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Tracking Visitors in Crowded Spaces Using Zenith Images: Drones and Time-Lapse.

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Highlights

- This paper explores drones and time-lapse photos to study tourists' behavior.
- Zenith images provides detailed data regarding in high density areas.
- Two case studies are conducted in cultural sites.
- Social use of space is due to negotiation processes.

*Manuscript (remove anything that identifies authors)

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Abstract

The aim of this article is to analyse the extent to which zenith images can be used to study visitor behaviour in crowded spaces. The paper presents two studies of zenith image capture in two micro-spaces (both monumental heritage sites) in the north-east of Spain: the first used drone images to conduct a quantitative study on patterns of visitor use at Empúries archaeological site; and the second was a qualitative study on conflicts of use in Cathedral Square, Girona, using time-lapse photography from a fixed camera.

Results of the study show that visitor behaviour at the sites does not alter in peak season when spaces become increasingly crowded.

Keywords: zenith image, drone, time-lapse, visitor behaviour, overcrowd, space-time

1.Introduction

An extensive range of tools for tracking tourists are increasing the volume of available data and introducing big data criteria in tourism studies (Li, Xu, Tang, Wang & Li, 2018). Over the past decade, one of the most common tools is GPS, which has been used widely since Shoval & Isaacson (2007) published their seminal article on its use. Tracking tourists using GPS enables researchers to identify the following: visitors' spatial use patterns (Edward & Griffin, 2013); how the use of space has evolved over time, (Birenboim, Anton-Clavé, Russo & Shoval, 2013); differences between visitors' journeys (Zheng, Zhou, Zhang, et al., 2019); and the anticipation of visitors' itineraries (Zheng, Huang & Li, 2017), among other possible areas of analysis (Shoval & Ahas, 2016).

More recently, smartphone signal capture devices have also been added to these tools with the aim of identifying the occupancy density of a space and the actual behaviour of visitors within it. This line of research has been developed very intensively in recent years using roaming signals (Raun, Ahas & Tiru, 2016), Bluetooth (Yoshimura, Sobolevsky, Ratti, et al., 2014; Versichele, de Groote, Bouuaert et al., 2014) and Wi-Fi signals (o , Barzan, Quax & Lamotte, 2013). These methods can be added to indirect tourist tracking methods, which include surveying activity in UGC environments such as social networks of photographs, or using transaction data such as visits to websites or credit card consumption data (Li et al., 2018). All of these data complement one another and offer a partial vision of tourists' general behaviour.

Zenith images (cameras placed in strategically high spots, and aerial, or drone photos) provide information on visitor behaviour at any given time in any given place (Yamanaka, Motohiko, Yoshiyuki & Susumu, 2006; i , Osori, Marino-Tapia et al., 2007; Balouin, Rey-Valette & Picand, 2014; King & McGregor, 2012), and can be used to show how visitors interact with one another. In crowded areas, visitors behave in certain ways for many reasons, but the presence of other visitors influences them in a way that particularly stands out.

Studies on visitor behaviour have generally centred on large-scale tourism, with a strong focus on regional and urban spaces (e.g. Ahas, Aasa, Mark, Pae & Kull, 2007; Ferrante, De Cantis & Shoval, 2018; Galí-Espelt & Donaire-Benito, 2006; Lew & McKercher, 2006; McKercher & Lau, 2008; Shoval & Isaacson, 2007; Sugimoto, Ota & Suzuki, 2019). Using technology in tourism research has been instrumental in the study of micro-spaces, especially natural spaces (e.g. Beeco, Hallo & Brownlee, 2014; Chhetri & Arrowsmith, 2008; Wolf, Hagenloh & Croft, 2012). Published studies on micro-spaces include the Summer Palace in Beijing (Xiao-Ting & Bi-Hu, 2012), Port Aventura theme park in Spain (Birenboim et al., 2013), the Aalborg Zoo in Denmark (Birenboim, Reinau, Shoval & Harder, 2015), and more recently, the study by Zheng et al. (2019) on Xiamen University Campus.

Two factors underpin the growing interest in micro-scale within the field of tourism research. Firstly, the consolidation of the mobility paradigm, which places high importance on the movement of people, ideas, and objects in a physical space (Sheller & Urry, 2006). The paradigm of mobility questions the binary concepts of modernism (tourism - non-tourism; local - visitor) and poses the need to integrate the different ways in which individuals move around in a space within the study of social sciences (Cohen & Cohen, 2012). This logic has been integrated by de Souza (2016), together with the concept of performativity in his proposal of tourism as practice (TAP). Research on mobility suggests that analysing large flows on a global scale must be complemented by further analysis on a regional or local scale, and indeed on a micro-scale: movement in public spaces, daily trips in the urban space, public transport routes, and so forth (Zheng, Wang & Li, 2017). Secondly, the proliferation of new devices has made it easier to gather very precise information on the mobility of visitors in confined spaces. In the era of the ICT, there is a growing number of sensors and devices that gather information on tourist behaviour in spaces (Li et al., 2018). Micro-scale research has many implications for managing and marketing tourism areas, as well as analysing visitors' perceptions and behaviours in destinations.

Using zenith micro-scale images to show times of day when areas are most crowded is particularly useful, as this is when visitors will show any change in behaviour due to over-crowding. Therefore, the aim of the present article is to analyse how congestion can affect how the space is used on a micro scale. As zenith images capture images of the space at any given time, this can be a very efficient tool to study interaction between visitors.

The study was carried out on two monumental micro-spaces in the north-east of Spain: Girona (the Cathedral Square) and Empúries (an Ancient Greek archaeological site). A quantitative study was conducted on the patterns of use of Empúries archaeological site based on drone images; and on a qualitative study of conflicts of use in Cathedral Square in Girona based on time-lapse photography obtained with a fixed camera.

2. Literature review

2.1. Tracking Visitors with Space-Time Technologies

Analysing visitor behaviour in a space is an essential tool for managing destinations. It enables researchers to identify the routes visitors follow and the main itineraries, the unequal distribution in space (in areas with heavy concentration and 'i visibl spaces'), the temporal distribution of routes taken and, more specifically, the differences in the use of space patterns. In this way, corrective mechanisms can be proposed, the results of diverse actions can be assessed, marketing strategies can be fine-tuned and actions can be targeted at diverse groups of tourists (Shoval & Ahas, 2016, Li et al., 2018).

One of the most common methods to track tourists is using a GPS, and one of the earliest references is the article by Shoval and Isaacson (2007), which outlined the potential of using

GPS to monitor the effective behaviour of visitors in three distinct cities: Heidelberg, Jerusalem and the Old City of Acre. The article highlights that the main benefits of using this method are that it provides a copious amount of very precise data, and that the results can be put to practical use. Ethical questions were also raised, however, along with possible bias in visitor behaviour due to the fact that visitors were aware that their itinerary was being monitored.

Following on from this initial study, various other authors have used GPS technology to analyse visitor behaviour in tourism destinations. Shoval and Ahas (2016) identified 29 research papers published in peer-reviewed scientific journals between 2007 and 2015 that used GPS to track tourists. GPS as a research tool has been mainly used in three fields of work. Firstly, to identify itineraries followed by tourists, as illustrated in studies by Edwards and Griffin (2013) in Melbourne and Sydney; Sugimoto, Ota and Suzuki (2019) in Veno District (Tokio); and Zheng, Huang and Li (2017) in the Summer Palace in Beijing. Secondly, there are simultaneous studies of space-time variables which analyse changes in the use of a space over time, e.g., Birenboim et al. (2013) in Port Aventura theme park in Salou (Spain), Xiao-Ting and Bi-Hu (2012) in the Summer Palace in Beijing, and Galí, Donaire, Martínez and Mundet, (2015) in the historical centre of Girona. Other studies have identified differences among groups or segments, e.g., McKercher, Shoval, Ng and Birenboim (2012) studied the differences between first-time visitors and repeat visitors, Petterson and Zillinger (2011) looked at the differences in spatial patterns according to the rating of the experience, and Zakrisson and Zillinger (2012) discovered three types of visitors according to their spatial behaviour: Main Attraction Visitors, Wanderers, and Specialists. These studies show how GPS can deepen insights into tourist behaviour. The level of detail of the route taken and the possibility of correlating spatial data with those obtained by means of a survey (Galí et al., 2015; Sugimoto, Ota & Suzuki, 2019) make it possible to gain exhaustive knowledge of spatial patterns. However, this technology also has limitations. Firstly, using GPS requires complicated logistics, and for this reason the number of recordings tends to be low, as visitors need to be supplied with the GPS, and the information downloaded from the GPS post-visit. Secondly, tourists are aware that their behaviour is being observed, and this introduces possible bias. Finally, the data show the particular itineraries of visitors in the space, but fails to offer information on how visitors interact with one another.

