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NIGHTTIME AND DAYTIME POPULATION ESTIMATION FROM OPEN DATA

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ABSTRACT:
Most of the studies on population loss and damage, due to earthquakes or any other natural or anthropogenic catastrophe rely on methodologies that usually make use of the resident population counted in the latest census. However, the need for disaggregated data for high extensions of territory and the increasing availability of open data opens new possibilities for the construction of population exposure models. Essential to emergency planning is determining where people are likely to be located, which varies from day to night, from weekdays or weekends and / or seasonally. Focusing on variations from day to night, using addresses open data, night populations are estimated at building level. To determine daytime population estimates, points of interest representing the locations of each business together with administrative and statistical data are used to establish how many people are employed or study on each building. The result for daytime population is 19% higher than the nighttime population confirming the commuting official values.

Key-words: *Population distribution, Population exposure, Open data, Earthquake.*

1. INTRODUCTION

Worldwide, there are a raising number of large disasters and among the variety of causes for such an increase we can list climate change, the rise of population densities in specific hazard-prone areas (especially in coastal regions and in areas at mountain slopes), and the susceptibility of the aging building stock (Vora *et al.*, 2008). It has also been argued that the magnitude and frequency of extreme events are increasing (Bosher *et al.*, 2009; O'Brien, 2008). Some authors suggest that several recent extreme natural events resulted in great humanitarian tragedies because of weak preventive disaster management (Ismail-Zadeh & Takeuchi, 2007), mitigation, and the lack of knowledge about the size, nature and geographical distribution of the present population potentially in danger. For instance, earthquake risk analysis involves quantitative estimation of damage, casualties and costs within a specified geographic area over a certain period of time (Vora *et al*., 2008). Obviously, estimation of the human damage and loss is highly relevant (Smith & Petley, 2009). Wenzel, *et al.* (2007) point out that during the last decade there has been an increasing potential for large scale disasters caused by severe earthquakes in regions with high population densities (for instance, around 6,000 deaths in Kobe, Japan, and 20,000 deaths in Izmit, Turkey, in 1995 or, recently, Japanese death count surpass 11,000 as a result of earthquake and tsunami in 2011).

Population exposure refers to human occupancy near or presence within the hazard-prone area and thus the population that would be potentially affected by an event (Freire & Aubrecht, 2012; Mileu & Queirós, 2018). In metropolitan areas due to densely populated areas and commuting (also due to tourism), the distribution of people depends on the time of a 24h day. Realistic earthquake loss estimations depend on reliable population exposure models. This is also a reason why "population exposure" estimation is increasingly important on the research and political agendas: to identify the potential population loss because of the present population exposed to hazardous events.

Exposure is simply defined as the number of people or amounts of assets (e.g., physical, economic, social, environmental, historical, cultural, etc.) exposed to a hazard (Kamranzad *et al.*, 2020). Having accepted this definition, exposure can be evaluated based on observed (census) or estimated data (Kamranzad *et al.*, 2020).

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In this research we estimate population exposure at the building level based on open data, and considered daily dynamics. This means population exposure in the perspective of its variations along daily periods, in time and space. We use this expression to underline the human dimension, which means drawing attention on population and not on buildings, roads, etc. Our core research is about understanding territorial and temporal patterns of people distribution. In this particular case, night and day population, and its occurrence during a journey is fundamental to risk science and critical for the region where the present population is permanent (residents) or temporarily (for labour or touristic reasons) located, particularly if it is a seismic area.

The estimation of the present population is however a methodologically difficult and controversial procedure (see a short but accurate identification of these problems in Chapter Two of Tools and Methods for Estimating Population at Risk (NRC, 2007). For instance, the estimates based in the lighted settlement and high-resolution imagery constitute important improvements in this research field, but they are uneven and static proxies, and with high levels of uncertainty.

Most of the studies on population loss and damage, due to earthquakes or any other natural (Tavares *et al.*, 2016; Santos *et al.*, 2016) or anthropogenic catastrophe rely on methodologies that usually make use of the resident population counted in the latest census. An area's resident population consists of those persons usually resident, where they stay most of the time (USCB, 2000). Nevertheless, only roughly can we consider these estimates based on residents, wrongly equated with the population present at nighttime, as an adequate estimate of present population. Current research in earthquake modelling (scenario or probabilistic) using the software program HAZUS for loss estimation usually doesn't consider population data about present population, which in both conditions of highly seismic and metropolitan areas should be crucial.

The estimation of the population exposure based on the census datasets usually overestimates or underestimates the present population and do not even consider the mobility during a daily or a weekly period. As we show in this paper, the present population is most often much higher than the resident population officially known.

Several approaches have been used to study the distribution of the population during daytime and nighttime and we can mention some of the more relevant for our purposes. Qi et al. (2015) established a relationship model for the three components of ‘population, land use and time (daytime or night)’ to explore the temporal and spatial characteristics of different types of population, and to estimate urban population during the day and night (and to analyse their spatial characteristics at a grid scale). In addition to population data aggregated in statistical areas, there are other geographic representations in the population distribution. Using a dasymetric mapping technique, Freire and Aubrecht (2012) obtained the population census data for daytime and nighttime in the metropolitan area of Lisbon, Portugal, to analyse variable spatiotemporal exposure of the population to earthquake hazard. Supported by a framework for modelling population distribution in space and time based on the integration of available information from census and administrative sources Renner *et al.* (2018) created high-resolution population data for different points in time for the region of the Autonomous Province of Bolzano. At the building level, Ara (2014) modelled total daytime and nighttime population based on the datasets from the Comprehensive Disaster Management Program and used a relationship between the occupancy classes and average space. Based on land use and land cover classes from different datasets, Freire (2007, 2020) modelled nighttime population using street centerlines to derive residential streets and allocating population in each census block group. The same author (2007; 2020), to model the daytime worker population georeferenced the addresses of private businesses and public services (including health care facilities and schools) and respective workforce. More recently, Ma *et al.* (2017) developed a model to estimate hourly dynamic changes in population at the community level based on subway smart card data exploring the possibilities given by big data.

