Estimation of Pedestrian Flows with Open-Source Crowding Data: An Integrated Modelin Nomentano-Tiburtina District, Rome

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Abstract. This research aims to investigate pedestrian crowding in the urban area of the Nomentano-Tiburtina district in Rome, through a methodology that sees an integrated approach between a configurational digital model, created with the Space Syntax tool by Qgis, and a physical model based on data collection through the mobile observer mode and therefore directly and through the use of Google Street View, in virtual terms. An innovative methodology was therefore developed to be able to obtain a physical model through virtual data collection, and this made it possible to calibrate the digital model. The calibration highlighted, with a Pearson of 0.88, the effectiveness of the methodology developed. At the same time, all the factors influencing the digital model, such as demand-driven and land-use, were also studied. From the analysis of these factors, it was found that the presence of shops on the pedestrian network plays a strategic role in the assessment of pedestrian crowding, recording a better correlation than the data measured on site. The conclusions drawn from this research, therefore, are of considerable help in urban planning, emphasizing concepts such as accessibility and pedestrian safety.

Keywords: Pedestrian crowding · Space Syntax · Configurational model · Physical model

1 Introduction

Nowadays, the concepts of sustainable mobility are increasingly of interest, as evidenced by plans such as the Agenda 2030 [1, 2], which provides for the achievement of sustainable development goals through the acquisition of specific tasks such as the reduction of environmental impacts caused by traditional transport systems by promoting more ecological and accessible travel.

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Among the sustainable modes of transport, the one that is becoming increasingly popular is the on-foot mode, defined as soft mobility. Certainly, an increase in walking helps to reduce greenhouse gas emissions that would be recorded if, on the contrary, a motorized vehicle was to be made [3, 4].

In addition to the aspect related to environmental sustainability, the increase in walking helps to contribute to the reduction of road accidents, due to the construction of a better infrastructure and the reduction of vehicular speed, thus ensuring better safety [5–7]. In this regard, it is necessary to investigate pedestrian flows that affect urban areas to guarantee safe pedestrian paths and avoid "not allowed" crossings, i.e., outside appropriately built crossings, by pedestrians, which leads to an increase in accident risk. However, several factors influence pedestrian behavior, on the one hand, the availability of dedicated infrastructure and the perception of safety, on the other hand, the geometry and configuration of the pedestrian network, the presence of commercial activities, as well as the socioeconomic characteristics of the population [8, 9].

Therefore, it becomes of primary importance to analyze the pedestrian flow of urban areas to understand how the various factors previously highlighted influence pedestrian behavior and how to create pedestrian paths that are as connected as possible to ensure the safety of their practicability.

In the literature, there are many studies that investigate pedestrian flow through the use of a configurational model [10–13], highlighting how urban morphology is a key element that conditions the movement of pedestrians. Other studies [14–16] describe how other important parameters, including land-use factors, population density, and so on, are of extreme importance to consider in the analysis of pedestrian flows. However, pedestrian flows are also estimated through direct observations [17–19] through sensors, mobile observatories, and video cameras.

What seems to be missing in the current literature is a combined approach, developed on an area of interest, which takes into account all these multiple aspects, i.e. the morphology of the urban environment, the influence of factors such as land-use or population density, and the calibration of these models through pedestrian flow data. The present research aims precisely at this objective, namely to develop a digital model, based on configurational analysis [12, 20–24] carried out with the Space Syntax tool [13, 25–27] of Qgis which allows to identify, through the magnitude of Integration, the pedestrian crowding that takes into account not only the geometry and configuration of the pedestrian network but also the socio-economic characteristics of the population.

In particular, a further influencing factor was analyzed, such as the presence of commercial activities along the pedestrian network, which was the most impactful of all, ensuring a better correlation with real data.

As far as real data is concerned, a new methodology has been developed for developing a physical model. The need to develop this methodology arises from the extension of the area of interest, such as the Nomentano-Tiburtina district located in the city of Rome.