Several studies using smartphone signals to track visitor behaviour have been published simultaneously (Shoval, Issacson & Chhetri, 2014). Information can be obtained from a smartphone in many ways; in some cases, the information is gathered from travellers roaming around throughout their stay in an international destination. An immense volume of information can be gathered in this way. For example, Raun, Ahas and Tiru (2016) measured the spatial, temporal, and compositional parameters of visits by foreign tourists in Estonia, with over a million recordings. On a national scale, the data enables researchers to identify the counties with the most visits, seasonal differences, preferences by nationality, and the most common itineraries. Data recorded by telephone masts in Estonia enabled several studies to be conducted, such as those by Ahas et al. (2007), and Ahas, Aasa, Roose et al. (2008).

A second way is to use GPS information obtained from visitors downloading applications. This is the method used by Yun, Kang and Lee (2018), who analysed seasonal differences among visitors to Bickchon Hanock Village (Seoul).

A third method that has drawn much attention in recent years is the use of Bluetooth signal sensors on mobile devices. These devices enable researchers to work in open spaces such as a festival (Delafontaine, Versichele, Neutens & Van de Weghe, 2012; Versichele, de Groote, Bouuaert et al., 2014), in Barcelona city centre (Yoshimura, Amini, Sobolevsky et al., 2017), or closed spaces such as a cathedral (Versichele , Neutens, Delafontaine & Van de Weghe, 2012) or museum, as in studies by Yoshimura, Sobolevsky, Ratti et al. (2014), and Yoshimura, Krebs and Ratti (2017) in the Louvre.

There is no doubt that the availability of mobile data has opened up a new line of work, which means researchers can work with a great deal more recordings than can be obtained from a GPS. The information obtained is highly detailed and enables researchers work on different geographical scales. However, both of these sources also have their limitations. Roaming data are difficult to obtain, and the quality of the information is inferior to that which can be obtained from GPS (Li et al., 2018).

The amount of data obtained from an application depends on the extent of coverage of the population studied. For example, Miyasaka, Oba, Akasaka and Tsuchiya (2018) point out visitors' low usage of a particular application (below 15%); furthermore, the profile bias of users who opt for the tool (younger people more likely to use technology, longer stays, a greater predominance of first-time visitor and groups). Finally, Bluetooth is constrained by the limitation of the s sors' radius (Li et al., 2018). In all cases, ethical issues arise around using sensitive information, and non-acceptance of this on part of participants.

More recently, the first studies and reports on visitor behaviour by tracking card use have emerged. However, this line of research is still at an initial stage, and accessing information proves difficult. For instance, Weaver (2008) studied visitor behaviour based on different forms of consumption recorded on credit cards.

Zoltan and Meckercher (2015) have mapped tourists' movements through data generated by card consumptions (cards sold by DMO offering free or heavily discounted tickets to attractions and activities, and access to free public transport in the area). Data on consumption are discontinuous, they only record visitor behaviour in terms of purchasing actions. Furthermore, obtaining these data is very costly. However, they provide vital information on consumption habits and are very useful if correlated with other data.

Li et al. (2018) identify the UGC (User Generation Content) data as the main field of research in big data in tourism. UGC data consist of both online textual data and online photo data. Among the former, Molz (2010) analysed temporal and mobile dimensions of tourists' performances using travel narratives published on online travel blogs. Leung, Wang, Wu et al. (2012) used online diaries of trips to investigate patterns of movement among visitors in Beijing during the 2008 Olympic Games. Hawelka, Sitko, Beinat et al. (2014) examined the mobility patterns of various nations using a billion tweets. Online photo data have become ever more numerous due to the widespread use of image-based social networks. Vu, Li, Law and Ye (2018) analysed 29,000 geotagged images from 2,100 tourists, with the aim of identifying visit itineraries. Önder (2017) worked with images obtained from Flickr to classify multi-destination trips in Austria. Cesario Iannazzo, Marozzo et al. (2016) studied the behaviour and mobility patterns of Instagram users who visited the 2015 Universal Exposition in Milan. UGC-based data are discontinuous because they only offer information on fragments of the tourist experience (those that the tourist feels merit a comment or an image); they also suffer from selection bias, as the user profile does not even correspond to the average profile. However, they are open sources, offering large volumes of information and with ever more sophisticated automatic analysis systems.

2.2. Zenith images for visitor observation

Zenith images have traditionally been used for geography and cartography, usually on a large scale. There is a long tradition of using aerial photographs and photointerpretation in studies on land use, urban planning, landscape or biogeography. In tourism, zenith images have traditionally been used for promotional purposes (Hughes, 2017), for the study of tourist geography (Prasenja, Alamsyah & Bengen, 2018), for the re-creation of spaces with augmented reality (Mirk & Hlavacs, 2015), and for the study of visitor behaviour in particular places (Yamanaka, Motohiko, Yoshiyuki & Susumu 2006); the last-mentioned being the least developed line of research. The advantage of using this method over other methods to observe visitors is that the camera does not restrict the size of the sample; thus, it can provide information on the behaviour of the whole set of individuals.

Muhar, Arnberger & Brandenburg, (2002) wrote a theoretical overview of monitoring techniques, including automatic cameras and time-lapse video, and concluded that cameras are an excellent method for monitoring visitors, despite the difficulties encountered when interpreting the results. Janowsky and Becker (2002), also explore the advantages and disadvantages of video monitoring in a preliminary study carried out in Stuttgart urban forest. The main aim of the study was to collect data on visitor numbers and composition.

Studies based on images from cameras have been conducted mostly in beach and coastal spaces. For example, Kammler and Schernewski (2004) combined webcam images and aerial photographs (taken from a plane) to study the intensity of beach tourism on the coast of the Baltic Sea, in Germany. Yamanaka et al. (2006) used video cameras to analyse the spatial-temporal behaviour of visitors during shellfish-gathering in Tokyo Bay. The data collected were distributed on a grid which made it possible to ascertain the space-time distribution of visitors to the bay. i , Osorio, Marino-Tapia et al. (2007) studied the b ach's load capacity using the 'salt & p pp r' Kernel function, which compares each pixel with that of its neighbour in order to infer the presence of individuals in the space. This method makes it possible to discover visitors' temporal distribution and geographical location. Images obtained from cameras in events have also been used. During the 2008 Östersund Biathlon World Championships, Petterson and Zillinger (2011) used a camera fixed 55 meters above the stadium area to take 60 pictures per hour during competitions, over five different days.

Preliminary research on using aerial photographs to monitor tourists reveals three main advantages of this method over other methods used to track tourists. Firstly, it is possible to collect the behaviour of all of the users who are in the ca ra’s operational radius during the period of the study. This means the problem that arises with other methods can be resolved, namely, that they cannot collect the behaviour of the users in the whole space being analysed. Secondly, recordings can be taken over long periods of time, and thus, different periods of the day or times of the year can be compared. Thirdly, when tourists come into contact with each other, their behaviour can be analysed, especially in high-density spaces.