When developing instruments for emergency planning, the knowledge of the difference between night and day population at building level is critical (ANPC, 2020), as the potential of human loss on a basis of the present estimated population (whether resident, worker, tourist or other) that really is in a specific area in a given moment (hour, day, week, month...), is more accurate that the official data for potential human loss. Our research demonstrates this closeness. Also, we suggest a new conceptual and methodological application, supported by the ratio referring to the number of employees per economic activity classification and administrative workforce data. For each building we established the day occupation with the purpose of establishing the population mobility between day and night periods. For the night period, we propose the use of open address data to estimate the resident population at the building level. The referred methodology allows the estimation of the potential human loss based on the present estimated population, which is the population that is in a specific area in each moment of a 24h day. Thus, the aim of this article is to estimate the people occupying buildings at different times of the day (day and night) based on open data. For our case study we choose the municipality of Oeiras in the Lisbon Metropolitan Area.

2. STUDY AREA

The municipality of Oeiras is located in the Lisbon Metropolitan Area, Portugal (**Fig. 1**). Given its location in the western Iberian Peninsula on the Atlantic Ocean, the Lisbon Metropolitan Area is susceptible to offshore earthquakes occurring on the Africa‐Eurasia plate boundary, particularly in the Gorringe Bank region (Tang *et al.*, 2012). This region has been affected by severe historical earthquakes, like the emblematic 1755 Lisbon earthquake with Mw = 8.5 − 9.0 (Costa *et al.*, 2009).

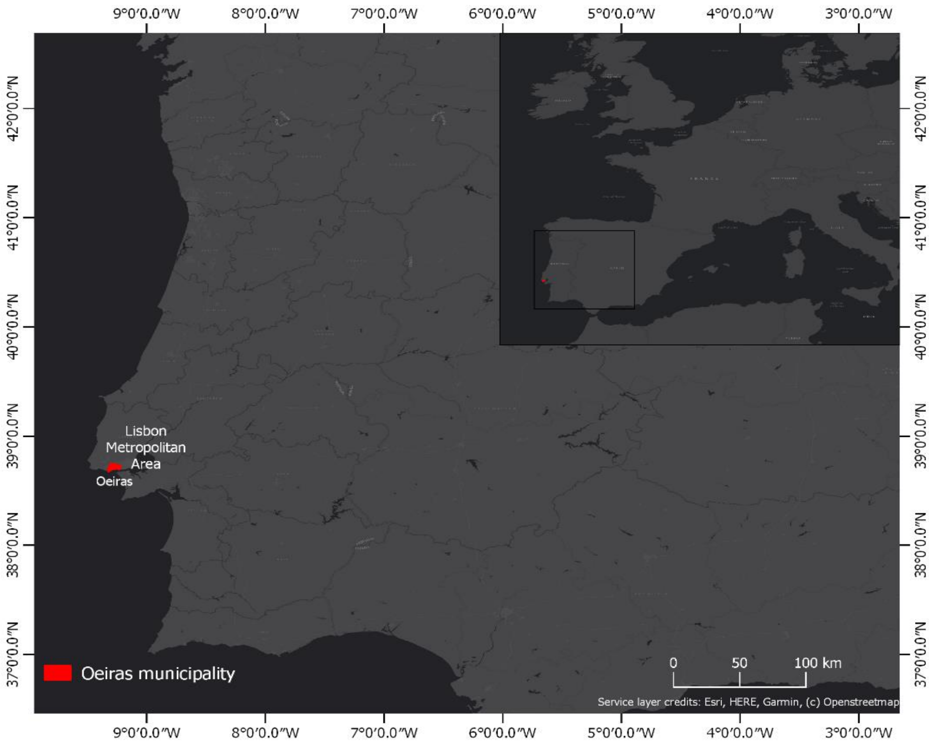

Fig. 1. Study area location.

The seismic hazard in this region has also a contribution of onshore, moderate to strong intraplate earthquakes on inherited crustal fractures like the Lower Tagus Valley fault zone (Vilanova e Fonseca, 2004). Oeiras is a predominantly urban municipality with a population of 172,167 inhabitants and a high economic development associated with medium-sized and large-sized business parks, mainly associated to higher tertiary activities. In the last years, Oeiras municipality has a positive growth rate of the locally employed population (INE, 2003). Due to the existence of several business parks and offices, Oeiras municipality attracts population from the contiguous municipalities of Sintra, Lisbon, Cascais and Amadora. It showed a significant increase in the employment polarization index and in the rate gross employee attraction and a decrease in the repulsion rate of employees (INE, 2003; INE, 2018), constituting for these reasons a case study with the necessary characteristics of a municipality with a high number of intra and inter-municipal commutes and located in a critical seismic region in Portugal. Additionally, the Oeiras city council was interested in an emergency plan focusing on the topic.

