Plan of Intervention in the Transport Infrastructure Network as a Measure of Heritage Conservation. Case Study: La Camelia Ropeway Station and Tower of Herveo-Manizales, Colombia

Diego A. Escobar and Jorge A. Montoya

Universidad Nacional de Colombia – Sede Manizales
Facultad de Ingeniería y Arquitectura
Departamento de Ingeniería Civil
Cra 27 # 64-60, Manizales, 170004, Colombia

Jorge A. Galindo

Universidad Nacional de Colombia – Sede Manizales
Facultad de Ingeniería y Arquitectura
Escuela de Arquitectura y Urbanismo
Cra 27 # 64-60, Manizales, 170004, Colombia

Abstract

Cultural development and heritage conservation currently present difficulties in their preservation models, given, in large extent, to the high impact of mobility in the surroundings of historical structures. This research develops an urban territorial accessibility analysis aiming to protect it physically and improve the relationship between the community and the heritage of cultural goods («BIC»), specifically, the La Camelia Ropeway Station and Tower of Herveo in the city of Manizales, through the evaluation of the surrounding road infrastructure from socio-economic variables and its intervention proposal.
1. Introduction

Current city development and planning is supported by the implementation of sustainability strategies that promote the proper articulation of variables as (a) urban structure, (b) land uses, and (c) mobility patterns. This requires a detailed analysis of the relationship between transport management policies and spatial distribution of activities [18]. In Colombia, cultural heritage includes material goods of movable and immovable nature which are attributed, among others, special historical interest (...) in areas such as (...) architectural and urban [8], which, depending on their current status and use, generate and attract residential visitors and tourists. This has a toll not only on mobility patterns of a city or region, but also on the likelihood of a greater or lesser tendency to deteriorate the heritage of cultural goods (BIC, acronym in Spanish). Manizales is the capital of the Caldas department, located at 5°3’58” northern latitude and 75°29’05” western longitude, on one side of the central mountain range of Colombia, about 2,150 MASL [2] (Figure 1). The municipality extends along 572 km² [15], of which approximately 6.14% (35.11 km²) correspond to urban areas with about 371,345 inhabitants [10]. City development has taken place adapting to the city’s topographic characteristics, despite the visible limitations in the expansion and urbanization processes [26]. There have been peripheral processes of informal development on steep slopes [7].

Figure 1. Geographical location of Manizales. Source: Authors.
In terms of mobility, there is a high percentage of daily trips that are made in sustainable modes of transport (71%), while the percentage recorded in private means reaches 29% [20]. However, the proportion of trips in sustainable transport is trending downward, with no evidence of large investments seeking to boost it. Transport infrastructure network in the city has a length of 749 km [12] and has been intervened periodically in order to solve the community’s mobility needs. In spite of this, high traffic congestion persists during rush hours related to access to specific sectors of the city, generating mobility issues in the nearby roads. This hinders citizen interaction with the different movable and immovable goods, and turns the vehicle into one of the main causes of urban deterioration in these sectors. In Manizales, from the 1,101 BIC [22], 9 are located in the Central Business District (Figure 2), the BICs from Manizales selected for this research are La Camelia Ropeway Station and the Tower of Herveo (Figure 3). It is proposed to conserve them with different intervention measures, some of them related to the management and control of motorized traffic [30]. They were part of a 73 km long Ropeway system between the cities of Mariquita and Manizales, built between the years 1913 and 1922 and which operated until 1967. Both of them were declared national heritage in August 1996 [23].

Control and management measures proposed in the sector are carried out based on a detailed study of the existing infrastructures, clearly identifying the need for interventions aimed at improving access conditions for the different modes of transport —self-employed (pedestrians and bicycles) and private—, and bearing in mind that the ability to attract and generate travel is quite high, generating congestion and mobility problems in nearby roads.