On this area it is expensive to collect pedestrian flow data through the mode of mobile observer, so it was calibrated, first, on a smaller reality [28–30] on which a previous study had already been conducted, a virtual data collection mode, through the use of the Street View application of Google Maps, which was then used for the case

study presented in this research. Thanks to the combination of digital model and physical model, and through the definition of a new methodology for the calibration of the model, it was possible to define, in detail, the pedestrian dynamics characterizing the study area. In addition, the weight of commercial activities present along the pedestrian path, on pedestrian behavior was analyzed, highlighting how this factor is predominant in terms of influence.

Compared to what has been investigated to date in the literature, the present study aims to define an integrated approach between configurational models, thanks to the use of Space Syntax, and physical models, which allow the collection of real data. In addition, an innovative methodology has been developed to obtain pedestrian flow data from open-source platforms (Google Street View) that guarantees good replicability with a reduced computational burden. The aim, therefore, of the present research is to develop an integrated model capable of accurately representing pedestrian flows and providing a useful tool for urban planning.

2 Methodology

To evaluate the pedestrian crowding present in the study area, taking into account completely and exhaustively the behavior of pedestrians, an integrated configurational model was developed that sees the combination of digital and physical approaches as described in Fig. 1.

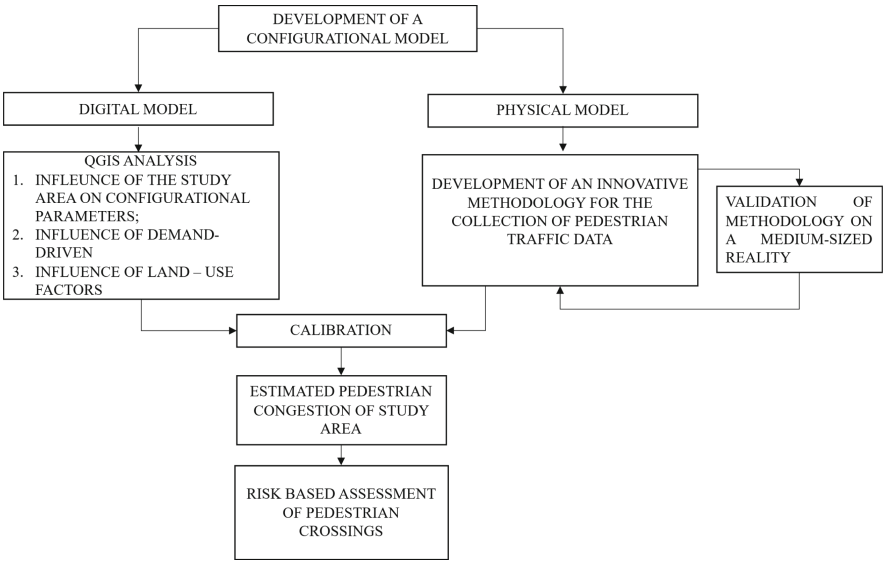


Fig. 1. Flow chart of methodology

As far as the development of the digital model is concerned, the QuantumGIS software was used. In particular, first it is planned to define the pedestrian network of the case study, then, through the Space Syntax application, explore the influence of the study area on configurational parameters, focusing on factors related to both demand drivers and land-use, which can have a significant impact on pedestrian density.

Among the factors considered are the population density, the estimate of which was possible thanks to data from the Italian National Institute of Statistics (ISTAT), and the presence of commercial activities along the pedestrian network, the data of which were retrieved from the Google platform in particular from the Google Street View application.

Alongside the digital model, a physical support model has been developed that aims to make the digital model, previously developed, as real and accurate as possible through a calibration of the data. Therefore, for the development of the physical model, it is necessary to carry out a collection of experimental data on the pedestrian crowding of the area under consideration.

The most common method of doing this is undoubtedly that of the mobile observer, which consists of an observer, or a team of observers, who physically moves around the study area, usually walking along a predefined path recording the number of pedestrians present in the areas and their relative position (if they are on the right and/or left sidewalk or if they are crossing). To obtain geolocated data, observatories can also be equipped with GPS devices.

