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Original Research

Accessibility and heritage: A measure of connectivity of the historic walled center of Cartagena de Indias

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Abstract

This research aims to analyze the conditions of geographical accessibility to the historic walled center of Cartagena de Indias, Colombia, through the application of geostatistical models based on the use of GIS digital tools, taking as a basis the available transport infrastructure, the location of the tourist arrival points (Land Transport Terminal, Airport) and being complemented, with socio-demographic coverage analysis.

The main result is that accessibility to the historic center of Cartagena is limited for a large part of the population, considering that the location of the historic center is on the western side and the urban expansion of the city is towards the eastern side due to its limited coastal condition. On the other hand, the main conclusion is that the accessibility assessment makes it possible to make decisions on interventions for preserving heritage, thus generating a more significant impact from the perspective of mobility and social inclusion.

Keywords: Accessibility; Heritage; Cartagena; Mobility; Historic Centre

1. Introduction

“This article is structured with the purpose of evaluating the accessibility conditions in order to guarantee the preservation of the heritage, taking as a basis a differential approach, with respect to the physical valuation of a structure and more towards the importance of preservation from a city impact point of view, in which importance is given to the road connectivity of the population and the most important mobility nodes”.

Heritage preservation and promotion play a significant role in the development and structuring of cities with a tourist vocation, considering the intrinsic value that goes beyond its mere aesthetics. It becomes an invaluable asset that boosts tourism, generates employment, promotes investment and stimulates the development of related economic activities. Architectural heritage can be considered a strategic economic resource for cities since its historical and cultural value attracts visitors from all over the world, thereby creating a significant economic impact [1]. However, this economic bonanza resulting from the exploitation and use of heritage assets must bear in mind the behavior of mobility during the expansion and development of heritage cities. Consequently, this is due to the impact on the circulation of users as a result of inadequate planning and traffic management, leading to problems of congestion, public health and, in some cases, direct effects on cultural assets.

Some measures used to control mobility for heritage assets have focused on restricting the use of private cars in essential sectors, linked to the possibility of congestion charges or even the promotion of public transport and autonomous transport [2][3][4][5]. However, despite the tourist and heritage vocation of these cities, adequate infrastructure should be guaranteed for the circulation of users in non-heritage areas, allowing efficient mobility and sufficient infrastructure for the joint development of the population.

In this regard, proper urban planning must be carried out to integrate all road users, enhancing the strengths and mitigating the problems that may exist. Here is where planners look for tools to guide or direct the city decisions that administrations must implement. Therefore, methods such as Territorial Accessibility facilitate infrastructure evaluation processes and visualize the effects on particular environments.

Breaking down the previous term and taking as a basis the definition established by Hansen [6], *Accessibility* is defined as the potential of existing opportunities in an environment for the interaction or development of human activities using different modes of transport [7], considering the existing limitations in the environment [8] [9].

This definition, although based on a formal or technical structure from a literary point of view, can be better understood as a quantitative measure of the ease of movement of an individual through existing infrastructure using an available mode of transport. It is necessary to be transparent about how accessibility measurements are made since there are several typologies according to the planner's needs, among which are relative accessibility, integral average accessibility and global average accessibility [10], which contemplate different estimation bases. In our particular case, we will focus on the Integral Average Accessibility, which does not allow us to evaluate the displacement conditions from any sector of a city or environment to one or several points of interest. All this is structured using geographic information tools, with support from the theory of graphs [11].

Some accessibility assessments carried out in recent years show important contributions in terms of connectivity [12] and urban restructuring [13], as well as the importance of heritage valuation and preservation [14][15].

Leaving aside the evaluation method, here is the research study area, which is located in the city of Cartagena de Indias, the capital of the department of Bolivar, located on Colombia's Caribbean coast at 10°25′25″ North latitude and 75°31′31″ West longitude (figure1), with an urban population of 924,867 inhabitants as of 2023 [16], distributed over an area of 76 km2 [17]. Known as the "Pearl of the Caribbean", Cartagena stands out for its impressive colonial architecture, fortified walls and rich history. Cartagena de Indias is a historical and cultural treasure that reflects the influence of the Spanish colonial era in its cobblestone streets, squares and monuments [18]. The city is strategically located in the Caribbean, which gives it a warm tropical climate and beautiful white sandy beaches. Its location makes it an attractive access point for national and international visitors. In addition to its architectural beauty, Cartagena offers a wide variety of tourist attractions, such as the Castle of San Felipe de Barajas, the colorful houses of La Calle del Arsenal, and the Historic Centre, among other attractions.