![Figure 2. BICs in Manizales. Source: Authors from [30].](image-url)
This is directly related to accessibility characteristics that the transport infrastructure network offers to specific sectors of the city, such as the one studied here, understanding that the term «accessibility» is closely related to land use development [17]: if a city has an adequate distribution of land uses and activities, it will lead to a recurrence of travel patterns in certain sectors [11], a situation that varies depending on the distances to be traveled and the modes of transport used. Hansen [17] provides what is considered the first technical definition of the concept «accessibility»: “The potential of opportunities for interaction”. The concept has been addressed as such since the second decade of the 20th century [3]. Currently, the concept has various approaches, including: (i) infrastructure, (ii) location; (iii) land uses; and (iv) a mixture of these [4, 19]. There are examples of the application of such approaches in various fields of science: access to opportunities or services [33, 6], social exclusion [4 28], transportation planning [25, 13, 14] sustainability [31, 11], among others. Based on the existing literature, the term is defined as «the ease with which the members of a population can access, through different modes of transport, the different opportunities or services offered in the city, subject to the physical limitations present in the system». Accessibility includes citizen interaction and its environment; however, the different components or actors involved must be differentiated (origin, destination and journey). According to Monzón de Cáceres [25], «origin» can be understood as the representation of potential users of the transport network, motivated by a «destination» attractive enough to overcome the difficulty of the «journey» that separates them. Thus, it is possible to establish accessibility as a measurement tool to determine different factors affecting a territory such as mobility, transportation, land use, affordability, etc. [28 32]. Detecting the need to improve territorial accessibility conditions to the sector where BICs are located, and understanding that all aforementioned approaches are supported in diverse mathematical and statistically valid methodologies, an analysis is proposed to determine the impact over land use that
would be generated given the modification or insertion of the transport infrastructure network. The analysis of accessibility is focused on the conservation of heritage and the inclusion of citizenship [29, 16, 21], through the evaluation of the current road network under socioeconomic parameters, followed by the analysis of the future scenario linking infrastructural interventions, management and control of flows. Henceforth, the research methodology, results obtained and their discussion are registered, followed by conclusions.

2. Methodology

The methodology addressed in this study consists of five main phases of a consecutive nature as shown in Figure 4 and described below.

![Figure 4. Research methodology. Source: Authors.](image)

2.1 Adjustment and updating of the transport infrastructure network

In stage 1, adjustments and updates are made to Manizales’s transport infrastructure network, using the Mobility Plan framework as a starting point [12]. It is composed of a total of 8,580 nodes (points or road intersections) and 11,374 arcs (links or track segments) located geospatially, in addition to the physical and operational characteristics of the network (speed, length, directionality, typology, topology, etc.). A review of municipal administration files dating from 2011 to 2017 is performed, in order to update the infrastructural interventions of the transport network, considering new infrastructures, road redirections, road closures, among others. Then, modifications are loaded into the transport infrastructure network using the «ArcMap» tool, in which nodes and arcs necessary for the correct functioning of the geostatistical calculations are eliminated and/or reconstructed.
2.2 Georeferencing of study points

Once the vehicular network is intervened, nodes of interest for the research are located (Figure 5). Node location considers the formation of the BIC’s delimitation polygon (Tower of Herveo and La Camelia Ropeway Station).

![Figure 5. Study points localization. Source: Authors.](image)

2.3 Determination of the BIC’s development timeline and diagnosis of current mobility

Through bibliographic and historical research, the BIC’s development timeline was determined, since its construction to the present time. Data on vehicular and pedestrian volumes were taken from roads surrounding the BIC, in order to diagnose the convergence of this type of flows in the transport infrastructure network. As a research complement, the number of people who arrived directly at the BIC was surveyed, discretizing the reason why they arrived at that site and mode of transport used.