However, this methodology can be applied to small and medium-sized areas but is more difficult to implement in larger areas, such as the one in the case study. To endorse this, a virtual data collection methodology was developed through the use of Google Maps' Street View mode, which could be appropriately calibrated, so as to have data as similar and precise as possible to that which could have been collected with the mobile observer method.

However, the collection of data from Google Street View has gaps and therefore, can be less reliable than the other methodologies mentioned above. To overcome this, the present research studies an appropriate calibration between data collected virtually and data collected through conventional methodologies.

From previous studies [28–30] in which the configurational model was applied to a small-medium-sized reality, there were data characterizing pedestrian flows collected through a mobile observer. For this area of interest, therefore, the same data were collected but in virtual mode, through the use of Google Street View. Then it proceeds to identify a literature pattern that could have a trend (in terms of peaks and softness) similar to that of the case study, to be able to scale the data collected virtually for all hours of the day. Once this was done, it was possible to find a discriminating factor between virtual data and data collected by the mobile observer. This parameter, therefore, allows for the calibration data collected virtually so that they are as reliable as those collected by other conventional methodologies.

It was therefore possible to use this scaling factor on the data collected virtually for the area of interest of the present research to calibrate the model.

2.1 Study Area

The case study falls on an area of the Municipality II of Rome called Nomentano-Tiburtina (see Fig. 2). Located in the north-east quadrant of Rome, the Nomentano-Tiburtina area sees the influence of numerous significant attractions such as the Tiburtina Station, one of the main transport hubs of the capital, to this is added the proximity to La Sapienza University and the Umberto I Polyclinic, which attract students, workers and visitors daily, creating a heterogeneous mix of constantly moving pedestrian flows. The main arteries, such as Via Tiburtina and Via Nomentana, are also significant for the impact on pedestrian crowding as they act as commercial streets. The medium-sized area that was used to validate the data collection methodology through the Google Maps Street View application falls within the municipality of Cassino (see Fig. 3) located about 140 km away from Rome.

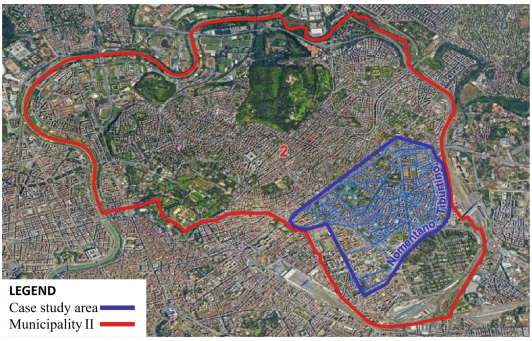


Fig. 2. Case study area (in blue) located in Municipality II (in red) [31]. (Color figure online)



Fig. 3. Case study area located in Cassino

The significant activities fall around Corso della Repubblica, the main artery that crosses the city, where there are shops and various commercial activities. Not far away, Piazza Labriola serves as a nerve center of city life. No less important is the presence of the University of Cassino and Southern Lazio, located near the city center. The university generates a constant flow of students, faculty, and staff, which adds to the daily movements related to commercial activities and public services.

2.2 Digital Model

As far as the digital model is concerned, it has been developed using spatial data analysis software such as Qgis and in particular the Space Syntax tool that allows to carry out a configurational analysis of the pedestrian network and obtain a quantity, called Integration [23–27], which allows to express pedestrian crowding. The study on pedestrian crowding in Cassino was developed from previous studies [28–30], while as regards the Nomentano-Tiburtina area, following an analysis previously carried out [31] where pedestrian crowding was expressed only in terms of Integration, an influence parameter such as the presence of shops was investigated.

First of all, it was necessary to identify the shops on each arch characterizing the pedestrian network of the Nomentano-Tiburtina area; to do this, the Street View application of Google Maps was used.

The distribution of the identified stores can be seen in Fig. 4.



Fig. 4. Identification of shops in the Nomentano - Tiburtina area

Once the shops that insist on the pedestrian network had been identified, it was possible to define an ad hoc methodology to be able to evaluate the value of Integration that takes into account the influence di shops.

