

## Article

# Geospatial Tools for Determining Visitor Carrying Capacity in Tourist Streets and Public Spaces of Historic Centres

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**Abstract:** This paper presents a methodology for using geospatial tools to enact efficient tourism planning and management in streets and other public spaces in historic centres. The study uses 3D laser scanning, GIS, and spatial data processing techniques to analyse the visitor carrying capacity of streets near cultural attractions. The methodology was tested on Miguelete Street in València (Spain), next to the Cathedral. The results show that these digital tools are efficient and accurate for the spatial analysis of visitor carrying capacity studies.

**Keywords:** geospatial tools; visitor carrying capacity; point cloud; GIS; cultural tourism planning and management; proxemics; historical centre; València; Spain

## 1. Introduction

In the field of urban management and public realm planning, it is essential to understand and address the various aspects that directly affect the quality of life of residents and the experience of visitors to these places. One of these aspects is the occasional saturation and congestion of people in public spaces.

This issue is related to the physical characteristics of streetscapes, the management of people flows, and the types of activities they undertake in public spaces. This study falls within the scope of recreational carrying capacity analyses which are usually conducted in tourist destinations by diverse authors [1–4]. The recreational carrying capacity of a site can be established for the various activities taking place on the site, but the most basic and fundamental approach is to determine the number of people (visitors and residents) in terms of presence that a site or element can accommodate at the same time. This analysis is referred to as visitor carrying capacity (VCC).

The visitor carrying capacity is one of the most widely recognised management tools for heritage elements (natural, cultural, urban spaces) that will be used for the visits of people, to ensure the environmental and social sustainability of tourist activity. This tool aims to determine the maximum number of people who can visit a site at the same time, without compromising the quality and comfort of the activity, and without risking damaging the heritage site or its surrounding area [5–8].

The analysis of the spatial aspects of the site or element is fundamental to this type of study, as well as the personal spatial needs of the visitor, and the types of activities to be developed. Since streets are key stages for the development of tourist activities, the aim of this study is to analyse the visitor carrying capacity of the public realm. Streets and squares are spaces where heritage sites are typically located, offering views of significant facades and also different viewpoints (static activity), but they are also spaces of transit from one attraction to another (functional dynamic activity), through which residents, commuters, and visitors circulate in the development of tours. In many cases, the streets and public spaces are very attractive to the public and destination sites unto themselves. In this



**Citation:** Orozco Carpio, P.R.; Viñals, M.J.; Escudero, P.A.; Rolim, R.C.V.S. Geospatial Tools for Determining Visitor Carrying Capacity in Tourist Streets and Public Spaces of Historic Centres. *Heritage* **2023**, *6*, 7100–7114. <https://doi.org/10.3390/heritage6110370>

Academic Editor: Francesco Soldovieri

Received: 4 October 2023

Revised: 25 October 2023

Accepted: 1 November 2023

Published: 6 November 2023

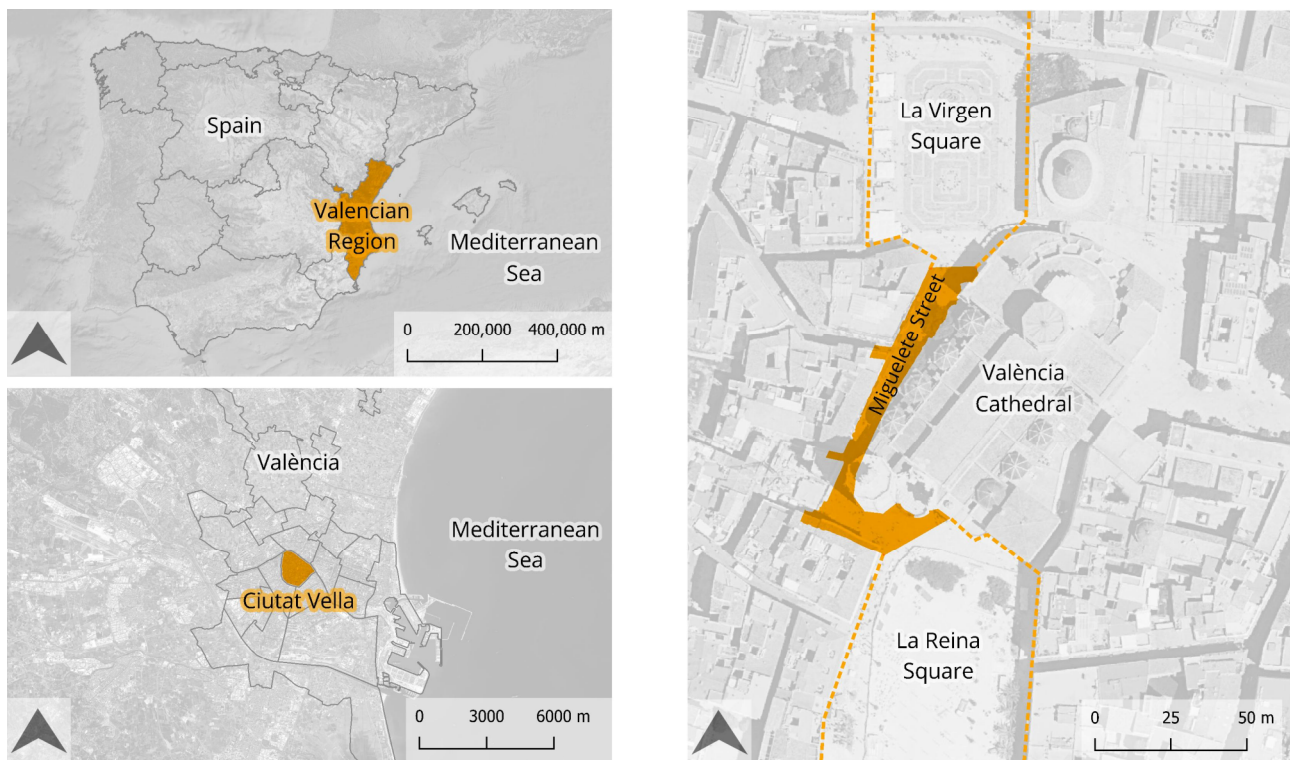


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context, it is worth mentioning that geospatial tools are very useful analytical instruments for determining the spatial characteristics of these urban spaces.

