Seeing Visitor Behaviours in Tourist Plazas with Computer Vision and Space Syntax

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Abstract

Urban public squares are key settings for social interaction, leisure and pedestrian movement, yet most behavioural studies rely on manual observation or surveys of limited spatial and temporal scope, and computer-vision studies generally treat square users as a homogeneous group. This study examines three tourist squares of contrasting morphology: Times Square in New York (amorphous), Senado Square in Macau (nuclear) and Piazza Santa Maria in Venice (closed). Public webcam footage was combined with open spatial data; pedestrian trajectories were extracted using YOLOv8 and BoT-SORT with an age-classification module; isovist area (IA) was calculated to quantify spatial openness; and generalised linear models were used to test how IA, points of interest (POI) and facility distance relate to the trajectories of children, adults and older adults. The results show that amorphous squares recorded the highest IA values, followed by nuclear and closed squares. Pedestrian volume rose from morning to evening in all three cases, but its spatial distribution differed by typology. Children's trajectories were most strongly associated with proximity to facilities, adults moved in a linear, destination-oriented manner, and older adults favoured open sightlines and proximity to POI. The framework offers a transferable method for evidence-based, age-friendly square design.

Keywords

Pedestrian behaviour, Isovist analysis, Age-friendly urban design

1. Introduction

As the life and spirit centre of the city, urban public squares are necessary places for people to gather, enjoy life, relax, meet others and do other daily activities. Squares are relatively open forms of public spaces that can accommodate various people and support many different types of activities, such as walking, resting, socialising, sightseeing and cultural events. The paths and stops of pedestrians in these Areas will affect the liveliness of the city, use of space and public security. Therefore, to build an all-age, high-quality public space, one needs to know how to move when a person walks.

The quality of the urban public space has been known to affect people's behaviour for a long time. Jan Gehl's ideas are concerned with how the space in an area affects people's behaviour, such as walking and relaxing, as well as what is visible to them and how they use public areas. Benedikt (1979) proposed the "isovist" theory to provide a way to quantify the visible area from a certain point of view, and it has now been used to examine spatial openness and visibility. A graph of distributed visible graphs (VGA) was also used to show the relationship between space and pedestrian flow later. Although isovist analysis has good theoretical support, it has not been widely applied in recent years to real-world, large-scale observational data on pedestrian behaviour in complex urban areas.

Recently, with the development of computer vision, we have been able to observe how pedestrians move in various areas and at different times more closely. Real-time feeds of public network cameras are used to detect and track pedestrians through deep learning-based object detection and multi-object tracking algorithms without the need for time-consuming and labor-intensive field surveys. Recently, some researchers have used computer vision to conduct research on activities in public spaces and urban social life. Although the above studies have mainly focused on pedestrian detection and crowd feature analysis, very few have incorporated spatial visibility analysis with computer vision to explain why pedestrians choose certain paths of movement or gathering areas.

The existing studies also have some deficiencies.

First, most prior research has used simple indices to describe the spatial environment, such as distance, width or accessibility, but has not explicitly analysed the visual structure of open spaces. Isovist theory can quantitatively describe spatial openness well, but there have been few comparative studies of different plaza types. As a result, it has not been known how visual openness differs according to space shape or how this affects the behaviour of pedestrians.

Second, most research on pedestrian behaviour has used only a single-case study or treats pedestrians as a single type, failing to systematically study the differences among children, adults and older persons. However, these groups are diverse in terms of physical abilities, space perception and behaviour. Failure to consider age differences in the observation may miss important differences in how various age groups use public areas.

Thirdly, many of the existing studies are based on manual observation, behavioural mapping, questionnaires or recall-based route records. These methods are labour-intensive and prone to human error and recall bias; they are also not suitable for long-term operation and cannot provide high-precision continuous pedestrian trajectory data efficiently. Although computer vision is also a kind of data, it has not yet been included in quantitative spatial analysis.

In light of the above research deficiencies, this paper proposes a general framework that integrates computer vision (CV) and Isovist analysis to study pedestrian behaviour in urban public squares. Three tourist plazas in different spatial distributions were selected as cases: Times Square in New York (irregular form), Senado Square in Macau (central-cluster form), and Campo Santa Maria Formosa in Venice (enclosed form). These cases are plazas in the main tourist areas of the three countries, and they offer high-quality, publicly accessible, real-time webcam feeds suitable for long-term observation of people. Quantify spatial visibility using isovist area (IA) and automatically extract trajectory data for the three demographic groups from video footage via YOLOv8 object detection, age classification and BoT-SORT multi-object tracking technologies. A comprehensive comparison of the distribution of people at different times and places will be conducted in an all-weather combined dataset.

Based on the above, the two research questions for this study are: (1) how do different plaza configurations vary in terms of spatial visibility (measured as isovist area), and (2) how do visual-spatial features affect the movement and stationary behaviour of children, adults and the elderly?

This paper has three contents. First, based on DepthmapX, it can be used to study and compare the degree of visual openness among the three kinds of plaza layouts. Second, it has introduced age-stratified pedestrian analysis in computer vision (CV) research to identify behavioural differences among children, adults and older persons and thus avoids treating pedestrians as a single group. Thirdly, a consolidated Computer Vision -Isovist framework has been created to jointly extract automatic trajectories and perform spatial visibility analysis of pedestrian behaviour in urban public spaces, and a scalable solution has been put forward. The results provide some information on the impact of space arrangement on people's movement and offer some ideas for building age-friendly areas and improving urban life and safety.

2. Literature Review

2.1. Theoretical Foundation of Research on Public Space Behaviour

Research on pedestrian behaviour in urban public spaces has a relatively strong theoretical basis and has also developed considerably over the past 50 years. Jan Gehl and his group of scholars led the field of research on public spaces in cities and profoundly altered the view that urban designers and planners held about the conception of these spaces, shifting their attention from pure aesthetics and functionality to people's life experiences and behaviours (Gehl, 2010). Gehl's "Public Space - Public Life" (PSPL) system set up an all-encompassing observation method to study who uses public areas, what kinds of activities are carried out there, where these activities take place, and how long people stay in a particular location (Gehl & Svarre, 2013). The first three ideas in this system are the edge effect, division of soft and hard edges, and a type classification for activities such as necessary, optional and social purposes; all of which have changed the direction of research on pedestrian behaviour in urban plazas. PSPL has applied the system of observation and behaviour mapping in some urban design work and continues to use it for research at present (Silvennoinen et al., 2022).