A correction coefficient, called K_{shop}, was first evaluated, which sees the relationship between the average length of the shops and the length of the stretch affected by them as expressed by Eq. 1

$$K_{shop} = \frac{L_{average,shop}}{L_{treat}} \tag{1}$$

where:

- $L_{average,\ shop}$ is the average store extension;
- L_{treat} is the length of the arch of the pedestrian network concerning which the value of Integration is to be evaluated.

Once the K_{shop} coefficient has been defined, it is possible to evaluate the Integration that takes into account the influence of the shops on the pedestrian network as described in Eq. 2.

$$INT_{shop} = INT_{P_{prox}} * K_{shop} \tag{2}$$

where:

- $INT_{P_{prox}}$ is the value of Integration corrected with the proximity weight;
- K_{shop} is the coefficient that takes into account the presence of the shops previously explained in Eq. 1

The results obtained in terms of Integration considering the influence of stores can be appreciated in Fig. 5.

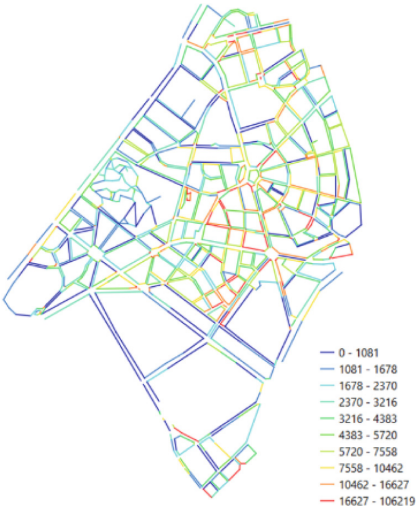


Fig. 5. Distribution of Intshop on the Nomentano – Tiburtina

2.3 Physical Model

The physical model is based on the evaluation of the number of pedestrians present on the network of pedestrians. In this case, as previously defined, a new methodology has been developed to carry out pedestrian counting in a "virtual" way on large areas such as that of Nomentano—Tiburtina. This methodology was validated on a medium-sized reality, such as that of Cassino, and then applied to that of the case study.

First of all, data were collected on the pedestrian count, on the Cassino pedestrian network, with the mobile observer method [28–30]. The processed data, used for this research, refer to average data of typical working days referring to the following time slots:

- Morning slot: 8.00–9.00 in order to consider the arrivals of students and workers in the places of study and/or work;
- Afternoon slot: 12.00–14.00 in order to consider the time of exit from school for students and the lunch break for workers;
- Evening slot: 18.00–19.00 in order to consider the return home of workers and students.

These data were collected along the arcs visible in Fig. 6.



Fig. 6. Arches where pedestrian counts were made [28–30].

The same work was conducted virtually, thanks to the use of the Street View application of Google Maps, which, however, returns the count of pedestrians in a single instant of a typical day, i.e., when the Street View car passed through the case study location. In light of this, on Google Maps, a date was set on a typical weekday, and data collection was carried out.

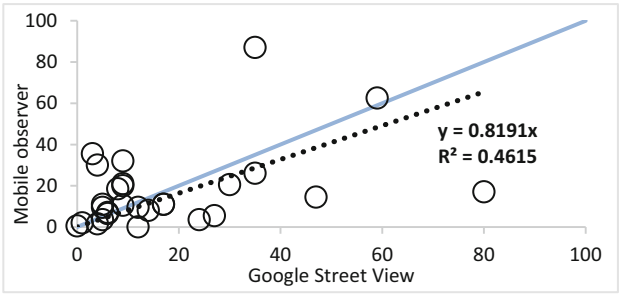
However, this is not enough; it is necessary to know the time slot during which the Google Street View vehicle made the passage, and therefore, which refers to the data collection carried out. Thanks to the use of software that allows, from the study of the shadows present in an image of interest, to define the time to which the image refers, it was possible to estimate the time of passage of the Google Street View car and therefore estimate the time of the "virtual" data collection of pedestrians (see Fig. 7) which turned out to be around 12:00 am.



Fig. 7. Defining the time of the passage of the Google Street View car [32].