The historic center of Cartagena de Indias is an architectural treasure that has left an indelible mark on Colombian tourism. Its majestic walls and rich history make it a world-renowned tourist destination. The Walled City of Cartagena is an exceptional example of Spanish colonial architecture and a living testimony to a bygone era. The imposing fortifications, built in the 16th century to protect the city from pirate attacks, are an impressive attraction for visitors who marvel at their magnificence and historical significance [18].

The impact of the Walled City of Cartagena on tourism is undeniable. It is one of Colombia's most popular tourist destinations and attracts thousands of visitors yearly. According to the Colombian Ministry of Commerce, Industry and Tourism [19], tourism in Cartagena has experienced steady growth in recent years, and much of this success is due to the charm and cultural richness of the Walled City. The influx of tourists has a significant economic impact on the city, creating jobs in the tourism sector and stimulating investment in hotel infrastructure, restaurants and related services.

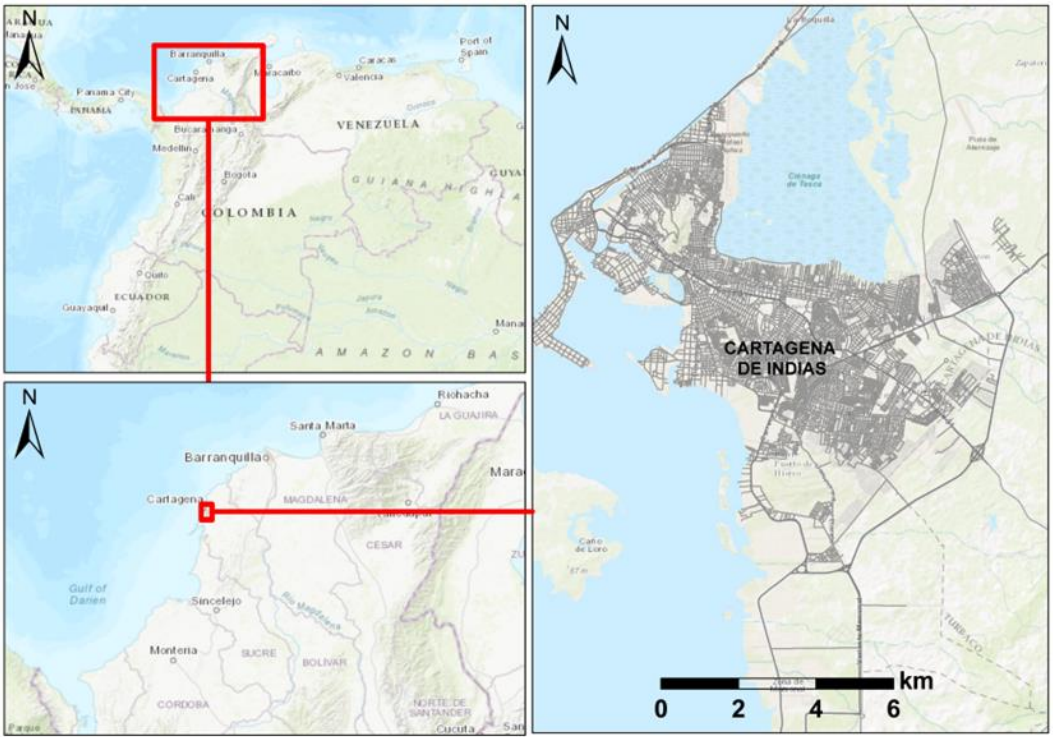

Figure 1. Location of study area

Therefore, in this research, an analysis of the average accessibility of the historic center of Cartagena de Indias is proposed to evaluate the conditions of movement of the resident population in the city according to their socio-economic status. Likewise, considering the tourist dynamics of the city, the evaluation of connectivity is linked to the most important transport hubs in the city, such as Rafael Núñez Airport and the Cartagena Land Transport Terminal, which concentrate a large part of the arrivals and departures of tourists in the city.

