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GIS-Based Spatial Analysis of Tourist Pressure in Ouro Preto, Brazil: Implications for Sustainable Heritage Tourism Management

Análise espacial baseada em SIG da pressão turística em Ouro Preto, Brasil: implicações para a gestão sustentável do turismo patrimonial

Análisis espacial basado en SIG de la presión turística en Ouro Preto, Brasil: implicaciones para la gestión sostenible del turismo patrimonial

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Abstract

This study analyzes tourist pressure in Ouro Preto, Brazil, using a spatial analysis approach based on geographic information systems. To achieve this, geolocated visitor records, heritage mapping, road network and field observation were integrated, which made it possible to identify concentration patterns, circulation corridors and critical areas within the historic center. Results indicate that tourist pressure is especially concentrated along the axis Praça Tiradentes–Museu da Inconfidência–Rua Conde de Bobadela–Largo de Coimbra, characterized by intervals of high presence, enduring spatial clusters, and increased loads in pedestrian traffic corridors. In this case, the study explains that heritage tourism sustainability is less a matter of overall visitor numbers, and more about visitor distribution in relation to sensitive heritage sites. Thus, the study reaffirms the effectiveness of geographic information systems in decision-making for planning, conservation, and tourism management.

Keywords: Tourism; Cultural heritage; Geographic information system; Historic city; Urban planning.

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Resumo

Este estudo analisa a pressão turística em Ouro Preto, Brasil, utilizando uma abordagem de análise espacial baseada em sistemas de informação geográfica. Para isso, foram integrados registros de visitantes geolocalizados, mapeamento do patrimônio, rede viária e observação de campo, o que possibilitou identificar padrões de concentração, corredores de circulação e áreas críticas dentro do centro histórico. Os resultados indicam que a pressão turística está especialmente concentrada ao longo do eixo Praça Tiradentes–Museu da Inconfidência–Rua Conde de Bobadela–Largo de Coimbra, caracterizado por intervalos de alta presença, aglomerados espaciais duradouros e aumento do fluxo de pedestres. Nesse caso, o estudo explica que a sustentabilidade do turismo patrimonial está menos relacionada ao número total de visitantes e mais à distribuição dos visitantes em relação a sítios patrimoniais sensíveis. Assim, o estudo reafirma a eficácia dos sistemas de informação geográfica na tomada de decisões para planejamento, conservação e gestão do turismo.

Palavras-chave: Turismo; Patrimônio cultural; Sistema de informação geográfica; Cidade histórica; Planejamento urbano.

Resumen

Este estudio analiza la presión turística en Ouro Preto, Brasil, mediante un enfoque de análisis espacial basado en sistemas de información geográfica. Para ello, se integraron registros geolocalizados de visitantes, mapeo del patrimonio, red vial y observación de campo, lo que permitió identificar patrones de concentración, corredores de circulación y áreas críticas dentro del centro histórico. Los resultados indican que la presión turística se concentra especialmente a lo largo del eje Praça Tiradentes–Museu da Inconfidência–Rua Conde de Bobadela–Largo de Coimbra, caracterizado por intervalos de alta presencia, agrupaciones espaciales persistentes y mayor carga en los corredores de tráfico peatonal. En este caso, el estudio explica que la sostenibilidad del turismo patrimonial no se trata tanto del número total de visitantes, sino más bien de su distribución en relación con los sitios patrimoniales sensibles. Por lo tanto, el estudio reafirma la eficacia de los sistemas de información geográfica en la toma de decisiones para la planificación, la conservación y la gestión turística.

Palabras clave: Turismo; Patrimonio cultural; Sistema de información geográfica; Ciudad histórica; Planificación urbana.

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1 INTRODUCTION

Heritage tourism has become established as one of the most complex expressions of contemporary tourism, not only because of its ability to boost local economies and strengthen the international visibility of certain territories, but also because of the challenges it poses in terms of conservation, mobility, use of urban space and coexistence between tourist and residential functions (De Luca et al., 2020).

In historical destinations, tourism activity is not distributed evenly; on the contrary, it tends to concentrate in corridors, hubs, and enclaves of high symbolic appeal, generating varying intensities of use that reshape the visitor experience, urban functionality, and the conditions for heritage preservation. In this context, the sustainability of heritage tourism cannot be understood solely as a regulatory aspiration, but rather as an operational problem of territorial management that requires a more precise understanding of how, where, and with what intensity tourism activity manifests itself in the space (Koens et al., 2018).

Recent literature has insisted that tourist destinations should be analyzed as true spaces of flows, where the trajectories, decisions and displacements of visitors produce dynamic spatial configurations, with concrete effects on the organization and evolution of tourist places (Beritelli et al., 2020).

This perspective is especially relevant in historic centers, where the concentration of visitors in small areas can lead to congestion, a diminished visitor experience, tensions with residents' daily lives, and increased demands for monitoring and maintenance (Falk & Hagsten, 2021). Therefore, understanding visitor flows is not a secondary issue, but rather a central condition for planning, designing routes, regulating tourism, and making decisions geared towards sustainability.

In parallel, the development of Geographic Information Systems (GIS) and geotechnology has notably expanded the analytical possibilities for the tourism study. From an applied perspective, GIS allows you to integrate spatial and non-spatial data, represent territorial distributions, identify concentration patterns, model accessibility, estimate usage capabilities and support planning decisions on an empirical basis (Gössling, 2017).

