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ACCESSIBILITY WITHIN 15 MINUTES

Development of an evaluation model for Lisbon

Maria Pilar Borges Palma Norte

Project Work

presented as partial requirement for obtaining the Master's degree Program in Information Management

NOVA Information Management School
Instituto Superior de Estatística e Gestão de Informação
Universidade Nova de Lisboa

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By

Maria Pilar Borges Palma Norte

Project Work presented as partial requirement for obtaining the Master's degree in Information Management, with a specialization in Knowledge Management and Business Intelligence

Supervisor: Miguel de Castro Neto, PhD.

Co-Supervisor: Pedro Sarmento, PhD.

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration. I further declare that I have fully acknowledge the Rules of Conduct and Code of Honor from the NOVA Information Management School.

Pilar Norte

Lisbon, 30th November 2022

ABSTRACT

While the phenomenon of urbanization takes place, it is critical to adapt cities to the ordinary citizen and not the other way around. The 15-minute city concept proposed in 2016 by the scientist Carlos Moreno comes as a way to achieve that goal by improving sustainable accessibility in urban spaces through proximity-based planning. Ultimately, the goal is to promote space-time efficiency, sustainability, and well-being. Aiming to support this urban ideal, the present study proposes a model to evaluate the municipality of Lisbon against a 15-minute city by employing an innovative accessibility mapping model. The purpose of the model is to investigate Lisbon's potential to become a 15-minute city and, ultimately, to aid governors and urban planners in supporting its redesign, as well as to inform citizens about nearby services of interest.

In this study, a comprehensive investigation was conducted on the most significant 15-minute city-related topics, followed by the creation of a framework based on essential urban amenities that must be accessible within a walking or cycling distance of 15 minutes. Afterwards, open geographical data was gathered for the identified services and used to develop an interactive and user-centric app, enabling on-demand analysis and providing presentation-ready reports.

KEYWORDS

15-Minute city; Proximity; Accessibility; Sustainability; Open Data; Business Analyst

Sustainable Development Goals (SGD):

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LIST OF ABBREVIATIONS AND ACRONYMS

FMC	15-Minute city
OSM	Open Steet Map
LM	Lisbon’s municipality
SDI	Simpson diversity index

1. INTRODUCTION

1.1. Background and Problem Identification

Some problems involve multiple and interdependent variables "interrelated into an organic whole" that cannot be solved through linear mathematics, such as two-variable problems or statistical methods (Weaver, 1948, p. 5). That happens to be the case for cities.

Over the years, cities have been experiencing the phenomenon of urbanization – the process through which cities develop and a higher percentage of people move from rural areas to urban centres due to population growth and economic industrialization (National Geographic Society, 2022). According to the United Nations (2019), the world's population is expected to keep growing, ranging between 8.5 and 8.6 billion in 2030 and between 9.4 and 10.1 billion in 2050. As cities strive to support this astronomic population growth, urban services and infrastructures reach their limits concerning scalability, environment, and security (Khatoun & Zeadally, 2016), leading to significant challenges within urban spaces. Local governments cannot keep up with the intensive urban growth, leading to poor service delivery and, consequently, greater poverty (Al-Dayyat, 2015). Moreover, the rapid urbanization of urban agglomerations threatens the sustainability of ecosystems (Chen et al., 2022), as it contributes immensely to carbon dioxide emissions (Ramos Bernardo et al., 2019), global climate changes (Wang & Wang, 2017), air pollution (Mage et al., 1996) and environmental degradation, leading to severe environmental and health issues (Allam, 2020). As a result of these emerging challenges, “making cities inclusive, safe, resilient, and sustainable has thus become a global priority” (Griggs, 2013, as cited in Graells-Garrido et al., 2021), setting the stage for urban planning to respond to urbanization by redesigning cities.

Another major problem concerning cities is accessibility, which gains importance as the phenomenon of urbanization takes place. Before the automobile era, citizens relied upon walking or slow-moving carts for reaching jobs and markets (Southworth, 2005). Therefore, accessibility and proximity to services within urban spaces were crucial for the good functioning of a city. However, the 19th century carried the emergence of the modern car, which was gladly accepted by society for the efficiency and fastness it brought to mobility while altering completely how urban planning was being executed. Over time, the adaptation of urban environments to vehicles and their increased demand has been answering the mass production of cars (Moreno et al., 2021). This development eventually led to the need for people to adapt to cities while cities were adapting to vehicles. Eventually, most successful and wealthy cities have become associated with car dependence, and, despite all the positive aspects, substantial economic, social, and environmental costs emerged (Newman, 1996). As brought out by Gössling (2020), the eventual embracing availability of cars submerging streets had conveyed increased traffic, leading to pollution growth and degraded quality air. Furthermore, there is a relation of direct proportionality between the car's availability and domestic financial costs because of the time and economic loss due to traffic, fuel expenses and vehicle maintenance costs (Appleyard, 1980, as cited in Moreno et al., 2021). Green reserves were also negatively influenced due to the urban sprawl generated by automobile accessibility and an increased willingness to run from urban chaos (Brown, 2001, as cited in Moreno et al., 2021).

In an urgent attempt to moderate the negative impacts of urbanization and urban population growth, several efforts have been made to bring smartness to cities, resulting in the emergence of the "Smart City" concept. According to UNECE and ITU, the “smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, the efficiency of urban operations and services, and competitiveness, while ensuring that it meets the needs of present and future generations concerning economic, social and environmental aspects” (Mohanty et al., 2016). The implementation of this relatively new conception consists of an efficient strategy to “reduce energy consumption, water consumption, carbon emissions, transportation requirements, and city waste” (Mohanty et al., 2016, p. 2). It intends to increase cities' resource efficiency and sustainability, converting cities into more sustainable and healthy environments.

Complementing and supporting the Smart City topic, the scientist Carlos Moreno introduced the "15-minute city" concept as a different perspective for urban planning, attempting to solve one of the most significant challenges facing cities, accessibility. It is a critical problem because it significantly influences human development, well-being, and environmental sustainability (Rode and Floater, 2017) as it brings together the core urban components: people, transport, and social activity locations (Järv et al., 2018). The concretization of the FMC (15-minute city) efforts to fill the accessibility gap with solutions that enable citizens to access urban services efficiently in terms of space-time, sustainability, and health.

As a relatively recent topic, FMC has been generating a growing amount of knowledge. However, FMC still lacks a theoretical framework for better understanding and evaluating the current state of implementation in cities.

1.2. SPECIFIC OBJECTIVES

The present study aims to develop and shape a theoretical framework for the FMC and, from there, build and implement an artefact applied to LM (Lisbon municipality), the capital of Portugal, evaluating how it is moving towards an FMC. Aiming to achieve that goal, a high-level roadmap for the project was developed by defining some intermediate objectives:

1. Study of the theoretical state of the art of the FMC
2. Definition of the most critical services that should be promptly accessible within neighbourhoods in a city in order to build a comprehensive framework for the FMC
3. Development of an evaluation artefact combining the use of Open Data with a Business Intelligence approach, which will be materialized in an app for LM
4. Application of the artefact to some of LM’s locations

1.3. STUDY RELEVANCE AND IMPORTANCE

Grasping the concept of an FMC is not difficult, however its implementation is far from easy, mainly because there's no scientific or mathematical formula to solve the problem. It was already mentioned that the city is an organized complexity kind of problem because each city has its own identity characterized by many variables simultaneously interconnected. These features need to be considered and analyzed as a whole, because "well-ordered complex systems we know in the world, all those anyway that we view as highly successful, are generated structures, not fabricated structures" (Alexander, 2002, p. 180), entailing different solutions for different cities. Aiming to ease and support the implementation and monitoring of the FMC notion, efforts were undertaken to develop an evaluation model for LM.

In particular, the present study was conducted to build an application capable of identifying services located within walking distance of 15 minutes from a given location, allowing citizens to get helpful information regarding the most sustainably accessible services. Moreover, the model would be able to provide information that "can be provided as a support service to assist decision-making of the city government, institutions, researchers, professionals and other individuals of society in general to improve the livability and quality of the lives of citizens" (Mora et al., 2017, p. 1). In particular, the model's output intends to identify which urban functions require more attention and intervention in each neighborhood.

Ultimately, the project output intends to assist the redesign of cities that are willing to become FMCs, because the process implies multiple challenges and constraints. To complement the study, a small study regarding the housing prices of LM was conducted in order to test the application developed.

2. LITERATURE REVIEW

A theoretical overview was developed based on a comprehensive literature review around the FMC topic. Complementarily, a number of dimensions and benefits are highlighted along with some of the most important notions related to the concept. Based on the literature review, an FMC framework was developed for walkable sheds within a radius of five and fifteen minutes. Moreover, in light of the study's objectives to create a model to be applied to LM, a brief context for the city is provided, as well as practical applications of FMC-like concepts in various cities.

2.1. SUSTAINABILITY

The theme of sustainability in cities has been gaining prominence over the years while urbanization takes place, as is evidenced by the creation of the 2030 Agenda for Sustainable Development where 17 sustainable development goals are established and adopted by all the United Nations' members. Specifically, the goal that most comprehensively reflects sustainability in cities is the eleventh – *Sustainable cities and communities*: "make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations, 2015).

Urban sustainability has been defined as "a desired state in which urban society strives for promoting environmental integration, economic development, and social equity within sustainable urban forms as long–term goals through the strategic process of sustainable urban development as a desired trajectory" (Bibri & Krogstie, 2017, p. 225). In 2006, a study identified numerous sustainable urban form design concepts, such as *Compactness*, *Sustainable Transport*, and *Mixed Land Uses*, all of which can sustainably enhance urban accessibility. *Compactness* is a broadly accepted strategy for achieving more sustainable urban forms, positively impacting the quality of life, accessibility to urban amenities, reduction of energy consumption and greenhouse emissions (Jabareen, 2006). *Sustainable Transport* refers to "transportation services that reflect the full social and environmental costs of their provision; that respect carrying capacity; and that balance the needs for mobility and safety with the needs for access, environmental quality, and neighborhood livability (Jordan and Horan, 1997, p. 72, as cited in (Jabareen, 2006). *Mixed Land Use* is considered to be a solution to urban sprawl through the utilization of various types of urban spaces, including residential, commercial, office, industrial, and civic purposes, encouraging travel on foot or by bicycle while preserving open spaces, saving on urban resources allocation, enforcing social interactions, among other benefits (American Planning Association, 1998, as cited in Song & Knaap, 2004). Overall, sustainable city forms must be conductive to walking, cycling, and efficient public transportation, and its compactness must encourage social contact (Elkin, McLaren and Hilman, 1991, as cited in Jabareen, 2006).

When acquainted with the notion of urban sustainability, it is difficult to neglect the myriad benefits it may bring to metropolitan areas. Urban sustainability plays the role of revitalizing and encouraging cities to become more livable, inclusive, and sociable, while fostering innovation, decreasing environmental impacts, and promoting the transition towards a low-carbon economy (European Environment Agency, 2022). Obviously, sustainability is not achieved instantaneously; rather, it is a long-term process that requires the participation of not only government bodies and urban planners, but all individuals. According to United Nations (2019b), urban sustainability entails that cities must create appropriate income and decent work opportunities; ensure water, sanitation, electricity, transportation, and communication needs; provide for education and healthcare; enable fair access to housing and services; and maintain a healthy ecosystem in the city and its environs.