2. Research method

As a methodological structure, a total of 6 consecutive steps are used, which are shown in Figure 2 and described below.

2.1. PHASE 1. Gathering baseline information

As a methodological starting point, the information necessary for the structuring of the model is compiled, taking as a base source the existing data from the Cartagena de Indias Land Use Plan, the Mobility Master Plan, Google traffic and the National Administrative Department of Statistics - DANE. The required information for the structuring includes the road infrastructure network, location of Cartagena de Indias historic center, municipal urban limit, population distribution, location of the airport and land transport terminal.

2.2. PHASE 2. Data analysis and optimization

As a second stage, the vehicular infrastructure network is redefined, considering that the base obtained from the mobility master plan does not have the structure of dual carriageways or enough road densification for accessibility modelling. Therefore, new road corridors are linked, existing pedestrian corridors are removed, and road connectivity is optimized, including directionality in one-way road corridors, in addition to the prevailing road typology as defined in the Land Use Plan (Primary et al., local) [20]. The verification and optimization process uses GIS software such as ArcMap and TransCAD through tools such as "*Topolgy*" and "*Check line layer connectivity*".

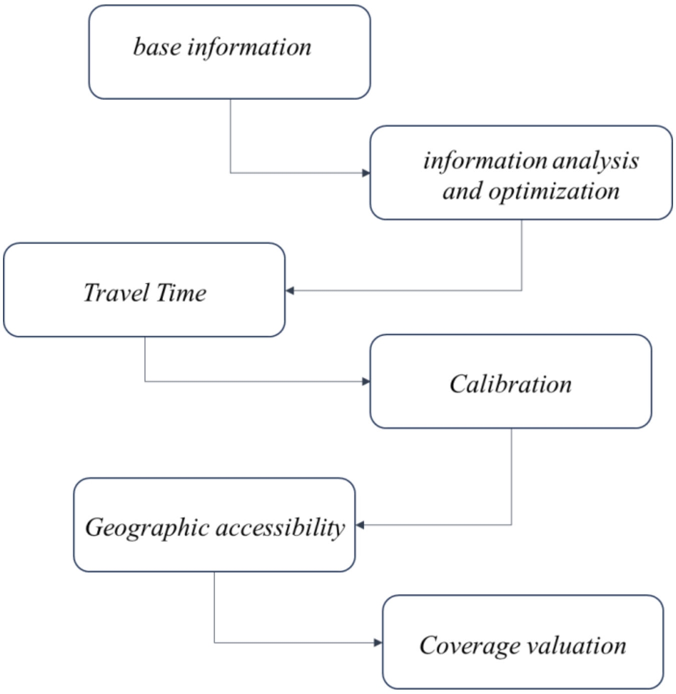

Figure 2. Methodology

Parallel to the structuring of the road network, the existing population distribution in the urban environment of the study area is evaluated, in which the population size of the modelling scenario (2023) is verified, considering the latest housing and population projections established by the National Administrative Department of Statistics - DANE [16]. At this point, the national census data are linked to the residential population polygons, allowing the population to be distributed in each residential sector associated with the model.

Once the road infrastructure and population inputs are optimized, the speed data that will control the modelling are linked, taking as a reference the existing road typology and the values defined by German Arboleda in his book "Vías Urbanas, una ciudad para todos" [21].

Given that the speed assessment is established as design data, the 85th percentile of the value defined as the operational speed of each type of corridor will be used as the starting point for calibration, assuming that the mixed composition of the corridors results in average speeds lower than the maximum design speed of the typology.

2.3. PHASE 3. Travel time

Once the base speed of each segment is linked, the travel times for each road are calculated from Equation 1, linking the length of each section and the assigned speed. This travel time allows for structuring the first accessibility assessment of the model, in which the control points for the calibration process will be interconnected.

$$TV_{arco} = \frac{longitud_{arco}}{velocidad_{arco}} x60(\text{min}) \quad (1)$$

The initial assessment is performed by applying Dijkstra's minimum path algorithm, where each available route within the road network is evaluated, and the one with the lowest cost between the defined origin and destination pair is selected [22], which is executed using the new wardrobes facility extension of ArcMap's Network Analyst extension.