In the field of heritage, its value is particularly significant, as sustainable management depends, to a large extent, on the availability of precise information about the location of their assets, their immediate surroundings and the intensity of the uses that affect them (Ciski et al., 2019). In terms of tourism, in addition, several studies have shown that geospatial tools can contribute to reconstructing visitor trajectories, delimiting areas of interest, monitoring saturation situations and designing management responses in complex historical environments (Zubiaga et al., 2019; Domènech et al., 2020; Viñals et al., 2024).

However, although the methodological advance is evident, the translation of these technical capabilities into concrete tourism management instruments continues to be uneven. Part of recent research has focused on the optimization of routes, the identification of points of interest or the monitoring of specific streets and corridors, while the other part has focused on the use of geolocated digital hues to recognize areas of tourist attraction and patterns of spatial behavior (Domènech et al., 2020; Nolasco et al., 2022; Capocchi et al., 2019).

These contributions have enriched the analysis of urban and heritage tourism, but can also see an important limitation: often, the spatial treatment of the tourist visit is approached as a technical or descriptive exercise, without sufficiently advancing its articulation with sustainable management decisions of the destination. In other words, a gap still remains between the analytical potential of GIS

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and its use as systematic support for managing heritage destinations subjected to intensive, concentrated and temporally variable uses (Gössling, 2021).

Ouro Preto represents a highly relevant case study within this framework. As a World Heritage Site, and former epicenter of Brazil's golden cycle, this city, recognized by UNESCO (2021), holds a remarkable urban and architectural complex of immense historical, artistic, and symbolic importance. Its irregular layout, adjusted to a rugged topography, along with the permanence of churches, bridges, fountains, civic buildings and residences that maintain the physiognomy of the XVIII and XIX, defends both its heritage singularity and its vulnerability to intensive uses of space.

UNESCO (2021) itself highlights that “Ouro Preto's value lies, to a large extent, in the preservation of its urban form, materials, and historical landscape, which together form a homogeneous whole of remarkable integrity” (P. 1). Precisely for this reason, tourism management in this destination cannot be limited to counting visitors or promoting attractions; it requires understanding how visitor flows are distributed, which areas experience the highest levels of use, and what the territorial implications of this concentration are for heritage conservation and the sustainability of the destination.

Based on these considerations, this study begins with the premise that tourism pressure on heritage destinations should not be understood solely as a matter of aggregate visitor volume, but rather as a spatially differentiated relationship between flows, concentration, accessibility, carrying capacity, and heritage sensitivity (Ruiz et al., 2023).

From this perspective, GIS-based spatial analysis offers a robust methodological approach for identifying territorial patterns of tourism use that often remain hidden in aggregate statistics. Furthermore, it allows us to move from a general interpretation of tourism growth to a nuanced understanding of its territorial manifestations, an essential condition for implementing sustainable practices (Kalvet et al., 2020).

Accordingly, the objective of this article is to spatially analyze tourist pressure in Ouro Preto, Brazil, using GIS tools, in order to identify visitor concentration patterns and discuss their implications for the sustainable management of heritage tourism. The study's contribution is twofold: first, it proposes a methodological approach that integrates spatial analysis and tourism management in a heritage destination with high urban complexity.

Finally, it provides useful evidence for destination planning, showing that the sustainability of heritage tourism depends not only on how often a place is visited, but also on how those visits are distributed, concentrated, and overlap with heritage-sensitive and functionally strategic areas. The aim is to strengthen a research and management agenda in which GIS is not merely a representational tool, but an analytical support for more precise, proactive, and territorially informed decision-making.

2 LITERATURE REVIEW

2.1. Tourist pressure and sustainability in heritage destinations

Recent discussions on heritage tourism have shifted their focus from solely on demand growth to the territorial effects of visits to particularly fragile historical sites. Within this framework, the literature on overtourism has been crucial in demonstrating that tourism-related problems stem not only from visitor volume, but also from their spatial concentration, the intensity of use of certain urban areas, and the limited responsiveness of heritage destinations (Kim et al., 2019).

Maeda et al. (2018) caution that “the phenomenon remains difficult to define, but emphasize that it is “multidimensional and complex, precisely because it simultaneously involves tourism, urban,

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and social dynamics" (p. 15). Similarly, Calle et al. (2020) argue that "the growth of urban tourism has generated great pressure on historic centers, intensifying externalities that compromise both heritage protection and the daily functioning of these spaces" (p. 18).