Another fundamental component of the visitor carrying capacity analysis is the personal spatial needs of people in order to develop leisure activities in comfortable conditions. It should be noted that these needs can vary according to the psychological and physiological profile of each type of visitor and the specific activity to be carried out.

Estimating visitor carrying capacity has so far followed traditional calculation methods, but today's geospatial tools greatly facilitate the researcher's work and prove to be very efficient. The aim of this paper is to explore the applications of Geographic Information Systems (GIS) and geospatial data for the determination of the visitor carrying capacity in a public space with tourist affluence. To address this issue, the methodological approach of Design Science Research (DSR) is adopted, involving the formulation of a solution and its subsequent implementation in a specific place to assess its feasibility and applicability. Having said this, Miguelete Street (Figure 1), located next to the Cathedral of València (Spain), has been used as an experiment with the proposed tools.



**Figure 1.** Location map of the study area. On the left, the location of Valencian Region in Spain, and the city centre in the city of València. On the right, Miguelete Street next to the València Cathedral. Cartographic source: aerial orthophoto 2022CVAl (Instituto Cartográfico Valenciano, 2022).

#### *Characteristics of the Testing Area*

The choice of Miguelete Street in València as an experimental area for testing geospatial tools is attributed to its strategic location and significance, positioned adjacent to one of València's most emblematic structures, the Cathedral, known for its captivating blend of architectural styles [9]. The Cathedral, in turn, features a prominent landmark within the city, the Miguelete Tower, from which the studied street derives its name. Simultaneously, Miguelete Street serves as a vital link connecting two socially and touristically significant squares in València, La Virgen and La Reina (Figure 2), experiencing substantial pedestrian traffic. It is important to highlight that this street also boasts various characteristics, including commercial establishments, changes in floor elevation, greenery and vegetation, and seating areas, both formal and informal, making it a noteworthy testing area.



**Figure 2.** A street view from Miguelete Street (Author: M.J. Viñals, 2023), and a figure-ground drawing showing the open public spaces around.

## 2. Background and State of the Art

From the year 2000 onwards, studies on carrying capacity increasingly gained significance, coinciding with emerging challenges related to the saturation and degradation of heritage sites, declining quality of tourist experiences, and negative social impacts on resident populations (e.g., gentrification, tourismphobia). This trend is evident in the works of García Hernández [10], Peran López [11], Kostopoulou & Kyritsis [12], López-Bonilla & López-Bonilla [13], Maggi & Fredella [14], García Hernández et al. [15], Alazaizeh [16], Santos & Pena Cabrera [17], Viñals et al. [18,19], Conti [20], Cruz Aragón [21], Becken & Wardle [22], Guo & Chung [23], Milano [24], and Muler González et al. [25]. Over the past five years, the literature demonstrated that recreational carrying capacity continues to be a crucial tool in managing natural parks, archaeological sites, and historical centres, as highlighted in the studies of Zubiaga et al. [26], Jurišić et al. [27], Llausàs et al. [28], Raj Sharma & Bisht [29], Bao et al. [30], Red de Parques Nacionales [31], Deffinika et al. [3], and Santos & Brilha [32], among others. Its application is also used in different contexts as evidenced in the study of indoor spaces by Petronijević et al. [33].

Among these new tools and methodologies that can help calculate the carrying capacity of heritage sites, Heritage Building Information Modelling (HBIM) stands out, as exhibited in the work of Salvador-García et al. [34], who analyse and zone visiting areas in a digital model. On the other hand, Geographic Information Systems (GIS) should also be mentioned, as applied in the studies of Makhadmeh et al. [35] and Simou et al. [4], who analyse the density of visitors to archaeological sites. Similarly, Almeida [2] uses this tool and collaborative geodata to conduct an urban-scale study of the carrying capacity of streets and open spaces in a tourist city such as Lisbon that deals with overtourism.

It is also worth mentioning that the concept of Spatial Syntax, initially developed by Hillier & Hanson [36], has garnered increasing relevance within these studies due to its versatility and applicability in multidisciplinary research [37]. To illustrate its integration Wang et al. [38] and Xu et al. [39] utilize Spatial Syntax methodologies and GIS to analyse urban spaces, offering valuable insights from a tourism perspective.

So far, it has been observed that recreational carrying capacity studies have been well solved in closed and/or confined spaces, but it is always complex to approach large areas with traditional methods. Digital geospatial tools allow such studies to be carried out efficiently with very reliable results. This work aims to provide results to support this fact. The authors of this paper consider that it is necessary to address this type of visitor carrying capacity research in large open spaces but with detailed analysis, especially in places with problems of overtourism, which is directly related to carrying capacity [24,25]. This is with the aim of preventing crowding and improving the users', residents', and tourists' experiences.

### 3. Materials and Methods

This paper employs the Design Science Research (DSR) approach, primarily focusing on designing a methodology related to determining visitor carrying capacity in a public space with tourist influx in historic city centres with geospatial tools. To this end, the research design aligns with the stages suggested by Peffers et al. [40], for Design Science Research: (1) problem identification; (2) definition of an objective-centred solution; (3) solution development; (4) solution implementation and demonstration; and (5) solution evaluation. For this purpose, in the present section, the developed solution is described and implemented in the previously designated testing area of Miguelete Street.

In addition to a literature review on the spatial analysis of public space and several in-depth interviews with tourism experts, fieldwork sessions based on direct observation of urban spaces were carried out to identify critical points and analyse pedestrian flows. The spatial characteristics of the urban space were defined by combining the use of 3D laser scanners and spatial data processing techniques.