2.2. ACCESSIBILITY

The latter efforts to improve the livability of cities while seeking for sustainable environments set the stage for a major topic – urban accessibility. According to Järv (2018), accessibility refers to opportunities for interactions, bringing together the core urban components - people, transport, and social activity sites – as a function of space and time. The transport component allows people to move to a social activity location, comprising different modes of travel, including motorized and non-motorized transport. Non-motorized transport, also known as active transport and human powered transport, relates to "walking, cycling, and variants such as wheelchair, scooter and handcart use (…), providing basic mobility, affordable transport, access to motorized modes" (Litman, 2011, p. 2), among others.

Accessibility using private vehicles or public carriers, that is, transit will be influenced by variables such as waiting times and traffic, depending on a level of service that can change all the time (Duany & Steuteville, 2021). On the contrary, transportation modes like walking or bicycling don't depend on such volatile variables and "are essentially door-to-door" solutions (Duany & Steuteville, 2021). Furthermore, traffic congestion contributes to vehicle emissions and pollution, leading to potentially harmful consequences for the environment and public health (Zhang & Batterman, 2013), in contrast with non-motorized transportation modes. As a result, accessibility can significantly influence human development, well-being, and environmental sustainability (Rode et al., 2014) depending on the type of transport used to move around the city. Also, as stated in the article of Rode et al. (2014), the more efficient the accessibility to urban services, the more significant the advantages through economies of scale, density effects and networking benefits.

Easing accessibility in cities can be done by combining urban forms and transport systems within metropolitan areas (Rode et al., 2014). Thereby, there are several types of accessibility depending on the urban environment and the method of transportation employed, which, as previously noted, has a significant impact on the population and the environment. Of course, the mode of transport chosen depends largely on the proximity from the origin to the destination. Therefore, increasing proximity to urban services is crucial to endorse more sustainable ways of accessibility, such as walking and cycling, and, consequently, decrease traffic pollution to a minimum and promote mental and physical health. Obviously, providing proximity to services is not always possible, so cities must offer an easy and efficient alternative of mobility with minor adverse environmental effects.

2.3. PROXIMITY

According to Haugen (2012), geographical accessibility of desired amenities can be achieved through two principal ways: “accessibility-by-proximity” or “accessibility-by-mobility”. This study focuses primarily on the former, considering proximity as “the location of people, services, and activities near one another”, reflecting the spatial distribution and dispersion of opportunities in the urban environment (Haugen, 2012; Solá & Vilhelmson, 2019, p. 3). Thereby, proximity-based planning can greatly improve accessibility as it brings urban amenities closer to citizens. Namely, by reducing distances between housing, working spaces and amenities, it potentially diminishes the use of monotonized vehicles while enhancing everyday accessibility (Marquet & Miralles-Guasch, 2014b).

Proximity has the potential to improve human relations, economic efficiency, and social cohesion, as well as the quality of life for citizens (Huriot, 1998, as cited in Marquet & Miralles-Guasch, 2014a; Solá & Vilhelmson, 2019). Additionally, by promoting non-motorized travel modes, proximity improves and encourages pedestrian and cycling conditions, leading to congestion and pollution minimizations and, consequently, environmental preservation (Litman, 2011). These benefits result in the optimization of economic and energy consumption, as well as in the promotion of a healthy lifestyle (Yazid et al., 2011). Moreover, proximity within urban functions generates mobility models that are more democratic (Marquet & Miralles-Guasch, 2014a) and accessible, avoiding discrimination due to economic or physical characteristics.

Ultimately, it is inevitable not to notice the relationship between sustainability, proximity, and accessibility within urban spaces. Proximity of services and accessibility greatly influence sustainability in city as proximity-based urban planning promotes less environmentally damaging means of accessibility, such as walking, cycling and public transportation.

Attempting to combine the urban goals related to proximity and accessibility in a sustainable way, the 15-minute city concept emerged. It conveys an innovative accessibility model that is founded on sustainability and on the proximity of urban activities and services (Ferrer-ortiz et al., 2022).

2.4. 15-MINUTE CITY

Pr. Carlos Moreno questioned why we have accepted to adapt to cities' dysfunctions such as unnecessary long distances, excessive time losses, pollution, noise, etc. (TED, 2021). Willing to align all these interconnected variables with the citizens' well-being, Moreno offered a new conceptual approach – the 15-minute city – related to the concept of chrono-urbanism, a time-based approach to urban planning, which has long been regarded merely from a spatial perspective (Moreno et al., 2021; Gwiazdzinski, 2014). The FMC grows within the concept of chrono-urbanism as Moreno (2021) advocates the existence of an inverse proportionality between the time invested in mobility and the quality of urban life.

Going back in time, the idea behind the FMC came as a derivative of the 'neighbourhood unit' concept, suggested by Clarence Perry, a New York planner and architect (Balletto et al., 2021), who defended that “every great city (...) is a conglomerate of smaller communities” and “it is the quality of life within these smaller communities that will shape individuals’ experiences” (Perry, 1929, p. 486). Perry's neighbourhood unit concept emerged from the need to insulate the community from the negative impacts of the growing vehicular traffic, ending by providing designers and city planners with a framework for presenting the city as a set of subareas (Singhal, 2011). Also, Perry suggested “cores of urban amenities (schools, retail, services, community centre, etc.), a hierarchical street network, green areas, public space, and a residential area” (Pozoukidou & Chatziyiannaki, 2021, p. 1) as principles to follow to achieve a functional urban design. Similarly, according to Moreno et al. (2021), the urban experience implies that every neighborhood should provide urban services including “work, housing, food, health, education, culture and leisure” without the need for excessive mobility. In spite of the fact that both concepts have elements in common, it was only when urban services’ segregation, car-oriented urban designs, landscape degradation and growing socio-economic clusters became evident in the modern city that the neighbourhood gained a significant role in the spatial planning of sustainable cities (Pozoukidou & Chatziyiannaki, 2021).

The urban activist Jane Jacobs also played a crucial role in the conception of the FMC. Jacobs (1961) argued that the “ubiquitous principle is the need of cities for a most intricate and close-grained diversity of uses that give each other constant mutual support, both economically and socially. The components of this diversity can differ enormously, but they must supplement each other in certain concrete ways” (Jacobs, 1961, p. 14). Furthermore, Jacobs warned against single-purpose zoning and alluded to the importance of mixed uses and people, defending that unsuccessful neighbourhoods consist of urban spaces lacking mutual support (Wendt, 2009). Thereupon, Jane Jacobs noted the importance of compact and supportive neighbourhoods. Likewise, the FMC notion intends to reorganize neighbourhoods in order to decrease sprawling zones and, consequently, enhance social interactions. All considering, the main difference between the FMC concept and other neighbourhood centred theories is that the FMC concept highlights the significant role that sustainability plays in urban spaces, which is in line with the importance it attributes to non-motorized transports, such as walking and cycling.

Although the formalization and contextualization of the concept is relatively straightforward, the practical application of the FMC involves a great deal of complexity depending on the particular form, necessities, and dysfunctions of each city. This complexity involves the promotion of urban services at a closer distance to citizens while changing the patterns of resource allocation, restructuring governance schemes within the city, and endorsing social interaction (Pozoukidou & Chatziyiannaki, 2021).

To better comprehend the concept, Moreno et al. (2021) Moreno stated that the FMC is characterized by 4 dimensions: density, diversity, proximity, and digitalization. Density is considered in terms of population by km square – a sustainable city should take into account the optimal number of people to which a given neighbourhood is capable of providing urban goods and services; Diversity encompasses the need for mixed-use neighbourhoods offering different kinds of services, as well as a variety of culture and people; Proximity encompasses both time and space, allowing citizens to access basic urban services in a reduced timespan with low environmental and economic impacts; Digitalization ensures the other dimensions are updated, promoting inclusivity, resident participation and real-time delivery of services.

2.4.1. Benefits

After understanding the concept, it is inevitable to consider the several benefits the FMC can bring to the world and society. The FMC is all about improving accessibility in terms of human development, life quality, and environmental sustainability, while prioritizing pedestrian and cycling mobility through proximity-based services. Specifically, the FMC leads to regional growth, increased public spaces, and stronger social interactions (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2020). Furthermore, it intends to decrease private-car dependency and the amount of transit within cities in order to reduce pollution, working for a more sustainable planet. Not only does walking and cycling reduce traffic and have low environmental influence, but it also adds social and recreational values to citizens' lives, as well as endorses mental and physical health (Southworth, 2005). Economically, the FMC can leverage employment, new innovations, costs' saving in fuel, road maintenance, among others. Overall, the FMC will generate more livable, sustainable, and inclusive cities, improving the quality of life of its citizens.

However, due to the efforts implied in the FMC concept to provide all neighbourhoods with core urban services to daily life, it is common to hear some criticism by saying that the idea is to isolate people from different areas, confining them to their own neighborhoods. Instead, it is imperative for FMCs to ensure accessibility and affordability to public transit, including walking and cycling, enabling connections to other parts of the city and, consequently, reducing citizens' commute times and easing social trips (C40 Cities Climate Leadership Group & C40 Knowledge Hub, 2021).

2.4.2. Urban services

The FMC is an unstable geographic ideal when discussing essential services to urban life. Moreno advocates citizens will have a better life if they can effectively access essential urban services, including living, working, commerce, healthcare, education, and entertainment (Moreno et al., 2021). In the present study, an analysis was conducted through the functions of care, education, provisioning, and entertainment, as it was made in the study conducted by Ferrer-ortiz et al. (2022). The functions related to working and living were excluded from the analysis because of the lack of geospatial data required to evaluate accessibility to them. Finally, access to public and non-motorized transport will be part of the analysis as "a set of components of access to sustainable mobility" (Ferrer-ortiz et al., 2022). Selecting the services related to each one of the selected urban social functions consists of the basis to build the evaluation model. To do that and to enrich the study, two sheds were considered: a 5-minute walkable neighbourhood and a 15-minute walkable neighbourhood similar to a 5-minute bicycle one. The areas covered by the walkable sheds involve much more than a single neighbourhood (Duany & Steuteville, 2021) because one amenity can serve more than one neighbourhood.

2.4.2.1. 5-Minute walkable neighborhood

The 5-minute walkable neighbourhood, also known as the "pedestrian shed", corresponds to the travel distance a citizen is willing to walk before recurring to drive (Nagy & Păcurar, 2020). The pedestrian shed is an urban measure that defines the walkable area around a given destination. In this case, the pedestrian shed covers a circle with a radius of a 5-minute walk, which corresponds to a quarter mile. In the 5-minute walkable shed, residents can walk to the essential urban services for daily life. With that in mind, the 5-minute walkable shed must offer what Clarence Perry argued to be the leading facilities within a neighbourhood unit: elementary schools, open spaces, local shops, and residential environments (Perry, 1929). Besides, the neighbourhood's urban fabric must be propitious to walking between places, involving a connected network of accesses, such as streets, sidewalks and passages, and small blocks uniting the communities (Duany & Steuteville, 2021; Perry, 1929).