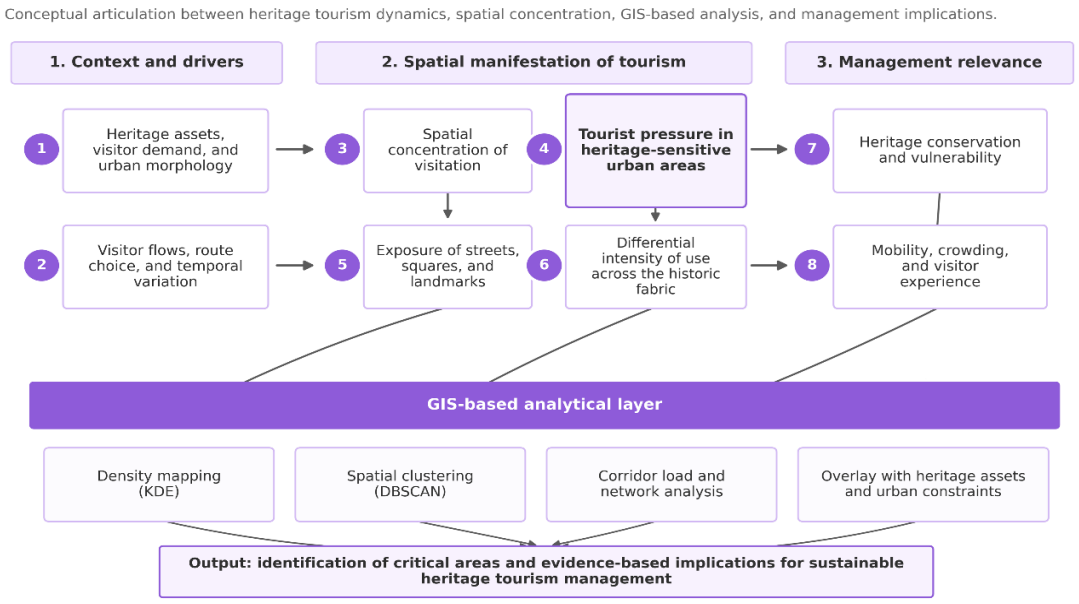
From this perspective, the notion of tourist pressure is particularly relevant for the analysis of heritage destinations, as it allows us to understand tourism not as an aggregated number of arrivals, but as a spatially differentiated relationship between flows, concentration, accessibility, density of use, and the sensitivity of the surrounding area. This interpretation is reinforced by the approach of Beritelli et al. (2020), who propose understanding "the tourist destination as a space of flows, that is, as a dynamic configuration produced by the trajectories, movements, and decisions of visitors" (p. 10). The analytical consequence of this approach is clear: in historic cities, the sustainability of tourism depends less on the absolute number of visitors than on how they are distributed in space and time, which nodes concentrate the greatest intensity of use, and what saturation thresholds are reached in heritage-sensitive areas.

2.2. GIS and spatial analysis for heritage tourism management

In this context, Geographic Information Systems (GIS) offer a particularly solid methodological basis for studying tourism pressure in historical destinations. Their main strength lies in their ability to integrate territorial information, represent distribution patterns, identify areas of concentration, and link tourism dynamics with the morphological, functional, and heritage characteristics of the urban space (Alvarez & Paniza, 2020).

Figure 1.

Analytical framework for examining tourist pressure in a heritage destination



Ciski et al. (2019) point out that "advancing sustainable heritage management requires "information on the location of objects and their concentration, an observation particularly relevant in historic cities where small changes in land use density can translate into significant effects on conservation, mobility, and visitor experience" (p. 14). Similarly, Teixeira & Ahlert (2012), in a paper published in RBTUR, argue that "geoprocessing tools can be "important allies" for tourism planning and emphasize that, due to its territorial nature, tourism necessarily requires a cartographic base to analyze and represent its impacts" (p. 312).

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The most recent research has further expanded the scope of GIS through the use of geolocated digital footprints and real-time monitoring systems. Jiang et al. (2021) show that "it is possible to reconstruct spatiotemporal trajectories of visitors in World Heritage cities from thousands of georeferenced photographs and advanced GIS techniques" (p. 15), while Viñals et al. (2024) demonstrate that "digital monitoring technologies can identify situations of congestion and overcrowding with high precision in micro-scale public spaces, something especially valuable in historic centers with narrow streets and sensitive pedestrian areas" (p. 13).

However, the review also reveals a gap: many of these studies focus on detecting or representing flows, but do not always explore their implications for the sustainable management of heritage destinations in sufficient depth (Arefieva et al., 2021). This is where the contribution of this article lies: using spatial analysis not only to describe visits, but also to interpret tourist pressure as a territorial management problem in Ouro Preto.

3. METHODOLOGY

3.1. Research Design

The study adopts a quantitative, non-experimental, and spatial design aimed at identifying, representing, and interpreting the territorial distribution of tourist pressure in an urban heritage destination. The methodological strategy is based on the integration of georeferenced information on visitor presence and mobility, urban structure, the location of heritage assets, and the functional attributes of the tourist area (Boers & Cottrell, 2007). This approach stems from the premise that tourist pressure is not a homogeneous phenomenon across the destination, but rather a territorially differentiated manifestation, observable through patterns of concentration, intensity of use, and overlap with heritage-sensitive areas.

From an operational perspective, the research unfolds in four interconnected stages. First, a geospatial database of the study area is constructed. Second, spatial visitation patterns are identified using geolocated user records and complementary territorial layers. In the third phase, areas of greatest tourist pressure are delineated based on indicators of density, frequency, and traffic load along circulation corridors. Finally, the results are interpreted in terms of sustainable heritage tourism management, with an emphasis on their implications for destination planning.

Figure 2.

Methodological framework for the spatial analysis of tourist pressure in Ouro Preto, Brazil



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3.2. Study Area

The study is being conducted in Ouro Preto, Brazil, a city inscribed on the UNESCO World Heritage List for its exceptional historical, urban, and architectural value. The inscribed core comprises 167.8 hectares and has a buffer zone of 2,036.9 hectares, providing a clear territorial basis for analytically delimiting the heritage area and its areas of influence (UNESCO, 2021).