Therefore, the need arises to obtain data that also refer to the other hours of the day in order to be able to compare them with those collected with the mobile observer method. First of all, the correlation between the data collected in a "virtual" way and those collected through the mobile observer method in the various time slots described above was studied to understand in which time slot the best correlation is recorded and to be able to confirm that the data collected virtually refer precisely to a late morning time, in particular at 12:00 am.

As can be seen from Fig. 8a, b and c the best correlation is obtained for the afternoon time slot (12:00–14:00) confirming what was previously defined.



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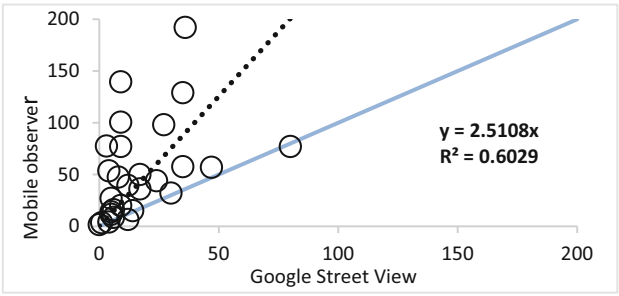

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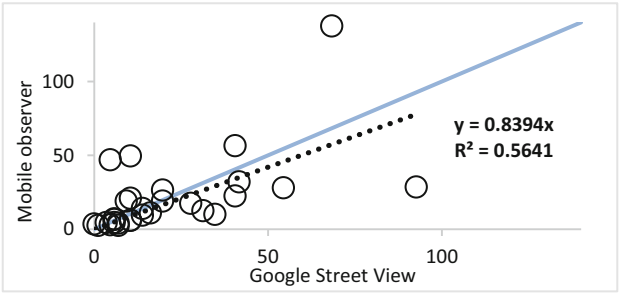


c.

Fig. 8. a. Pedestrian flow data (8:00 am – 9:00 am). b. Pedestrian flow data (12:00 am – 14:00 pm). c. Pedestrian flow data (18:00 pm – 20.00 pm)

To obtain data that refers to the entire pedestrian flow pattern, a literature pattern [33] that reflects the trend of the case study pattern was considered. In both patterns, there is a peak in the lunch slot around 13:00 with periods of softness in the night and the later evening slots (see Fig. 9).

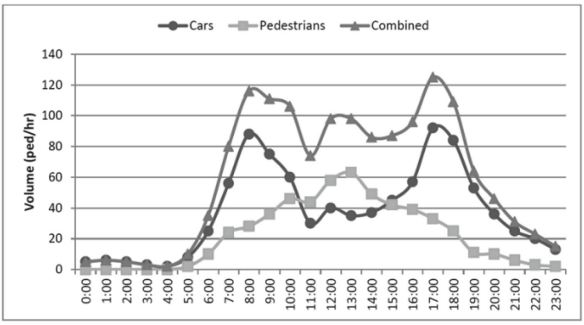


Fig. 9. Reference Literature Pattern [33]

The methodology adopted sees the identification of the value of the pedestrian flow, in the literature pattern, relating to 12:00 noon, considered as a reference base. Therefore, for each hour of the day, an hourly coefficient was evaluated by dividing the value of the pedestrian flow corresponding to 12:00 by the value of the pedestrian flow corresponding to the other hours of the day (see Eq. 3).

$$C_{l,i} = \frac{P_{l,12}}{P_{l,i}} \tag{3}$$

where:

- $P_{l,\,12}$ is the pedestrian flow value referred to 12:00 noon of the literature pattern;
- $P_{l,\,i}$ is the value of pedestrian flow referred to the i-th hour of the day of the literature pattern.

Once this was done, in order to evaluate the values of the pedestrian flow for each hour of the day, referring to the case study, a proportional approach was adopted. More specifically, for each hour, the value of the pedestrian flow observed, with the use of Google Street View, at 12:00 relating to the case study was divided by the corresponding coefficient calculated from the literature data (see Eq. 4).

$$P_{sw,i} = \frac{P_{sw,12}}{C_{l,i}} \tag{4}$$

This has made it possible to obtain an hourly distribution of a typical weekday of the pedestrian flow falling within the area of the case study, consistent with the pattern reported in the reference literature. This evaluation was carried out for each arch of the pedestrian network of the case study, for which there are counts of the pedestrian flow (see Fig. 6). The pedestrian flow pattern, therefore, relating to the case study, shows the trend shown below (see Fig. 10).