The consulted bibliography allowed the generation of a framework for the 5-minute walkable shed (Table 2.1).

Table 2.1 – Urban services for the 5-minute walkable shed

Service	Literature
Local retail shops (including at least one fresh market and convenience store)	Perry (1929) Duany & Steuteville (2021) Balletto et al. (2021) Weng et al. (2019)
Housing diversity (single homes, hometowns, and multifamily)	Perry (1929) Duany & Steuteville (2021) Pozoukidou & Chatziyiannaki (2021)
Community centre (public square or main street)	Perry (1929) Duany & Steuteville (2021) Pozoukidou & Chatziyiannaki (2021)
Small parks	Duany & Steuteville (2021) Balletto et al. (2021) Graells-Garrido et al. (2021) Pozoukidou & Chatziyiannaki (2021) Weng et al. (2019)
Kindergarten and elementary school	Perry (1929) Duany & Steuteville (2021) Graells-Garrido et al. (2021) Pozoukidou & Chatziyiannaki (2021) Weng et al. (2019)
Eldercare	Weng et al. (2019)
Walkable street network	Perry (1929) C40 Cities Climate Leadership Group and C40 Knowledge Hub (2020)

	Duany & Steuteville (2021)

2.4.2.2. 15-Minute walkable neighborhood

Increasing the neighbourhood's area to a radius of a 15-minute walk, three-quarters of a mile from centre to edge, leaves us with the 15-minute walkable neighbourhood. This shed is considered similar to an area of a radius of a 5-minute cycling distance. Within 15-minute walkable neighbourhoods, people must have at their disposal general merchandise stores, supermarkets, healthcare (medical and dental services), entertainment amenities, pharmacies, public schools (middle and secondary), eldercare, larger parks, larger employers, religious venues, social services, financial and governmental facilities, working spaces, car parking, and public transport stations (Balletto et al., 2021; Duany & Steuteville, 2021; Pozoukidou & Chatziyiannaki, 2021; Weng et al., 2019). Likewise to the 5-minute walkable shed, the neighbourhood's urban fabric must connect places through cycling infrastructures to enable citizens to efficiently travel around the city using bicycles (Moreno et a., 2021, C40 Cities Climate Leadership Group and C40 Knowledge Hub, 2020).

The consulted bibliography allowed the generation of a framework for the 15-minute walkable shed (Table 2.2).

Table 2.2 – Urban services for the 15-minute walkable shed

Service	**Literature**
Public transportation station	Balletto et. al (2021) Graells-Garrido et al. (2021) Duany & Steuteville (2021)
General merchandise	Duany & Steuteville (2021)
Supermarkets	Weng et al. (2019)
Larger parks and green spaces	Balletto et al. (2021) Graells-Garrido et al. (2021) Pozoukidou & Chatziyiannaki (2021)
Religion venues	Balletto et al. (2021) Graells-Garrido et al. (2021)
Car parking	Balletto et al. (2021)
Schools and higher education	Balletto et al. (2021) Graells-Garrido et al. (2021) Pozoukidou & Chatziyiannaki (2021) Weng et al. (2019)
Offices (smaller scale) and co-working spaces	C40 Cities Climate Leadership and C40 Knowledge Hub (2020)
Healthcare (medical and dental services)	Graells-Garrido et al. (2021) Pozoukidou & Chatziyiannaki (2021) Weng et al. (2019)
Pharmacies	Balletto et. al (2021) Duany & Steuteville (2021)

Financial services	Graells-Garrido et al. (2021)
Government facilities	Graells-Garrido et al. (2021)
Social services	Ferrer-ortiz et al. (2022)
Entertainment	Graells-Garrido et al. (2021) Pozoukidou & Chatziyiannaki (2021) Weng et al. (2019)
Bicycle lanes	Moreno et al. (2021) Pozoukidou & Chatziyiannaki (2021) C40 Cities Climate Leadership and C40 Knowledge Hub (2020)

2.4.2.3. 15-Minute city applications

Although the FMC is a relatively new topic, several variations on the topic already existed or have emerged followed by practical applications. For instance, an urban master plan for the 15-minute walkable neighbourhood was issued by Shanghai Municipal Government in August 2016, advocating the concept as an enabler to deliver citizens with 15-minute walkable access to urban services and, consequently, to encourage walking and overall health (Weng et al., 2019). Since the initiative started to be implemented, positive consequences have already been noticed in the community life circle. In fact, the chief of the Planning Finance and Economy Section of the United Nations Human Settlements Program, referred that Shanghai's communities have been coming to appreciate a more sustainable environment due to the current urban plan, stating that "It has raised awareness of collaboration, participation and communal cohesion" (Jian, 2021). Also, the initiative has brought a "people-oriented" perspective to Shanghai, as supported by the vice minister of China's Ministry of Natural Resources (*Art Season Centered on 15-Minute Community Life Circle Opens*, 2021).

The '20-minute city' is another related idea that emerged in Plan Melbourne to promote a more sustainable living in Melbourne, Australia, less dependent on private automobiles (da Silva et al., 2020), and to address the challenges caused by population growth and employment (Pozoukidou & Chatziyiannaki, 2021). It conceptualizes a city capable of fulfilling essential needs through the provision of most services and activities within a 20-minute walking, cycling or public transport distance (Stanley et al., 2015). Da Silva (2020) advocates that the 20-minute city brings into practice the notion of accessibility because involves the prioritization of accessibility, suggesting that urban planners should prioritize accessibility by focusing on readjusting urban infrastructures. However, they note that there are several challenges originating from the gap between the availability of accessibility instruments withhold potential and its implementation in planning practice due to the actual usefulness and usability of existing tools (Te Brömmelstroet et al., 2016).

In 2020, the 15-minute city emerged as a post-pandemic strategy included in mayor Hidalgo's campaign for re-election, *Paris en common*, having 4 strategic axes concerning ecological measures, solidarity-centred ecological transformation, hyper-proximity, where the FMC is included, and the commitment of citizens to the plan (Annehidalgo2020, n.d. as cited in Pozoukidou &

Chatziyiannaki, 2021). To accomplish the plan, several policies have been adopted with a focus on reducing the use of cars, fostering the mixed-use of public spaces, providing more green areas and enhancing pedestrian mobility, while increasing citizens' involvement in implementing the strategy (Pisano, 2020). In fact, over the last few years, more urban spaces were reserved for pedestrian cycling infrastructures, and school grounds were re-used out of hours for other needs (European Science Foundation, 2021). Moreover, Private cars account for 12% of journeys, down from 35% in 1990, while cycling has doubled in recent years (*Paris: The 15-Minute City Makes Timely Progress*, 2022).

Also in Barcelona, efforts have been made to mitigate the effects of challenges common to the previous cases. As a result of the desire to mitigate the effects of a dense city with lots of traffic and improve citizens' well-being, Barcelona started to follow the Superblock model - an urban planning project aimed at recovering space for citizens, reducing motorized transport, promoting sustainable mobility and healthy lifestyles, providing urban green areas and countering climate change effects (Rueda, 2018 as cited in Mueller et al., 2020). This innovative approach has already revealed several positive impacts, such as the provision of green spaces, pedestrian and bicycle infrastructures from road space or car parking; the decrease in vehicular traffic and the increase in the number of ground-level commercial establishments (C40 Cities Climate Leadership Group & City of Buenos Aires, 2022; Raj, 2022). To additionally support Barcelona's superblock model, a study has proved its potential to reduce premature mortality while increasing life expectancy as a result of increased green spaces and improved performance of physical activity related to transport, as well as reduced air pollution, noise, and heat Mueller et al., 2020).

2.4.3. Lisbon municipality

The city of Lisbon, placed on the Atlantic coast, is the capital of Portugal and one of the 18 municipalities integrating the metropolitan area of Lisbon of over 2.800.000 inhabitants. According to the preliminary census of 2021, there are 545 923 people currently living in Lisbon municipality (INE, 2021).

Lisbon is one of the oldest cities in the world, having been occupied by several nations and cultures, which makes it a place replete with a great legacy of history and culture. It contains 24 civil parishes (CML, 2021), which are subsequently divided into several neighbourhoods. In fact, Lisbon is commonly referred to as a "City of Neighborhoods", reflecting a sense of localism and community, tending to have well-defined community groups covering a variety of activities (Oliveira et al., 2015). Lisbon municipality has recently launched an urban strategy as a commitment to the sustainable future of the city between 2010 and 2024, aiming to reinforce the existing character of the "City of Neighborhoods", noting that the neighbourhood must be the structuring unit, in space and time, promoting a well-being both for living and working. In practice, mobility within neighbourhoods must be essentially on foot and, therefore, built at the human scale using as reference the dimensions of medieval cities. Also, neighbourhoods should be planned based on the logic of proximity of services, aiming to respond to daily needs and problems (Caraça et al., 2009). This strategic plan for the city redevelopment aligns perfectly with the urban ideal proposed by Carlos Moreno as it emphasizes pedestrian accessibility and proximity of services.

3. MATERIALS AND METHODS

3.1. METHODOLOGICAL APPROACH

The ultimate purpose of the present study was to address a current world issue by developing and applying an artefact. Therefore, the chosen methodology was the Design Science Research Methodology (DSRM) based on the steps defined by Peffers et al. (2006).

A careful and thorough literature review was conducted to acknowledge and contextualize the state of the art of the topic under discussion, leading to the emergence of the following research question:

> **RQ**: How can we evaluate the current state of Lisbon municipality on the roadmap to become a 15-minute city?

Afterwards, specific objectives were inferred to address the problem. To achieve them, it was necessary to build a framework that would support the aspired model. Specifically, urban amenities that should be accessible within a walking or cycling distance of 15 minutes were identified and rationally allocated in two different sheds of the FMC.

After collecting, systematizing and structuring the relevant material to define the framework, the required data to populate it was collected, initiating the artefact's development. Then, procedures of data exploration and data pre-processing were put into place to ensure the accuracy of the model.

Following data collection and subsequent preparation, all datasets were integrated into a mapping application. Afterwards, infographics were created and connected to the app in order to deliver on-demand results and analysis.

When the artefact was complete, some simulations were performed using specific neighbourhoods from LM, which were chosen in an attempt to represent the heterogeneity of the municipality. The criterion consisted of selecting three locations from Lisbon municipality based on residential prices – the lowest, the average and the highest.

Finally, the outputs of the model were examined in an attempt to extract relevant inferences and conclusions regarding the points of interest accessible from the considered sites. The results were analyzed using two statistical measurements, the z-score, and the SDI (Simpson diversity index).

3.2. OPEN DATASETS

Data was one of the most critical assets applied in this project because the artefact's accuracy will depend on it. Therefore, a considerable amount of effort and time was put into data collection and preparation to ensure that the final model was as representative of reality as possible. Specifically, the development of the artifact required the collection of information concerning LM's urban spaces and services.