Whilst the use of cameras has played its part in relatively wide-ranging academic studies, those based on drones are much less frequent. Birtchnell and Gibson (2015) discuss various civilian uses of drones, including their application in different fields of research. Until now, technology has mostly been used in studies outside the social sciences. However, there is clear potential for their use in human geography and social science research, especially to capture "the subtle choreographies of crowds" (Birtchnell & Gibson, 2015: 187). One example is a study by Britchnell and Gibson (2015) in which a drone captures video footage of the aerial crowd dynamics at the 2013 Burning Man Festival (Codel, 2013). Birtchnell (2017) also mentions drones being used in geography studies to obtain more aerial views of spaces. Although the study focuses on how the technology is used for other purposes (e.g. surveillance, management, deliveries, or conservation), its potential for anthropological research of Amazonian tribes is acknowledged. The author points out that when compared with other tracking technology (CCTV, smart phones, etc.), drones show key potential as they provide "access to three-dimensional space" (Birtchnell, 2017: 236). Dolesh (2015) discusses the potential use of drones for mapping, managing, and monitoring natural parks and remote areas for the purpose of public-safety, among other uses. Song and Ko (2017) discuss using drones in national park surveillance, both for the safety and security of visitors as well as the environment. Among several civilian uses of drones, Hayat, Yanmaz, and Muzaffar (2016) talk about their use in search and rescue missions for monitoring, mapping and surveillance purposes.

In the case of time-lapse, it is used as a cinematographic technique, where events that generally occur at slow speeds are captured, and played back at normal speeds (Liu & Li, 2012). With time-lapse photography, a very long situation over a period of time or long temporal sequence can be presented in a much shorter time.

This technique is quite often used in the fields of biomedicine and biology, and is currently being used to examine the embryonic development processes of different species (Chitnis & Nogare, 2018). Its use in geographical research is less intensive, but also important (Kycko, Zagajewski, Zwijacz-Kozica et al., 2017; Walter, Jousset, Allahbakhshi et al., 2020), as with the field of geology (Cayla & Martin, 2018). Time-lapse photography is less popular in other fields.

In tourism, time-lapse technology is mainly used to advertise destinations. It has been little-used in academic research, despite the obvious advantages it offers to the study of visitor behaviour (Muhar et al. 2002). Cessford and Muhar (2003) conducted a study on national parks and nature conservation areas by monitoring visitors with time-lapse video. The authors stress that automatic cameras and time-lapse video footage constitute an excellent method for monitoring visitors, despite the difficulties encountered in interpreting results. Also, Arnberger, Haider, and Brandenburg (2005) published an article in which they studied visitor behaviour to the Danube-Auen National Park in Austria, using time-lapse video footage. Among the benefits highlighted by the authors are time-lapse as an excellent source of information, a tool that is easy to manage and that provides very precise results regarding visitor behaviour. With the same aim of analysing visitor behaviour, Arnberger and Eder (2007), conducted a study in the urban forests of Vienna (Austria) using the same time-lapse technique on a continuous basis, and combining this with tallies made by observers on sampling days.

2.3 Summary

Table 1 shows the main characteristics of the various methods of tracking visitors found in the literature, and compares them with using zenith images. As seen, all of the methods used have both advantages and disadvantages, and serve different purposes.

All the methods can manage an enormous amount of information in non-participatory methods and non-specified discontinuous space-time data. Quantitative tools predominate. Using these types of tools can lead to ethical problems when it comes to guaranteeing tracked visitors' privacy. Although all the tools have some criteria in common, each one responds to a specific need and brings different advantages. Therefore, a single method does not exist, as each problem is unique and requires a different method. The analytical capacity grows exponentially if several methods are employed simultaneously, and this will be one of the future trends in the consolidation of big data in tourism studies (Li et al., 2018).

Table 1. Characteristics of zenith images in relation to other forms of tracking visitors.

The principal advantage of zenith images is that they cover the behaviour of the total users of the space in the area subject to analysis and during the period of data collection. This is especially important for the study of collective behaviour, more than individual behaviours, and the interaction among individuals occupying a space. Like most methods, it is not self-reported, which avoids the behavioural bias of observed users. Moreover, it allows the use of both quantitative methods and qualitative methods of analysis and, potentially, the combination of both. Zenith images can be a useful instrument for space planners, because they enable collective behaviour, and reactions to the various external stimuli as a whole, to be ascertained. Zenith images also have limitations that must be considered, as they are not a method that can replace existing ones, but rather complement them.

The case studies test the two zenith image systems: drones and aerial cameras; as well as both quantitative and qualitative methods. The aim of using these methods in the two spaces is to analyse how visitors react to congestion on a micro-scale.

3. Two Case Studies: Drones in an archaeological site and Time-lapse in a Cathedral Square

In this section the results of two case studies using both zenith techniques are presented. In the first analysis, drones were used to track visitors' behaviour at Empúries archaeological site. The site is an archaeological complex of Ancient Greek and Roman origin. The visit is organized via a series of paths running between the ruins, and organized in such a way that the space can be considered a grid of sights and vertices. The second case study analysed visitors in Giro a's Cathedral Square using a fixed camera that took time-lapse videos. Girona is a monumental city in the region of Catalonia (as mentioned above, in northeast Spain), and Cathedral Square is its most visited space.

Figure 1. Map of the region

3.1. Case Study #1: Empúries Archaeological Site

3.1.1 Study area

For the Greeks, Empúries was the gateway to the Iberian Peninsula, and they made a permanent settlement here between 6th century BC and 5th century AD. The archaeological site is located close to the French border, in the heart of the Costa Brava. It is one of the few archaeological sites conserving both a Greek and Roman city together. The Greek city

(Neapolis) has been almost completely excavated, but most of the Roman city is still awaiting excavation. The museum is located between the two cities, and the site receives about 150,000 visitors per year, 40% of which access the site during the months of July and August. The month when most visitors are received is August, which coincides with the month with the highest numbers of tourists drawn to the tourist region of the Costa Brava.

3.1.2. Methodology

In Spain, drone use is regulated by Decree 1036/2017, which permits flight above urban areas and agglomerations, subject to many restrictions on their use and provided that the operator follows certain rules; furthermore, it requires the controller to hold a drone pilot's licence. The site at Empúries overlooks the sea, which made it possible to conduct flights from above the sea, at an angle of 45 degrees. The drone used was a DJI Phantom 4, which has a built-in camera, model DJI FC6310 f/8-1/240 s. This drone can only fly for 15 minutes before needing recharged, and as batteries have to be replaced regularly, temporary information is therefore not continuous. This problem could be solved by using two or three drones simultaneously.

As the objective of this study was to analyse visitor behaviour during the period of maximum visitor concentration, August was selected for the study, and data were collected for both weekdays and weekends. The most active time slot was from 11:00 a.m. to 1:00 p.m., so images were taken between these times on the three days.

The camera recorded one image every five seconds, reaching a total of 1,965 photographs. As it was impossible to identify the people filmed, ethical issues did not need to be taken into consideration.

There are various ways to transfer the visual information collected by zenith images to data. In some cases, the cartography presents heat or density maps to represent the intensity of use. In other cases, the space is divided into grids, which makes it possible to assign occupancy values to each cell (Yamanaka et al., 2006). The information can also be transformed into vectors, which allows the researcher to establish routes within the space (Zheng, Huang & Li, 2017).

The spaces formed by streets or paths can be represented in a graph. The graph shows a set of nodes connected by edges representing the relationships between the nodes. In tourism studies, graph theory has been used to analyse mobility of visitors in urban spaces (Sugioto, Ota, Suzuki, 2019; Hu, Li, Yang & Jiang, 2019), in natural spaces (Taczanowska, González, Garcia-Massó, et al., 2014; Taczanowska, i lański, Go al , Garcia-Massó, & Toca-Herrera, 2017), or on routes within a region (Shih, 2006).

Graph theory has been used in this study to analyse the topological structure of the archaeological site. The archaeological site is represented on a graph by identifying the nodes as if they were intersections of roads, thus enabling different routes to be plotted. Using this criterion, Empúries is organized into 13 nodes connected to each other with 14 edges, as illustrated in the figure 2.