2.4. PHASE 4. Calibration

Once the network is structured, the calibration process begins, in which the parameters are configured to compensate for the valuations obtained from the model about reality. This calibration starts with the identification of the control points, in which a total of 13 random points are distributed in various areas of the city, as shown in Figure 3, followed by estimating the travel times between the 13 points of the city from the existing data in the Google Traffic Network, by running the readings of the Distance Matrix API application, structuring the matrix base of 169 times, which serve as a reference for the model. The data collection is defined in a daytime condition in the time slot from 12:00 to 14:00, one of the most essential traffic peaks in the city.

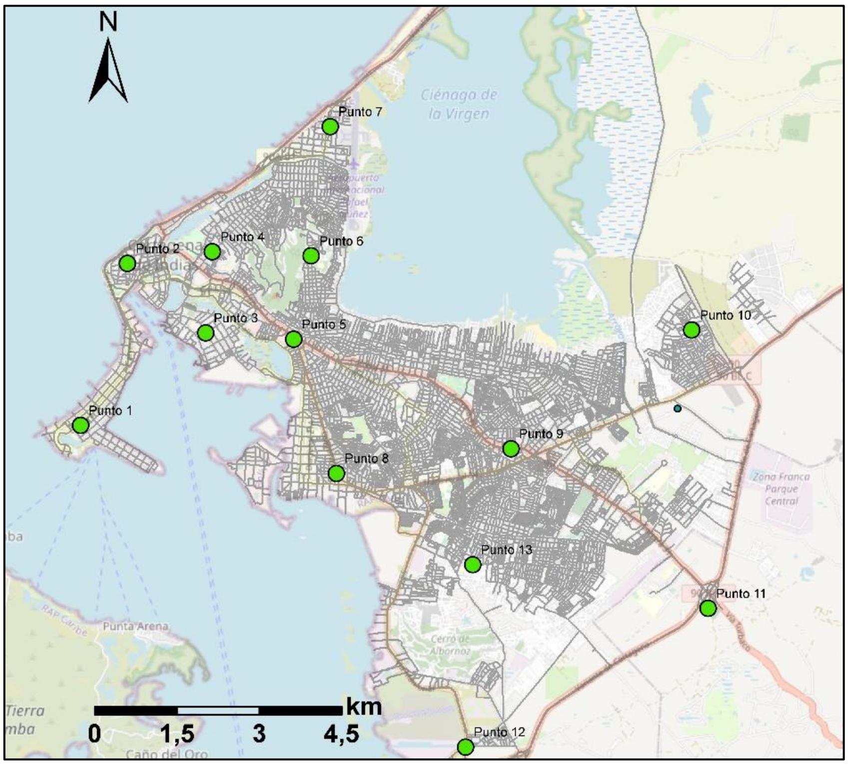

Figure 3. Modelling checkpoints

After obtaining the Google travel times, the cost of travel between the points in the defined network is estimated, initiating an iterative process in which the Google ratings (considered as actual behavior) are compared with the travel times of the model (*Tv Google=Tvmodel*), figure 4. This comparison seeks to equalize the travel times obtained, modifying the speeds and penalties per turn until a regression adjustment with slope one and intercept of 0 is achieved. However, considering the variations existing in each road arch immersed in the iteration process, a tolerance of up to 10% is allowed in the calibration variations, in order to establish a convergence interval.