In addition to Gehl's observation method, Hillier and Hanson (1984) developed a school of space that quantified how the layout of spaces affects the behaviour of people, and they were known as the "Space Syntax" school. Turner and others (2001) proposed a way to study urban area shape and layout, as well as how linked and usable such places are, by creating a Visibility Graph for analysing people's movements in a city through Visibility Graph Analysis (VGA). These researchers have shown that spatial geometry can influence people's movements and uses of public areas for different purposes to a large extent (Turner et al., 2001). Early studies in Space Syntax focused on the analysis of buildings and urban areas and paid relatively little attention to the behaviour patterns of different groups of people. Space Syntax methods and behavioural observations have not been combined for in-depth research at the individual or group level for many years.

Benedikt's (1979) initial research on "isovist" theory has also offered a way to study space and behaviour. An isovist is the set of all points visible from a particular observation position within a spatial environment, and thus it is possible to use geometry to measure how accessible or open a space is. This idea can be used to observe how people perceive and feel about the world around them; as visual information enters our brains rapidly, it can lead to various responses such as movement, immobility or others (Benedikt, 1979). The Area Visible from a Specific Location (IA) is the entire area that can be observed from that position, and it has been shown to be positively correlated with the density of people.

2.2. Methodological Development in Pedestrian Behaviour Analysis

The ways in which we study the behaviour of people have changed a lot recently; now, most research is done using computer vision. Gehl's PSPL framework and traditional methods have been used to count and map pedestrians in public spaces manually for a long time (Gehl & Svarre, 2013). Although the above methods provide some detailed descriptions, they are also limited in terms of the accuracy of observation, scope of time and potential for observer bias (Krukar et al., 2020). Krukar and others (2020) have added eye-tracking and sensor technology to study how people move in indoor spaces, and found that a person's attention to the wayfinding system can be determined from their eyes and surroundings. However, the above methods still have deficiencies in terms of spatial coverage and scalability, and are thus not suitable for large-scale urban analysis (Salazar-Miranda et al., 2025).

With the development of computer vision, large-scale and automatic analysis of pedestrian behaviour can be carried out now (He et al., 2026). Salazar-Miranda et al. (2025) have shown that, by integrating public webcam data with a computer vision pipeline, it is possible to study social behaviour in the urban areas of New York City, and automated tracking can collect large-scale data on people's time spent and how they interact socially. Ventura and others (2025) have expanded the scope of research by using street-view videos and computer vision for pedestrian tracking and behaviour analysis, and found that automated methods are more objective, cover time-series data and space-time data more completely, and have a higher space-time resolution. Although these studies have made some progress in terms of methods, they generally treat pedestrians as homogeneous subjects and have not considered different behaviours of older age that may affect the use patterns of public spaces (Salazar-Miranda et al., 2025).

YOLOv8 is a relatively new object detection algorithm that can identify and categorise people in various parts of a city. Xiao and Feng (2023) presented the results of an improved YOLOv8 + OC-SORT model for multiple-object pedestrian tracking in crowded urban environments and achieved high-precision tracking. The above technologies can extract trajectory data and automatically label attribute information about pedestrians, such as general age ranges; thus, age-based stratification analysis can now be conducted automatically without the need for manual processing (Ventura et al., 2025). Silvennoinen et al. (2022) used computation to investigate how Gehl's urban design guidelines impact the walkability of a place; such studies are now being extended through computational methods in urban design research. With the development of computer vision and spatial analysis, new ways have been found for studying urban phenomena; therefore, this study will apply these methods to advance the research in urban studies.

2.3. Empirical Studies of Age-Related Behavioural Differences

Experiments in public space behaviour have repeatedly identified certain trends that provide support for the construction of modern cities. Zhai and others (2018) combined GPS tracking with a survey in two urban forest parks in Shanghai and found that user groups with different visit motivations also differ in age composition and in how they occupy the park: visitors who came to have contact with nature and relax were more dispersed and covered larger areas, whereas those who came to play with children or to meet families and friends concentrated in settings that accommodate group activities, such as amusement areas, lawns and barbecue sites. Other studies have found that older pedestrians tend to be more random in their movement and explore randomly, whereas children are generally more cautious about safety. Research has shown that adults have more goal-oriented behaviour, move efficiently through the space, and only stop for a short time when they reach their destination.

Fulman and others (2025) reviewed empirical studies of how older people choose walking routes and how accessible those routes are; factors such as pavement quality, gradient, resting places, greenery, lighting and perceived safety all play a role in this selection. Their review shows that older adults are sensitive to environmental comfort and to whether a route feels safe, and that these attributes determine whether a walk is feasible at all rather than merely whether it is pleasant. The above environmental conditions indicate that age-friendly design should pay more attention to micro-environmental features that are frequently ignored in traditional planning.

2.4. Research Gaps and Study Contributions

Based on the above literature review, the three main research deficiencies this study will address are presented below. Although the Spatial Morphology is known to affect people's behaviour, very few studies have compared how different kinds of squares - such as amorphous, nuclear and closed - influence the behaviour of pedestrians in an organised manner with the same objective metrics. Most studies have been single-case studies or use simple indicators, such as distance and width measurements, and thus are unable to reflect the complex visual structure of public spaces (Benedikt, 1979; Turner et al., 2001). The above deficiency prevents the generalisation of the study to all areas in urban development and the establishment of typical design rules. A series of case studies with various spatial forms can be systematically compared to explore how spatial form affects behaviour.

Secondly, although research has found that older and younger people exhibit different behaviours in this field, most studies based on Computer Vision of urban areas still treat all pedestrians as a single group without dividing them by age in their analysis (Salazar-Miranda et al., 2025; Ventura et al., 2025). The combination of automated age classification and trajectory analysis can be used to study these differences at a larger scale and with higher spatial and temporal resolution (Xiao & Feng, 2023). Therefore, age-stratified variables have been added to the analysis in this paper to explore how behaviour differs among children, adults and older people.