3.2.1. Data collection

The data collection strategy was to prioritize the collection of data concerning urban amenities from *Lisboa Aberta*, an open data portal for sharing data produced by LM and by partner entities of the Open Lisbon Program (CML, 2018). All the data retrieved from this source came from *Geodados*, a platform owned by Lisbon City Council that offers geographical data that can be automatically and regularly updated (Câmara Municipal Lisboa - Geodados, n.d.), conferring a dynamic nature to the data and, consequently, adding value and utility to the model. After collecting data from those data sources, many crucial data were still missing. Although not as efficient as the prime source as it requires manual data updates, the remaining urban amenities were obtained from OSM (OpenStreetMap). OSM is an open data map continuously developed by a community of mappers (OpenStreetMap contributors, 2022), whose data is available under the Open Data Commons Open Database License (ODbL). To finalize the collection process, the extracted datasets were grouped into 5 categories of urban functions which were earlier identified: Care, Education, Provisioning, Entertainment and Public and non-motorized transport (Table 3.1).

Table 3.1 – Urban functions, respective datasets, and data sources

Urban function	**Dataset**	**Source**
Care	Health Centres Public Hospitals Military Hospitals Private Hospital	Lisboa Aberta
Education	Public Preschools Public Primary Schools Public Middle Schools Public High School Private Preschools Private Primary Schools Private Middle Schools Private High School Higher Education	Lisboa Aberta
Provisioning	Shopping Malls Pharmacies Parking Spaces (emel) Parking Lots (emel) Places of worship (discontinued in 2017) Parish Councils Central Administration - Finances	Lisboa Aberta
	Financial Services – Banks Supermarkets Coffee Shops Convenience Stores	OSM

	Restaurants	
Entertainment	Gardens – Urban Parks Playgrounds Sports Entities Cultural Centres Theaters Museums Cinemas Libraries Archives and Documentation Centers	Lisboa Aberta
Public and non-motorized transport	Bicycle Paths - Bicycle Parking Subway Stations Train Stations	Lisboa Aberta
	Bus Stops	OSM

The data gathered from OSM involved more effort because it was necessary to extract only the required amenities from an extensive database of Portugal's point features and limit those amenities to LM. To download the required geospatial data from OSM, we used OSMnx (Boeing, 2017; Siew, 2021), which is a python package consisting of an open collaborative project to create a map service offering free spatial data. For this particular study, the geometry data type of the datasets used consisted of nodes, defining spatial points.

Considering the urban amenities identified as required to be part of the model that were still missing, all the correspondent points of interest were retrieved using the method *geometries_from_place* from the OSMnx package, specifying the amenities through OSM tags (Table 3.2).

Table 3.2 – OSM tags and correspondent urban services

OSM tag	**Urban service**
restaurant, fast_food	Restaurants
cafe	Coffee Shops
supermarket	Supermarkets
convenience	Convenience Stores
bank	Banks
bus_stop	Bus Stops

3.2.2. Data pre-processing

Following what was described in the previous section, only the data extracted from the OSM was subject to cleansing and improvements in python. Otherwise, the possible processing that could be applied would suppress the real-time dynamics of the data extracted from Geodados. Thus, taking advantage of the inconvenience of the data nature extracted from OSM, the data has been explored and cleansed to ensure its quality and improve eventual insights. Using *geopandas* in python, some GeoDataFrames were framed in order to check missing and duplicate values, as well as to eliminate out-of-scope columns.

3.3. DATA APPLICATION

Having finished all the necessary data preparation, it was time to manage and map the data so that it could be used and analyzed through the deployment of an app built upon a geographic container, a GIS map, using ArcGIS Online and Business Analyst.

Firstly, all the datasets were integrated as layers into a GIS map, which was then shared and embedded in a user-focused and interactive app, working virtually from everywhere (Esri, n.d.-b).

Afterwards, ArcGIS Business Analyst was utilized to deliver on-demand analysis and presentation-ready reports and maps (Esri, n.d.-b) allowing the user to visualize key indicators and information concerning urban amenities through the creation and customization of infographics (Esri, n.d.-a). For each of the urban functions' categories – Care, Education, Provisioning, Entertainment and Public and non-motorized transport - an infographic was created.

Finally, to improve our app, as well as to address in full the research question, the infographics were connected to the app so that the user could have access to all relevant information in a single artefact.

3.4. ASSESSING ACCESSIBILITY

In order to test the application and demonstrate that the artifact serves to answer the research question, three LM locations were chosen based on their residential prices - the lowest, the average and the highest within LM:

- *1900-025, Penha de França* = location1
- *1170-094, Arroios* = location2
- *1250-018, C. Ourique* = location3

For each location, the application generated two service areas corresponding to walkable sheds of five and fifteen minutes, for which the number of accessible services in each area was calculated. Then, two numerical measurements were calculated using the results provided by the application – the z-score (Kirkwood & Sterne, 2003) and the SDI (Balletto et al., 2021).

3.4.1. Z-score

The z-score indicates how far a value is from the population mean in terms of the number of standard deviations (Kirkwood & Sterne, 2003), that is, the z-score quantifies how many standard deviations a point differs from the mean. It is calculated according to the formula $z\text{ - }score = (x - \mu)/\sigma$, where x corresponds to the observed value of a given population, μ to the mean value and σ to the standard deviation of the reference data, assuming values between -1 and 1. Given our study's circumstances, the z-score enabled the comparison between the number of urban services accessible within a 15-minute walking distance in each one of the locations mentioned above, letting us understand whether a certain location falls within the norm for a given amenity or deviates from it.

3.4.2. Simpson Diversity Index

Following the methodology from the study conducted by Balletto et al. (2021), the SDI was used to measure the variety of urban boundary functions. It is applied in statistics to populations with a finite number of elements, considering both the total number of species present and the relative abundance of each species. Normally, it is applied in ecology to measure biodiversity, and it has been analogously adapted to urban use (Borruso et Porceddu, 2009; Borruso, 2006, as cited in X. SDI can assume values ranging between 0 and 1 with greater values indicating greater diversity (Momeni & Antipova, 2022), being determined using the formula: $D = 1 - (\sum_j n_j(n_j - 1)/N(N-1))$, where n_j represents the total number of organisms of a particular species, and N the total number of organisms of all species (Barcelona Field Studies Centre, 2022).

4. RESULTS AND DISCUSSION

Following the methodology and methods earlier described, this section is devoted to the presentation and analysis of the results. First, a description of the application's structure and features, along with an easy-to-understand user manual, is provided. Then, the use of the application is exemplified and illustrated for three specific LM locations, followed by an evaluation of the sites' accessibility to urban amenities, based on the results of some evaluation measures.

4.1. WEB MAPPING APPLICATION

The deployed app contains 31 datasets from Lisboa Aberta, and 5 from OSM, thus comprising 36 LM urban services. By manipulating all this data, the app allows users to get information about urban services, and respective categories, that surround a chosen location from LM, delivering on-demand analysis and presentable infographics for walkable service areas with radius of five and fifteen minutes.

To introduce and display the application, a user's guide was developed to instruct users on how to seamlessly use it:

1. When opening the web mapping application, the user is introduced to the home page which consists of an interactive map view (Figure 4.1).

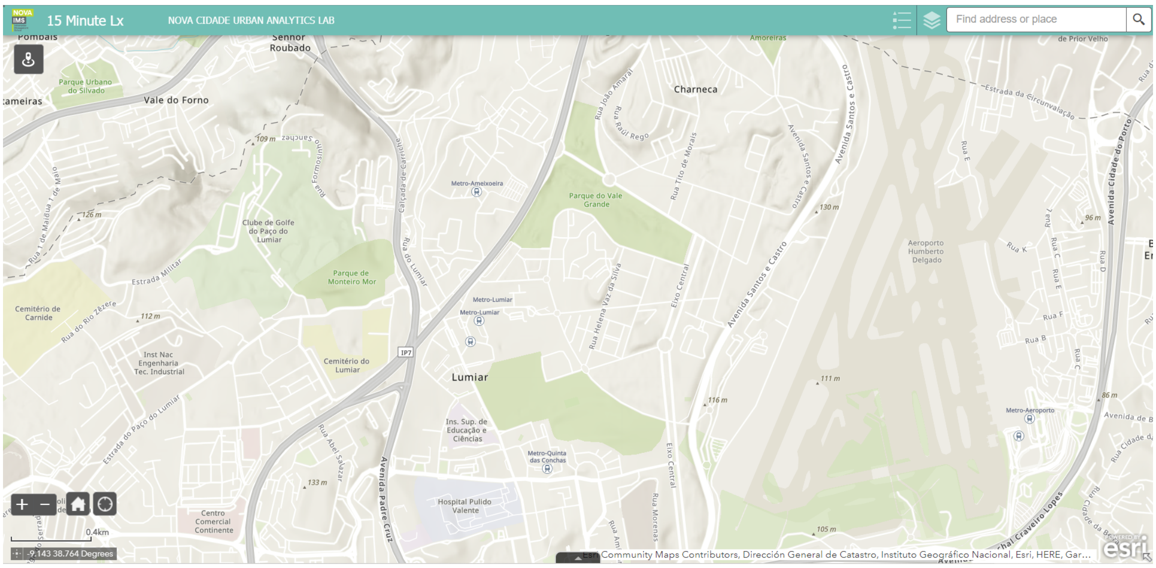

Figure 4.1 – Home page of the web mapping application in ArcGIS

2. By clicking on the Business Analyst widget in the upper left corner, the user is asked to enter a location of his/her choice (Figure 4.2).

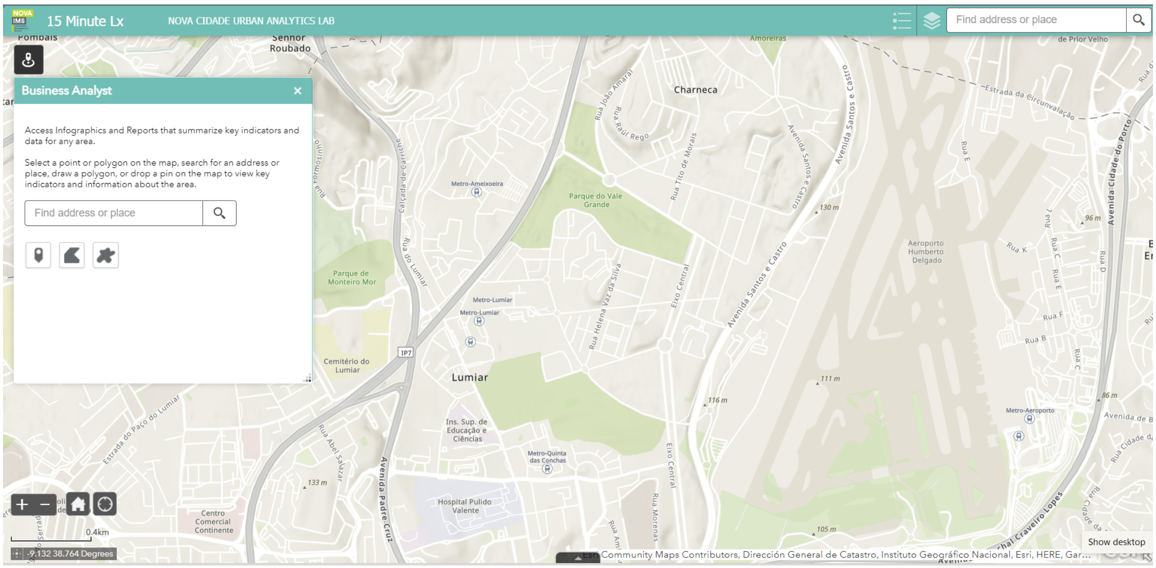

Figure 4.2 – Business Analyst interface of the web mapping application in ArcGIS (1/4)

3. After selecting the location of interest, the user is required to define the service area (e.g., 5, 10 or 15 minutes) about which the user would like to get information regarding the available services (Figure 4.3).