Various indicators enable the topological structure of the graphs to be analysed. The density of the graph measures the number of existing edges in relation to the total number of edges. The higher the density, the higher the diversity of possible network paths. Modularity measures the structure of networks or graphs, and is used to measure the strength of the division of a network into modules (also called groups, clusters or communities). Networks with high modularity have solid connections between nodes within modules, but few connections between nodes in different modules (Bolobás, 2013).

Figure 2. Graph of Empúries

In addition, the intensity of use of the different sights and vertices has been estimated in order to identify the areas of greatest agglomeration. Each edge can contain several vertices, which enables differentiated data for each of the fragments that make up an edge to be recorded. For example, from a strictly topological structure, the first edge extends to the first intersection. However, figure 3 shows that the edge is made up of three distinct units: the entrance, the sanctuary area, and the area connecting the main corridor. Each of these vertices has a different use and logic; thus, the data have been recorded differently. The model in figure 3 is therefore made up of 11 sights and 33 vertices.

Figure 3. Graph with vertices and sights at Greek Empúries

The degree of concentration also depends on the surface of each space. In large spaces such as the Agora, many visitors can be dispersed throughout the area, while in smaller spaces it is inevitable that the density of visitors will be high. We have calculated the density (square meters per person) in each image captured by the drone, and have set two capacity thresholds: high density (under 6 square meters per person), and very high density (under 4 square meters per person). These statistics were extracted from the study on occupancy of the Alhambra in Granada (Spain), which preceded the management model based on the limitation of the load capacity (Hernández, 2001).

3.1.3 Results from zenith images taken by Drone

The graph of Empúries has a diameter of 5, which is the maximum number of edges that need to be covered to join the farthest nodes. The average degree is the average number of edges that connect all the nodes, which in the case of Empúries, is slightly over 2. When the number of edges is very close to the maximum, the graph is very dense with extremely high connectivity. In contrast, low density shows that the number of edges is very limited, and alternative routes are therefore significantly reduced. In the case of Empúries, the graph density is 0.179, which shows that visitors have very few alternative routes. The indicator that measures the connection between subgraphs or secondary groupings is the modularity indicator. High modularity shows a strong relationship, but a weak connection between the various secondary groups. The modularity index for Empúries is 0.378, which is a relatively low value. This means that generally, there is little connection between the nodes, nor is there a strong connection between nearby nodes. The system identified three groups: Main path, Northern path and Western path.

The analysis of the topological structure of Empúries reveals that there are very few alternative routes, and that visitors can only make a few decisions that condition their itinerary.

Table 2 shows the centrality measures of each of the nodes making up the graph. The eccentricity shows the distance to the furthest node, and the closeness centrality is calculated as the reciprocal of the sum of the length of the shortest paths between the node and all other nodes on the graph. Finally, the between centrality of each node is the number of shorter paths connecting all the nodes that cross each other. The three measures coincide in the centrality of node 5, located at the Agora, and node 11, in front of one of the main sights, the house with the mosaic.

Table 2. Centrality measures of each node

Graphs can be weighted according to various criteria. This enables values to be assigned to the edges or nodes, so that the topology can be mapped to the physical structure of the space or the behaviour of the visitors in the enclosure.

Firstly, an edge weighting based on effective distance was considered. Thus, the shortest path between node 5 and node 12 is two edges (K and L) from a topological point of view.

However, if we take the effective distance of each edge into account, the shortest path is route D - B - M. Table 2 represents the weighted values (in meters) for each node. The nodes with greater centrality have now moved towards the entrance of the enclosure (nodes 3 and 2), but node 5 continues to be at the centre of the graph, and coincides with the Agora. Secondly, we have weighted each edge according to the average number of visitors recorded in the data.

A study on the volume of use in the vertices and different sights was carried out to complement the analysis of the graph in order to obtain more precise knowledge regarding the congested areas. The average number of people in the Greek section of Empúries during the period studied was 81.34 with a deviation of 13.91. The archaeological site as a whole (the Greek city, the Roman city and the museum) received an average number of 212 visitors over the three days.

Table 3 shows the average occupation of the main vertices. Visitors spend two thirds of their time in only five vertices. In contrast, the average percentage of occupation is less than 1% in 16 vertices. If all visitors were distributed evenly among the 33 vertices it is made up of, the proportion of visitors in each of them would be approximately 3%. The temporary distribution of this occupation is very irregular. At certain times, a single vertex can concentrate more than half of the total number of people visiting Greek Empúries at any one time. Table 3 shows the maximum values for the main vertices and, as can be seen, the concentration of visitors is high at certain points.

Table 3. Average and maximum occupation in the main vertices (%).

Spatial concentration is one of the main management problems in tourist destinations, especially at heritage sights. This happens on all levels, from regional to micro-level (Van der Borg, Costa, & Gotti, 1996; Russo, 2002; Shi, Zhao, & Chen, 2017). In the case of Greek Empúries, the spaces with the greatest intensity of use are: (1) those located in the central corridor, (2) those with the more interesting sights, and (3) those located in the first phase of the visit. Areas showing low intensity are the most peripheral areas, with nodes of less relevance, and those in the final phase of the visit. Figure 4 shows the vertices of the highest frequency of use: the platform in front of the Temple of Asclepius, the Agora, the main street next to the market, the factory, and the Peristyle house.

Figure 4. Photo showing vertices of highest frequency of use

As mentioned above, the degree of concentration depends on the surface of each space. Therefore, after calculating the density at each vector and sight (taking the two capacity thresholds into account: high and very high density), the results demonstrate that the two spaces with the highest pressure have also the largest surface, and so do not show a high degree of average occupancy.

Table 4 shows the vertices with the highest density. The maximum values can be seen at the entrance vertex (also the exit), and in smaller vertices opposite significant sights: vertex 3 (opposite the factory), vertex 4 (in front of the peristyle house), vertex 17 (in the Early Christian basilica) and vertex18 (at the manor house mosaic). In this way, the main nodes' capacity to attract affects the over-occupancy of the vertices in the surrounding area.

Table 4. Times of high and very high-density crossing at the main vertices (%).

The map in Figure 5 shows a concentration of visitors in the central vertices which connect the main sights. In contrast, a large part of the archaeological ruins has extremely low occupation, mainly the Northernmost and Western areas of the site. As is common in spaces with monuments, there is a concentration in areas of greater interest and a low intensity of use in more peripheral areas.

Figure 5. Map showing the concentration of visitors

Using a drone means that the degree of occupation for each element in the space can be systematically analysed. It also gathers very useful information on congestion levels in different sections of the visit. Like most heritage sites, Empúries takes carrying capacity criteria into account, but bases it on general occupation of the space. The zenith images are used to measure degrees of visitor traffic in the space and identify areas showing extreme density, a factor which negatively affects the quality of the visit.

In order to determine whether extreme concentration generates evasion reactions, the Ancient Greek site at Empúries was divided into three areas: (1) The main path (Path 1) connecting the entrance to the mosaic and taking in the most important stops on the itinerary; (2) the Northern path (Path 2) goes along the Northernmost part; and finally, (3) the Western path (Path 3) goes to the city's Acropolis. These three paths were identified using modularity analysis. Path 1, which contains 11 of the 32 vertices, accounts for almost 90% of the space used. Table 5 shows the average distribution of occupation on each path and compares this with occupation in periods of maximum concentration, when the 100-visitor threshold is crossed. The results show that an increase in density does not lead to people taking secondary roads, which, if they were used, would decongest the main road.

Therefore, it can be concluded that there is no difference in the pattern of use between high-density situations and medium or low-density situations.

Table 5. Times that high and very high-density are crossed at the three paths (%).