The first step in the digital spatial analysis was a 3D laser scanner survey of the surroundings of the most representative urban spaces using point clouds. In addition to the survey of the Metropolitan Cathedral of València, 126 positions were taken in the La Reina and La Virgen squares as well as Miguelete Street to reconstruct the geometry of these areas and, thus, analyse the distribution and spatial configuration of the key elements of the study area. Environmental factors are negligible as weather conditions were similar on all sampling days, but due to pedestrian and vehicular traffic, data collection was difficult in some places. Nevertheless, it was possible to obtain a complete point cloud with a point density higher than 1 point per cubic millimetre. Different types of scanners were used for this purpose. These varied according to the complexity of each area. For open spaces, the Leica RTC 360 scanner (manufactured by Leica, Heerbrugg, Switzerland obtained from Leica España) was used due to its higher resolution. In the narrower lanes, the FARO<sup>®</sup> Focus 3D X130 and FARO<sup>®</sup> Focus Premium scanners (both manufactured by FARO, Lake Mary, Florida, USA obtained from FARO España) were used, both of which have sufficient resolution for subsequent data analysis. FARO<sup>®</sup> SCENE version 2022.1.0 was used to process and register the scanned points. This software facilitated point cloud cleaning and segmentation as well as the extraction of orthophotos.

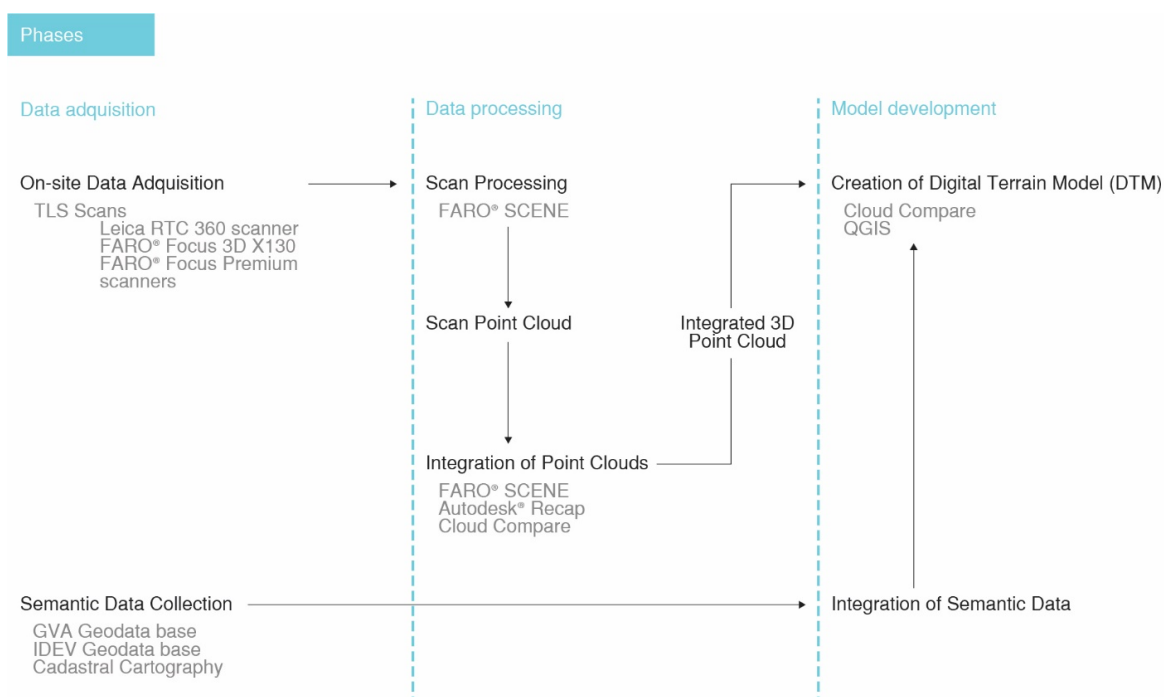
To identify any imperfections and to minimise errors between the different clouds, the point clouds were visually inspected in plan and elevation. The final registration of the point cloud used in the geometric analysis had an average error of 2.3 mm. The point cloud was prepared in .rcs format for import into Autodesk<sup>®</sup> Recap 2023 version 23.0, where an initial clean-up of point noise was carried out to improve processing in the open source software Cloud Compare version 2.13 alpha. At this stage, only the points representing the paving of Miguelete Street were retained. In Cloud Compare, filters were again applied to refine the point cloud using the "CSF Filter" tool, which operates using the CSF (Cloud Simplification Filter) algorithm. This method of point reduction allows the elimination of redundant or unnecessary points while maintaining a visually coherent and accurate representation of the surface.

The next step was to calculate the point normals using the Dip/Dip Direction SFs (Dip and Dip Direction Structure Functions). This algorithm is commonly used to describe the

orientation and geometry of rock layers or geological structures; in this case, it was used to distinguish the dip angle and direction of surfaces in relation to a horizontal plane. This tool made it possible to eliminate the points belonging to the vertical planes and separate them from the points corresponding to the pavements of the Cathedral.

Cloud Compare was then used to rasterise the resulting point cloud and the residual elements of the filtrations to obtain the paving layer and, separately, the urban furniture and the edges of the buildings; all of this was then used in QGIS version 3.28.3-Firenze to complete the missing areas in the raster.

For this purpose, the GDAL tool “fill without data” was used. In this way, a Digital Terrain Model (DTM) was obtained which contains the elevation data for each point. A representative workflow, based on Liu et al. [41], can be found in Figure 3. After that, using the QGIS raster tools, it is possible to obtain a hillshade map that allows better visualisation of the model, and a slope map that enables the identification of reliefs, ramps, and level changes in the pavement. Taking the latter, together with the previously purged raster of furniture and building edges, it is possible to find all the edges present in the street and the surfaces that can be used as seating, whether formal or informal. This data is then vectorised into polygons that will serve as the basis for further analysis and evaluation in the context of the project.