The city maintains an irregular urban layout adapted to steep slopes, with a high concentration of churches, civic buildings, bridges, fountains, and public spaces of great symbolic value; at the same time, UNESCO notes its vulnerability to urban growth, traffic, and the impact of tourism. These characteristics make Ouro Preto a particularly suitable case study for examining how tourist visits are distributed across the historic area and how this distribution can affect the sustainable management of the destination.

In analytical terms, the main spatial unit of the study will be a regular 50 x 50-meter grid, superimposed on the heritage site and its immediate surroundings. This decision allows for the capture of subtle intra-urban variations, preventing the analysis from becoming diluted across overly broad administrative units. Additionally, the pedestrian and road network will be used as a linear unit of analysis to estimate the load on tourist corridors and traffic axes.

3.3. Data Sources

The methodology integrates four datasets.

The first layer corresponds to the destination's heritage and tourism base, comprising the location of churches, museums, viewpoints, plazas, tourist facilities, and other points of interest relevant to the visitor experience. This layer should be constructed using official inventories, municipal maps, and public heritage databases.

The second layer includes the road network and urban structure, with particular attention to streets, stairways, plazas, slopes, and pedestrian connections. This information allows for modeling accessibility, spatial continuity, and probable travel paths (Reinhold et al., 2020).

The third layer consists of geolocated visitor records obtained from an open digital platform with a verifiable spatial footprint, preferably Flickr, due to its established use in tourism and heritage research (Zubiaga et al., 2019). Previous studies in World Heritage cities have shown that georeferenced photographs allow for the reconstruction of spatiotemporal trajectories and the detection of congested streets, underutilized areas, and relationships between visitor behavior and urban structure.

The fourth layer corresponds to field validation through structured observation at critical points in the historic center. This phase aims to compare the patterns identified in the study with empirical evidence of pedestrian concentration, space occupation, mobility conflicts, and visible signs of overuse (Pasquinelli & Trunfio, 2020).

To ensure temporal comparability, digital records should be limited to a clearly defined analysis period—for example, two full years—and cleaned to remove duplicates, records from outside the study area, and publications lacking sufficient spatial consistency (Calle et al., 2020).

3.4. Operationalization of tourist pressure

In this study, tourist pressure is operationalized using three complementary dimensions: intensity of presence, spatial concentration, and load on circulation corridors.

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Intensity of presence is estimated using the density of geolocated records per cell. This indicator allows for the identification of the areas of the destination where tourist activity is most frequent.

Spatial concentration is analyzed using density and spatial clustering techniques. In particular, the use of Kernel Density Estimation (KDE) is proposed to detect areas of concentration, combined with the DBSCAN algorithm to identify clusters of visits with high spatial proximity (Li et al., 2018). This procedure has proven useful in recent studies on tourist behavior and heritage appeal based on georeferenced photographs.

Load on corridors is calculated by projecting records and probable trajectories onto the pedestrian road network in order to identify segments with higher tourist traffic. For users with more than one temporally sequenced record, probable trajectories will be reconstructed using network analysis, following the criterion of the minimum viable distance between successive points (Liu et al., 2023). This procedure allows us to move from an isolated point to a more robust reading of visitor flows, in line with studies that have reconstructed visitor trajectories in historic cities using advanced GIS techniques.

Based on these three dimensions, areas of high tourist pressure will be considered those cells or segments that meet at least two of the following conditions:

a) being located above the 75th percentile of record density;

b) belonging to a high-concentration spatial cluster;

c) coinciding with high-traffic circulation corridors.

This criterion avoids relying on a single index with arbitrary weightings and promotes a more transparent and replicable identification of critical areas.

3.5. Spatial analysis procedure

All processing will be carried out in a GIS environment, preferably QGIS, due to its traceability and reproducibility. In the first stage, the spatial layers will be standardized within a single reference system and subjected to topological quality control. Subsequently, the study's geodatabase will be constructed with four main layers: heritage and attractions, road network, geolocated visitor records, and an analytical grid (Kovalcsik et al., 2022).

In the second stage, point distribution, density, and cluster maps will be created. In the third stage, the results will be cross-referenced with contextual territorial variables, especially: proximity to heritage sites, pedestrian accessibility, centrality of traffic axes, and the morphological narrowness of the urban space (Martí et al., 2021). This cross-referencing is fundamental because tourist pressure depends not only on the presence of visitors but also on the physical and functional capacity of the space that receives them.

Finally, a synthetic map of critical areas will be generated, classified into low, medium, and high-pressure levels using Jenks' natural breaks. This mapping output will allow discussion of concrete management implications, such as redistribution of routes, regulation of access, reinforcement of signage, prioritization of maintenance and intervention on conflict points.

3.6. Validation, reliability and ethical considerations

To strengthen the validity of the analysis, a triangulation strategy will be adopted, combining spatial results, field observation, and heritage inventory. On-site validation will be conducted at

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different times of use—for example, weekdays and weekends—to verify whether the areas identified as critical actually exhibit higher visitor concentrations and greater usage pressures.

It is also acknowledged that geolocated digital footprints have representativeness biases, since not all visitors post content, nor are all platforms used equally by all groups. However, the specialized literature has shown that, even with these limitations, such records constitute a promising source for reconstructing trajectories and recognizing spatial patterns of visits, provided they are combined with other sources and interpreted with caution (McKercher & Zoltan, 2014).