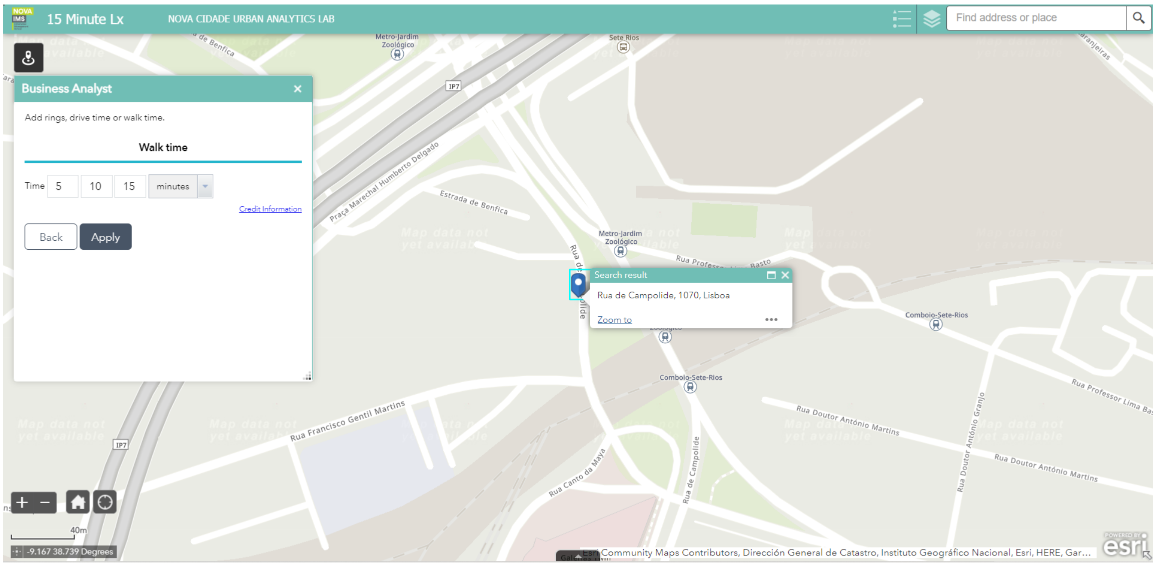

Figure 4.3 – Business Analyst interface of the web mapping application in ArcGIS (2/4)

4. The next step is to select the infographic corresponding to the urban function category the user wants to analyse (Figure 4.4).

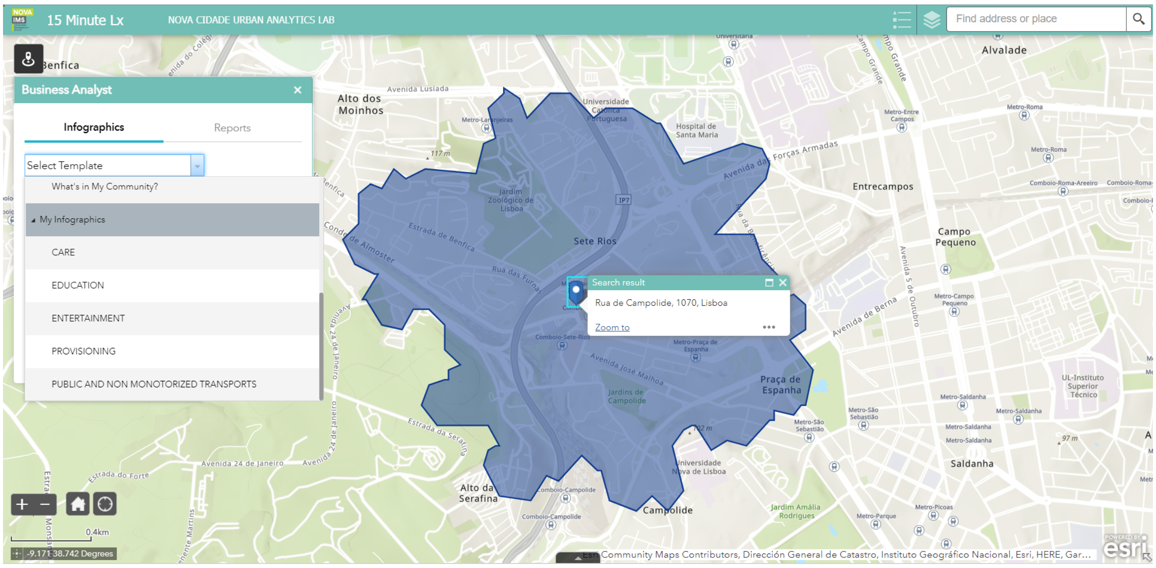

Figure 4.4 – Business Analyst interface of the web mapping application in ArcGIS (3/4)

5. Having defined the category to be analysed, the user must click on “Run the infographic” (Figure 4.5).

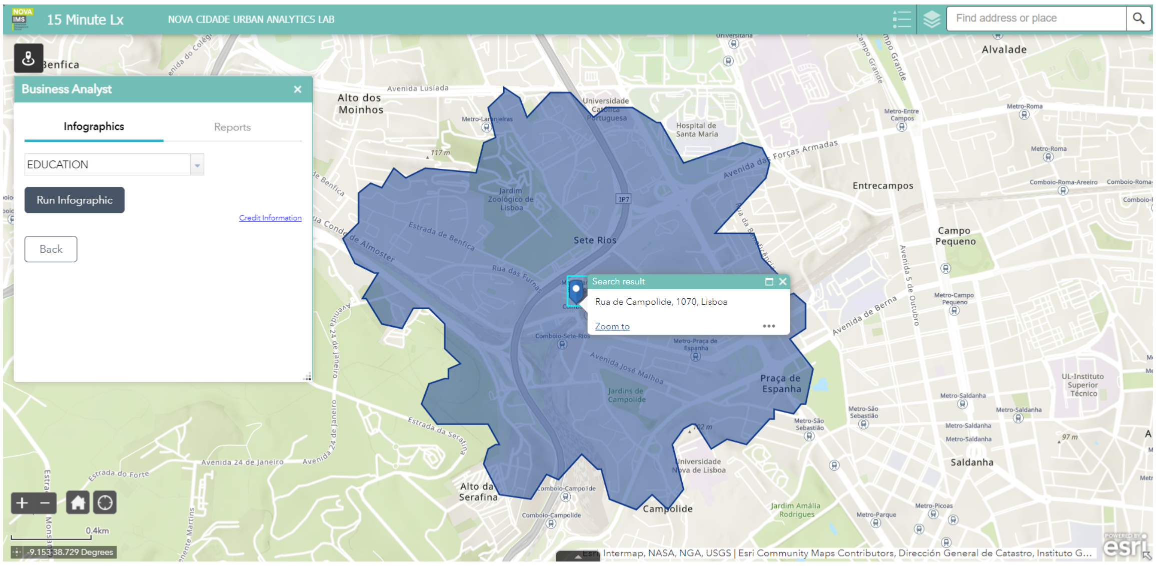

Figure 4.5 – Business Analyst interface of the web mapping application in ArcGIS (4/4)

6. The selected infographic is displayed, showing the number of interest points from the urban functions within the designated category, as well as an interactive map view with the exact points' location (Figure 4.6).

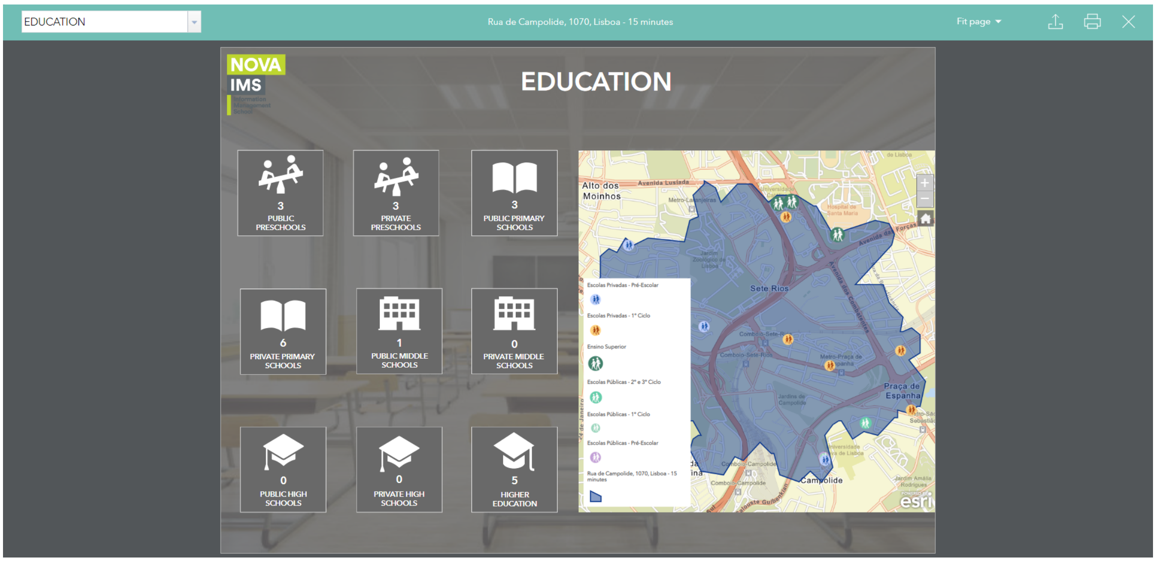

Figure 4.6 – Infographic view (Education) of the web mapping application in ArcGIS (1/2)

7. By hovering the cursor over a particular card, the user can click on "Explore for more" and view the data in a table format for more detailed information, including the names of the interest points and their distance from the selected location (Figure 4.7).