Third, existing research has had methodological deficiencies, such as reliance on recalled routes, labour-intensive manual counting, and limited temporal coverage, thus restricting the scope and objectivity of pedestrian behaviour studies. The application of Computer Vision-based automatic trajectory tracking and the use of passage threshold criteria for objective path extraction have all been integrated to achieve a high-precision, all-encompassing and extensible analysis of pedestrian behaviour in urban squares (Ventura et al., 2025). This paper provides a new methodology to address the above issues by building and applying an integrated framework of Computer Vision and Isovist anal-

Paper	Region / Context	Topic	Data Source	Square Context	Isovist Area (IA) Included	Age Stratified	CV-based Tracking	Key Analysis / Model
Benedikt, M. L. (1979)	Theoretical	Spatial geometry foundation	Geometrical derivation	×	✓	×	×	Mathematical derivation of isovist fields
Turner, A., et al. (2001)	London, UK	Visual Graph Analysis (VGA)	CAD plans / Virtual agents	×	✓	×	×	Agent-based pedestrian simulation
Gehl, J., & Svarre, B.(2013)	Global Contexts	Public space & public life interaction	Manual observation (Counting, mapping, tracking)	✓	×	✓	×	PSPL framework (Who, Where, What, How long)
Zhai, Y., et al. (2018)	Shanghai, China	User group spatial distribution in urban forest parks	GPS trackers + survey	×	×	✓	×	ANOVA, logistic regression & spatial statistics
Krukar, J., et al. (2020)	London, UK	Indoor pedestrian behaviour	Eye-tracking + Sensors	×	✓	×	×	Spatial cognition & gaze-duration analysis
Salazar-Miranda, A., et al. (2025)	New York, US	Social life of urban spaces	Public webcam videos	✓	×	×	✓	Computer Vision pipeline & stay-duration
This Study	NY, Macau, Venice	Pedestrian Movement in Urban Squares	Webcam Livestream + OpenStreetMap	✓	✓	✓	✓	CV + Isovist Area Data Integration

Table 1. Literature Review

ysis for the three different square typologies in New York, Macau, and Venice, with specific age-stratified analyses of movement and stay behaviours.

3. Data and Methods

3.1. Research Design and Study Area

A framework of Computer Vision (CV) and Isovist is employed in this paper to study the behaviour of pedestrians in various morphologies of urban squares. The three links of this study are as follows: First, spatially visible is measured by Isovist analysis to determine how much a study area is visible. Second, using a computer vision pipeline and age classification, extract pedestrian trajectories from public webcam videos automatically. Finally, in conjunction with pedestrian trajectory data, spatial visibility indicators are employed to study the movement behaviour of children, adults and older persons in various spatial Areas.

The three tourist squares selected as cases are Times Square in New York (amorphous square), Senado Square in Macau (nuclear square) and Piazza Santa Maria in Venice (closed square). The three squares were selected for the fol-

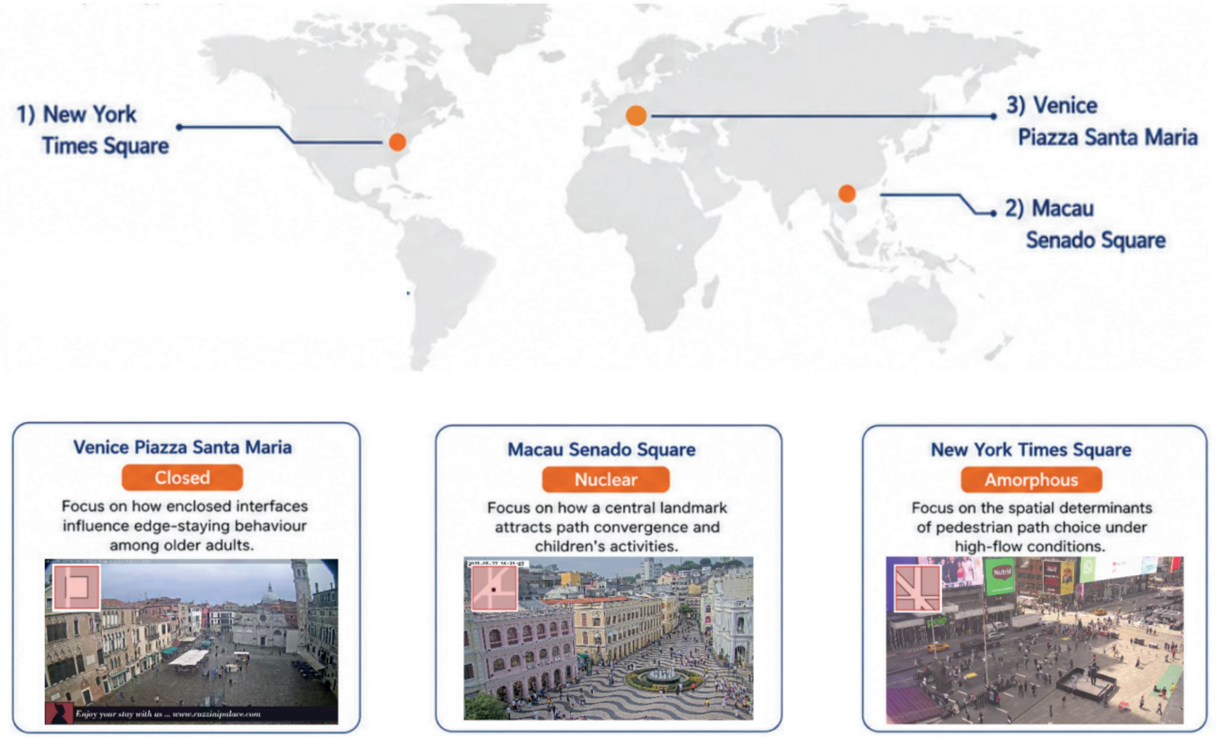


Figure 1. Study Area

lowing reasons. First, they are all squares that fit the concept of urban morphology and can be compared spatially. Second, they are well-known tourist attractions with a large number of visitors and a wide range of ages. Thirdly, all three locations have publicly available high-definition webcam live-streamings that can be viewed continuously and consistently for data collection. Collect pedestrian videos at the local level during the day (08:00-20:00) for a period of one week in both summer and winter to obtain representative pedestrian behaviour.

3.2. Data

The two kinds of datasets in this study are pedestrian trajectory data and spatial visibility data. Pedestrian trajectory data were obtained from publicly available webcam live streams on YouTube and Skyline Webcams. Between 8:00 AM and 8:00 PM on both summer and winter observation days, videos were recorded. A computer vision pipeline is used to generate an individual trajectory ID, a time-of-occurrence, location information, and an age category (e.g., children, adults or older adults) for each detect-

Variable	Data Source	Description
Pedestrian Trajectory	YouTube/Skyline Webcams	Video Time(Local Time): 11-12am_Week2_May_Mon_2025 9-10am_Week2_May_Wed_2025 13-14pm_Week2_May_Wed_2025 18-19pm_Week2_May_Wed_2025
Isovist Area	OpenStreetMap/Google Earth	The visible area size from one viewpoint (1m*1m).
POI Distance	OpenStreetMap	Distance from each grid cell(1m*1m) in the video range to points of interest
Facilities Distance	OpenStreetMap	Distance from each grid celll(1m*1m) in the video range to facilities
Facade Quality	Video observation	Classification as active/mixture/friendly

Table 2. Data Sources and Variables

ed pedestrian.