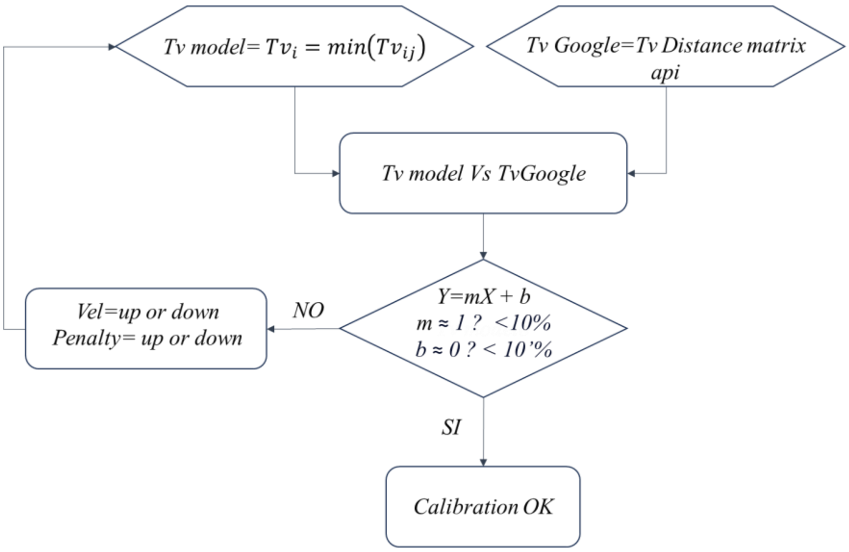

Figure 4. Iterative process

Within the process, 23 iterations are carried out until the best possible adjustment is achieved, resulting in a final speed rating between 12 km/h and 74 km/h. Similarly, the best adjustment is achieved with values per turn penalty of 3.8 seconds in the straight direction, 20 seconds for a right turn and 22 seconds for a left turn. Figure 5 shows the regression behavior, in which a slope of 1.0096 and an intercept of 0.57 minutes is achieved.

It must be considered that although the regression behavior shows an intercept value higher than 0, it is an acceptable time given that the maximum time obtained in the network is 53 minutes, thus representing 1% of the longest time and 10.1% in the minimum range of 5 minutes. These values show a significant stability that allows completing the calibration.

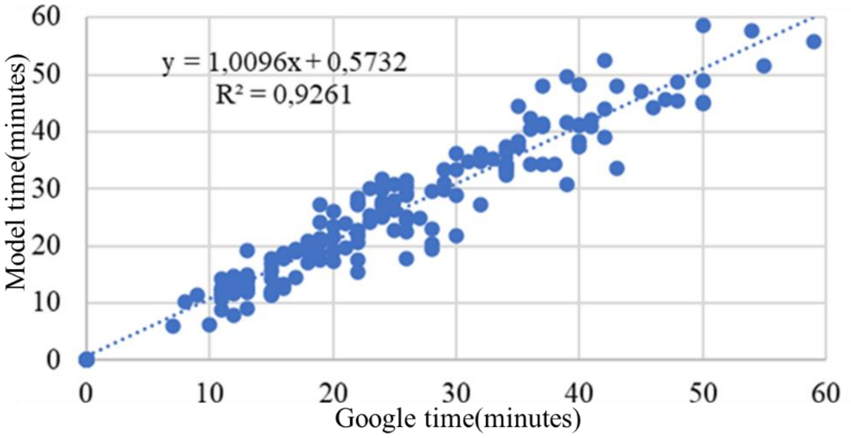

Figure 5. Achieved set values

2.5. PHASE 5. Geographical accessibility

Once the model calibration is completed, the access points to Cartagena de Indias historic center are defined, allowing the travel time to the sector to be estimated from the different points of the city. This assessment defines the vector of travel times, plotted using the ArcMap Geostatical Wizard extension, applying the ordinary Kriging interpolation method as a spatial measure of connection. Finally, the time range is defined at 5-minute intervals, and the points of interest (Land Transport Terminal and Rafael Núñez Airport) are located for the respective analysis.

2.6. PHASE 6. Coverage assessment

In phase 6, the assessment of population coverage and area for the study area is carried out, in which the sociodemographic data of the city is linked to the accessibility curves resulting from the model. This process considers the intersection of the graphic layers through the Geoprocessing intersect tool, associating a time value to each incorporated population polygon. When the intersection is performed, the initial assessment of population and area can be altered due to the subdivision of the areas. Therefore, the corresponding correction must be made to minimize the error. Equation 2 shows the correction structure applied, where the final area of the population layer corresponds to a portion of the initial part, resulting in a percentage that compensates for the increased population value, assuming that the population is distributed equally over the area defined in each residential area.