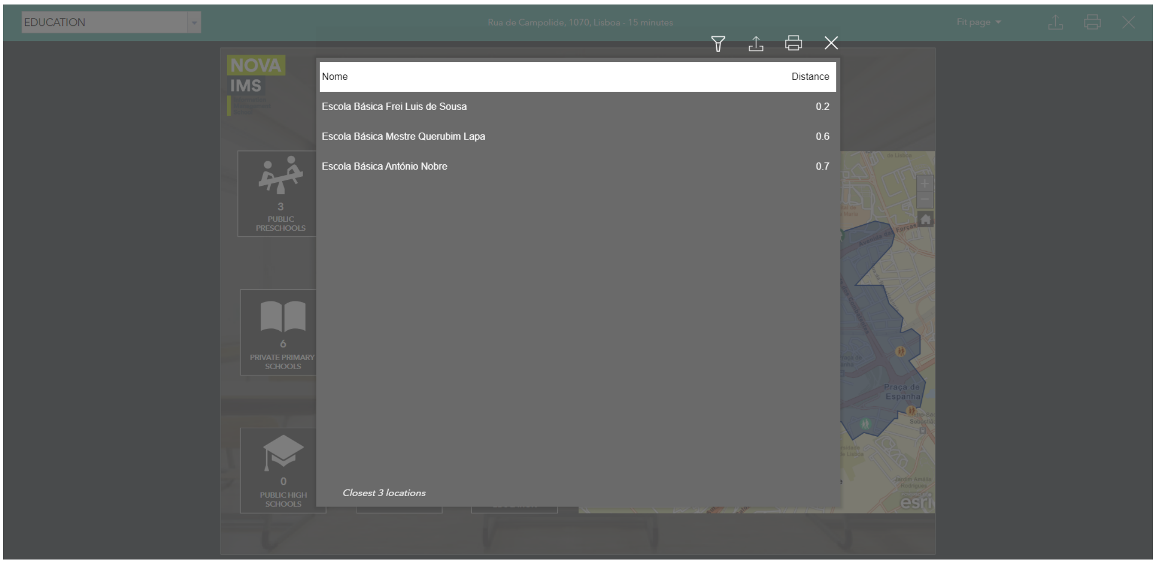

Figure 4.7 – Detailed infographic view of the web mapping application in ArcGIS

8. Instead of launching the application again to analyse another category, the user can immediately select another category in the upper left corner (Figure 4.8).

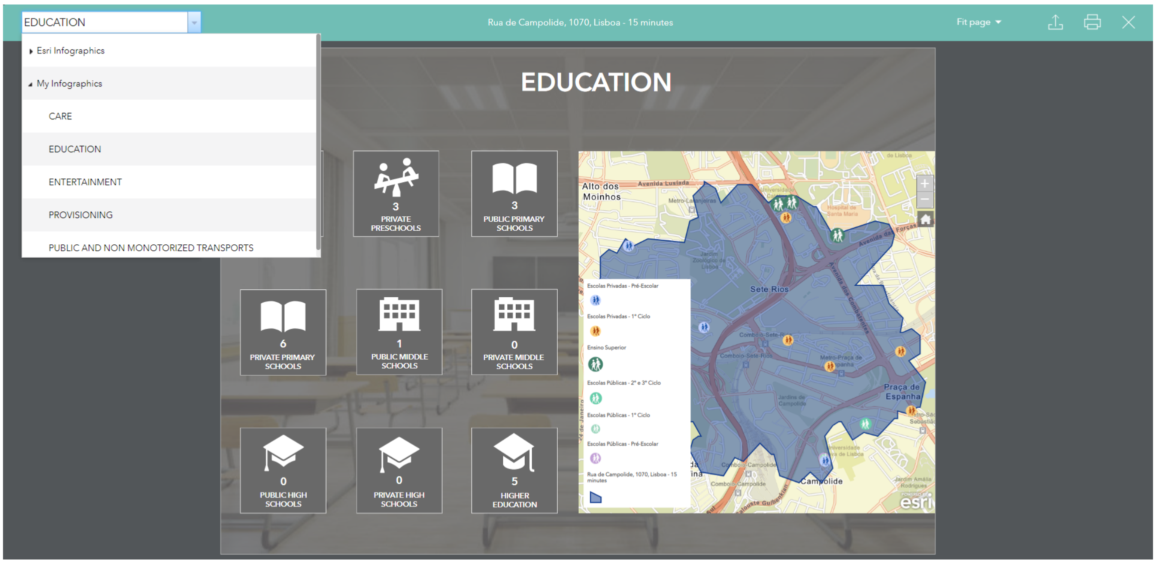

Figure 4.8 – Infographic view (Education) of the web mapping application in ArcGIS

In addition to Education, the other categories of urban functions – Care, Entertainment, Provisioning and Public and non-motorized transport - are available for selection within the app (Figures 4.9, 4.10, 4.11 and 4.12).

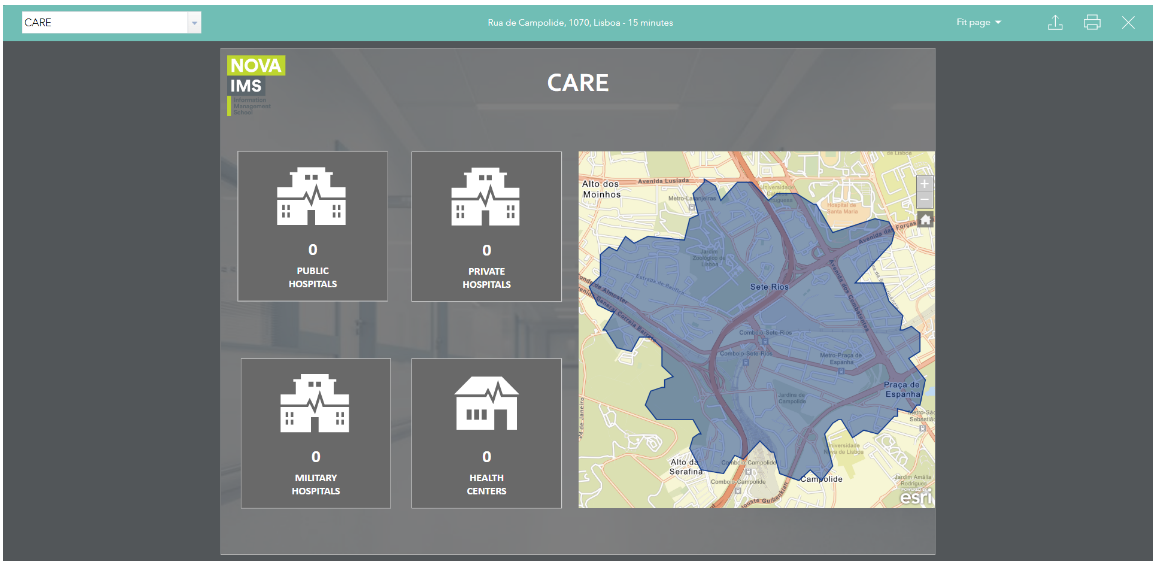

Figure 4.9 – Infographic view (Care) of the web mapping application in ArcGIS

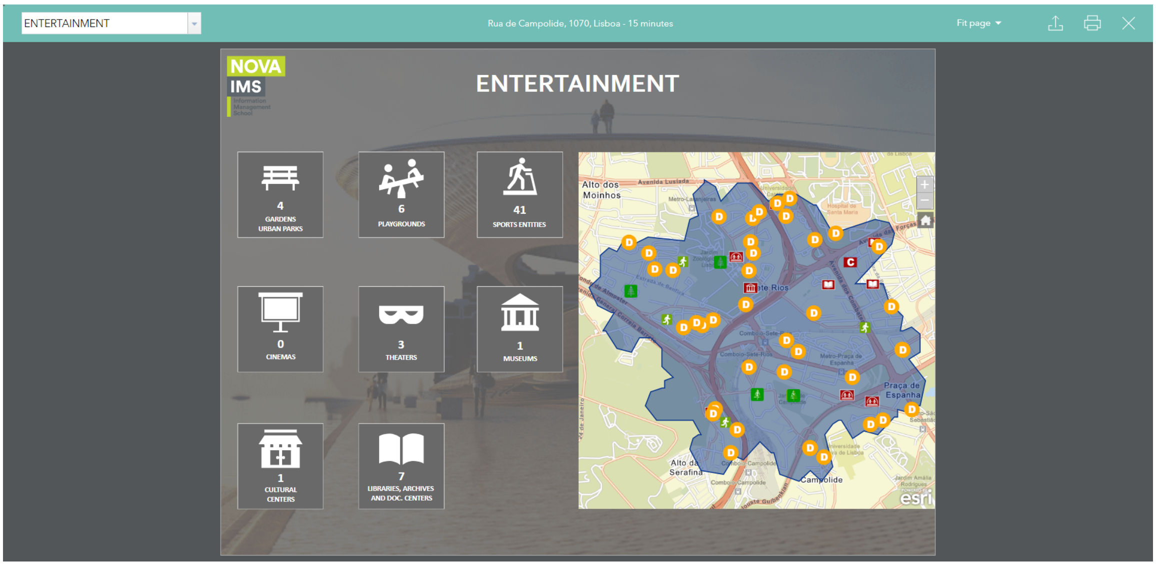

Figure 4.10 – Infographic view (Entertainment) of the web mapping application in ArcGIS

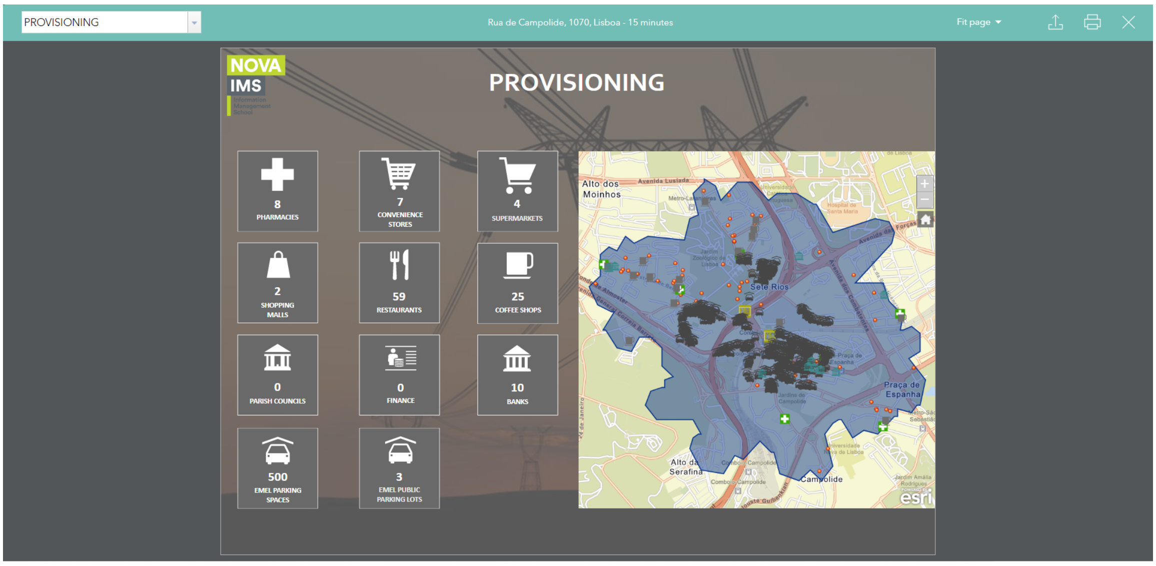

Figure 4.11 – Infographic view (Provisioning) of the web mapping application in ArcGIS