**Figure 3.** A representative diagram of the DTM creation workflow.

## 4. Results and Discussion

While other studies, exemplified by Almeida [2] and Zubiaga’s [26] research, address visitor carrying capacity in public spaces within tourist cities, they adopt a macro-urban perspective, emphasising a more quantitative approach to carrying capacity analysis. In contrast, the findings presented below arise from a micro-urban analysis of an urban open area, focusing on the physical characteristics of the space and its relationship with visitor carrying capacity and proxemics studies.

### 4.1. Spatial Analysis

The visitor carrying capacity study begins with a spatial analysis of the subject site. Thus, after obtaining the Digital Terrain Model (Figure 4), the surface of the studied space was calculated. In this way, and based on the calculations made in QGIS, the area of the

street would be 1246.56 m<sup>2</sup>. In addition, the slopes were also calculated, using the tool “GDAL Raster Analysis—Slope”, most of which are less than 3%, although there are parts that reach 6% corresponding to the existing ramps. Figure 5 shows a plan where changes in level, such as steps or staircases, can be identified.

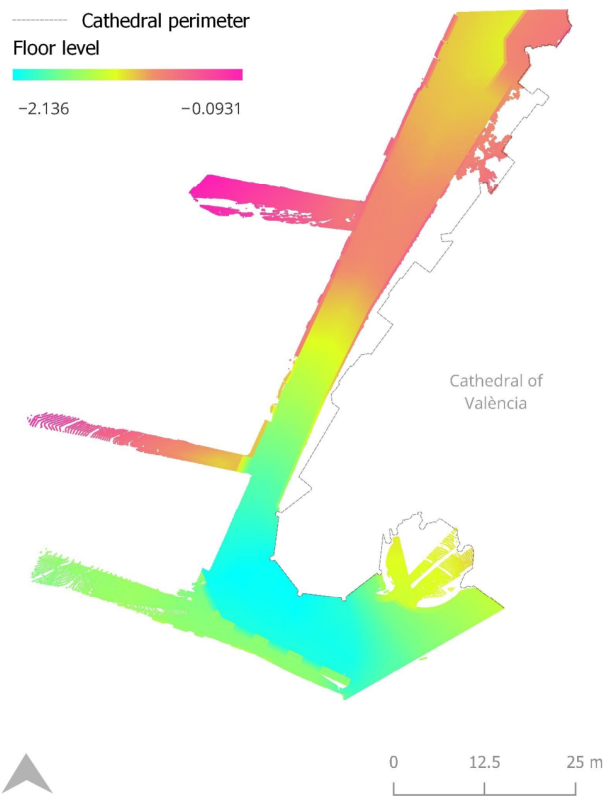


Figure 4. Digital Terrain Model (DTM) of Miguelete Street based on the point cloud.