Spatial visibility data was sourced from OpenStreetMap and Google Earth. OpenStreetMap was imported into QGIS to generate a high-precision vector base map, which was then converted into a geometric model to enable Isovist analysis in DepthmapX. The Isovist area (IA) for each grid cell (1 m × 1 m) within the Video Square area was calculated to quantify the degree of spatial openness. In addition, two spatial explanatory variables were included: the distance from each grid cell to the nearest point of interest (POI) and the distance to the nearest public facility. The dependent variables were the number of trajectories for children, adults and older adults within each 1 metre × 1 metre grid cell. These datasets contain both behavioural information—necessary for analysing the relationship between urban form and pedestrian activity—and spatial information.

3.3. Method / Model Architecture

Computer Vision, spatial analysis and statistical models will be used in this paper. The three steps in the pedestrian extraction process are shown below. First, the YOLOv8 object detection model is used to find pedestrians in the video frames. Second, detected pedestrians are divided into children, adults and older persons according to age. Thirdly, employ the BoT-SORT multi-object tracking algorithm and planar coordinate transformation to produce smooth pedestrian trajectories in geographic coordinates.

Spatial visibility is represented by the Isovist Area (IA) of each 1m × 1m grid cell in the video range using DepthmapX. Pedestrian trajectories

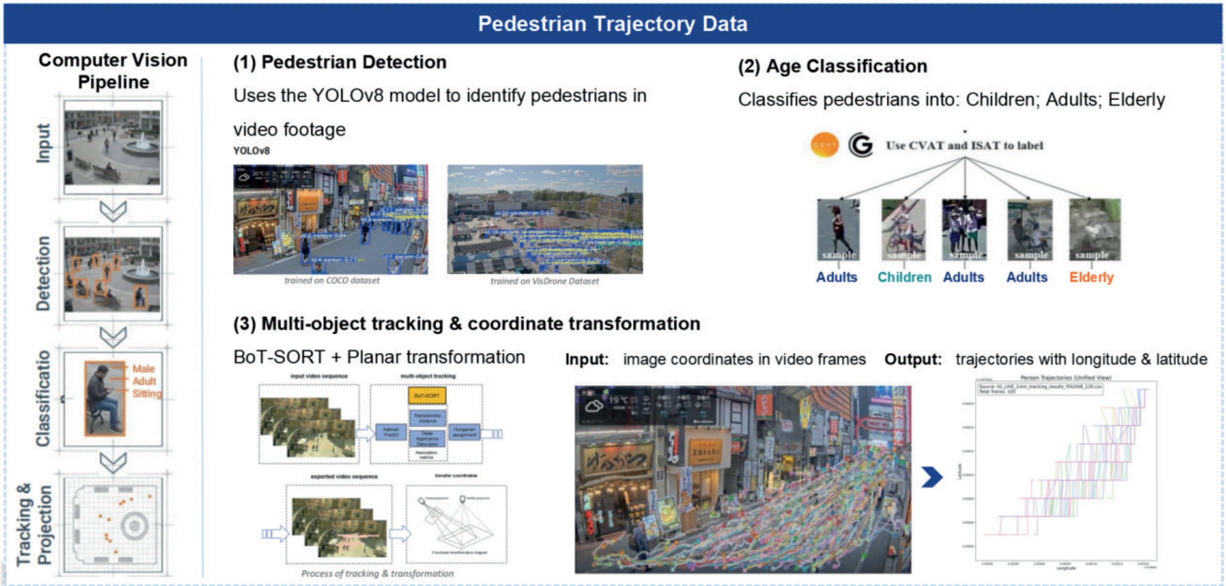


Figure 2. Workflow for Pedestrian Trajectory Data

are then superimposed on the grid in QGIS, and behavioural observations can be linked to the corresponding space. The three independent variables are IA, the distance from a single grid cell to the nearest POI, and the distance from a single grid cell to the nearest facility. The dependent variables are the number of children's, adults', and elderly trajectories in each grid cell. General linear models (GLMs) are then employed to examine the relationships among spatial features and alterations in the movement patterns of pedestrians of different ages in various types of squares. The two are combined into one CV-Isovist framework to conduct automated behavioural observation and quantitative analysis of the impact of spatial visibility on pedestrian behaviour.

4. Findings and Discussion

4.1. Spatial Visibility Characteristics of the Three Square Types

According to the Isovist analysis, the three typical square shapes have different levels of spatial visibility, and thus the urban form will affect the visual quality of public spaces. As shown by the calculated Isovist Area (IA), the amorphous square (Times Square) has a relatively large degree of visual openness, followed by the nuclear square (Senado Square), and the closed square (Piazza Santa Maria) is the least spatially open.

Times Square is large and lacks physical obstructions. The average Isovist Area (IA) is over 10,900 square metres, and the maximum value is 26,769 square metres; thus, most of the surrounding area can be observed by pedestrians