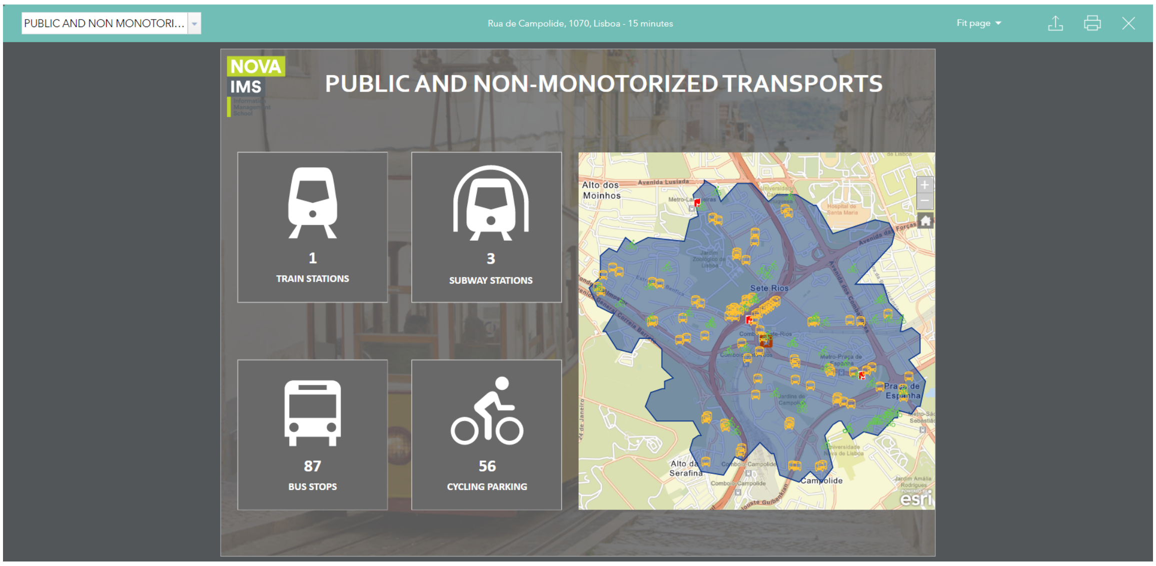

Figure 4.12 – Infographic view (Provisioning) of the web mapping application in ArcGIS

4.2. Evaluation Measures

The evaluation of three LM's locations was based on two statistical measurements - z-score and Simpson diversity index - the results of which are presented and discussed below.

4.2.1. Z-score

The z-score was calculated for all locations, two service areas and 36 urban amenities (Table 4.1). Firstly, a high-level analysis was conducted only considering the overall z-scores calculated for each one of the five urban function categories contemplated in the study: Education, Provisioning, Care, Entertainment and Public and non-motorized transport. For the 5-minute service area, there was no evidence of a correlation between the housing price and the number of amenities within a 5-minute walk. For instance, location2 is the location that stands out with a positive difference from the average in Education; location1 excels in Provisioning and Care, and location3 stands out in Entertainment and Public and non-motorized transports. As for a 15-minute service area, the absence of a direct relationship remains, although the overall z-score reflects a prominence of accessibility for the majority of categories in the location with the most expensive housing price, location3.

In particular, in the education sector within a 5-minute radius, location2 has, in general, more access to private schools than the average by more than one standard deviation. Location1 stands out by being below the average with regards to private preschools by more than one standard deviation. Location3 has one accessible higher education facility, while the others have none, which is reflected by a higher z-score. Meanwhile, with regards to a 15-minute service area, location2 stands out by being placed below the mean by more than one standard deviation, mainly due to relatively low access to public middle schools and high schools. By contrast, it presents the highest relative z-score for public primary schools and private middle schools. As for location3, it has the highest z-score for private preschools, public high schools, and higher education facilities, being positioned above average by one or more standard deviations. Additionally, location3's z-scores reflect the lowest relative access to public primary schools and private high schools.

In Provisioning, location1 clearly outstands as being above average by 1 or more standard deviations relative to pharmacies, convenience stores, restaurants, and coffee shops. Also, there's a considerable positive difference in location3 with regards to banks, presenting a z-score of 1,15. In the case of a 15-minute service area, location3 considerably diverges with regard to pharmacies, restaurants and banks which is reflected by the z-score. For instance, those particular amenities are positioned above the mean by more than one standard deviation. Location2 also stands out by having the highest z-score within the analysis scope for supermarkets, shopping malls and coffee shops.

When it comes to Care, there are no hospitals within a 5-minute walking or cycling distance to any of the locations, only 2 health centres in location1, thus justifying the highlight mentioned at the beginning of this section. As for a 15-minute service area, there is one public hospital accessible from location2 and a private one from location3, whereas a considerable number of health centres is spread out by the three locations, with location3 reaching the maximum, thus explaining the higher overall z-score attributed to location3.

In Entertainment, even though some amenities present a relatively high z-score in location3, it is only because the other locations don't provide access to any or almost none of the related services. Remarkably, all the locations have relatively high values for the number of sports entities, highlighting location3 as being almost one standard deviation above the mean. Meanwhile, location3 significantly stands out for the 15-minute service area with the higher z-score within the analysis scope for gardens – urban parks, playgrounds, sports entities, cinemas, theatres, museums, and libraries, being these amenities positioned above the mean by more than one standard deviation. By contrast, there are no theatres nor cultural centres accessible within a walking distance of 15 minutes from location1, which is reflected by a z-score ranging between -1 and $-0{,}9$.

Concerning Public and non-motorized transport in a surrounding area of 5 minutes, the z-score for cycling parking stands out for location3, particularly as it positions the place above the mean by slightly more than one standard deviation. As for a service area of 15 minutes, location1 has significantly high access to cycling parking, while location3 has the worst access. Subway stations are less accessible from location3 when compared to location1.

Table 4.1 – Z-score (z) results by urban function category

		Location1				Location2				Location3				AVG		SD	
		5-Min		15-Min		5-Min		15-Min		5-Min		15-Min		5-Min	15-Min	5-Min	15-Min
		n	z	n	z	n	z	n	z	n	z	n	z				
Education	Pub. preschools	1	-	4	1,15	1	-	3	-0,58	1	-	3	-0,58	1	3,33	0	0,58
	Priv. preschools	0	-1,15	17	-0,32	4	0,58	16	-0,8	4	0,58	20	1,12	2,67	17,67	2,31	2,08
	Pub. primary schools	1	-	5	0	1	-	6	1	1	-	4	-1	1	5	0	1
	Priv. primary schools	2	-0,22	12	1,15	4	1,09	10	-0,58	1	-0,87	10	-0,58	2,33	10,67	1,53	1,15
	Pub. middle schools	0	-	3	1	0	-	1	-1	0	-	2	0	0	2	0	1
	Priv. middle schools	0	-0,58	5	-0,22	2	1,15	7	1,09	0	-0,58	4	-0,87	0,67	5,33	1,15	1,53
	Pub. high school	0	-	2	0	0	-	0	-1	0	-	4	1	0	2	0	2
	Priv. high school	0	-0,58	2	0,58	1	1,15	2	0,58	0	-0,58	0	-1,15	0,33	1,33	0,58	1,15
	Higher education	0	-0,58	1	-0,58	0	-0,58	1	-0,58	1	1,15	4	1,15	0,33	2	0,58	1,73
	Total	4	-0,96	51	0,58	13	1,03	46	-1,15	8	-0,07	51	0,58	8,33	49,33	4,51	2,89
Provisioning	Pharmacies	8	1,14	24	-0,26	2	-0,44	21	-0,84	1	-0,7	31	1,10	3,67	25,33	3,79	5,13
	Convenience stores	11	1,15	44	0,29	2	-0,58	55	0,82	2	-0,58	15	-1,11	5	38	5,20	20,66
	Supermarkets	3	1	24	-0,22	1	-1	30	1,09	2	0	21	-0,87	2	25	1	4,58
	Shopping malls	1	1,15	6	0,09	0	-0,58	2	-1,04	0	-0,58	9	0,95	0,33	5,67	0,58	3,51
	Restaurants	22	1,15	126	-0,72	8	-0,58	141	-0,42	8	-0,58	221	1,14	12,67	162,67	8,08	51,07
	Coffee shops	12	1	116	0,12	9	0	130	0,94	6	-1	96	-1,05	9	114	3	17,09
	Parish councils	0	-1,15	4	-0,58	1	0,58	4	-0,58	1	0,58	6	1,15	0,67	4,67	0,58	1,15
	Finance	0	-	1	-0,58	0	-	2	1,15	0	-	1	-0,58	0	1,33	0	0,58
	Banks	1	-0,58	33	-0,21	1	-0,58	21	-0,88	5	1,15	56	1,09	2,33	36,67	2,31	17,79
	Emel parking spaces	500	-	500	-	500	-	500	-	500	-	500	-	500	500	0	0
	Emel parking lots	0	-	2	-1	0	-	4	1	0	-	3	0	0	3	0	1
	Total	558	1,15	880	-0,91	524	-0,60	910	-0,16	525	-0,55	959	1,07	535,67	916,33	19,35	39,88

Care	Public hospitals	0	-	0	-0,58	0	-	1	1,15	0	-	0	-0,58	0	0,33	0	0,58
	Private hospitals	**0**	**-**	**0**	**-0,58**	**0**	**-**	**0**	**-0,58**	**0**	**-**	**1**	**1,15**	**0**	**0,33**	**0**	**0,58**
	Military hospitals	0	-	0	0	0	-	0	0	0	-	0	0	0	0	0	0
	Health centres	2	1	5	-1	0	-1	6	0	1	0	7	1	1	6	1	1
	Total	2	1	5	-1,09	0	-1	7	0,22	1	0	8	0,87	1	6,67	1	1,53
Entertainment	Gardens – urban parks	2	1	9	-0,38	0	-1	8	-0,76	1	0	13	1,13	1	10	1	2,65
	Playgrounds	**1**	**-1**	**12**	**1,12**	**3**	**1**	**9**	**-0,32**	**2**	**0**	**8**	**-0,8**	**2**	**9,67**	**1**	**2,08**
	Sports entities	9	-1,03	83	-0,23	14	0,07	74	-0,86	18	0,96	102	1,10	13,67	86,33	4,51	14,29
	Cinemas	0	-	0	-0,58	0	-	0	-0,58	0	-	3	1,15	0	1	0	1,73
	Theaters	0	-0,58	0	-0,93	0	-0,58	2	-0,13	1	1,15	5	1,06	0,33	2,33	0,58	2,52
	Museums	0	-0,58	0	-0,58	0	-0,58	0	-0,58	1	1,15	9	1,15	0,33	3	0,58	5,20
	Cultural centres	0	-	0	-1,15	0	-	1	0,58	0	-	1	0,58	0	0,67	0	0,58
	Libraries	0	-0,58	10	-0,5	0	-0,58	8	-0,65	2	1,15	31	1,15	0,67	16,33	1,15	12,74
	Total	12	-0,91	114	-0,41	17	-0,15	102	-0,73	25	1,07	172	1,14	18	129,33	6,56	37,43
Public and non-motorized transport	Train stations	0	-	0	0	0	-	0	0	0	-	0	0	0	0	0	0
	Subway stations	**1**	**-**	**5**	**1**	**1**	**-**	**4**	**0**	**1**	**-**	**3**	**-1**	**1**	**4**	**0**	**1**
	Bus stops	15	0,22	119	0,32	11	-1,09	116	-1,12	17	0,87	120	0,80	14,33	118,33	3,06	2,08
	Cycling parking	13	-0,22	150	0,98	10	-0,87	129	0,03	19	1,09	106	-1,01	14	128,33	4,58	22,01
	Total	29	-0,04	274	1,03	22	-0,98	249	-0,07	37	1,02	229	-0,96	29,33	250,67	7,51	22,55

4.2.2. Simpson diversity index

Complementing the z-score analysis, an alternative method to evaluate accessibility was applied using SDI. Similarly to z-score, the SDI was calculated for all locations, two service areas and 36 urban amenities (Table 4.2). Overall, for both service areas, the results suggested that there was no direct relationship between housing price and the number and diversity of amenities accessible within a 5-minute or 15-minute walking distance, considering all locations.

