept, focusing on accessibility within a 15-minute walk or bike ride
Key features	Proximity metrics for services. Accessibility analysis including transportation and infrastructure. Data integration from GIS and urban databases.	In-depth project analysis. Highlights challenges, solutions, and outcomes. Provides practical lessons and impact assessments.	Accessibility measurement for key services and amenities. Urban planning metrics for walkability and bikeability. Interactive dashboard for visualizing data.
Strengths	Proximity metrics for services. Accessibility analysis including transportation and infrastructure. Data integration from GIS and urban databases.	Provides real-world examples and insights into specific projects. Offers valuable lessons and context-specific recommendations. Help understand practical implications and success factors.	Emphasizes improving urban liveability and sustainability. Provides actionable insights for enhancing urban design. Supports creating more walkable and bikeable cities.
Limitations and weaknesses	Proximity metrics for services. Accessibility analysis including transportation and infrastructure. Data integration from GIS and urban databases.	Specific to the case study, so findings may not be universally applicable. Focuses more on qualitative insights rather than quantitative metrics.	Fixed-radius approach may not capture all urban complexities. Requires accurate local data for effective assessment.
Application	Proximity metrics for services. Accessibility analysis including transportation and infrastructure. Data integration from GIS and urban databases.	Learning from specific urban projects and applying lessons to similar initiatives. Evaluating project success and areas for improvement.	Urban design and planning to achieve the 15-minute city concept. Enhancing walkability and bikeability in urban areas.

Source: Authors.

8. Conclusions

The 15-minute city, with its origins rooted in historical urban planning principles focused on proximity and walkability, represents a contemporary vision for sustainable urban living. By ensuring that all essential services, such as healthcare, education, workspaces, and recreational facilities, are accessible within a 15-minute walk or bike ride, the model offers a solution to many of the pressing challenges faced by modern cities. In this paper, we traced the historical context of the 15-minute city, emphasizing how its core pillars—proximity, diversity, density, and accessibility—are aligned with older urbanist ideals while addressing the needs of contemporary, fast-growing urban populations.

The key features of this model include the creation of mixed-use neighborhoods, improved pedestrian and cycling infrastructure, and a focus on community engagement and social integration. These features form the foundation of a city that prioritizes well-being, social equity, and environmental sustainability. In our comparative analysis of evaluation tools—the Next Proximity Index, the CityCompass case study, and the 15-Minute City Index Dashboard—we explored how each framework measures the success of these key features in urban environments.

The Next Proximity Index assesses how well essential services are distributed within urban areas, while CityCompass offers a comprehensive case study on how the 15-minute city model can foster spatial equity and social inclusion. The 15-Minute City Index dashboard, enhanced by artificial intelligence, provides dynamic, real-time data analysis to identify gaps in service provision and optimize urban planning strategies.

This paper has demonstrated that AI and computational tools can significantly enhance the practical implementation of the 15-minute city by enabling urban planners to assess current conditions more accurately, simulate development scenarios, and foster social integration. As cities face increasing pressures from climate change, post-pandemic recovery, and rapid urbanization, the 15-minute city model offers a resilient, adaptable framework for creating liveable, inclusive, and sustainable urban spaces. Going forward, the integration of AI-driven tools will be key in ensuring that the vision of the 15-minute city can be fully realized, making cities more responsive to the evolving needs of their residents.

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