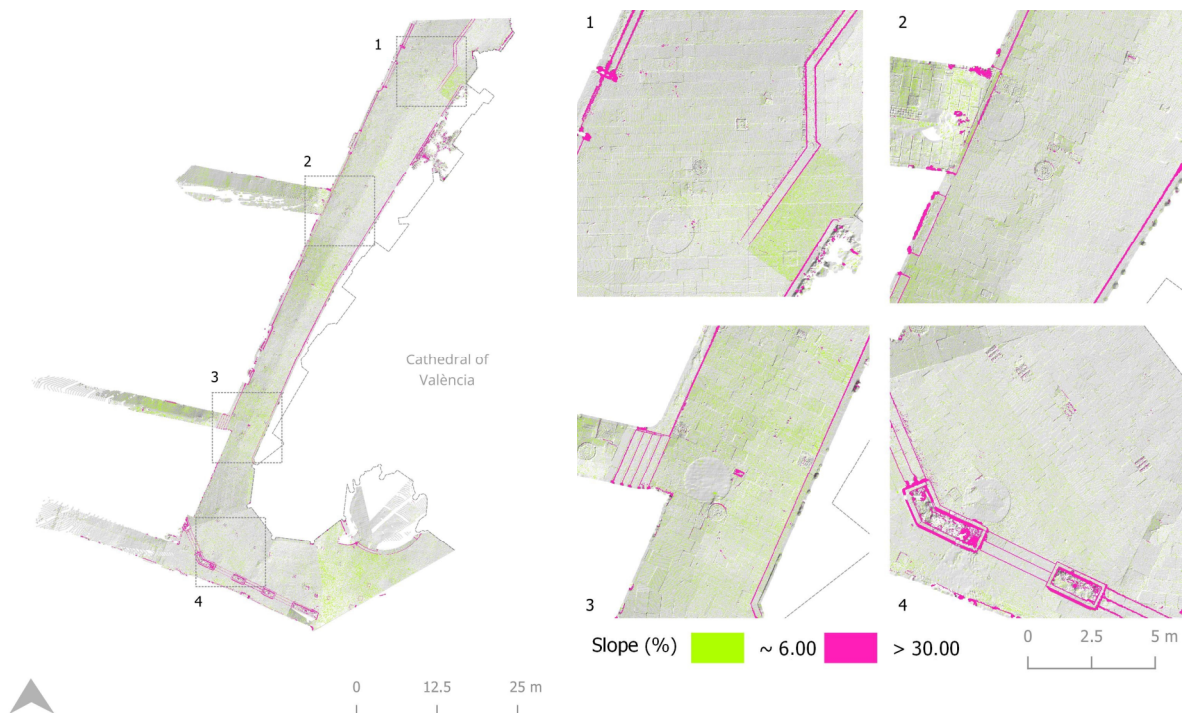
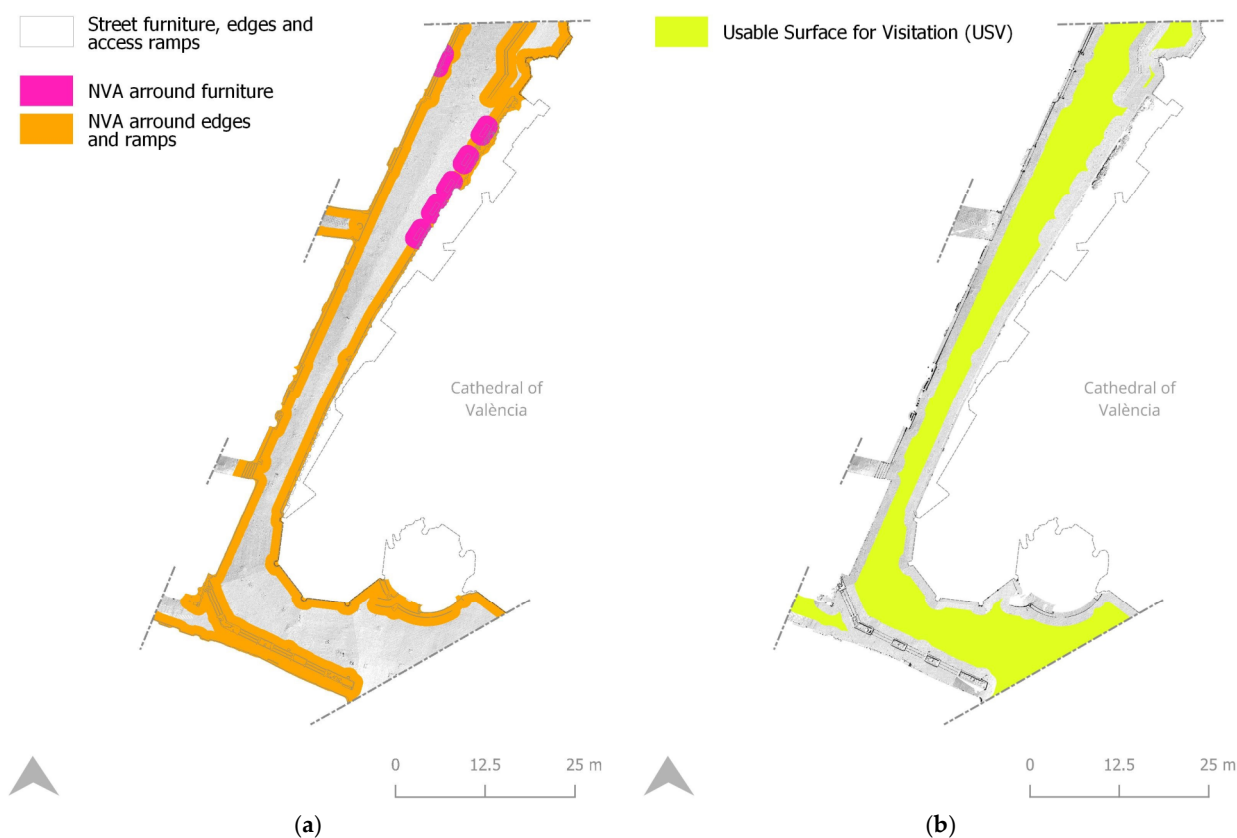


Figure 5. Slope and hillshade maps of Miguelete Street. General view and details.

Given the homogeneous characteristics of Miguelete Street (e.g., few topographical differences, lighting, etc.), the dimensions of this urban space and the functions associated with it (pedestrian traffic) have been considered for the study as a single spatial unit. It is an open-air space, longitudinal in shape, with a clear delimitation on the flanks thanks to the built fronts of the Cathedral and the buildings on the opposite side; the delimitation of the ends has been more arbitrary, based on the criterion of a change of morphology towards more ample spaces, the squares.

Next, we determined the Usable Surface for Visitation (USV), which is defined as the area that remains available for recreational visiting activities after discarding all spaces that are not useable for reasons of conservation, safety, fragility, incompatibility of uses, or due to the distribution of their components [19,34]. Similarly, areas parallel to walls and other edges have been excluded from the calculation of the Usable Surface for Visitation (USV), either for conservation reasons or because of the repulsive force that obstacles exert on people when deciding where to walk [42]. This has been carried out in QGIS using the vector tool “Buffer” with a distance of 1.20 m from the walls.

Therefore, the Non-visitable Areas (NVA) have been estimated and they totalled 617.216 m<sup>2</sup>. The constraints identified, which reduce the space available for visitation recreational activities, are mainly related to the spatial arrangement of internal components, in particular street furniture, edges, and access ramps (Figure 6a).