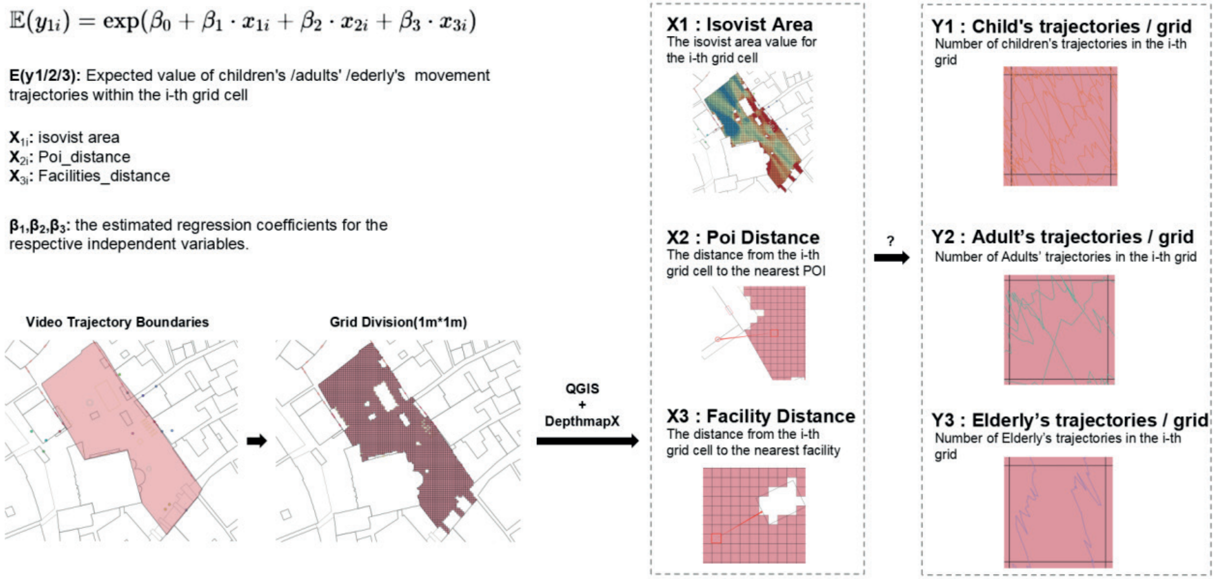


Figure 3. Workflow Setup: The Impact of the Three Independent Variables on Pedestrian Trajectories

Venice Piazza Santa Maria

Figure 4. Venice Piazza Santa Maria Video

Macau Senado Square

Figure 5. Macau Senado Square Video

New York Times Square

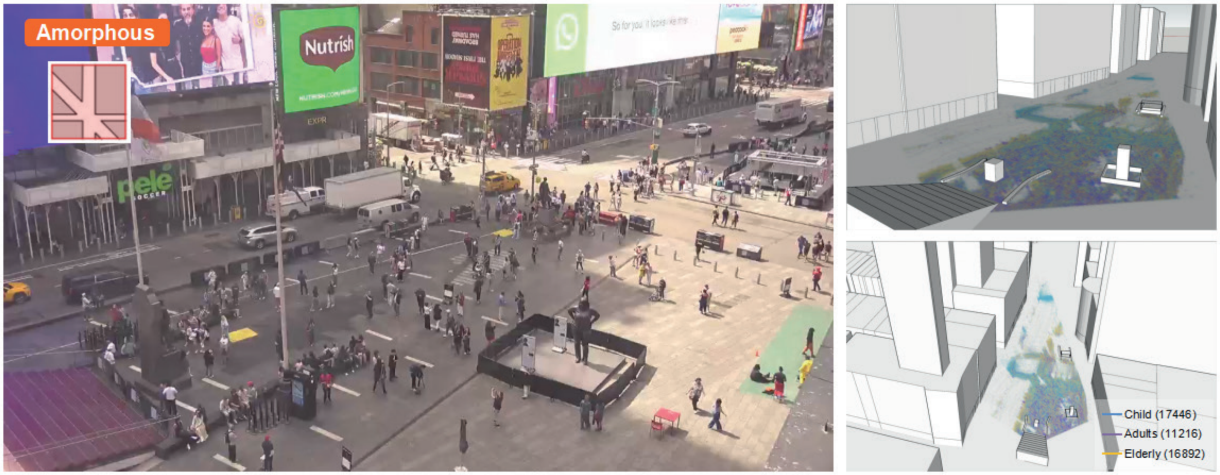


Figure 6. New York Times Square Video

from various locations. A relatively open view can offer some people an expansive view and multiple walking paths. On the other hand, Senado Square has a moderate-to-high level of visual openness. The area with the greatest visual scope is in the middle square, and the width of the line of sight decreases gradually away from it towards the edges. Therefore, the layout will be highly eye-catching and effectively draw attention to the fountain and the people's meeting place. Piazza Santa Maria has, on the other hand, a relatively closed-off space. The buildings around the square are relatively high in height; as a result, the Isovist Area (IA) is relatively small and there is a distinct division between inside and outside.

Different Plazas have shown diverse visual spaces in their research. Therefore, it can be concluded that Benedikt's (1979) idea of "isovists" is still suitable for spatially visible objects. Turner and others have shown in previous studies using Visibility Graph Analysis that visibility is related to people's perception and spatial cognition (2001). Based on the existing body of work mentioned above, this paper will not examine individual urban areas but rather conduct a comparative study of three representative plaza configurations through a unified analytical system.

From the perspective of urban design, different degrees of spatial openness offer various occasions for public life. Large-scale open spaces are suitable for long-distance viewing and can accommodate many people; enclosed Areas have clear space division and tend to form concentrated activity areas. Core-focused plazas are a type of intermediate space that uses a central feature to create an order-of-view, yet is still rel-

Facade Quality Assessment —— Venice Piazza Santa Maria

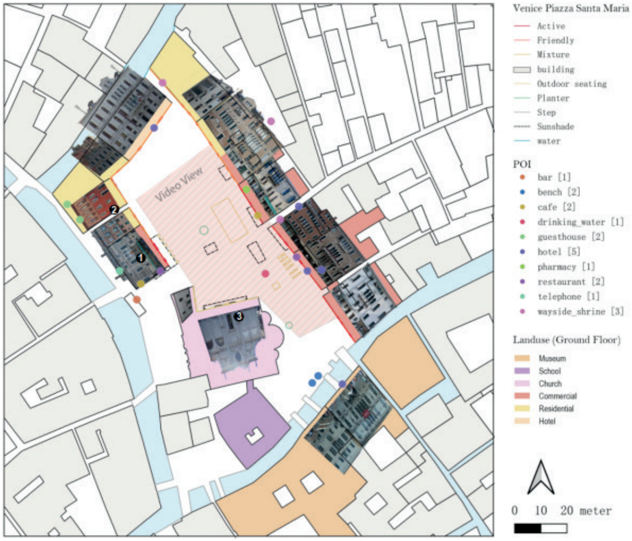


Figure 7. Venice Piazza Santa Maria Master Plan

Table A3. Façade evaluation based on classic PSPL (Gehl & Svarre, 2013)

Venice Piazza Santa Maria	Evaluation
	**Active** ✓ Small units, many doors (15-20doors per 100 m328 feet). ✓ Large variation in function. ✓ No blind, and few passive units. ✓ Lots of character in the facade relief.Primarily vertical facade articulation. ✓ Good details and materials
	**Friendly** ✓ Relatively small units (10-14 doorsper 100 m/328 feet). ✓ Some variation in function. ✓ Few blind and passive units. ✓ facade relief. ✓ Many details.
	**Mixture** ➤ Large and small units (6-10 doors per 100 m328 feet). ➤ Some blind and passive units. ➤ Modest facade relief. ➤ Few details.

https://www.google.com/maps/place/Ruzzini+Palace+Hotel/

Macau Senado Square

Figure 8. Macau Senado Square Master Plan

Table A2. Façade evaluation based on classic PSPL (Gehl & Svarre, 2013)

Macau Senado Square	Evaluation
 	**Active** ✓ Small units, many doors (15-20doors per 100 m328 feet). ✓ Large variation in function. ✓ No blind, and few passive units. ✓ Lots of character in the facade relief.Primarily vertical facade articulation. ✓ Good details and materials
	**Friendly** ✓ Relatively small units (10-14 doorsper 100 m/328 feet). ✓ Some variation in function. ✓ Few blind and passive units. ✓ facade relief. ✓ Many details.