3.2. Case Study #2: Cathedral Square in Girona's Old Quarter

3.2.1. Study area

The city of Girona, north of Barcelona, is located close to both the Costa Brava (Spain) and the French border. The city has Roman origins, and like many European monumental cities, conserves characteristic remains of Roman, Romanesque, Gothic and Baroque art. Among the highlights are the Carolingian walls surrounding the Old Quarter and the Medieval Jewish and Christian Quarter. The main attraction in the city is the Gothic Cathedral, which is located in the Cathedral Square, the most frequently visited space in the city (Galí-Espelt & Donaire-Benito, 2006; Galí et al., 2015). The square is directly in front of the baroque steps that lead up to the Cathedral and has an area of 403 m² accessible by pedestrians. Situated in the highest part of the Old Quarter, where there was once a Roman temple, the cathedral and the square (figure 6) are little frequented by locals, so the majority of the people found there are visitors.

Figure 6. Cathedral Square in Giro a's Old Quarter

3.2.2. Methodology

As mentioned above, Spanish laws place many restrictions on using drones over urban areas. Therefore, we were unable to use a drone in Girona, and thus opted for time-lapse technology. A camera was fixed to the top of a building overlooking Cathedral Square (located at the top of a hill in the old quarter of Girona). The camera (model 4K) was positioned at an angle that enabled 100% coverage of the square. The camera took pictures of the square every 3 seconds, between 10 a.m. and 8 p.m. (during the cath dral's opening times), on different days (one Saturday and two weekdays) in the summer season, which is the period with the highest number of visitors according to the Tourist Information Office.

Following on from this, 10 hours of pictures (equivalent to 12,000 photos per day) were compressed into a video, and a time-lapse video lasting a few minutes was made for each day. As in the case of Empúries, it was impossible to recognize the people in the pictures, so no ethical issues needed to be taken into consideration. Figure 7 shows one of the images of visitors in Cathedral Square during the study period.

Figure 7. Photo showing visitors in Cathedral Square

The process of analysing the data follows an ethnographic approach. The ethnographic method is a qualitative method that sets out to describe the behaviour of social groups in a systematic manner, and uses a diverse range of techniques such as direct observation, participant observation, in-depth interviews and data collection (Hammersley & Atkinson, 2007). The ethnographic method has been used extensively in tourism studies to describe the behaviour of groups of visitors, and in particular, the interactions between the visitors themselves (Sørensen, 2003; Palmer, 2005; Buckley, 2012; Barbieri, Santos & Katsube, 2012). Images and video footage have been part of the ethnographic method since its inception, and can be used to collect information on the interaction between individuals, the social action of a group, and study various reactions in a detailed way. Scenes can be reviewed several times to check for nuances and detect consistencies. Specific frames from the time-lapse can be analysed in order to capture freeze frames, or follow the general evolution of a day. In direct observation, the researcher experiences more difficulty in capturing the integrity of the scenes and all of the details that might occur at a particular moment. Zenith images, therefore, enable researchers to learn the collective "chor ography" in a situation of tension due to the mass use of the space.

3.2.3 Results from Time-lapse videos

The ethnographic analysis of the images shows a very common pattern in how the space is used. Time spent in the square is extremely ephemeral. Visitors spend relatively little time looking at details or monuments in the space, especially if we consider the heritage value of the various attractions in the square. The most common pattern is to approach a monument (especially the Cathedral), look at it briefly and, almost immediately take a photograph. After that, visitors cease interacting with the attraction, and normally leave the space or engage in a social act with a companion, usually a conversation.

The way a visitor relates to the space can be divided into three main categories which are followed in sequence contemplative relationship, photographic relationship, and accommodation in the space. The first step is usually a contemplative relationship. This is an individual attitude, based on the relationship between the subject and the object. The Baroque facade of the Cathedral and its Baroque steps paint a very powerful picture which usually draws admiration. This is a common reaction in monumental spaces, especially if, as in this case, it is reinforced by a photogenic backdrop. The second reaction can be observed on both an individual and collective level, and is related to taking photographs. Most of the visitors who contemplate the Cathedral take at least one photograph. First, they normally capture the general viewpoint of the monument from the end of the square. Later, they include themselves in the photographs, adding a human element to them. These pictures sometimes include various people or groups, which leads to the third point: the "appropriatio of spac ", and the notion of "b i g th r ". After the rituals of contemplating the space and taking photographs, visitors then blend into it and become part of it. Sometimes they sit on parts of the spaces that can be used as seats, such as steps. More often, they initiate interaction with the people who are accompanying them. In this way, they move from the dimension of the individual to one of collective logic. Shortly afterwards, visitors leave the space and continue their journey in the adjacent streets, or very occasionally, they go up the cathedral steps. On the whole, the average length of stay in the square is very short.

The behaviour of visitors in the presence of the other visitors follows two essential guidelines: negotiation and evasion. To understand negotiation, it is essential to understand that a public space is a collective asset with free access for everyone, one that is shared and that has particular attributes. The public space is understood as a 'plac of actio ' and also as a forum of communication - whether ‘v rbal or non-v rbal’ (Joseph, 1999). The sociologist Goffman (1979) considers public spaces to be scenarios for encounters, where visitors must tackle complex situations in accordance with socially predetermined rules.

From the analysis of time-lapse videos, it is perceived that the members of the group relate to one another through verbal and non-verbal communication, thereby achieving negotiations in space (Pruitt, 1998).

Visitors tend to occupy the free spaces, thus creating a model of use for the dispersed space in which each ‘us r’ appears to have their own living space. The arrival of new visitors slightly rearranges how individuals are organized in the space so that each us r’s 'vital space' is optimized. This is also the case when visitors share the space with a group. The group tends to condition how the rest of the visitors are arranged. In all negotiation processes, the average length of time visitors spend is very similar for medium and low densities, and behaviour patterns are also similar.

Figure 8 shows an indirect negotiation of space through their body language between individuals who enter and leave the site. In this way, a non-verbal communication is transmitted about their intentions in the place as the ‘ d to move arou d’ or the ‘s arch for a free spac ’ in the space.

Figure 8. Indirect negotiation of space

In certain situations, the visitor’s behaviour is evasion (Chiou &Chen, 2010; Nowak & Schadschneider, 2012). The arrival of new visitors to the square triggers a replacement response, so they leave the space and seek an alternative, which conditions both the average length of stay and visitors’ usual behaviour. A sudden influx of visitors, for example, two groups arriving simultaneously, influences this behaviour more than the total number of visitors. This is due to a process of non-verbal communication on the part of new visitors who indirectly require space to move around (Henein & White, 2010; Suma, Yanagisawa & Nishinari, 2012).

At times of high density, it is possible to identify some attitudes within the groups and individuals that can be described as coping mechanisms (Hall, 1969; Popp, 2012) visitors use to avoid congestion. These mechanisms are revealed in human behaviours that respond to a series of variables such as: (a) the sensation of threat to personal space (Holden, 2007; Perry, Rubinsten, Peled & Shamay-Tsoory, 2013), which is closely linked to culture (Cohen, 2011; Holden, 2007); (b) the rules of the place and its physical and spatial configuration (Hernández, 2012; Santos Solla & Pena Cabrera, 2014); (c) the behaviour of other visitors and the intensity of the contact; and (d) the actual number of people compared to the number of people expected (Zehrer & Raich, 2016).

It can be concluded that the ritual behaviour of visitors in a space can thus be detected, as well as the way in which visitors behave in the presence of other visitors. Unlike other research methods, this method lends itself to tracking sets of visitors more comprehensively.

4. Conclusions

Both consolidation of the mobilities paradigm, and the widespread use of new technologies have favoured the development of tourist tracking methods (Shoval & Ahas, 2016). Today, researchers have a wide range of available tools such as User Generated Content (UGC), Global Positioning System (GPS), mobile phone information, or Bluetooth, which have four key advantages: (a) they give a high degree of detail regarding visitor behaviour; (b) they provide information on real behaviour, and not claimed behaviour; (c) they provide spatial information enabling various scales to be analysed; and (d) direct participation from visitors is not usually required, so the bias of intervention is reduced. Zenith images, taken using drones or high-altitude cameras, should also be considered in the catalogue of analysis resources.