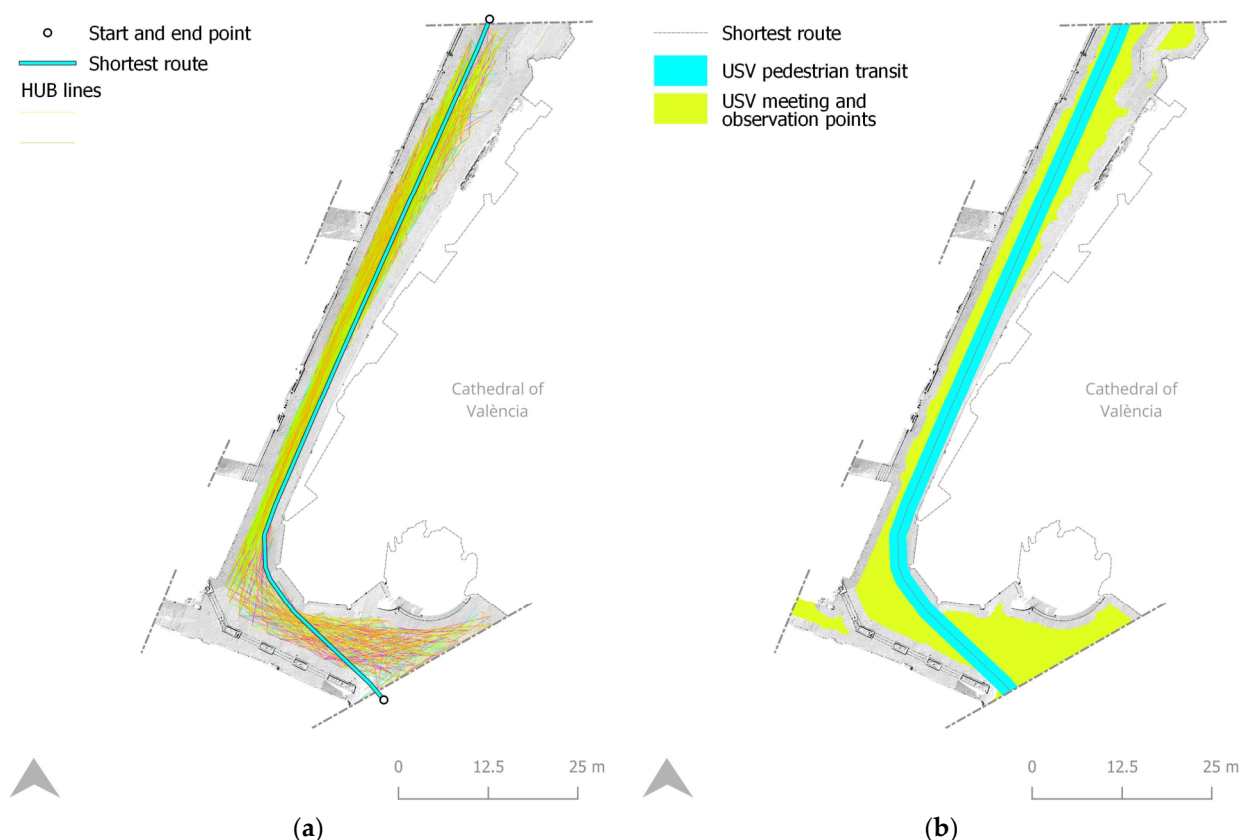


**Figure 6.** (a) Delimitation of the Non-visitable Areas (NVA); (b) delimitation of the Usable Surface for Visitation (USV).

This NVA must be subtracted from the initial total surface area of the street, and in this way, the Usable Surface for Visitation (USV) of 639,344 m<sup>2</sup> is obtained (Figure 6b).

The USV determined is basically the same as the Suitable Visiting Area (SVA), which is the space whose intrinsic characteristics are suitable for the development of certain recreational activities, for the location of facilities and/or for transit areas, coinciding where the impact is minimal [19]. In this case, the vocation of this urban space is essentially

pedestrian sightseeing tour activities. To this end, an analysis of routing options was carried out using QGIS, by generating random points within the polygon of Miguelete Street, connecting them using the “HUB lines” tool, and finally applying the “Network Analysis—Shortest Route” tool (Figure 7a,b). The pedestrian transit options have few variations in terms of the physical effort required by the visitor and the time taken to complete the route. Therefore, the whole street was considered to have the same comfort characteristics in terms of pedestrian accessibility, walkability, and spatial convenience. In addition, it should be considered that the same space serves as an observation viewpoint and meeting place for the groups. Therefore, the whole USV is considered a Suitable Visiting Area (SVA).



**Figure 7.** (a) Detection of the different possible routes, highlighting the shortest route; (b) calculation of the shortest route of Miguelete Street and areas preferably considered to potentially accommodate observation viewpoints and meeting places for groups.

#### 4.2. Spatial Needs of the Visitors

Once the usable visiting space has been analysed, it is necessary to know the spatial needs of each visitor, bearing in mind that visitors must carry out the activity under spatial comfort conditions. In the case of tourist visits, and in accordance with the in-depth interviews carried out with local tourist guiding companies, for this study we have considered the “general tourist” (both individuals and, above all, groups) to be the most common in the historic centre of València.

To estimate the interpersonal distance, it was also taken into account that this is basically a dynamic activity, since people are on the move most of the time. This issue has been addressed by authors such as Costa [43] and Gorrini et al. [44], who have devoted their attention to the study of groups and their behaviour and proxemic interactions while walking.

Interpersonal distance for pedestrians is largely determined by the physical constraints imposed by other pedestrians and by the environment [43]. In high-density conditions,



individual proxemic behaviour is based on the need to avoid collisions with other pedestrians and, if in a group, it is further characterised by the need to maintain spatial cohesion among its members to facilitate social interaction and communication during locomotion. In the case of individual visitors (who do not know each other) and because it is a dynamic activity, the interpersonal space requirements are greater than in indoor spaces; therefore, a proxemic standard of “public distance” applies, which could range from 3.50 m to 7.25 m [45].

If the visit is made in a group, a standard of “social distance” (1.2–3.5 m) or even “personal distance” (0.5–1.20 m) could be established between the members of the group (even if they do not know each other), as they may sometimes identify themselves as belonging to the same group and carry out an activity together in which they need to have visual and auditory contact with the guide–interpreter. The size of the group, its composition and the similarities between its members will ultimately determine these distances. What is important in this case, however, is the distance between the groups and the number of encounters with other groups. Distance between groups is related to traffic congestion issues for large groups in long and narrow spaces such as the one in question. Regarding the number of encounters between groups, works such as that of Stewart & Cole [46] establish relationships between the number of encounters and the quality of the experience. In natural areas, McCool [47], based on empirical studies, finds that encountering more than 10 groups during a recreational experience in a natural area is perceived negatively by visitors. For our case study, since it is an urban public space, much smaller than a natural park, this number is excessive; we could identify between 1 and 3 encounters, which may seem excessive, and there will be visual contact between them, but we must bear in mind that the general tourist does not expect to have an experience based on privacy and solitude in a public space.