3. DATA AND METHODS

3.1. Dynamics of Present Population and Commuting

Information on the expansion or contraction experienced by different places in terms of nighttime and daytime populations is important for many planning purposes, including those dealing with disaster relief operations (NRC, 2007; Freire, 2020). If in every seismic risk assessment, the seismic hazard computation for the studied area is a key issue (Sleeter & Wood, 2006) it is also true that the identification of people location and the consideration of its movement are crucial. Interactions between resident, working (and other reasons) population are critical factors on the overall human dynamics of a metropolitan area. This frequently leads to consider the importance of the forces responsible for temporal mobilities, often difficult to determine. There are also conceptual and methodological challenges to estimate the timeframe period and place specific location of a population. It is known that in metropolitan areas the population fluctuates and commuters (those who travel some distance to work and/or study reasons on a regular basis) are often in higher numbers than residents. An identified problem related to this increase of population is its variation according to the time of the day, week, and season. To be able of producing data on these dynamics of present population will substantially help disaster relief efforts.

For our purposes it is relevant that every worker or student (or even a tourist/visitor) that shows up in one place in a functional metropolitan area, might have started the day in another place. Thus, some places experience a daytime decline as people depart, while others have population peaks late in the day. Following the Openquake Platform exposure model (GEM, 2022) we assume two periods for the buildings' number of occupants (**Fig. 2**): night and day.

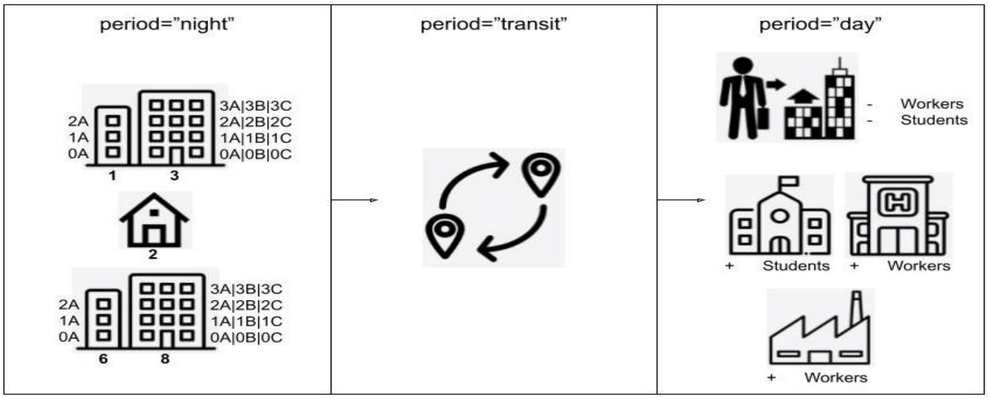

Fig. 2. Overview of three periods considered in population exposure model.

The integration of population data as an exposure layer into risk assessments for sudden hazard events needs to account people mobility (Renner *et al.*, 2018). Due to the lack of open traffic data, this period was not considered in this work. There is a certain relationship of this method with methodologies using satellite images (Sutton *et al*., 2001; Deichmann *et al*., 2011), extrapolations of Resident Population, or the administrative data available (Kamranzad *et al.*, 2020). Nevertheless, while these are mainly static methodologies, the method applied in this research is based on the powerful idea of flows between places (spatial interaction) using simple formulas that make estimates with an acceptable accuracy.

3.2. Data

Table 1 lists open data sets used in this work. They comprise building polygons, points of interest (POIs that include workplaces, schools, health facilities, touristic accommodations, restaurants), addresses and the enumeration units for the municipality of Oeiras. All these items are openly accessible, making it possible to build models of exposure of the population on a building scale.

Table 1.

Summary of geographic data used.

Dataset name	Source	Year
Buildings	OpenStreetMap	2021
POIs	OpenStreetMap	2021
Addresses	Statistics Portugal	2011
Enumeration units	Statistics Portugal	2011

Fig. 3 shows the geographic information layers used in the work, where the urban and metropolitan context of the case study can be verified.