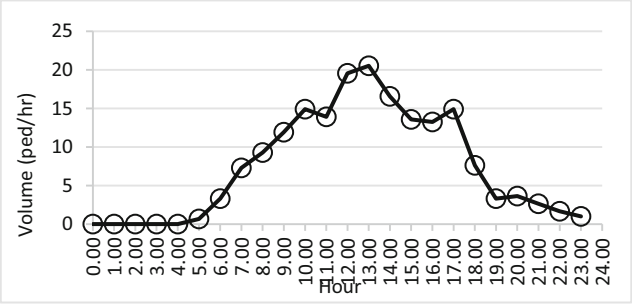


Fig. 10. Pedestrian flow patterns of the case study

In order to make comparable, in terms of time slots, the counts of pedestrian flow obtained with the method of the mobile observer and the related ones obtained thanks to the "virtual" collection with Google Street View, the latter have been reorganized.

Comparing the counts, the result obtained is shown in Fig. 11.

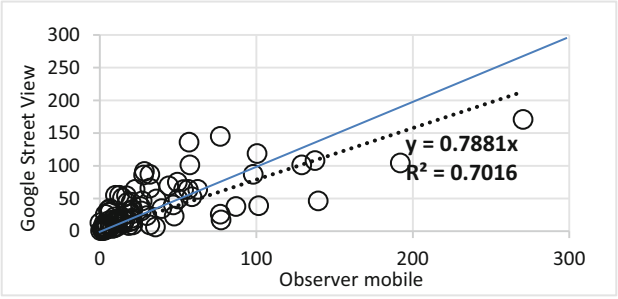


Fig. 11. Estimated pedestrian flow comparison using the mobile observer method and Google Street View

As shown in Fig. 11, it is possible to define the relationship between the data collected with the mobile observer method and those collected through the use of Google Street View, reaching an agreement that sees the definition of a Pearson equal to 0.73.

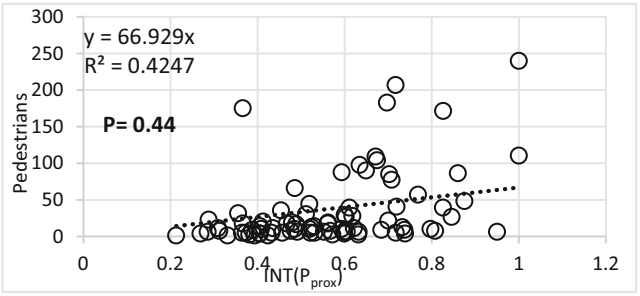
Thanks to this relationship it was possible to collect data on pedestrian flow in the Nomentano-Tiburtina area and appropriately scale these data using the relationship defined in Fig. 11.

3 Analysis of Results

In order to have a model as close as possible to reality, a calibration was carried out between the digital model created with the Qgis application, Space Syntax, and the physical model, from which it was possible to obtain data relating to the pedestrian flow. However, as far as the digital model is concerned, several cases are analyzed to understand which digital model best fits the physical model.

The analysis evaluates the relationship between the estimated pedestrian flows, appropriately corrected with different weighting factors, and the pedestrian flows observed through Google Street View. In particular, two different corrections of the digital model were considered: one based on a weight of proximity, which takes into account the distance concerning certain areas of interest, and another that integrates a factor related to the presence of commercial activities along the pedestrian network.

The survey was conducted both in the case where the study area, corresponding to the Nomentano-Tiburtino district, was considered in isolation, excluding the influence of the neighboring municipalities, and in the case where this influence was maintained. The comparison between the pedestrian flows deriving from the corrected digital model and those estimated through Google Street View made it possible to evaluate the impact of each weighting factor on the accuracy of the forecasts and to understand how the territorial configuration affects the distribution of pedestrian traffic. By this, the Pearsons of the various proposed cases were evaluated, obtaining the following results (see Fig. 12a, b, 13a and b).