New York Times Square

Table A1. Façade evaluation based on classic PSPL (Gehl & Svarre, 2013)

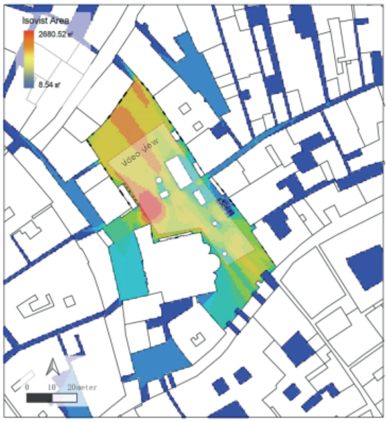
New York Times Square	Evaluation
	**Active** ✓ Small units, many doors (15-20doors per 100 m328 feet). ✓ Large variation in function. ✓ No blind, and few passive units. ✓ Lots of character in the facade relief.Primarily vertical facade articulation. ✓ Good details and materials
	**Friendly** ✓ Relatively small units (10-14 doorsper 100 m/328 feet). ✓ Some variation in function. ✓ Few blind and passive units. ✓ facade relief. ✓ Many details.

https://www.google.com/maps/place/Times+Square/

Figure 9. New York Times Square Master Plan

Comparison of Isovist Area for Three types of squares

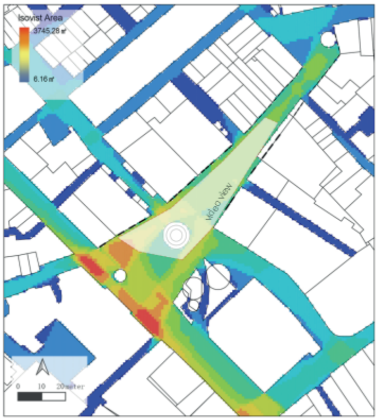
Closed Venice Piazza Santa Maria



Minimum:	Maximum:	Average:	Std Dev:
8.54㎡	2680.2㎡	844.43㎡	787.204

Closed squares are **the least open**

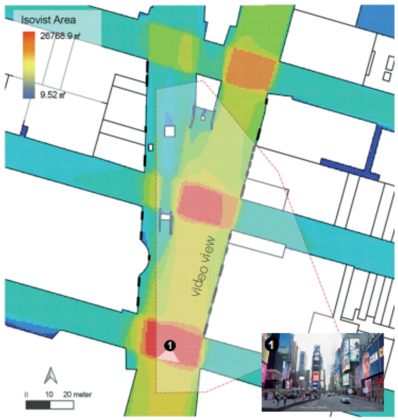
Nuclear Macau Senado Square



Minimum:	Maximum:	Average:	Std Dev:
6.16㎡	3745.28㎡	1127.96㎡	801.70

The Nuclear-style square has a **moderate level of openness**

Amorphous New York Times Square



Minimum:	Maximum:	Average:	Std Dev:
9.52㎡	26768.9㎡	10902.7㎡	6343.14

Amorphous squares offer the **highest degree** of **openness**

Figure 10. Comparison of Isovist Areas for the Three Types of Squares

atively accessible. The above studies reveal how the urban structure influences the visual conditions of public squares and provide a space for the follow-up analysis of pedestrian flow paths.

4.2. Pedestrian Behaviour Patterns in Various Square Types

The three types of plazas have different pedestrian behaviours due to changes in spatial form; thus, their activities and people's habits are not the same. Computer vision-based behaviour mapping has revealed that each plaza type has different areas of high activity and functions.

In the closed type plaza, the majority of pedestrians congregate in the central open area, primarily engaging in standing and taking photographs. Mobile phone usage and photography are more frequent in the northern section of the plaza; due to the nature of the space's openness, pedestrian movement paths remain relatively concentrated. The surrounding buildings create clear spatial boundaries, prompting pedestrians to linger in open areas with unobstructed sightlines rather than dispersing throughout the entire plaza.

The square of the nuclear type has an irregular distribution of activity. Most of the people walking around the centre fountain, the area for sitting and the adjacent shopping street are close together. Activities such as walking, standing, resting and taking pictures are clustered in this key area; a fountain is set up there to be seen and to hold a meeting of the people. A soft change occurs at the junction of the central