$$Pop_{fin} = \frac{Area_{fin}}{Area_{in}} \; x \; Pop_{in} \tag{2}$$

Finally, the accumulated coverage graphs are constructed according to the socio-economic stratification available in the city, where the population with greater ease of access to the historic center and the population with fewer possibilities are identified. It is essential to remember that *socio-economic stratification* is defined for Colombia as a classification of residential properties that receive public services into groups. It is mainly carried out to charge for residential and public services differentially, allowing subsidies to be assigned and contributions to be collected in this area [23]. This classification was established in 1994, based on the subdivision into six groups where stratum 1 corresponds to the population with the most minor facilities and stratum 6 to the population with the best conditions [24].

3. Results and discussion

As a result of assessing accessibility to Cartagena de Indias' historic center, Figure 6 shows the behavior in terms of travel time at 5-minute intervals. The location of the historic center allows for a rapid displacement for the North and West zones, with a maximum time of up to 15 minutes. However, given its structure and coastal condition, up to 53 minutes are presented on the eastern and southern sides. In this sense, two different conditions are identified for the transport points, in which the Rafael Nuñez airport has a much shorter travel time than the land transport terminal (15 minutes); however, it should be borne in mind that the current location of the land transport terminal (45 minutes) avoids the circulation of large vehicles inside the city, which helps to reduce congestion and therefore to maintain more favorable travel times, and also, being in an external sector, allows the exit of vehicles from the city with greater ease and connection to the national road network. On the other hand, on the upper margin of the airport, it is possible to appreciate a confronted behavior of accessibility, where the left side has a travel time of less than 15 minutes, while the right side requires up to 50 minutes to travel to the historic center; this behavior is due to the low connectivity between the avenues, where users of the left side must make longer trips to return on the corridor that leads to the historic center. Therefore, a greater interconnection between the roads should be generated to improve the displacement.

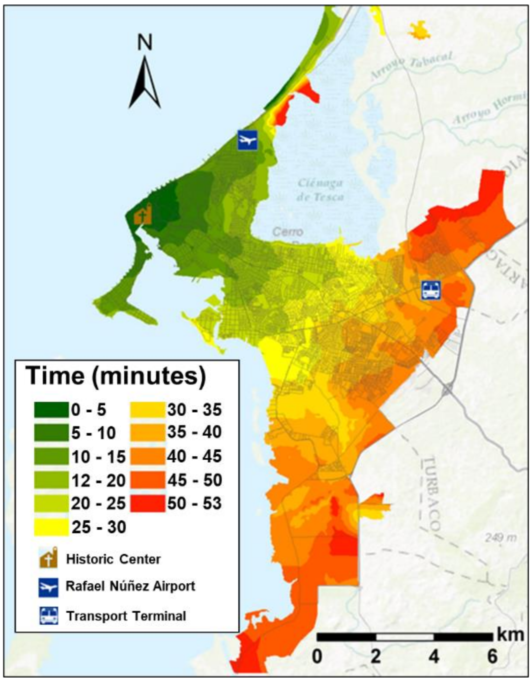

Figure 6. Medium comprehensive accessibility to Cartagena's historic center

Regarding population coverage, in Figure 7 (left), it is possible to see that the population distribution is similar to the area covered up to 20 minutes, thus indicating a population density proportional to the inhabited area. However, after 20 minutes, there is an increase in population coverage, which translates into a process of densification of the city, in which users reside closer to the historic center. In terms of socio-economic evaluation, figure 7 (right), it is possible to appreciate how strata 5 and 6 have the best coverage, requiring a time of 15 minutes to supply more than 70% of their population, which translates into a tendency of people with greater purchasing power to reside near the historic center. However, the population with less purchasing power (1, 2 and 3) reside in peripheral environments, with time evaluations of up to 30 minutes to supply around 50% of their population. On the other hand, stratum 4, being a slightly intermediate valuation, has some concentrations near the historic center. However, after 20 minutes, it is distributed throughout the other sectors of the city, assuming a similar behavior to the lower strata. It can be translated into a transition population, which seeks a better benefit, but its capacities still need to allow it to occupy sectors closer to the historic center.