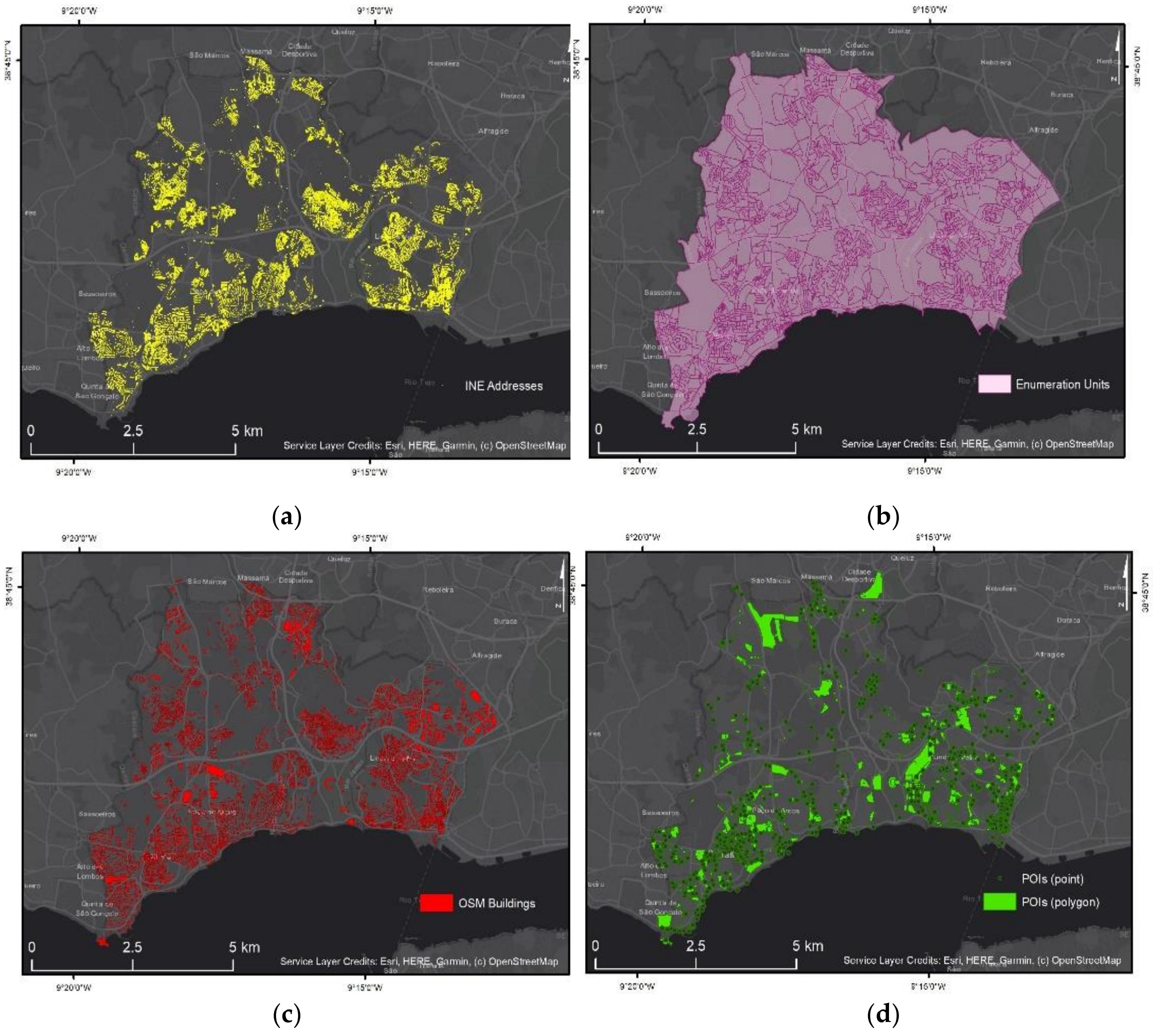

Fig. 3. (a) INE Addresses point layer; (b) INE Enumeration units (polygon layer); (c) OSM building layer (polygon layer); (d) OSM points of interest layer (polygon and point layer).

In addition to geographic data, administrative information was used to obtain the number of workers or students, such as a list of schools with the number of students, teachers and staff, health facilities, or administrative buildings. For establishments where it was not possible to determine the number of workers from the lists, this value was obtained from a rate value calculated from the information published by Statistics Portugal regarding the persons employed by establishments by geographic localization and economic activity classification division (**Table 2**) or subdivision. The economic classification codification by division or subdivision was critical to associate the number of workers to the establishment(s) in the building(s).

Table 2.

Number of workers per establishment by division of economic classification.

Economic Classification Division	Workers/Establishments (workers per building)
Agriculture, animal production, hunting, forestry and fishing	1.5
Extractive industries	1.0
Manufacturing industries	9.9
Electricity, gas, steam, hot and cold water and cold air	1.8
Collection, treatment and distribution of water; sanitation, waste management and depollution	29.6
Construction	7.0
Retail trade; car and motorcycle repair	6.6
Transport and storage	5.4
Accommodation, restaurants and similar	4.1
Information and communication activities	10.2
Real estate activities	1.4
Consulting, scientific, technical and similar activities	3.0
Administrative and support services activities	3.8
Education	1.9
Human health activities and social support	3.5
Artistic, show, sporting and recreational activities	1.6
Other service activities	1.6

Source: Statistics Portugal (INE)

3.3. Nighttime Population Estimation

Data on the resident population are traditionally aggregated to the statistical areas and do not exist at the building scale. For this reason, a methodology was established for calculating the resident population from open data on addresses (**Fig. 4**). The building-scale resident population is calculated using open address data and enumeration units (polygons).

To determine the number of residents per building, the number of people per housing unit was calculated for all enumeration units. This value is associated with each existing housing unit in the building, making it possible to calculate the resident population through the sum of the average population of the housing unit in each building.

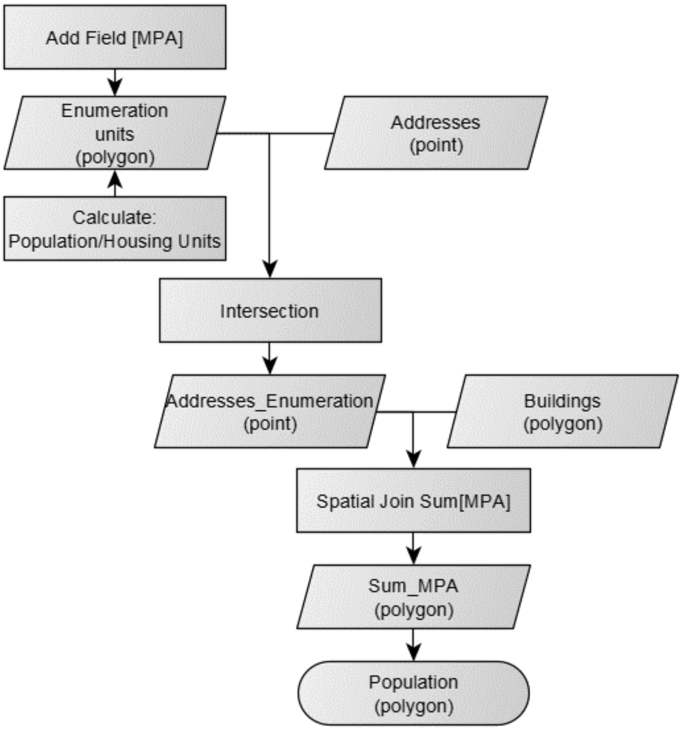

Fig. 4. Flowchart to calculate nighttime population for buildings.