In Education, specifically for a 5-minute walkable radius, location1 and location2 have the highest SDI – 83,33% – even though location2 has a higher number of accessible amenities. This is explained by the fact that the SDI is not only related to the number of organisms per species but also the similarity of abundance from species to species. On the other side, location3 stands out by having the lowest SDI, despite not being the site with the smallest number of accessible amenities. Therefore, location3's SDI suggests a low level of diversity given the number of accessible amenities. In the case of a 15-minute radius, although location1 has the same number of accessible amenities as location3, its SDI indicates a high-level of accessible diversity within a 15-minute radius.

The index stands out by having the lowest SDI, despite not being the site with the lowest number of accessible functions, thus suggesting a low level of diversity given the number of accessible functions

Concerning Provisioning, location1 reveals a significantly high SDI relative to the other locations, although being low when compared with other urban functions' categories. As for a 15-minute service area, location3 presents the highest SDI, even though not widely divergent from the others.

When it comes to Care, there are no significant SDIs as location2 has no accessibility to any of the urban functions, while location1 and location 3 have two and one amenities, respectively, from only a single type of urban function. Meanwhile, with regards to a 15-minute service area, even though location3 has a larger number of accessible sites, location2 presents a higher SDI, which means the number of accessible points is more distributed across different urban functions.

In Entertainment, location3 stands out by having the highest SDI, deviating by more than 10% from the others. However, it is not as significant as its total number of amenities accessible within 5-minutes, diverging from the others by more than three hundred.

As for Public and non-motorized transport, location2 is slightly highlighted by its SDI, although not having by far the highest total number of accessible amenities, thus suggesting a relatively high diversity. In fact, location3 has almost 900 more facilities than the location previously mentioned. Within a 15-minute service area, location2 barely excels relative to the rest.

Table 4.2 – SDI results by urban function category

		Location1				Location2				Location3			
		5-Min		15-Min		5-Min		15-Min		5-Min		15-Min	
		n	n(n-1)	n	n(n-1)	n	n(n-1)	n	n(n-1)	n	n(n-1)	n	n(n-1)
Education	Pub. preschools	1	0	4	12	1	0	3	6	1	0	3	6
	Priv. preschools	0	0	17	272	4	12	16	240	4	12	20	380
	Pub. primary schools	1	0	5	20	1	0	6	30	1	0	4	12
	Priv. primary schools	2	2	12	132	4	12	10	90	1	0	10	90
	Pub. middle schools	0	0	3	6	0	0	1	0	0	0	2	2
	Priv. middle schools	0	0	5	20	2	2	7	42	0	0	4	12
	Pub. high school	0	0	2	2	0	0	0	0	0	0	4	12
	Priv. high school	0	0	2	2	1	0	2	2	0	0	0	0
	Higher education	0	0	1	0	0	0	1	0	1	0	4	12
	Total	4	2	51	466	13	26	46	410	8	12	51	526
	N(N-1)	12		2550		156		2070		56		2550	
	SDI	**83,33%**		**81,73%**		**83,33%**		**80,19%**		**78,57%**		**79,37%**	
Provisioning	Pharmacies	8	56	24	552	2	2	21	420	1	0	31	930
	Convenience stores	11	110	44	1892	2	2	55	2970	2	2	15	210
	Supermarkets	3	6	24	552	1	0	30	870	2	2	21	420
	Shopping malls	1	0	6	30	0	0	2	2	0	0	9	72
	Restaurants	22	462	126	15750	8	56	141	19740	8	56	221	48620
	Coffee shops	12	132	116	13340	9	72	130	16770	6	30	96	9120
	Parish councils	0	0	4	12	1	0	4	12	1	0	6	30
	Finance	0	0	1	0	0	0	2	2	0	0	1	0
	Banks	1	0	33	1056	1	0	21	420	5	20	56	3080

	Emel parking spaces	500	249500	500	249500	500	249500	500	249500	500	249500	500	249500
	Emel parking lots	0	0	2	2	0	0	4	12	0	0	3	6
	Total	558	250266	880	282686	524	249632	910	290718	525	249610	959	311988
	N(N-1)	310806		773520		274052		827190		275100		918722	
	SDI	**19,48%**		**63,45%**		**8,91%**		**64,85%**		**9,27%**		**66,04%**	
Care	Public hospitals	0	0	0	0	0	0	1	0	0	0	0	0
	Private hospitals	0	0	0	0	0	0	0	0	0	0	1	0
	Military hospitals	0	0	0	0	0	0	0	0	0	0	0	0
	Health centres	2	2	5	20	0	0	6	30	1	0	7	42
	Total	2	2	5	20	0	0	7	30	1	0	8	42
	N(N-1)	2		20		0		42		0		56	
	SDI	**0**		**0%**		**-**		**28,57%**		**-**		**25%**	
Entertainment	Gardens – urban parks	2	2	9	72	0	0	8	56	1	0	13	156
	Playgrounds	1	0	12	132	3	6	9	72	2	2	8	56
	Sports entities	9	72	83	6806	14	182	74	5402	18	306	102	10302
	Cinemas	0	0	0	0	0	0	0	0	0	0	3	6
	Theaters	0	0	0	0	0	0	2	2	1	0	5	20
	Museums	0	0	0	0	0	0	0	0	1	0	9	72
	Cultural centres	0	0	0	0	0	0	1	0	0	0	1	0
	Libraries and doc. centres	0	0	10	90	0	0	8	56	2	2	31	930
	Total	12	74	114	7100	17	188	102	5588	25	310	172	11542
	N(N-1)	132		12882		272		10302		600		29412	
	SDI	**43,94%**		**44,88%**		**30,88%**		**45,76%**		**48,33%**		**60,76%**	

Public and non-motorized transports	Train stations	0	0	0	0	0	0	0	0	0	0	0	0
	Subway stations	1	0	5	20	1	0	4	12	1	0	3	6
	Bus stops	15	210	119	14042	11	110	116	13340	17	272	120	14280
	Cycling parking	13	156	150	22350	10	90	129	16512	19	342	106	11130
	Total	29	366	274	36412	22	200	249	29864	37	614	229	25416
	N(N-1)	812		74802		462		61752		1332		52212	
	SDI	**54,93%**		**51,32%**		**56,71%**		**51,64%**		**53,90%**		**51,32%**	

Overall, looking at the scores obtained from the z-score and the SDI, the results can be summarized in the table reflecting how many times each location was referenced as the best given the intrinsic criteria of both z-score and SDI (Table 4.3).

Table 4.3 – Overall results of z-score (z) and SDI by urban function category

	Location1			**Location2**			**Location3**		
	z	**SDI**	**Total**	**z**	**SDI**	**Total**	**z**	**SDI**	**Total**
Education	-	2	2	2	1(5)	3	-	-	0
Provisioning	1(5)	1(5)	2	-	-	0	1(15)	1(15)	2
Care	1(5)	-	1	-	1(15)	1	1(15)	-	1
Entertainment	-	-	0	-	-	0	2	2	4
Transports	1(5)	-	1	-	2	2	1(5)	-	1
Total	-	-	**6**	-	-	**6**	-	-	**8**

Looking at the table, it is noted that location3 gets the highest possible score in the entertainment category, being rated as the best in both service areas for both z – score and SDI. It is also worth remarking on the cases where a location for a certain category and service area gets the best rating from both the z-score and the SDI: (location1, *Provisioning*, 5-min), (location2, *Education*, 5-min) and (location3, *Provisioning*, 15-min). Ultimately, location3 receives the highest overall score (8), which could be explained by its more expensive housing. Nonetheless, location1 and location2 are equivalent in terms of their overall score (6), despite the fact that their housing costs vary.

In summary, the analysis based on the two applied measures suggested that there was no clear evidence of an existing correlation between the housing price of each one of the three specific locations chosen for analysis and the amenities accessible by walking five or fifteen minutes . In other words, a higher housing cost does not necessarily equate to better access to services in the sample under consideration.

5. CONCLUSIONS AND FUTURE WORK

The present study intended to develop a 15-minute city artefact to evaluate the current state of Lisbon municipality on the roadmap to become an FMC. A theoretical investigation was conducted to gain a comprehensive understanding of the urban amenities and respective categories that should be accessible within a 15-minute walkable shed, enabling the construction of a 15-minute city framework. Moreover, the framework was enriched by covering not only a 15-minute service area but also a 5-minute one. Based on the developed framework, an application was created using open databases covering the needed urban services currently spread throughout LM.

The developed application comes, first of all, to allow urban planners and governors to understand how to design or redesign the city to provide a better quality of life to its citizens mainly supported by a more sustainable and healthy urban development. In practice, it aims to continuously support the implementation and monitoring of the 15-minute city notion by prioritizing accessibility on foot or by bicycle. Secondly, the app pretends to assist common citizens with regard to the most accessible services within a particular service area to help them make better use of their time.

Finally, the application was deployed using three heterogeneous locations which were selected in terms of financial value. From the results of the z-score and the Simpson Diversity Index, there is no direct relationship between the price of the co-housing considered and the number of amenities accessible within 5-min or 15-minute walking or cycling distance.

During the investigation, there were some limitations regarding the collection of the necessary data corresponding to the different points of interest in Lisbon's municipality. In fact, eldercare and working facilities, although present in the framework, were not considered in the application since no sources were found. Consequently, the real application of the framework was compromised, opening the door for future research and discovery. An additional constraint was obtaining dynamic data that did not require the need to constantly update the application manually. Therefore, even though most of the data required by the framework has been obtained, not all of it contributes to the automation of the application, namely the data extracted from the *Open Street Map*.

In attempting to build the most universal and reliable framework possible, only urban amenities sustained by reviewed literature were considered and included. Therefore, the complexity of the framework may be limited to existing articles in the present study's bibliography.

Moreover, due to the time limit, the application couldn't be tested for the various neighbourhoods of Lisbon, therefore a criterion based on heterogeneity had to be chosen for the selection of only some locations to be analyzed. Accordingly, the analysis covered only three of forty-eight of Lisbon's neighbourhoods, which probably limited and hindered the accuracy of the insights obtained.

A further significant limitation is the lack of data outside the city limits of Lisbon, which means that locations on the city's edge will integrate fewer amenities, resulting in skewed results in these instances. In other words, situations in which the service area exceeds the LM limits are restrictive because the application lacks data beyond these limits.

Regarding further developments, the application could be improved by gathering the data required by the framework and which was not found during this investigation. Additionally, the application's static data sources must be replaced by dynamic sources as soon as they become available. These action points will certainly make the application completer and more efficient as more and more dynamic information is incorporated.

Considering the continuous urban development and the growing knowledge related to city planning, a beneficial improvement would be the continuous review of the framework and the application update.

Finally, an important follow-up of this study would be the further analysis of the remaining neighbourhoods in order to collect interesting insights to widen the understanding of Lisbon's municipality, as well as to support a potential urban redesign and promote citizens' well-being.

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