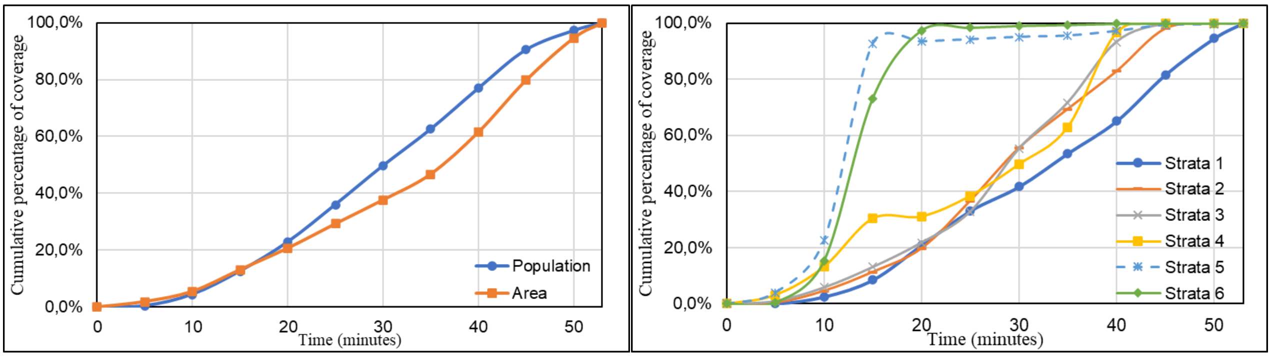

Figure 7. Percentage coverage warheads to Cartagena's historic center

As a final discussion, the table 1 presents a comparison of the results obtained in the city of Cartagena versus the city of Manizales [15], in which it can be seen that, despite higher travel costs to the historic center of the city of Cartagena, as well as a greater travel time requirement to cover at least 50% of the population, the total number of citizens is almost 2 times the population of the city of Manizales, which shows that, in terms of population, Cartagena has better accessibility to the historic center of the city, the total number of citizens is almost twice the existing population of the city of Manizales, which shows that, in terms of population, Cartagena has better accessibility to the historic center, thus giving greater prominence to its heritage assets and envisioning better connectivity as a preservation measure.

Table 1. Cartagena and Manizales comparison

Item	Cartagena	Colombia	Description
Max Travel Time	53 (min)	51 (min)	The cost of travel in the urban areas of each city are in similar magnitudes, with a maximum cost for Cartagena. for Cartagena
Travel time for 50 % Population	30 (min)	21 (min)	Increased time cost for the population of Cartagena
Population (2023)	924,867	458,432	Greater population in Cartagena

4. Conclusions

Based on the evaluation, it is possible to conclude that the location of the historic center of Cartagena limits the city's accessibility, considering that its coastal condition obliges the expansion of the eastern sector, increasing the travelling time of users in the coming years. However, this also facilitates the preservation processes, as it does not require significant affectations in the surrounding areas.

On the other hand, although the condition by strata shows a variable behavior, in general, 50% of the population manages to access in a travel time of less than 30 minutes, which shows great robustness with respect to the accessibility condition, however, mechanisms should be found to improve this condition.

Regarding the current population layout, it can be concluded that the population of higher strata tends to live near the historic center due to the ease of commuting to the area, which is different from other cities, where the population of higher strata tends to live in more peripheral environments.

Finally, it is possible to state that accessibility assessments facilitate the evaluation of urban environments, giving a graphic interpretation of the existing conditions in an environment, thus making it easier to make decisions by locating potentialities or shortcomings in the infrastructure.

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Author contributions

Conceptualization, J.A.M. and D.A.E.; methodology, J.A.M., D.A.E. and C.A.M.; software, J.A.M. and C.A.M.; validation, D.A.E. and C.A.M.; formal analysis, J.A.M. and C.A.M.; investigation, D.A.E. and J.A.M.; data curation, J.A.M.; writing - original draft preparation, J.A.M.; writing - review and editing, D.A.E. and C.A.M.; visualization, J.A.M. and D.A.E.; supervision, C.A.M.; project administration, D.A.E. All authors have read and agreed to the published version of the manuscript

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