#### *4.3. Determination of Visitor Carrying Capacity*

This process began with the calculation of the number of people that could be accommodated simultaneously and in a static manner on the Usable Surface for Visitation (USV) defined for Miguelete Street, taking into account an interpersonal distance of 1.20 m. This estimate was made by applying the vector research tool “random points within polygon”, with the point-to-point distance set to the previously mentioned proxemic value (Figure 8).

The result shows a picture of a random distribution of visitors along the USV. Thus, the number of people that could be accommodated in the street, respecting the proxemic distances, would be 386 people; it can be distinguished that 278 could stand and 108 could sit on edges, benches, or steps, the use of non-formal seating is normally seen in this space and respecting a free circulation space, which would be the shortest route identified. It should be noted, however, that this is not the normal distribution of people in a street. Tourist groups of around 15 people, dyads, triads, as well as individuals are more common in urban spaces. Also, not all benches are fully occupied.

The next step was to spatially organise the visitors into groups and identify areas where the activity could take place (observation viewpoints and meeting points). This will allow carrying out such activities simultaneously and under conditions of physical and psychological comfort. This was carried out using the QGIS tool “Heatmap” (Figure 9), from which it is possible to extract the areas with the highest concentration of points. In this way, up to 3 areas with the potential to receive tourist groups were identified at a distance of at least 15 metres with elements, in this case, individual pedestrians, that break up the viewshed and thus prevent direct visual contact between the groups. The avoidance of encounters between groups, is a key indicator of the quality of the visit.



Figure 8. Point count on Usable Surface for Visitation (USV).

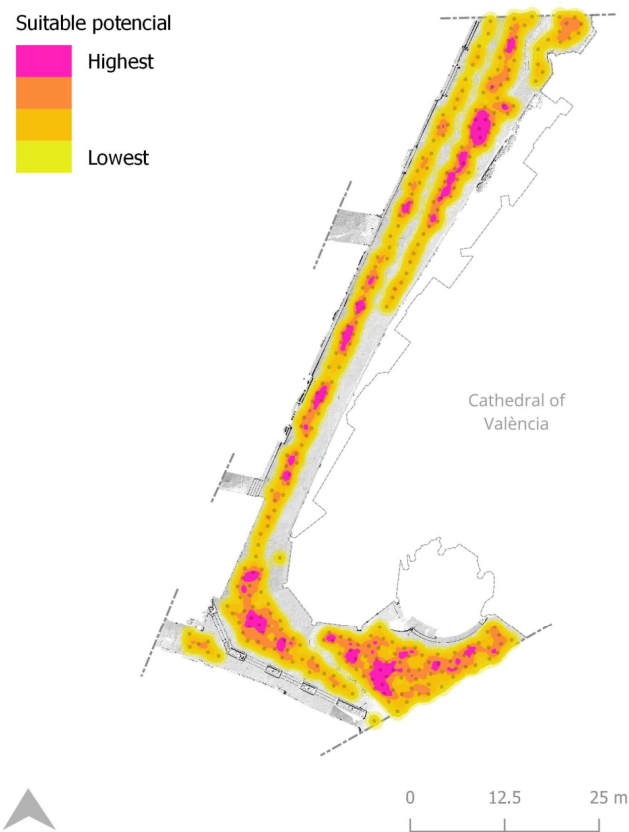
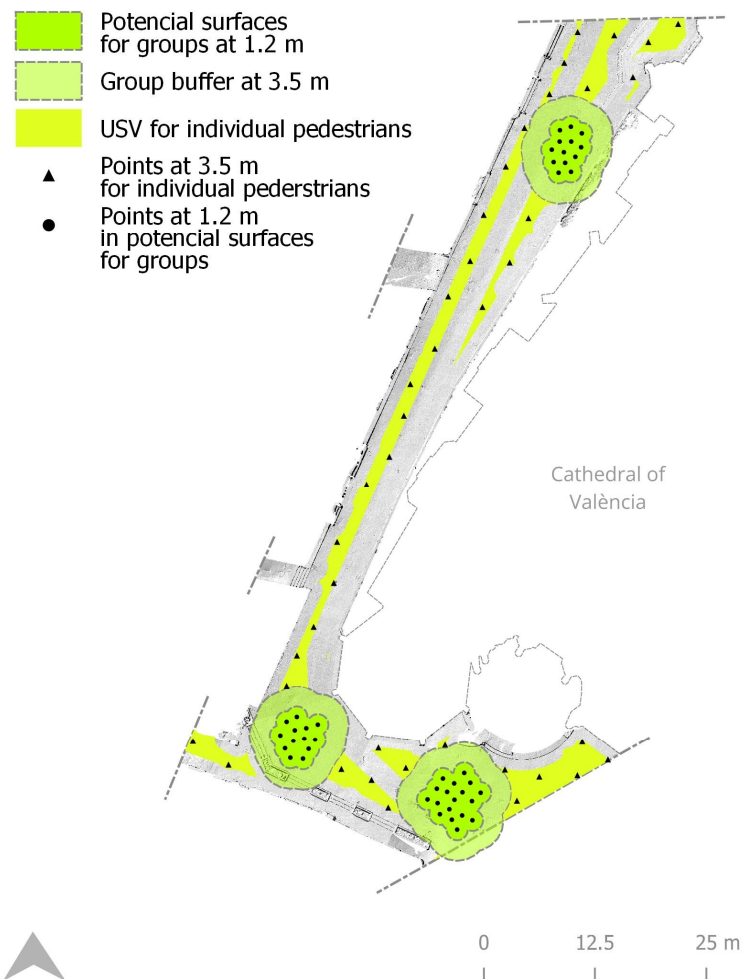


Figure 9. Areas potentially suitable for hosting groups.

Local guiding companies report that these groups usually consist of about 15 people. Although a simple calculation shows that it would be possible to accommodate 18 groups at the same time, this would be totally unfeasible for reasons of safety and personal comfort. Thus, based on the calculation of suitable areas to accommodate groups where 3 appear, and derived from the studies on the maximum number of encounters between groups, a maximum of 3 groups at the same time in Miguelete Street is proposed. Using the “point sampling tool”, the points located in the areas of greatest concentration are determined, allowing the proximity-based grouping of approximately 15 people per group.