2.4 Urban territorial accessibility estimation

This estimation opts for the construction of isochronous curves using «ArcMap». They allow observing travel times towards study points from any place in the network. The construction of these curves focuses on the formulation of the travel time vector (TV), which uses the calculation of transit cost over each arc, expression (1), from an origin-destination pair, by loading operational and physical characteristics of their arcs.

\[ T_{v_i} = \frac{L_i}{v_i} \quad i = 1,2,3, \ldots, n \]  

(1)
The mathematical mechanics behind the construction of the travel time vector is based on the Dijkstra algorithm or minimum path algorithm, which considers the cost of transiting over a system of arcs, therefore determines the shortest path between nodes. This basic tool is included in the «Network Analyst» of «ArcMap». The algorithm structure determines the shortest path between a vertex of origin ($O$) and a final node ($F$) if there is a connection between them. A $d_{ij}$ value is associated to each arc $a_{ij}$, which will be infinite if there is no connection between $i$ and $j$ vertices. Then, the set of vertices connected in the current iteration is called $S$ and it is added to the origin vertex $O$. Next, $P$ labels are designated: $P_0 = 0$, and $P_i = \infty$. If $i$ is different from the origin, $t_i = O$ variable will be added. Then the last vertex incorporated to the $S$ set is designated ($y$). For every $z$ vertex not incorporated to $S$, an estimation must be made: $P_z = \min\{P_x, P_y + d_{yz}\}$ if $P_y + d_{yz} < P_z$ it becomes $t_z = y$, and then $z*$ is determined from all $z$ vertices that fulfill $P_{z*} = \min\{P_z\}$, If $P_z = \infty$ the search is completed and it is understood that there is no finite length path between the $\bar{F}$ and $\bar{F}$ set vertices. However, if a connection exists, the procedure is continued and $z*$ is incorporated into the $S$ set, where $P_{z*}$ will be the value of the minimum distance between $z$ and $O$. Finally, if $F = z*$, the iteration process is completed; otherwise the process is repeated [27]. After obtaining travel time vectors, a minimum travel time matrix which implements geospatial coordinates for each node, relating them to each estimate of travel time obtained previously, is built. Finally, the graphic construction of accessibility curves is made by means of the ordinary Kriging method with linear semivariogram, as a projection model. This method of interpolation determines the properties of spatial dependence between points within a sample by means of the expression (2), where $Z_{(x)} = $ value of the variable at a point with coordinates $x$, $y$; $Z_{(x+h)} = $ next sample value separated by a distance $h$; $n = $ number of couples that are separated by $h$ distance.

$$\gamma(h) = \frac{\sum(Z_{(x+h)}-Z_{(x)})^2}{2n}$$  \hspace{1cm} (2)

2.5 Coverage analysis

As a final methodological step, socioeconomic variables are considered: socioeconomic strata, population, and variable area. Socioeconomic strata are defined as an approximation to hierarchical socioeconomic differences [9], i.e., the differentiation through scales of citizens’ economic capacity. In Manizales, there is a 6-level differentiation, where number 6 represents the population with the highest income level, and number 1, the most vulnerable. These variables were related to travel time curves using ArcMap’s «Intersect» tool, to later build the graphs of cumulative percentage of coverage and determine the level of impact.
3. Results and Discussion

3.1 BIC’s development timeline
As previously mentioned, La Camelia Station and Tower of Herveo [23] are part of the Ropeway system between Mariquita and Manizales, built after 1913 under the address of the New Zealand engineer James Ferguson Lindsay. Along with eight English technicians and a Spaniard, he employed 376 iron towers as a fundamental part of the system. Their heights varied between 4.00 m and 66.0 m. One of them was called Tower of Herveo, and was later transferred to Manizales in 1984. In 1915, the first section between Mariquita and Fresno (17 Km) was put into service; in 1922, it reached Manizales, using 9 steam engines of 40 HP effective in each one. By then, it managed a maximum capacity of 20 tons through a route that lasted between 10 and 12 hours. Along its route, the system came to have 22 stations, including the two terminals: Mariquita Station, in its namesake town, and La Camelia station, in Manizales. The concession of private Ropeway system expired early, so it spent its last operational years in the hands of Ferrocarriles Nacionales until 1962. Its operation was intermittent, and all stations experienced remarkable decay, until finally entering disuse. At present, its stations have practically disappeared. By 1969, only La Camelia Station and its surrounding urban areas became part of the National University of Colombia, hosting the newly created School of Architecture. Several intervention processes were carried out between 1999 and 2002, in order to adapt its old facilities to academic uses. In 2005, the computer building was constructed, complementary to the national monument. In 2016, the seismic structural vulnerability of the building was studied, finding the latent need to carry out a structural reinforcement of the roof. Finally, in 2017, the structural reinforcement of the roof was carried out, as well as the drafting of the Special Management and Protection Plan (PEMP, acronym in Spanish) of BICs [30].