3.4. Daytime Population Estimation

The methodological approach for estimating the present population, at the building scale, followed an adaptation of the methodology proposed by Sleeter & Wood (2006). The daytime population estimation considered total in-commuters (workers and students) and total out-commuters to each building. The estimation of the daytime population was performed using 3 iterations (**Fig. 5**).

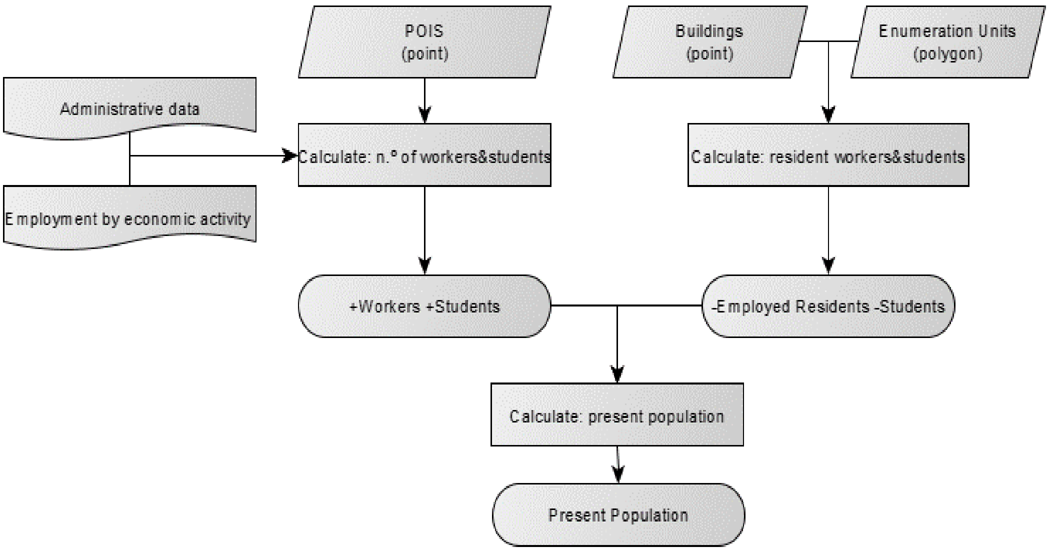

Fig. 5. Flowchart to calculate daytime population for buildings.

The first iteration represents all persons who are not employed or in school and who are assumed to remain in the household. As these data do not exist at the building scale, they were obtained through the statistical data available in the enumeration unit, allocating to each building the average value obtained per housing unit. In the second iteration, administrative data is used regarding the number of employees/students that are associated with each record in the points of interest layer. For the commercial and services where it was not possible to establish the number of workers, an average value was established, obtained from the employment by economic activity statistics. The third iteration estimates for each building the diurnal population through the difference between the mobile population (workers and students), without-going trips and the mobile population with incoming trips. This approach does not focus on the destination of the worker or student, but rather on the fact that the worker or student leaves home. Once the worker or student is determined away from home, the worker or student gets subtracted from the building.

4. RESULTS AND DISCUSSIONS

4.1. Aggregated Night and Day Population Distribution

According with the methodology described in the previous section, it was estimated the resident (night) and present (day) population for all the buildings in Oeiras municipality. These data were stored in a point layer where we can retrieve the population for both periods, by building, or by any aggregate administrative unit like places or parishes. **Fig. 6** illustrates the estimation of night population, for 2011, aggregated in a hexagonal tessellation. This aggregation demonstrates the possibility of obtaining an exposure model aggregated to different geographic units and the distribution of the resident population.