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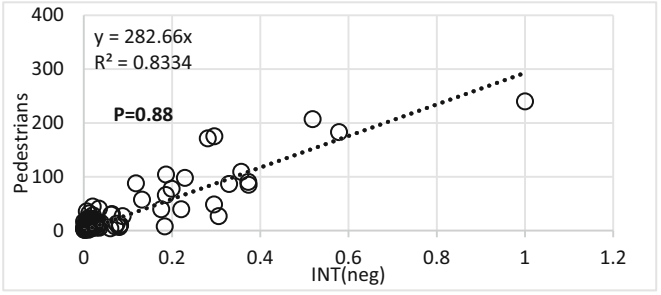
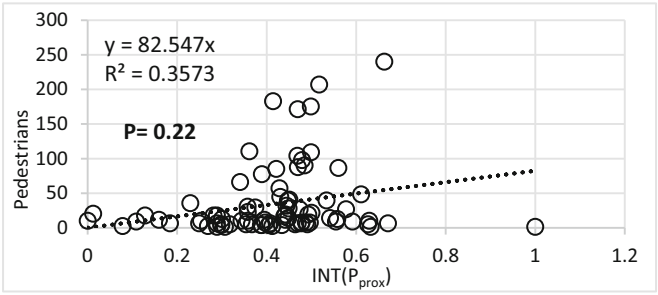


b.

Fig. 12. a. Relationship between pedestrian flows estimated with the digital model corrected with the proximity weight and pedestrian flows estimated with Google Street View, in the case of isolated Nomentano-Tiburtina. b. Relationship between pedestrian flows estimated with the digital model corrected with the weight that takes into account the presence of shops and pedestrian flows estimated with Google Street View, in the case of Nomentano-Tiburtina isolated



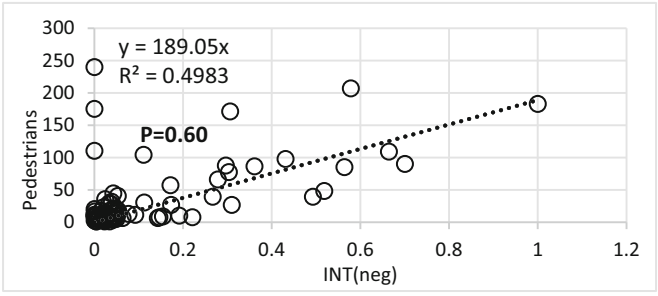


Fig. 13. a. Relationship between pedestrian flows estimated with the digital model corrected with the proximity weight and pedestrian flows estimated with Google Street View, in the case of Nomentano-Tiburtina with the influence of neighbouring municipalities. b. Relationship between pedestrian flows estimated with the digital model corrected with the weight that takes into account the presence of shops and pedestrian flows estimated with Google Street View, in the case of Nomentano-Tiburtina with the influence of neighboring municipalities.

As can be seen from the figures above, the best correlation between the digital model and the physical model can be obtained by considering only the area of the Nomentano-Tiburtina case study without the influence of the neighboring municipalities and considering the digital model that takes into account the presence of shops along the pedestrian network, with a Pearson equal to 0.88 (see Fig. 12b).

Once this was ascertained, it was possible to calibrate the model (see Fig. 14).

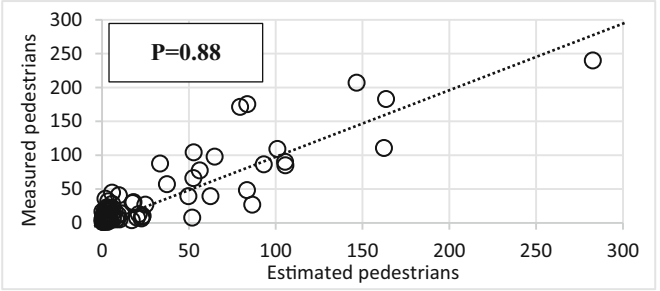


Fig. 14. Calibration between the digital model and the physical model

This research has allowed the development, on the one hand, of a digital model, concretized thanks to the use of the Space Syntax tool by Qgis, which has allowed the creation of a configurational model capable of defining pedestrian crowding through the value of Integration, and on the other hand the development of a physical model that has allowed the definition of a methodology capable of obtaining data on pedestrian flow in a "virtual" way through the use of Google Street View.