Unlike other methods of analysis, such as GPS, which provide individual data, zenith images can track collective behaviour, and monitor the way visitors react to other visitors. We know very little about how a group of visitors behave in a given space in relation to concentration, crowding or the presence of groups. Using zenith images means visitors, who are seen as network of relationships, can be observed and analysed as a whole. Whilst the data collected by GPS enables researchers to ascertain each visitor's exact sequence of use, zenith images procure information about the behaviour of the group and in this way, it is possible to collect possible responses to the (over)crowding. In short, using drones and time-lapse images to gather aerial information about visitor behaviour in a particular space takes all visitors into consideration. This degree of detail means that the spatial and temporal concentration can be measured on a micro-scale.

Firstly, a relatively universal 'pattern of behaviour' was identified in both tourist areas under study. The majority of visitors follow the same route in the archaeological site of Empúries, and the visitors to Girona Cathedral Square adopt the same contemplation - capture - appropriation sequence of the space. The quantitative and qualitative analysis both show that the visitors use the spaces in a 'touristic' way, albeit with many variations, as pointed out by MacCannell (2011) in his essay on the *The ethics of sightseeing*. One of the main problems of managing heritage spaces is crowding and overcrowding, and moving from micro to macro scale, as visitors tend to concentrate on seeing certain areas, and barely look at the rest. Zenith images enable the relationships between visitors in situations of maximum crowding to be analysed by collecting comprehensive information on a certain time period in a limited space. Both the cases studied in the present paper show that visitor behaviour remains unchanged by the presence of a high number of other visitors. No significant deviation to secondary or peripheral areas was detected among visitors at Empúries during periods of maximum concentration. Therefore, the increased number of visitors does not trigger a shift of visitors to other areas of the site; instead, it leads to overcrowding at the most popular sights.

In Girona, in periods of maximum concentration, assimilation strategies (i.e., the integration of behaviour patterns with those of the whole) and adaptation (visitors change some parameters of using the space such as reducing the time spent at the most crowded sights) predominate over evasion (when some of the visitors frequent spaces that are normally less visited, in order to avoid the pressure of overcrowding).

4.1. Policy implications

Zenith images are also useful for gathering information on visitor behaviour in tourist spaces, and complement information gleaned from other tools. They are especially useful for assessing the collective behaviour of visitors at any given time, and thus give an understanding of how visitors interact with each other. This is especially relevant for spaces that suffer from overcrowding at peak times. The increased number of surveillance cameras used for security reasons has led to a significant ease of access to these images. By analysing the information given on the routes mapped on the graph, the structure of the itinerary system in a given space can be estimated. Denser graphs enable more alternative routes, while lower density graphs (as in the case of Empúries) severely limit the range of decisions the visitor can take. The qualitative study provides information on individual and collective reaction mechanisms engaged when the space becomes increasingly congested and overcrowded.

Overall, both studies show that visitors respond adaptively to congestion. In Empúries, they fail to use peripheral areas as decongestion spaces; and in Cathedral Square, visitors change how they occupy the space to adapt to the increased occupancy. This demonstrates that visitors' own systems of self-regulation are inefficient, and managers need to anticipate congestion and put strategies in place to avoid it; for example, setting limits for maximum load capacity, designing alternative itineraries and making secondary sights more attractive.

The study shows that in contexts of overcrowding, the use of space does not change significantly. In Empúries, the increase in visitors generates greater pressure on the most visited areas, but greater interest in other attractions is not detected. Visiting secondary sights or taking alternative paths does not spontaneously occur to visitors. This requires specific management actions such as programming visits, dynamic signposting, establishing maximum visitor numbers at each attraction, or using ICT (augmented reality, or audiovisual information).

Visitor behaviour in Cathedral Square shows that visitor patterns are not altered by overcrowding, for which tolerance threshold appears to be very high. Once again, visitors do not change their behaviour due to crowds, and continue with the same ritual use of space detected at times when there are less people. To improve the quality of the visit, space planners should consider introducing a number of possible actions: regulating the schedule of visitor groups, setting limits for maximum load capacity, regulating access at entrance and exit points, designing alternative itineraries, making secondary sights more attractive, adopting demarketing strategies, or employing dynamic signage.

4.2. Limitations

Among the main limitations of this study are the coverage, autonomy and maneuverability of drones, the effect of various noises accompanying the images and the large volume of information gathered. Camera coverage has a very specific range; if too low, the anonymity of participants is compromised; if too high, it is difficult to interpret the information.

Moreover, while cameras can have considerable autonomy and take recordings for long periods of time, drones consume a great deal of energy and need a constant change of battery, which limits the exposure time. Regulations are very restrictive on the use of drones in spaces frequented by large numbers of people, and special conditions must be met. Lateral captures (like the one conducted in Empúries) partially resolve this problem, but certain elements of space (shadows, trees) can alter the results. In addition, the large number of images obtained in a day creates an abundance of information, and this slows the researcher's work.