From an ethical standpoint, the study will use only publicly available data and will work with aggregated and anonymized information, without identifying individual users. If field observation with systematic recording of individuals is incorporated, the principle of non-identification must be upheld, and the procedure must comply with the corresponding institutional requirements (Martí et al., 2019).

Table 1.

Variables and indicators for the spatial analysis of tourist pressure

Dimension	Variable	Operational indicator	Main source	Analysis technique
Tourist presence	Intensity of visitation	Number of geolocated records per grid cell	Geotagged photographs / digital traces	Spatial count and KDE
Spatial concentration	Spatial clustering	High-proximity clusters of visitor activity	Geolocated records	DBSCAN
Mobility	Corridor load	Frequency of passage along street segments	Reconstructed visitor trajectories	Network analysis
Heritage sensitivity	Asset exposure	Proximity to heritage assets and sensitive public spaces	Heritage inventory / official cartography	Buffer and spatial overlay
Urban condition	Morphological constraint	Slope, street narrowness, and corridor centrality	Street network and urban spatial data	Multilayer spatial analysis

4. RESULTS AND DISCUSSION

4.1. Spatial distribution of tourist presence

The spatial analysis of the geolocated records showed that tourist presence in Ouro Preto is distributed in a markedly unequal way within the heritage perimeter. Instead of a uniform occupation of the historic center, tourist activity is organized around a central axis of high intensity, structured by Praça Tiradentes, the Museu da Inconfidência, Rua Conde de Bobadela (Rua Direita) and the immediate surroundings of the Igreja de São Francisco de Assis. These spaces, widely recognized as emblematic nodes of the city's historical ensemble, appear as the main anchor points of the visit and as articulators of tourist pedestrian mobility (Ferreira & Teixeira-da-Silva, 2023).

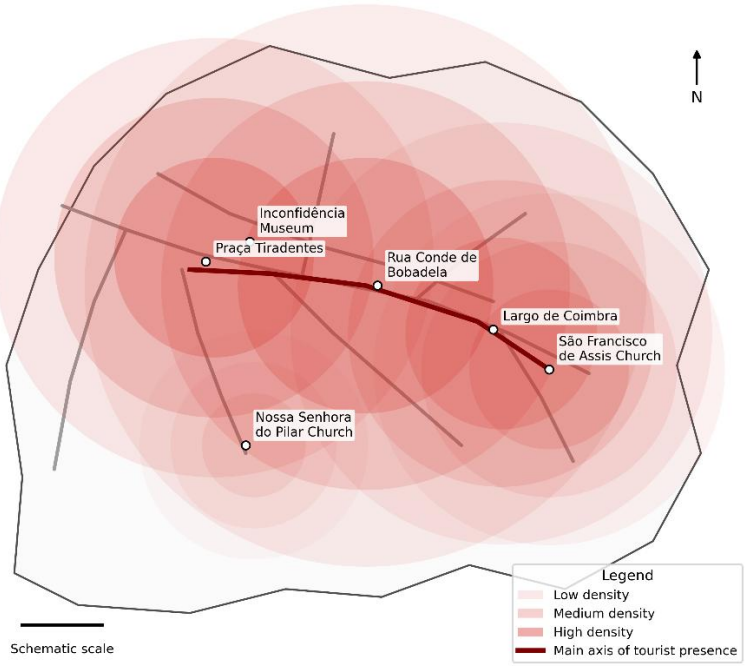
The density surface derived from the KDE confirmed the existence of a high concentration of tourist presence in the Praça Tiradentes–Museu da Inconfidência area, which functions as a central point of arrival, lingering, and redistribution of tourist flows (Silva et al., 2015). From that core, the intensity extends linearly along the Rua Conde de Bobadela, whose historical, commercial and symbolic relevance favors a longer stay for visitors and a continuous flow throughout the day. This pattern is also projected towards the Largo de Coimbra–Igreja de São Francisco de Assis sector, where the artistic and heritage value of the baroque complex reinforces the attraction and densifies the tourist use of the space.

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In contrast, areas further from the central monumental axis exhibit a comparatively lower level of tourist activity. This suggests that heritage tourism in Ouro Preto follows a logic of selective centrality, in which a few spaces concentrate the majority of the tourist experience, while large portions of the historic urban fabric remain in secondary positions within the tourist circuit. Analytically, this result confirms that tourist pressure depends not only on the volume of visitors but also on their spatial concentration in specific nodes of the heritage landscape, in line with the concept of destinations as spaces of flows proposed by Beritelli et al. (2020).

Figure 3.

Spatial distribution of tourist presence in Ouro Preto



4.2. Spatial concentration and configuration of tourist centers

Spatial clustering analysis using DBSCAN made it possible to distinguish more precisely the sectors where the presence of visitors is not only high, but also territorially persistent and structured. Unlike the density map, which shows continuous areas of intensity, spatial clustering revealed the existence of three main tourist hubs within the analyzed area (Zhang et al., 2019).

The first and most intense hub corresponds to the area around Praça Tiradentes and the Museu da Inconfidência, which concentrates a sustained volume of visitor data and acts as the main node for heritage attraction and route redistribution. The second nucleus is articulated along the Rua Conde de Bobadela, a historic corridor with a strong commercial, cultural and pedestrian charge, whose condition as a passage axis favors the accumulation of tourist activity. The third hub is located in the Largo de Coimbra–Igreja de São Francisco de Assis area, where the unique architecture and art of the church, combined with the scenic views of the surrounding landscape, consolidates an area with a high concentration of visitors. The centrality of these points within the heritage image of Ouro Preto is widely documented by official and local sources.