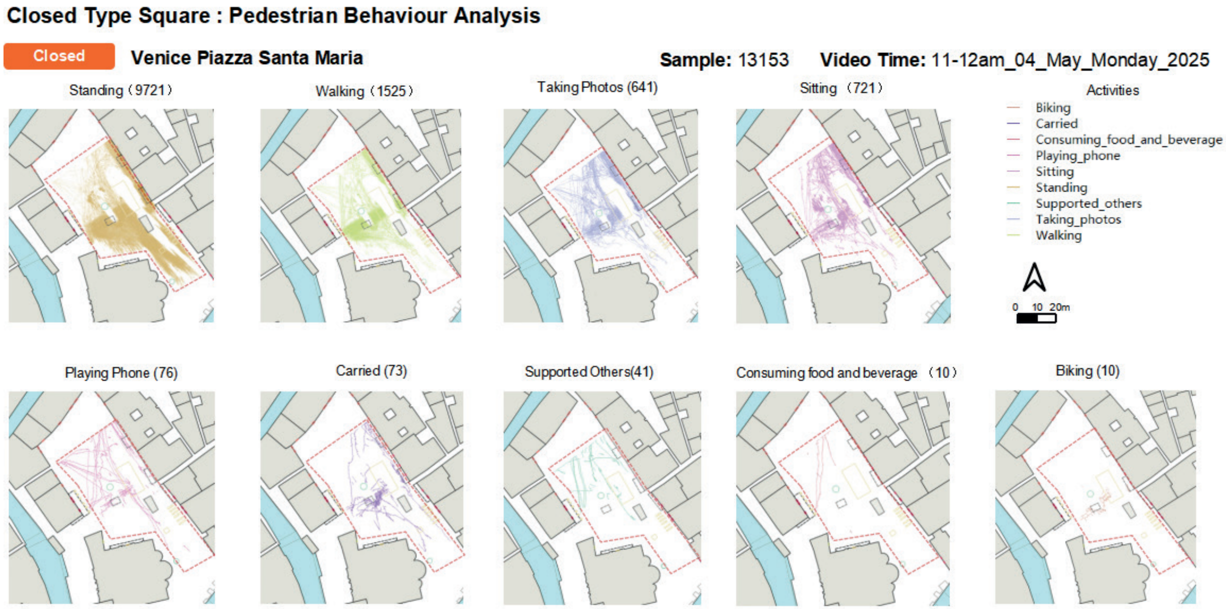


Figure 11. Closed Type Square: Pedestrian Behaviour Analysis

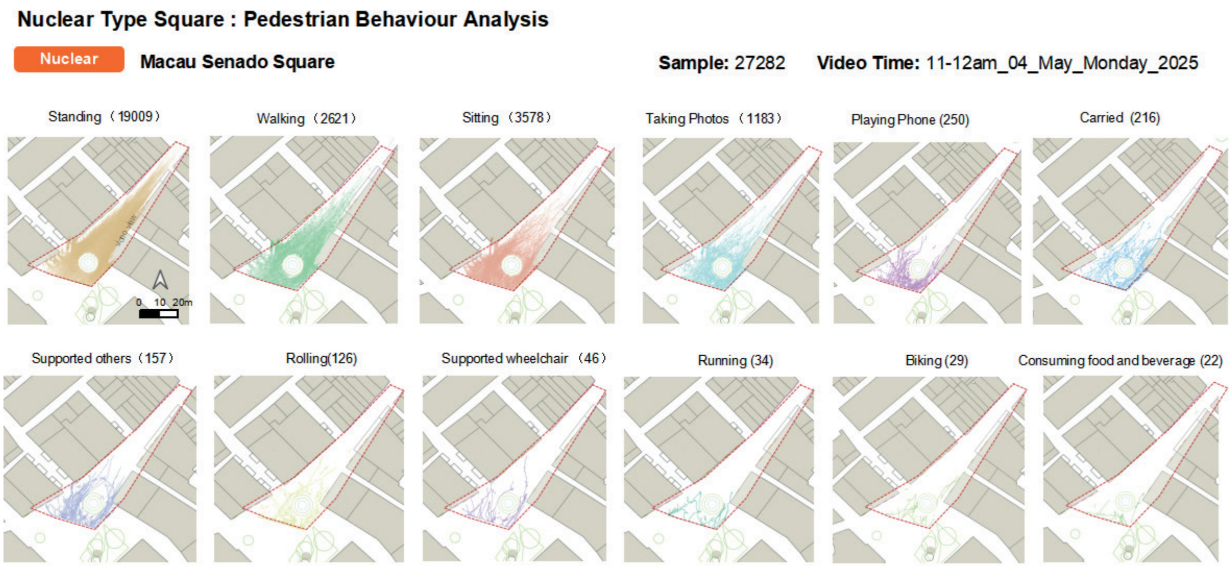


Figure 12. Nuclear Type Square: Pedestrian Behaviour Analysis

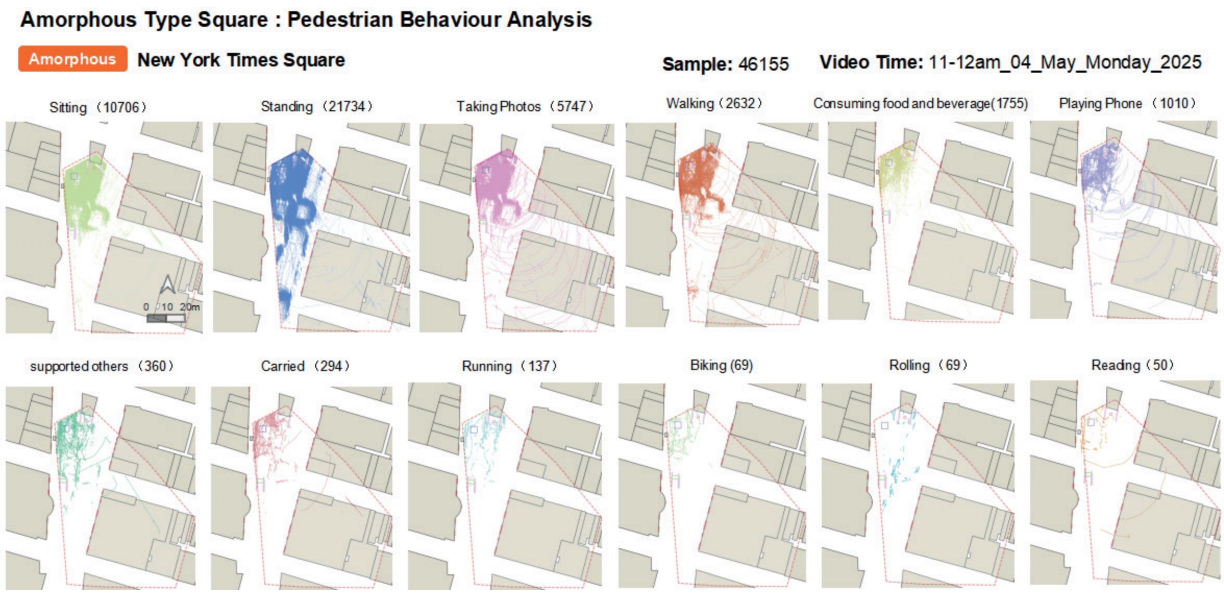


Figure 13. Amorphous Type Square: Pedestrian Behaviour Analysis

square and the outer streets to reduce noise and disturbance.

On the other hand, the area of pedestrian activities in this irregular-shaped square is relatively dispersed. Most of the activity hotspots are in the middle stepped terraces, large advertising screens and outdoor dining areas. Although this plaza is for a relatively large number of people, the density of crowd activity is still relatively low; therefore, it is an open-space type with many activity centres. Resting, standing, taking pictures and eating are all distributed in various places and are not restricted to a single area.