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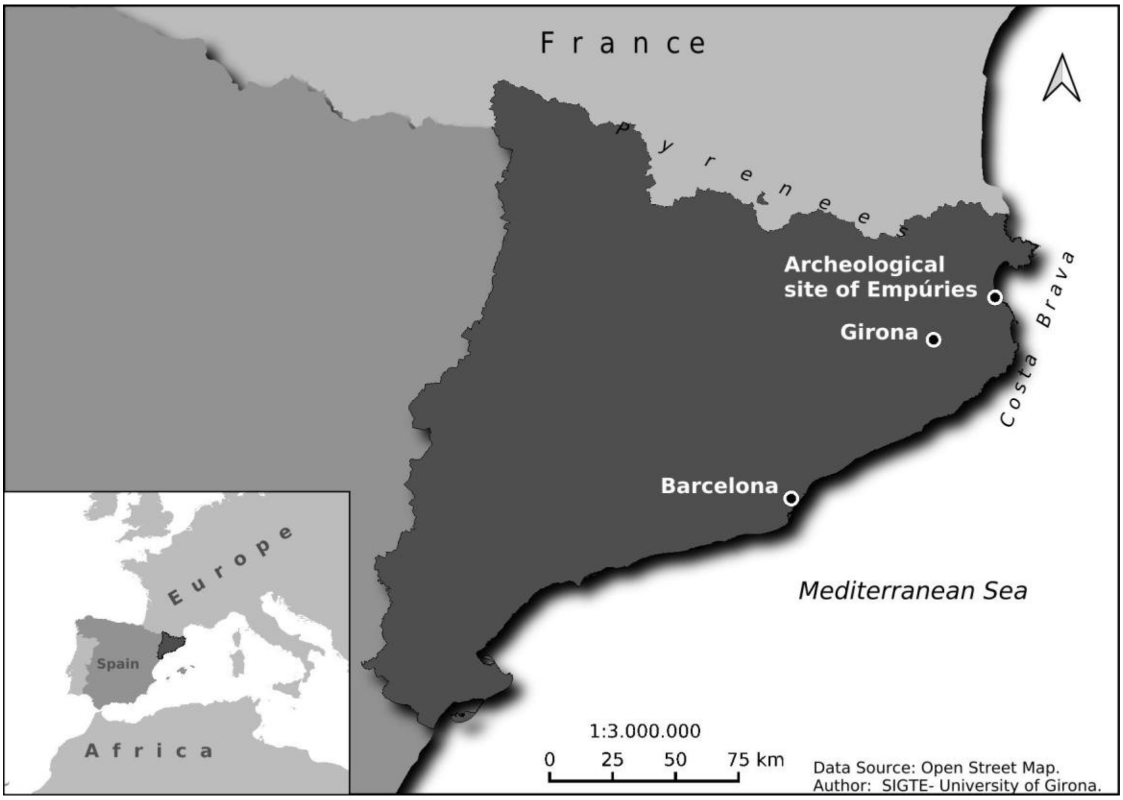
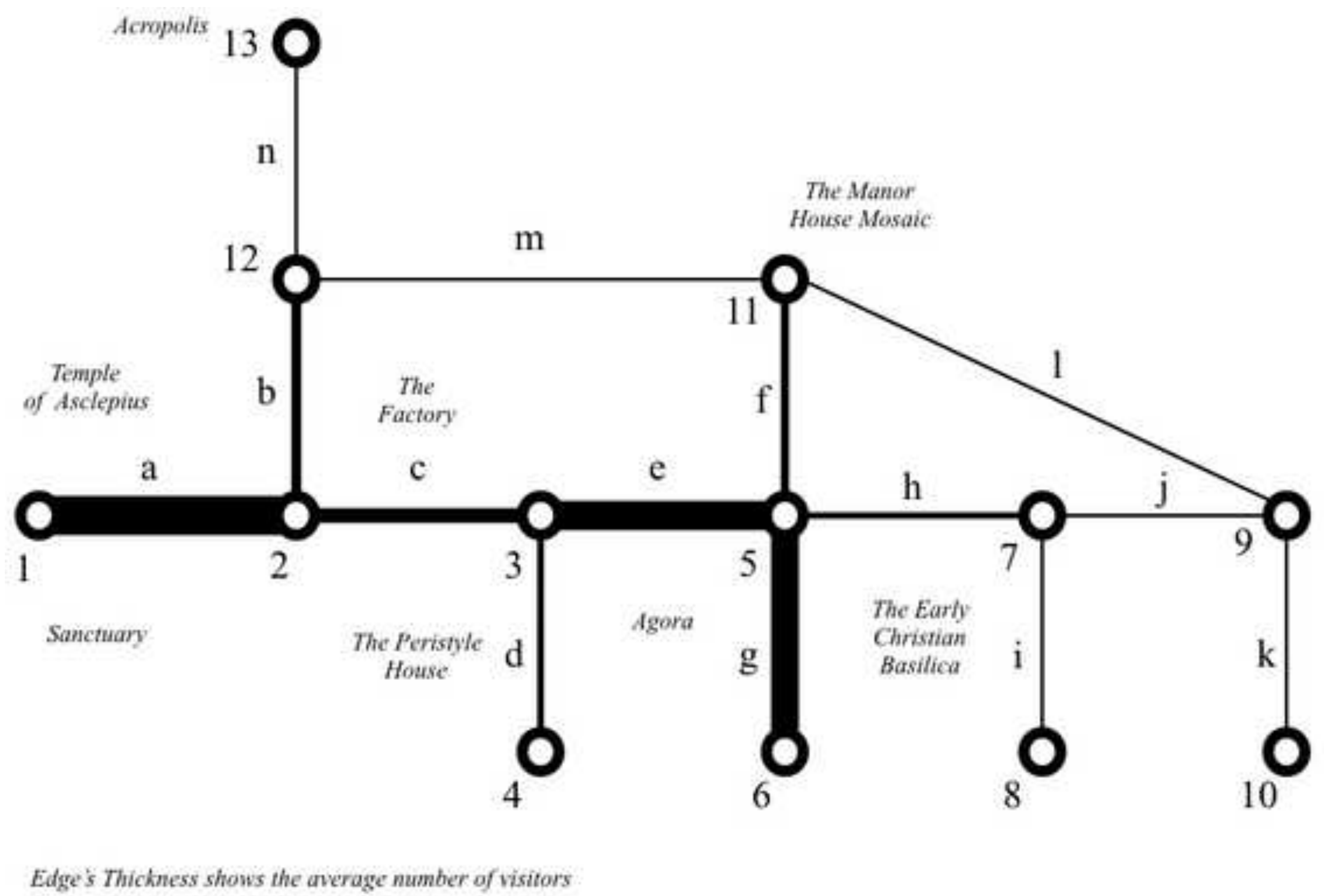
Figure (including maps and photographs)

Figure 1. Map of the region

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Sanctuary
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Edge's Thickness shows the average number of visitors

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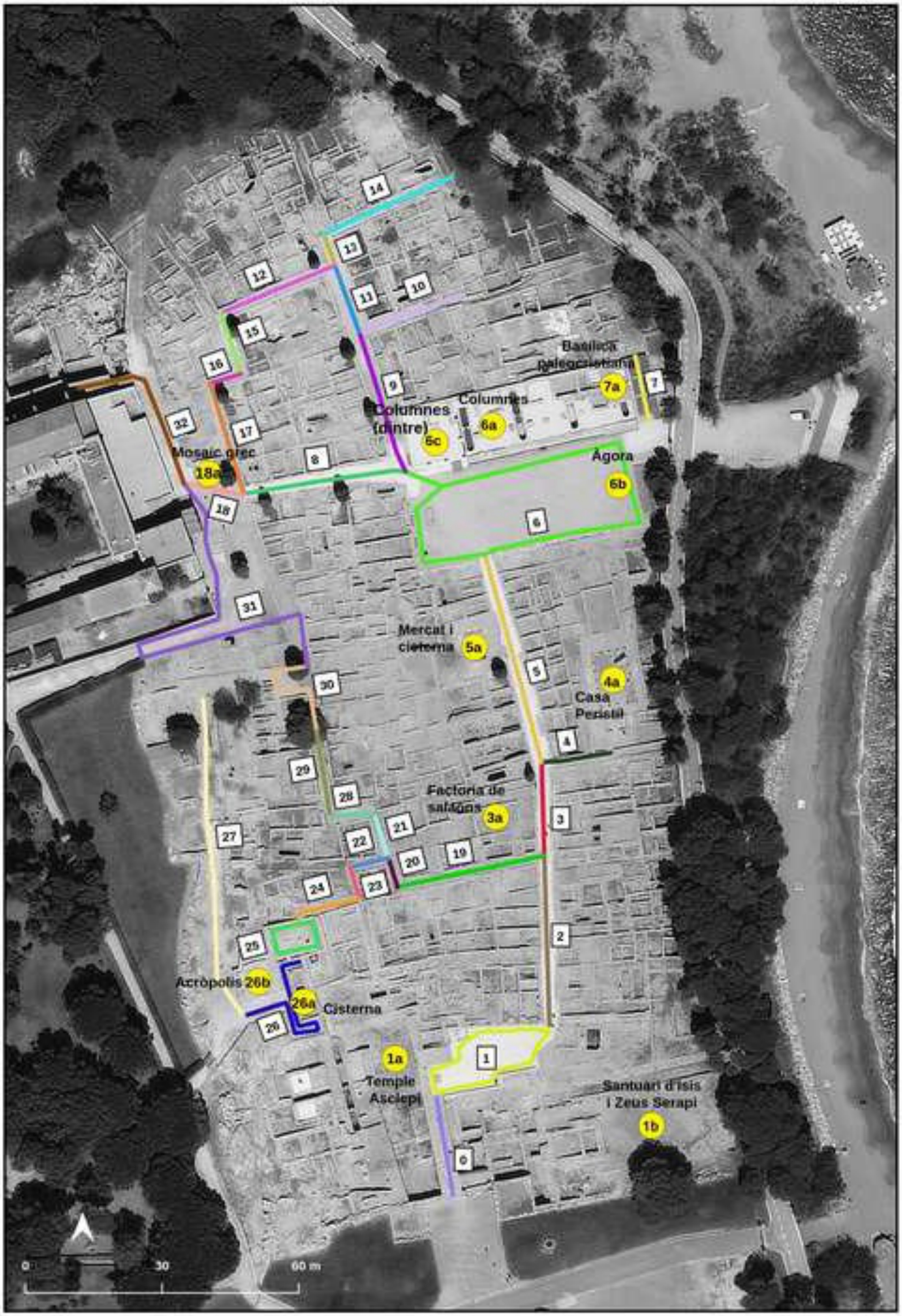