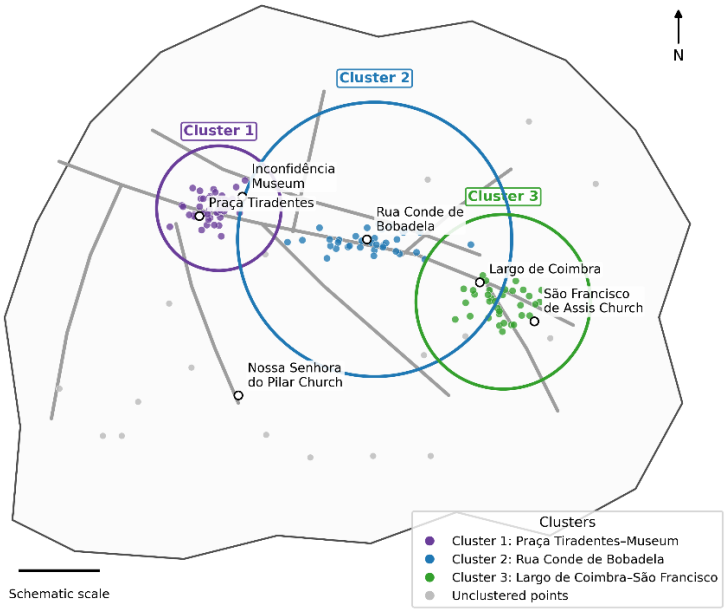
The existence of these three hubs allows for a more nuanced understanding of tourist pressure. These are not simply “highly visited” spaces, but rather areas where repetition, proximity, and recurring tourist activity create zones of intensive and sustained use, potentially more susceptible to congestion,

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functional friction, and heritage degradation (Martí et al., 2017). This territorially consolidated concentration confirms that tourist activity in Ouro Preto is based on a highly hierarchical spatial structure, where a few sectors articulate most of the tourist consumption of heritage.

Figure 4.

Tourist concentration nuclei identified througt DBSCAN



4.3. Burden on circulation corridors and exposure of heritage

The reconstruction of probable trajectories and their projection onto the pedestrian network revealed that tourist mobility is not randomly distributed throughout the historic center, but rather is preferentially channeled through corridors with high symbolic and functional connectivity (Martí et al., 2021).

The corridor with the highest traffic volume corresponds to the axis linking Praça Tiradentes with Rua Conde de Bobadela, from where the flows extend towards the Largo de Coimbra area and the Igreja de São Francisco de Assis. Additionally, an extension of the flow towards the area surrounding the Igreja Matriz de Nossa Senhora do Pilar was also observed, which is integrated into the central heritage circuit due to its proximity and monumental significance (Hernández, 2022).

This pattern shows that tourist pressure in Ouro Preto is not only expressed in tourist accommodations, but also in the routes connecting those locations. The load on these corridors indicates which streets and segments of the historic urban fabric bear the greatest volume of traffic, and therefore where tensions related to pedestrian circulation, visual saturation, occupation of public space, and maintenance demands are most likely to accumulate.

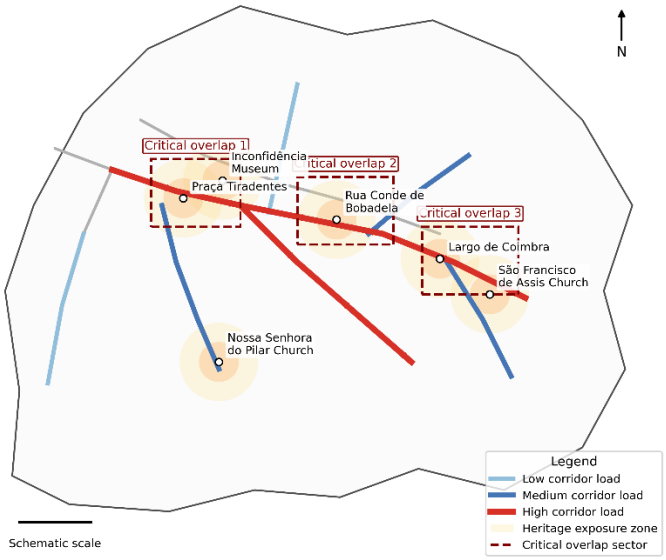
When these corridors intersect with heritage sites and sensitive urban spaces, the result is particularly significant. The busiest sections coincide with areas of high monumental density and high heritage visibility, increasing the exposure of the historic center to forms of intensive use that, while not necessarily destructive in the short term, can produce cumulative effects on the experience of the place, urban functionality, and preventive conservation. In this sense, the traffic load of these corridors becomes a decisive dimension of tourist pressure, revealing that the vulnerability of the destination

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occurs both in the areas where visitors stay and along the axes that structure their routes (Su et al., 2018).

Figure 5.

Tourist corridor load and heritage exposure in Ouro Preto



4.4. Territorial synthesis of tourist pressure

The integration of the three operational dimensions defined in the methodology —intensity of presence, spatial concentration and load on corridors— allowed for the construction of a synthetic reading of tourist pressure in Ouro Preto. The main result was the delimitation of a high tourist pressure sector on the axis formed by Praça Tiradentes, Museu da Inconfidência, Rua Conde de Bobadela and the area around Largo de Coimbra–Igreja de São Francisco de Assis. In this central strip, the highest density of records, the most consistent spatial groupings, and the highest pedestrian traffic load converge simultaneously.