Hence, an area of 320.264 m<sup>2</sup> is occupied by the 3 groups of around 15 people each, leaving the remaining area of 244.678 m<sup>2</sup> for individual visitors. If we apply a “public distance” proxemics standard of 3.50 m<sup>2</sup> to the latter, we will have a total of 40 individual walkers.

Therefore, the visitor carrying capacity in terms of comfort for people in Miguelete Street would be 3 groups of an average of 15 people and 40 individual pedestrians at the same time. The ideal location for a meeting and observation viewpoint for the groups is shown in Figure 10.



**Figure 10.** Random distribution of the three groups of visitors within the USV.

## 5. Conclusions

The use of geospatial tools and the generation of the point cloud from 3D laser scanning data were key to determining the physical characteristics of the urban tourist areas as was the result of the study carried out in València. In addition, the use of different algorithms to interpret the point cloud made it possible to obtain the information resulting from the analysis. It was also possible to generate a georeferenced GIS model incorporating the obtained data.

It should be noted that the combined use of random point tools with heatmaps allows the identification of potentially suitable areas for a meeting or gathering points for tourist groups. The communication of this finding could be facilitated through the integration of digital tools and mobile applications for tourism and heritage managers, who could designate ideal areas for visitor groups. A follow-up study could delve deeper into the practical implementation of this concept. It could investigate how such designated meeting areas impact visitor flow, satisfaction, and the overall management of tourist groups. Additionally, examining the feasibility of incorporating these findings into urban planning and heritage site management strategies could be a valuable avenue for future research.

In addition, it is possible to say that the understanding of the physical environment alongside human behaviour in an analytical way, draws parallels between the present research and Spatial Syntax theories.

For all these reasons, this study offers an innovative approach for efficiently and accurately determining the maximum number of visitors in a public space, ensuring their quality and comfort. This not only enhances the visitor experience but also mitigates the impact on heritage sites and benefits local residents' quality of life.

Insights from other studies conducted at a macro-urban scale, compared to our micro-urban focus, underscore the significance of integrating carrying capacity assessments, pedestrian flow analyses, and GIS tools for achieving long-term, socially sustainable tourism management, thus concluding that these strategies hold the potential to redistribute tourist flows within historic city centres, stimulate economic activity, and ensure the protection of heritage sites and visitors from potential threats.

A micro-urban scale study applied to an open space, such as a street, offers the advantage of not only calculating the suitable visitor carrying capacity but also identifying optimal zones for accommodating groups, taking into account physical interpersonal distancing, spatial characteristics, and predominant pedestrian flows.

The results of the application of this geospatial method to Miguelete Street show that the visitor carrying capacity to develop tourist visitation activities is 3 groups of 15 people and 40 individual pedestrians.

The proposed methodology should be technically accessible and easy to apply. It can be an extremely useful tool for town councils in the efficient management of historic centres, as it includes a GIS analysis that allows the visitor carrying capacity to be determined. However, it is important to acknowledge potential challenges that may arise during its implementation, like the need for accurate point cloud data collection, or the consideration of changing visitor behaviours and preferences. Despite these challenges, the methodology offers valuable insights into determining visitor carrying capacity, which can significantly enhance the management of tourism activities and heritage public spaces.

In the context of this work, new lines of research have been launched in the use of sensors to obtain real-time information on visitor flows to know the comfort conditions (vs. saturation/congestion) in which the activity is taking place, and thus to relate people counts to the visitor carrying capacity values. As further research, it is crucial to validate the obtained results by comparing them with the existing tourist group formations. Additionally, the suitability of these areas can be assessed in conjunction with various physical and comfort-related variables. Furthermore, this methodology is not limited to streets but can also be upgraded to be applied to squares and other open spaces, not necessarily in urban contexts. Exploring the adaptation of this tool to interior spaces within tourist complexes or heritage buildings is another potential research avenue.

These findings are valuable for tourism management and urban public realm planning. They offer detailed and easily updatable information that supports decision-making processes related to visitor management, efficient space allocation, and urban infrastructure improvement. Understanding visitor behaviour and spatial usage patterns can enhance the overall visitor experience in heritage spaces and contribute to their preservation. Additionally, this knowledge can help to mitigate overcrowding, minimize negative impacts on local

residents and cultural assets, and inform strategies for optimal space distribution and group management, ultimately leading to improved urban infrastructure within heritage sites.

**Author Contributions:** Conceptualization, M.J.V. and P.R.O.C.; methodology, P.R.O.C., M.J.V., P.A.E. and R.C.V.S.R.; software, P.R.O.C.; validation, M.J.V. and P.R.O.C.; formal analysis, P.R.O.C. and M.J.V.; investigation, P.R.O.C., M.J.V., P.A.E. and R.C.V.S.R.; resources, P.R.O.C., M.J.V., P.A.E. and R.C.V.S.R.; data curation, P.R.O.C.; writing—original draft preparation, P.R.O.C., M.J.V., P.A.E. and R.C.V.S.R.; writing—review and editing, P.R.O.C. and M.J.V.; visualization, P.R.O.C.; supervision, M.J.V.; project administration, M.J.V.; funding acquisition, M.J.V. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the project “Analysis and Development of HBIM Integration into GIS for Creating a Cultural Heritage Tourism Planning Protocol” (ref. PID2020-119088RB-I00), funded by the Ministry of Science and Innovation, Government of Spain.

**Data Availability Statement:** The datasets used and/or analysed during the current study are available from the first author upon reasonable request.

**Acknowledgments:** The authors gratefully acknowledge the critical review of this paper by Danielle Willkens of Georgia Tech University (USA).

**Conflicts of Interest:** The authors declare no conflict of interest.

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