It was therefore possible to calibrate the digital model with the data obtained from the virtual collection through Google Street View, showing an excellent correlation, with Pearson equal to 0.88, considering, for the digital model, the Nomentano-Tiburtina district, isolated from the influence of neighboring municipalities, and the variable linked to the presence of shops along the pedestrian network.

From the processing of the data obtained, it was possible to evaluate the propensity to cross pedestrians (see Fig. 15).

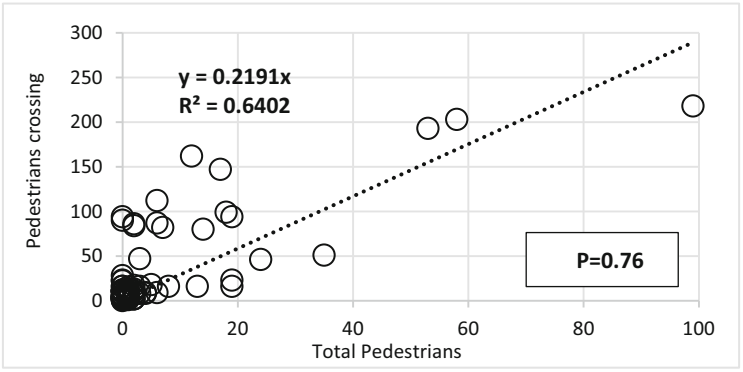


Fig. 15. Relationship between pedestrians on the network to pedestrians crossing

This analysis shows the link between the size of the pedestrian flows insisting on the network of the case study, and the number of crossings of the latter. It is therefore confirmed that proximity to commercial attractions greatly influences pedestrian behavior.

Thanks to these results, it is possible to say that the present research has set out to define an innovative methodology for the evaluation of pedestrian crowding in a district of Rome (Nomentano-Tiburtina) that involves the combination of a configurational model and a physical model; this methodology has been calibrated thanks to data collected with an innovative technique through open-source tools (Google Street View) which ensures easy replicability even in different urban contexts.

All this allowed, in the end, to be able to evaluate the propensity to cross in the case study area. This becomes a tool of fundamental importance for authorities and urban planners, as it allows them to make accurate assessments of pedestrian safety.

4 Conclusion

From the results obtained, it is possible to confirm the validity of the proposed integrated approach, highlighting how the combination of digital and physical models represents an effective tool to analyze pedestrian flows and support urban planning.

From the analyses carried out on the area of interest, such as the Nomentano-Tiburtina district of the city of Rome, it was possible to identify the predominant factor that influences pedestrian behavior, such as the presence of shops along the pedestrian network.

In addition, a new "virtual" data collection methodology has been developed, suitably calibrated, which allows data on pedestrian flows of larger areas of interest to be collected quickly and easily. In light of the results, therefore, the present research aims to make a significant contribution to the understanding of pedestrian dynamics and offers a starting point for future studies aimed at optimizing soft mobility in complex urban contexts.

The calibration of the digital model obtained from the correlation with real data, which results in a Pearson equal to 0.88, demonstrates the effectiveness of the analysis and how the model developed is as close as possible to reality.

In the future, the goal is to improve and investigate more about the "virtual" data collection method in order to optimize it and make it computationally as simple, but at the same time, as accurate as possible. In order to have not only data relating to a specific time of day, such as that offered by Street View, but also to have a complete pedestrian range pattern, we propose to exploit existing technologies for complementary applications, such as cameras installed for monitoring climatic events.

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C.G.; **supervision**, D.A.M., N.V. and P.M.; **project administration**, D.A.M. and N.V.; **funding acquisition**, D.A.M. and N.V. All authors have read and agreed to the published version of the manuscript.

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