From this main core, a zone of medium pressure is distinguished, expanding into adjacent sectors of the historic center, particularly those connected to the main monumental axis, but with less intensity of permanence and less frequent visitor activity. In these areas, tourist presence remains significant, although less persistent and less structured than in the central core (Xiao et al., 2020). Finally, the low-pressure zones correspond to more peripheral segments of the historic fabric, where tourist visits are more dispersed and less capable of consolidating stable patterns of concentration.

From an analytical perspective, this differentiation confirms that tourist pressure in Ouro Preto is a territorially selective phenomenon, concentrated in areas where heritage centrality, pedestrian accessibility, visitor density, and functional connectivity overlap. Therefore, the main contribution of this analysis is not only to demonstrate that some areas are more visited than others, but also to clearly show where tourist use intensifies, how it is spatially articulated, and which sectors require priority management attention.

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Figure 7.

Integrated spatial synthesis of tourist pressure in Ouro Preto



4.5. Implications of the results for the sustainable management of the destination

The results obtained allow us to draw concrete implications for the sustainable management of heritage tourism in Ouro Preto. First, the highly concentrated nature of visits indicates that management strategies should not focus exclusively on the destination as a whole, but rather primarily on the critical sectors of the central heritage axis, where visitor activity, circulation, and exposure to heritage converge. Second, the identification of high-traffic corridors suggests the advisability of designing route redistribution measures to alleviate the intensity of use on the most heavily used sections, especially those connecting Praça Tiradentes with Rua Conde de Bobadela and the São Francisco de Assis area.

Third, differentiating between high, medium, and low-pressure areas provides an empirical basis for prioritizing interventions. High-pressure areas require continuous monitoring, interpretive signage, preventive maintenance, and regulation of pedestrian use. Medium pressure areas can be incorporated into deconcentration and circuit diversification strategies (Zejda & Zelenka, 2019). Low-pressure areas, meanwhile, open up opportunities for a more balanced management of the destination, by allowing the incorporation of new heritage routes that reduce over-reliance on the main monumental axis.

Taken together, these results show that the value of spatial analysis is not limited to the cartographic representation of tourist visits. Its main contribution consists of translating dispersed dynamics of mobility and permanence into territorially useful evidence for decision-making. In this way, the study confirms that the sustainable management of heritage tourism in Ouro Preto depends not only on controlling visitor volume, but also on a detailed understanding of their distribution, concentration, and overlap with heritage-sensitive areas.

Table 2.

Summary of results by analytical dimension

Dimension	Main indicator	Result obtained	Territorial interpretation	Management implication
Tourist presence	Density of geolocated records per grid cell	Highest intensity along the Praça Tiradentes–Inconfidência Museum–Rua Conde de Bobadela axis	Tourist use strongly concentrated in the central monumental core	Prioritize monitoring and regulation of pedestrian use

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Spatial concentration	DBSCAN clusters	Three main nuclei: Praça Tiradentes, Rua Conde de Bobadela, and Largo de Coimbra–São Francisco de Assis	Persistent concentration in heritage nodes with high centrality	Intervene in areas of saturation and prolonged stay
Mobility	Corridor load	High circulation along the Praça Tiradentes–Rua Conde de Bobadela–Largo de Coimbra axis	Predominance of selective trajectories and recurrent routes	Redesign routes and redistribute visitor flows
Heritage sensitivity	Overlay with sensitive assets	Overlap between high-load corridors and monumental sectors of the historic center	Greater heritage exposure to intensive use	Strengthen preventive maintenance and signage
Territorial synthesis	Integrated pressure classification	High pressure in the central monumental axis; medium pressure in adjacent sectors; low pressure in peripheral areas of the historic fabric	Spatial hierarchy of the tourism pressure problem	Define priority areas for management and conservation

Table 3.

Territorial classification of tourist pressure in the historic center of Ouro Preto

Sector	Presence intensity	Spatial concentration	Corridor load	Heritage exposure	Pressure level
Praça Tiradentes–Inconfidência Museum	High	High	High	High	High
Rua Conde de Bobadela (Rua Direita)	High	High	High	High	High
Largo de Coimbra–São Francisco de Assis Church	High	High	Medium-High	High	High
Area surrounding Nossa Senhora do Pilar Church	Medium	Medium	Medium	High	Medium
Peripheral sectors of the heritage polygon	Low	Low	Low	Medium	Low

4.6 Discussion

The results show that tourist pressure in Ouro Preto is organized around a central heritage axis, rather than as a homogeneous occupation of the historic center. The concentration detected in Praça Tiradentes, the Museu da Inconfidência, Rua Conde de Bobadela and the surroundings of São Francisco de Assis confirms that heritage visits are structured through nodes and high-frequency routes. This configuration coincides with what was observed by Domènech et al. (2020) in Toledo, where georeferenced photographs made it possible to reconstruct visitor trajectories associated with the urban network and the location of the main heritage resources; Similarly, in Ouro Preto, the spatial distribution of the records does not follow a random logic, but rather a territorial organization strongly linked to the historical and functional centrality of the destination. In this sense, the findings also support the idea of the destination as a “space of flows,” in which the tourist experience depends on corridors and points of articulation rather than a simple sum of isolated attractions.