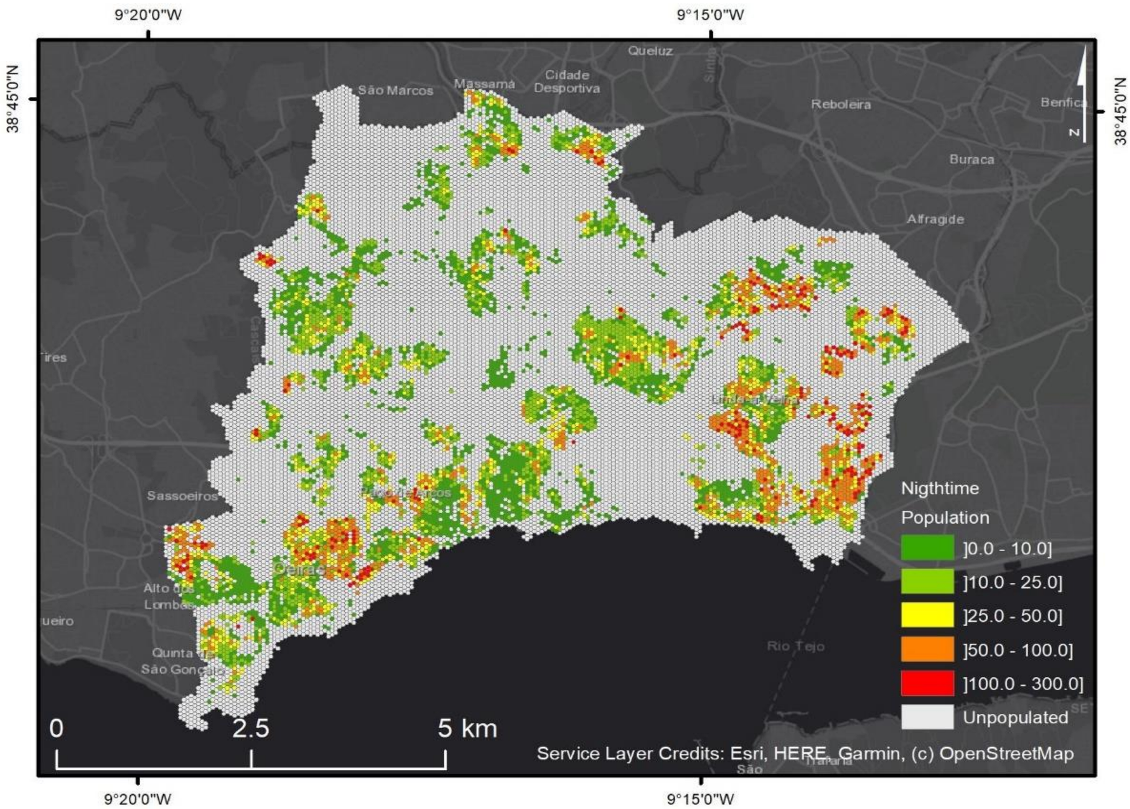

Fig. 6. Aggregated night population distribution (data).

The resident population is unevenly distributed across the territory, with low-density residential neighbourhoods (as it happens in Valejas, Gandarela, Quinta da Moura, Linda-a-Pastora neighbourhoods), as opposed to more densely populated residential urban areas, located mostly on the Algés-Miraflores-Carnaxide axis. According to the population exposure model, in 2011, the estimated total population for the night period was 165,614 residents (**Table 3**). The parishes with the largest number of residents are the coastal ones – Algés, Linda-a-Velha and Cruz Quebrada-Dafundo. The parishes with the lowest number of residents are located north of the A5 motorway – Porto Salvo and Barcarena.

Table 3.

Night population by parish.

Parish	Population
Union of parishes of Oeiras and São Julião da Barra, Paço de Arcos and Caxias	**56219**
Union of parishes of Algés, Linda-a-Velha and Cruz Quebrada-Dafundo	**46504**
Union of parishes of Carnaxide and Queijas	**34928**
Porto Salvo	**14625**
Barcarena	**13338**
TOTAL	**165614**

Fig. 7 illustrates the estimation of day population, for 2011, aggregated in a hexagonal tessellation.

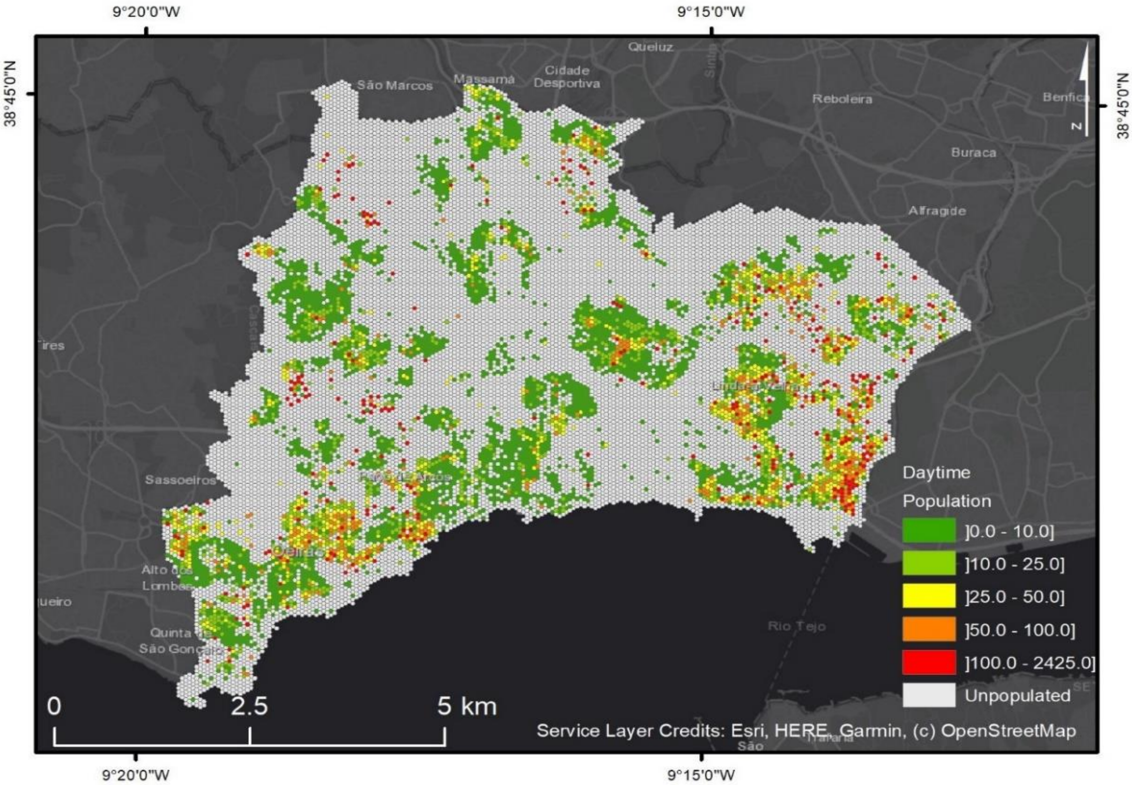

Fig. 7. Aggregated day population distribution (data).