3.2 Mobility diagnosis in the BIC sector and urban territorial accessibility in the current scenario
Within mobility analysis in the BIC sector, it was possible to determine different characteristics and components related to pedestrian mobility and motorized users. Main results are listed below: i) The study sector has a total of 2,685 linear meters of sidewalks, of which 89% (2,395 m) provide continuity in travel, while 11% (289 m) provide discontinuous mobility not adapted for people with disabilities. There is a tactile band to help people with visual limitations in only 6.6% of the existing sidewalks length. There are pedestrian fords in only 33 points, while the need for them has been identified in a total of 58 points; ii) The most neuralgic point in the BIC sector was identified considering motor vehicles and pedestrian flow confluence: the intersection of 65th Street and Santander Avenue. During rush hour, a total of 3,699 vehicles were registered (64% cars, 26% motorcycles, 7% public transport, and 3% bicycles), converging with a pedestrian flow of 2,294 people (31),
of which 36% crossed the intersection in prohibited sites. A greater pedestrian recurrence was identified in late afternoon and evening hours than in daytime hours;

iii) Incoming and departing vehicular data was also provided in the area of interest. Eight perimetal counting stations were defined, identifying peak times on Thursdays between 17:30 and 18:30, registering 8,365 Direct Equivalent Automobiles (DEA or ADES, Equivalent direct vehicles): 4,043 incoming DEA, and 4,322 departing DEA (Figure 6); iv) Regarding people access to the property of La Camelia Station, the highest pedestrian volume was found on Thursdays between 5:30 p.m. and 6:30 p.m. totaling 280 users. The reason for attendance was distributed as follows: 73% for study purposes, 12% for work and 15% for other uses. The parking for motor vehicles located in the building allows the location of 30 cars and 36 motorcycles. Approximately 18% of its users do not access the rest of the infrastructure.

Figure 6. Incoming and departing vehicular flow in the BIC’s direct zone of influence. Source: Authors.

Figure 7 shows the results of the evaluation of urban territorial accessibility towards the BIC. Isochronous curves offered by the transport infrastructure network in the current scenario take place in 2.5-minute intervals. A large part of the city is limited by travel times of less than 45 minutes, focused on the main road network in Santander, Parallel and Kevin Angel avenues. This may be due to an easier access to the BIC when moving on these road corridors, considering higher travel speeds, and that its trajectory must rarely be modified. Maximum mean travel time interval occurs between 80 and 82.5 minutes in the peripheries of the city.
Figure 7. Urban territories accessibility curves in current scenario. Source: Authors.

Figure 8a shows curves of accumulated coverage by socioeconomic stratum. Strata 5 and 6 are identified as those with better coverage given their average travel times, the configuration of the transport infrastructure network, and their location in regards to the BIC. Their coverage reaches percentages greater than 70% in travel times lower than 20 minutes. Meanwhile, for strata 1, 2 and 3, 35 minute travel times must be employed to achieve population coverage.

Figure 8b shows population coverage and area variables.

Figure 8. Accumulated coverage percentage in current scenario according to: a) socioeconomic strata, and b) population and area. Source: Authors.

Therefore, current accessibility to BIC is more favorable for the upper strata than for the lower strata. Figure 8b shows population coverage and area variables.
Plan of intervention in the transport infrastructure network

Considering 50% population coverage, 30 minutes must be used for travel; while considering 50% of the area, 37 minutes of average travel time should be invested. Curve separation is due to high density within the city, allowing better population coverage. As this research considers average speeds of all transport systems, an understanding of travel costs is provided in regards to BIC visitors. Observing different mean travel times across different cities in the world exceeding 50-minutes (32, 33), it may be established that a 45-minute travel time towards the BIC is acceptable considering an 80% population coverage.