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At the same time, the identification of three high-concentration areas and corridors with high traffic volume places the case of Ouro Preto within a problem already documented in other historic centers subjected to intensive use. Zubiaga et al. (2019) show that monitoring visitor flows in historic centers constitutes an operational basis for smarter management of overtourism, while Viñals et al. (2024) emphasize the need to detect situations of overcrowding and congestion in micro-scale historic spaces. The results from Ouro Preto converge with this research by demonstrating that tourist pressure intensifies precisely where permanence, transit, and heritage sensitivity overlap. However, the Brazilian case adds a relevant nuance: the rugged topography and irregular morphology of the urban fabric seem to reinforce the concentration of visits on a few structuring axes, making the pressure not only a matter of density but also of restricted spatial connectivity.

From a methodological standpoint, the results confirm that the use of GIS combined with geolocated digital footprints allows us to move from a descriptive reading of tourism to a territorially operational interpretation. Nolasco et al. (2022) demonstrated in Bucharest that geolocated data can delimit urban areas of tourist interest and support the design of future strategies; similarly, in Ouro Preto, the analysis not only located areas of intense visitation but also allowed for the integration of density, clustering, and load on corridors into a spatial synthesis of tourist pressure. This articulation represents a significant contribution because it avoids reducing the analysis to isolated heat maps and transforms it into a tool for prioritizing critical sectors. Along the same lines, Ciski et al. (2019) emphasize that heritage management requires “information on the location of objects and their concentration”; precisely herein lies one of the main contributions of the study: translating tourist visits into spatial evidence useful for the management of a complex heritage destination.

In terms of management, the results suggest that responses should not be directed toward the historic center of Ouro Preto as a homogeneous whole, but rather through a logic of spatial prioritization. The correlation between visitor density, visitor clusters, and traffic volume along the central monumental axis indicates that monitoring, route redistribution, signage, and preventive maintenance efforts should be concentrated there. This interpretation is consistent with the literature that understands tourist pressure as a “multidimensional and complex” phenomenon and recognizes that the growth of urban tourism exerts “great pressure on the historic centers”. Consequently, the main contribution of this study is not only to confirm that Ouro Preto has areas that are more visited than others, but also to show that tourist pressure can be identified, defined, and discussed as a concrete territorial problem, comparable to other historical contexts, but with its own characteristics derived from its urban morphology and the spatial structure of visitor activity (Park & Kim, 2018).

5. CONCLUSION

Taken together, the results allow us to conclude that tourist pressure in Ouro Preto is not simply explained by the number of visitors the city receives, but by the way in which that visit is concentrated and moves within the historic center. The study clearly shows that the greatest intensity of use is organized around the central heritage axis, where the main nodes of attraction, the most used circulation corridors and the spaces of greatest heritage sensitivity coincide. This finding is relevant because it places the problem on a specific territorial scale and allows us to understand that the sustainability of heritage tourism depends, above all, on how flows are distributed in urban space.

Based on this, one of the article's main contributions is demonstrating that tourism pressure can be addressed as an operational analytical category, not merely as a general notion associated with tourism growth. The integration of geolocated records, density analysis, spatial clustering, and corridor modeling allowed for the identification of consistent patterns of concentration and mobility, providing a more precise understanding of tourism use of heritage sites. In this sense, the study reinforces the

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value of GIS not only as a cartographic representation tool, but also as an analytical resource capable of revealing spatial relationships that are often hidden in aggregate statistics.

From an applied perspective, the findings suggest that tourism management in Ouro Preto should not be guided by uniform measures across the entire historic district. On the contrary, the results show the need for differentiated interventions, prioritizing areas with higher visitor density, persistent concentration, and high traffic volume. This moving toward more selective strategies for monitoring, route redistribution, preventive maintenance, and pedestrian regulation. Thus, the study's contribution is not limited to a spatial diagnosis of the problem but also offers a useful empirical basis to support more precise and territorially informed planning decisions.

At the same time, it is worth recognizing that the use of geolocated digital footprints has limitations, especially in terms of representativeness and coverage of the actual behavior of visitors. However, these restrictions do not detract from the approach taken; rather, they highlight the advisability of complementing it, in future research, with pedestrian counts, more detailed time-based records, and other sources of spatial observation.

In this regard, the case of Ouro Preto confirms that spatial analysis based on GIS constitutes a solid way to understand tourist pressure in complex heritage destinations and, at the same time, a promising tool to strengthen a more preventive, more balanced and more sensitive management to the particularities of the historical territory.

Authors' contribution statement

Rodrigo Esteban Salas Vaca: Conceptualization, Supervision, Validation, Writing –Original Draft Preparation.

Diana Gabriela Carpio Álvarez: Funding Acquisition, Data Curation, Investigation, Writing –Review & Editing.

Jairo Andrés Terán Andrade: Formal Analysis, Methodology, Project Administration.

Pablo Xavier Andrade Montalvo: Software, Visualization, Resources, Writing –Review & Editing.

Declaration of conflict of interest

The authors declare that there is no conflict of interest.

Data availability statement

The research data are included in the manuscript itself.

AI Usage Statement

The ChatGPT artificial intelligence tool has been used to assist in the grammar review of the text and the standardization of references.

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