This figure shows a predominance of the residential function in all urban areas, including in those where there is some importance of employment, such as Algés or Oeiras. The employment centres clearly stand out from the other areas, namely the business parks of Taguspark, Lagoasparque, Quinta da Fonte, Outurela/Portela, the industrial area of Carnaxide, the office parks of Miraflores and the industrial area of Queluz de Baixo. At the same time, school, and university areas such as the Faculty of Human Motricity, Atlantic University or Instituto Superior Técnico stand out. On the other hand, there are some areas where there is a mixture of residential and employment components, namely Linda-a-Velha, Dafundo or Miraflores. According to the population exposure model, in 2011, the estimated total population for the day period was 197,076 people (**Table 4**). All parishes have a population in the day period higher than the night period. It is important to highlight the high attractiveness of this municipality as a destination for commuters in the Lisbon Metropolitan Area, particularly from the neighbouring municipalities of Lisbon, Cascais, Sintra and Amadora. The parish of Porto Salvo registers the biggest difference between the two periods (+69%), this value being explained by the fact that it constitutes an employment centre through a set of office parks. The parishes of Barcarena, Carnaxide and Queijas, register the smallest difference between the night and day period.

Table 4.

Day population by parish.

Parish	Population
Union of parishes of Oeiras and São Julião da Barra, Paço de Arcos and Caxias	64576
Union of parishes of Algés, Linda-a-Velha and Cruz Quebrada-Dafundo	55737
Union of parishes of Carnaxide and Queijas	37289
Porto Salvo	24787
Barcarena	14687
TOTAL	197076

4.2. Night and Day Population Distribution by Building

Fig. 8 illustrates the estimation of exclusive day population and residential or mixture of residential and employment components, for 2011, by building.

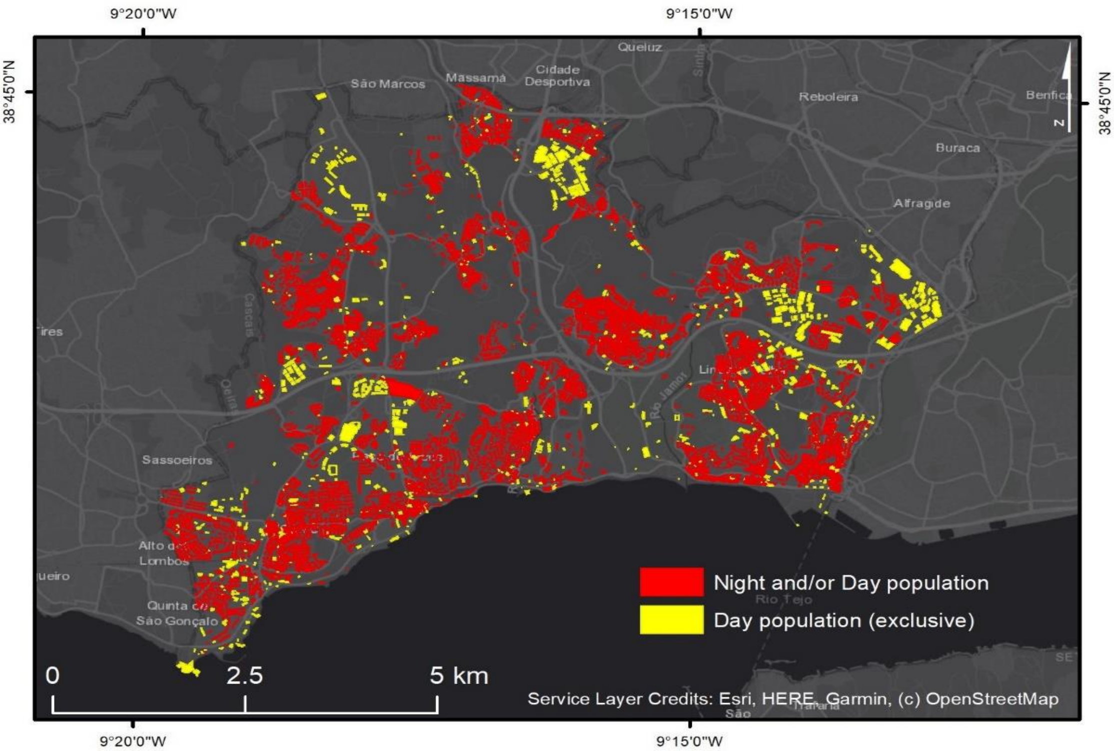

Fig. 8. Building distribution classified by exclusive day population and night and/or day population.

This figure shows a predominance of the residential or mixed function in all urban areas. The business parks stand out from the other areas, namely Taguspark, Lagoasparque, Quinta da Fonte, Outurela/Portela, the industrial area of Carnaxide, the office parks of Miraflores and the industrial area of Queluz de Baixo. In a more dispersed way, we can observe buildings with an exclusively daytime population, such as schools, hospitals, shopping centers or cultural buildings.