3.3 BIC sector proposed interventions
Considering these results, 3 specific interventions are proposed to the transport infrastructure network (Figure 9), aiming to facilitate citizen connection with the BIC sector, besides guaranteeing heritage preservation: a) Pompeian Pass: construction of a Pompeian-type semi-pedestrian corridor, which would comprise a total area of 4,890 m² between Santander Avenue and Carrera 23b, Juan Antonio Toro Avenue and 64th Street, complemented by 32 signaling units and 264 m² of horizontal demarcation. The approximate cost of this proposal is USD 0.5 million; b) Vehicular tunnel: construction of a vehicular tunnel that would significantly reduce the need for vehicles to cross over the BIC sector. It aims to divert vehicular flows from Lindsay Avenue to Santander Avenue and Juan Antonio Toro Avenue. The total length of the tunnel is projected at 330 linear meters and its approximate cost is USD 9 million; c) Road redirection: modification of Lindsay Avenue in order to direct vehicular flows to the tunnel, in addition to increasing vehicular capacity of the infrastructures that would support flows coming from the Parallel Avenue. Its approximate cost is USD 0.2 million.

Figure 9. Proposed interventions. Source: Authors.
3.4 Urban territories accessibility impact given proposed interventions

Taking into account the proposed infrastructural interventions, and through the urban territorial accessibility methodology, when comparing current and future scenarios, it is possible to determine the impact of said interventions in the city. As a result of the geostatistical analysis of the percentage gradient values of change in average travel times, the estimation in Figure 10 was possible. There, average percentage of travel time saving curves behavior is observed every 2.5 minutes. The north-western zone of the city, sector of Villa Pilar and La Linda (upper left region of the image), has higher saving percentages in average time of travel, with values reaching 24%. BIC surroundings refer savings in average travel time between 6% and 15%.

Figure 11 shows the behavior of savings in average travel time of the population according to socioeconomic status. The greatest savings are identified in strata 5 and 6 (high) with saving percentages greater than 8% covering 50% of these populations, which is aided by its proximity to the BIC. For their part, 50% of the strata 2, 3 and 4 population refer average travel time savings between 3% and 6%. Lastly, stratum 1 has the lowest coverage values, with average travel time savings of less than 2% for 50% of their population.

Figure 10. Percentage savings curves. Source: Authors.
4. Conclusions

Currently, this sector is ready for vehicular mobility, although it has evolved as an intensive trade and services center, which demands a redesign of its space to meet the needs of these new types of activities, e.g., consumption (restaurants, discotheques), education (University campus), commerce and business (Cable Plaza Shopping Center). A conflict between land uses and the prioritization of existing mobility is evident. There is a latent need to intervene in the BIC sector in order to protect it from the negative impact that high vehicular volume crossing in all directions gradually generates. Vehicular flow diagnosis in the BIC’s direct influence area has a rush hour between 17:30 and 18:30, with a similar amount of incoming and departing vehicles. Ergo, this sector is in fact a high transit area. The BIC’s key point refers an important convergence of vehicles (3,699) and pedestrians (2,294); therefore, it is a site that needs an intervention in relation to traffic management and control in order to minimize odds of accident occurrence. In relation to urban territorial accessibility to the BIC analysis, its access level can be considered good, noting that the population and area coverage in 40-minute travel times is 80% and 70%, respectively, which contrasts to different average travel times in other cities of the world (32, 33), as they exceed 50 minutes. The total cost of the proposed infrastructural interventions, which include major modifications and improvements to the control and management of mobility, seeking to drastically reduce the possibility of vehicular flows going to the surface and converging with pedestrians, is approximately USD 9.7 million. The assessment of road intervention considering transport demand is recommended for future research, seeking to complement these results.

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Diego A. Escobar et al.

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