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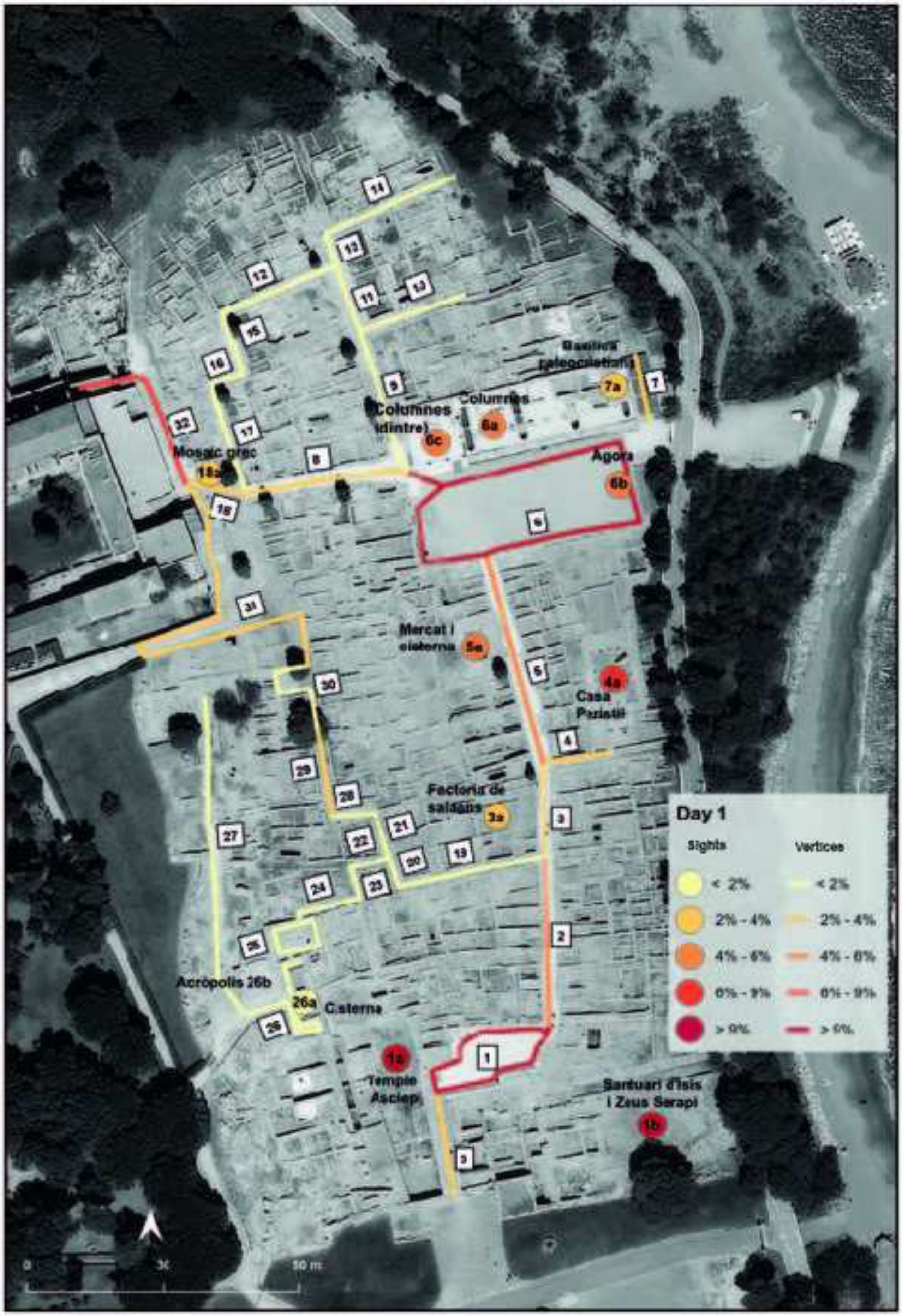

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Figure 9. Indirect negotiation of space

Figure (including maps and photographs)

Figure 9. Indirect negotiation of space

Table

Table 1. Characteristics of zenith images in relation to other forms of tracking tourists

		Devices data				Zenith images	
	UGC	**GPS**	**Smartphones**	**Bluetooth**	**Transaction data**	**Drones**	**Cameras**
Population	User segment	Participants	Users with devices	Users with devices	Users who conduct transactions	Users captured by a drone	Users captured by cameras
Volume of data	Very high	Limited	Enormous	Very high	Very high	Very high	Very high
Participated	No	Selection of the users	Only in apps	No	No	No	No
Scale	Multi-scale	Multi-scale	Multi-scale	Micro-scale	Usually micro-scale	Micro-scale	Micro-scale
Space-time data	Discontinuous	Highly accurate	Highly accurate	Discontinuous	Discontinuous	Constrained by the drone's autonomy	Long-duration
Types of analysis	Quantitative Qualitative	Quantitative. Data associated with a survey	Quantitative Data related to the mobile device ID	Quantitative	Quantitative Credit card-related data	Quantitative Qualitative	Quantitative Qualitative
Ethical issues	Difficulty to maintain anonymity	Requires the participants' consent	Need to encrypt the ID data	Users do not consent to their participation	Access to sensitive data	The distance must preserve anonymity	The distance must preserve anonymity
Access to the data	Openly available data	Logistics of supply of GPS and information collection		Openly available data with the use of devices	Data are very costly and hard to obtain	Digital images that can be recoded	Digital images that can be recoded

Source: Authors

Table

Table 2. Centrality measures of each node

Nodes	Unweighted			Weighted	
	Eccentricity	Closness centrality	Betweenness centrality	Eccentricity	Mean distance
1	5	0.307692	0	254	183,92
2	4	0.428571	15	164	95,42
3	4	0.461538	19	144	87,09
4	5	0.324324	0	178	108,25
5	3	0.521739	28	180	82,92
6	4	0.352941	0	216	115,92
7	4	0.428571	15	246	95,42
8	5	0.307692	0	260	109
9	4	0.413793	14	225	105,75
10	5	0.3	0	254	132,33
11	3	0.5	20	215	101,5
12	4	0.444444	17	202	116,42
13	5	0.315789	0	233	144,83

Source: Authors

Table

Table 3. Average and maximum occupation in the main vertices (%).

		Day 1		**Day 2**		**Day 3**	
		Average	Maxim	Average	Maximum	Average	Maximum
Vertex 1	Asclepius Temple	22.5	44.7	22.4	46.7	18,5	41.7
Vertex 4	House with peristyle	11.5	37.7	10.4	26.9	8.0	18.5
Vertex 5	Market & Cistern	10.7	37.1	11.4	34.9	11.9	40.5
Vertex 6	Agora	17	55.0	17.0	43.9	19.5	39.2
Vertex 32	Exit to Roman City	9.8	34.9	11.4	30.3	11.1	33.3

Source: Authors

Table

Table 4. Times that high and very high-density is crossed at the main vertices (%).

		Day 1		Day 2		Day 3	
		High density	**Very high density**	**High density**	**Very high density**	**High density**	**Very high density**
Vertex 0	Entry & Exit	2.0	0.7	9.5	1.4	2.0	0.8
Vertex 3	Salt factory	6.7	6.0	10.1	1.7	3.4	1.0
Vertex 4	House with peristyle	67.3	44.3	81.8	62.6	49.2	23.9
Vertex 7	Paleo-Christian Basilica	10.1	3.7	25.5	4.0	13.8	4.9
Vertex 18	Mosaic	5.5	0.2	30.7	12.1	7.3	1.3

Source: Authors

Table

Table 5. Times that high and very high-density is crossed at the three paths (%).

		Day 1		Day 2		Day 3	
		Average	High density	Average	High density	Average	High density
Path 1	**Main Path**	86.1	89	86.7	85.4	87.4	86.0
Path 2	**North Path**	2.8	0	3.0	3.3	3.9	3.4
Path 3	**West Path**	11.2	11	10.3	11.3	8.6	10.6

Source: Author

*Credit Author Statement