In **Fig. 9**, the result of the population distribution for the day and night period in two locations can be observed. In the first, corresponding to Algés, the distribution of the population by buildings shows a predominance of the residential function. As it is an area with some expression of proximity commerce, it is possible to verify the relevance of this use in some buildings. In the second location, corresponding to the Lagoaspark business centre, the distribution of the population by buildings allows checking the exclusive use during the day in some of the office buildings.

(**a**)

(**b**)

(**c**)

(**d**)

Fig. 9. (a) Night population by building in Algés; (b) Day population by building in Algés; (c) Night population by building in Lagoas Park Business Park; (b) Day population by building in Lagoas Park Business Park (data).

5. DISCUSSION

This paper presents the results of a building-scale population exposure model based on open data for earthquake loss estimation. The results of the analysis reveal that with some effort and additional work in associating the number of employees from administrative sources or from the average number of workers obtained from statistical sources to buildings polygons, is possible to locate the employed population for all buildings and create a population day exposure model. For the night period, the location and quantification of the resident population per building was possible to determine from a source of open addresses. These results represent an enhancement to existing population data sets such as the official data set (enumeration units) provided by Statistics Portugal since they allow its use with models of physical vulnerability (buildings) for two periods: day and night. The results obtained for the two periods allowed the identification of several limitations and problems associated with the methodology and open data. Most of these issues are related with inaccuracies and incompleteness on the building and points of interest datasets. For the building dataset we observed that some polygons do not have a geographic correspondence with the addresses layer. The geometry of buildings assumes aggregations and disaggregations that do not correspond to reality. It was also verified the inexistence of some polygon geometries of the OSM buildings dataset. The POIs layer is not exhaustive of the set of economic activities existing in the municipality, which is reflected in the underestimation of the present population in some buildings.

In this study, for the day period, the approach does not consider the different occupations during the day (e.g. markets, shops) or during the week or month (e.g. hotels), assuming the maximum capacity of the establishments as a principle. Due to commuting movements highly relevant in metropolitan areas, the determination of the population exposed in transit is of great importance. However, its inclusion in this work was not possible due to the lack of open data, being one of the aspects to be evaluated in future works.

The validation of the results allows to verify for the night period, a difference of 6506 inhabitants for the total of residents counted in the 2011 censuses. In the absence of an open dataset for the buildings with the true value for the resident population, an aggregation of the results of the night exposure model was carried out, which allowed a comparison with the enumeration units of the censuses. This comparison showed that in 28% of the enumeration units the model population coincides with the resident population and in 50% of the enumeration units the error varies between -2 to 2.

For the day period the results allow us to confirm Oeiras municipality as a generator/attractor of travels. For a basic quantitative validation daytime model results were compared against the total number of workers in various business parks. For example, in Quinta da Fonte business park we observed a difference of -63 workers. However, in Lagoaspark or Taguspark business parks the differences are more significant (-1469 and -1217). These differences can be explained by the completeness of the points of interest dataset representing the economic establishments, since they directly influence the calculation of the number of workers in the buildings.

Since that one of the verified difficulties related with the implementation of the methodology was the time spent in the search for administrative or auxiliary information related to the number of workers, in future works the possibility of integrating these data into open data datasets should be considered. This finding was also stated by Renner *et al.* (2018) in his work where the preparation of the diverse input datasets for the spatiotemporal models resulted in a time-consuming and cost-effective task.

6. CONCLUSIONS

There are many potential benefits in the use of the presented methodology based on open data. The empirical outcomes we used, as an application example, clearly demonstrate that there is an obvious difference between the night population and the day population.

By 2011, the official resident population in Oeiras was about 172 120. Our estimated present population for the municipality, was 197 076, more than 14% times the official resident population.

According to the differences found in this study, we concluded that the population exposure in metropolitan contexts is a dynamic concept as the night and day population change significantly. These findings are in agreement with the study carried out by Freire (2020) in the Lisbon Metropolitan Area. In risk assessments these differences emphasize the importance of considering daytime complementary to nighttime population, as traditional administrative census data are only based on a static perspective/view of resident population. It is also fair to consider that “while it is generally true that any data are better than no data in an emergency situation, the best decisions are those made with the best data… (p.66)” (NRC, 2007).

There are significant outcomes in the calculation of present population deriving from the use of indirect techniques, as those that apply satellite images, but the uncertainty of these estimates and the limited information they produce make them insufficient methods to support emergency and mitigation plans.

We also keep in mind that the present population is not a static variable since it moves in time and space. According to the presented methodology, the use of open data like addresses and points of interest is a useful contribution to build population exposure models that can be integrated in software tools for assessment of earthquake risk, like OpenQuake Platform.

The dimension of the differences we found concerning the size of the resident population makes clear the necessity of enlarging the debate about traditional methods and the application of new ones, which can integrate innovative elements and processes of calculation, to estimate the dimension and space-time nature of population exposition. Despite the growing possibility of mapping the distribution and dynamics of the population based on Big Data and on sources such as mobile phones, the difficulty in accessing this data and the need for information at the building level to model earthquake loss estimation only emphasize the relevance of the methodology used in this research.

Beyond this contribution to the debate, we are sure that the improvement of estimations of the exposed present population will allow the production of better preventive plans for emergency situations, an improved efficiency of the reactive protocol, and an adequate foundation for infrastructure, equipment, and management of human resources.

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