In short, the above results are in line with Gehl's idea of a supportive environment for "spontaneous" and "social" life. Although most of the prior work has used manual observation, this study will automatically detect activity changes and connect them to the layout through computer vision. Comparative analysis shows that spatial arrangement is also related to the number of people and the distribution of various activities.

The above research provides a certain reference for public space design. Closed-type plazas have fixed areas for people to gather, and for unstructured plazas that lack a specific form, many other attractions need to be developed to stimulate interest in different parts of the area. The Nuclear Plaza can be used as a general area for organising people's activities and promoting socialisation, as shown in the above case. In short, the above results show that all types of people in a public square should be taken into account during the planning stage of such spaces.

4.3. Temporal Variation of Pedestrian Trajectories

Pedestrian Trajectories are different at different times of the day for the three squares. Morning, midday and evening observations all show an increase in pedestrian activity from early morning to late evening, but the amount of this increase is different in the three squares.

The closed square has had a consistently lower volume of pedestrians than the other two case studies. Although the number of pedestrians is relatively high in the morning and evening, their paths are also mainly confined to the central open area due to a relatively confined structure and lack of space for spread.

The nuclear square has a moderate amount of people and is not very busy. Pedestrian trajectories are relatively longer at noon when commercial and tourism activities are most active, and then they remain relatively unchanged in the evening. Although the number of pedestrians has fluctuated, most of their paths have remained relatively close to the central fountain and the surrounding streets; thus, the space arrangement of the square has not changed over time.

The amorphous square has the highest number of people at all times of observation. The number of routes is relatively large in the morning and evening; therefore, it is a well-known shopping and tourist area with a large number of visitors throughout the day. As more people visit in the evening, they spread out across many different places at the same time.

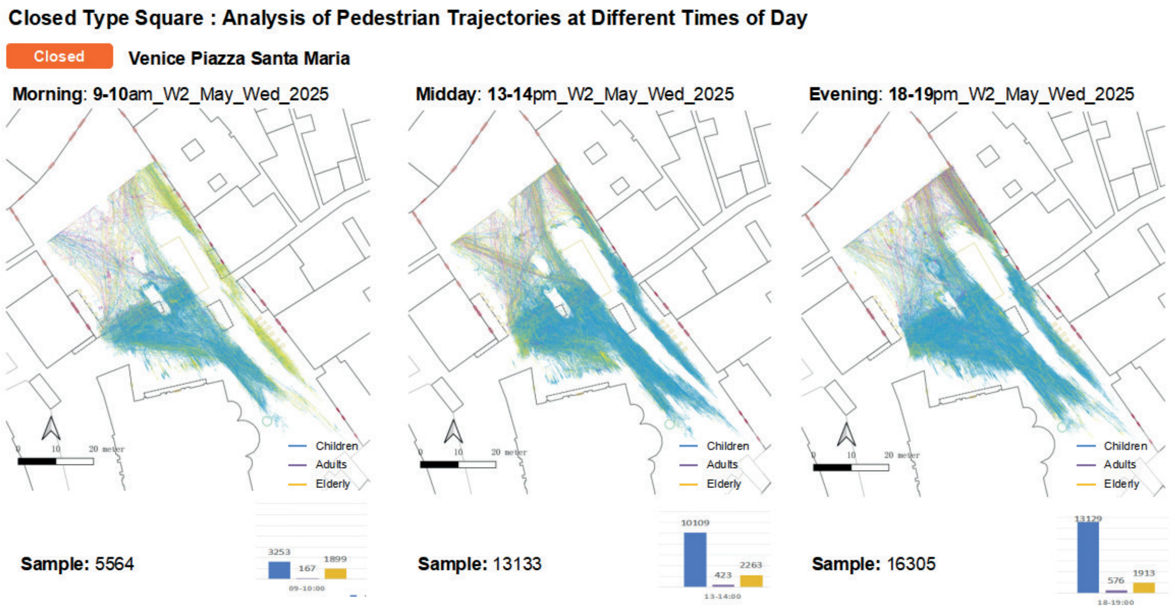


Figure 14. Closed-type Square: Analysis of Pedestrian Trajectories at Different Times of Day

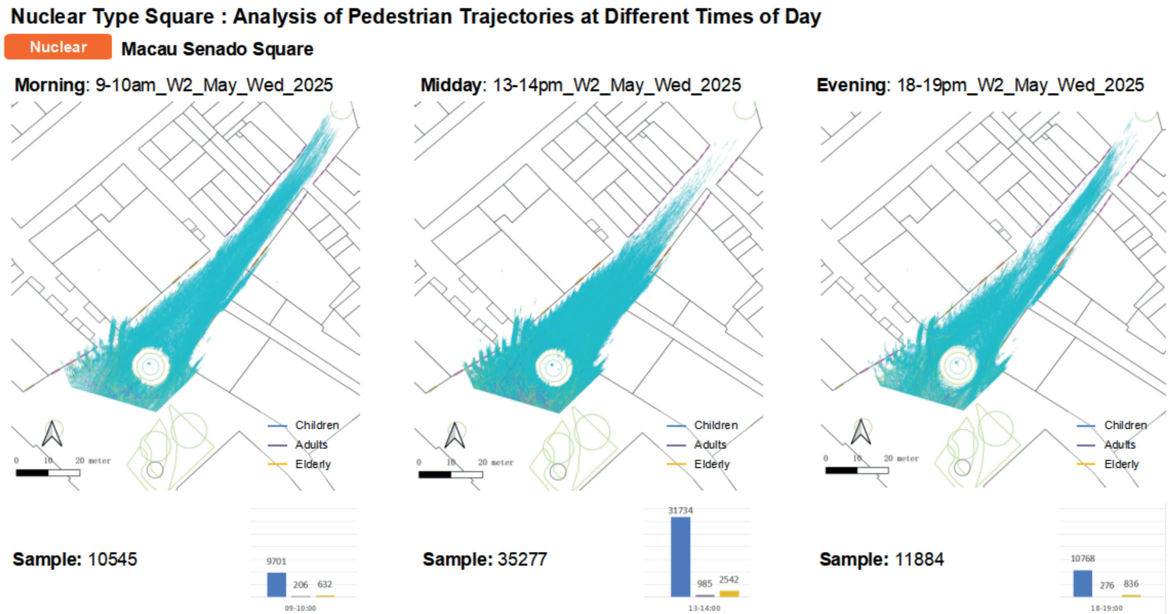


Figure 15. Nuclear Type Square: Analysis of Pedestrian Trajectories at Different Times of Day

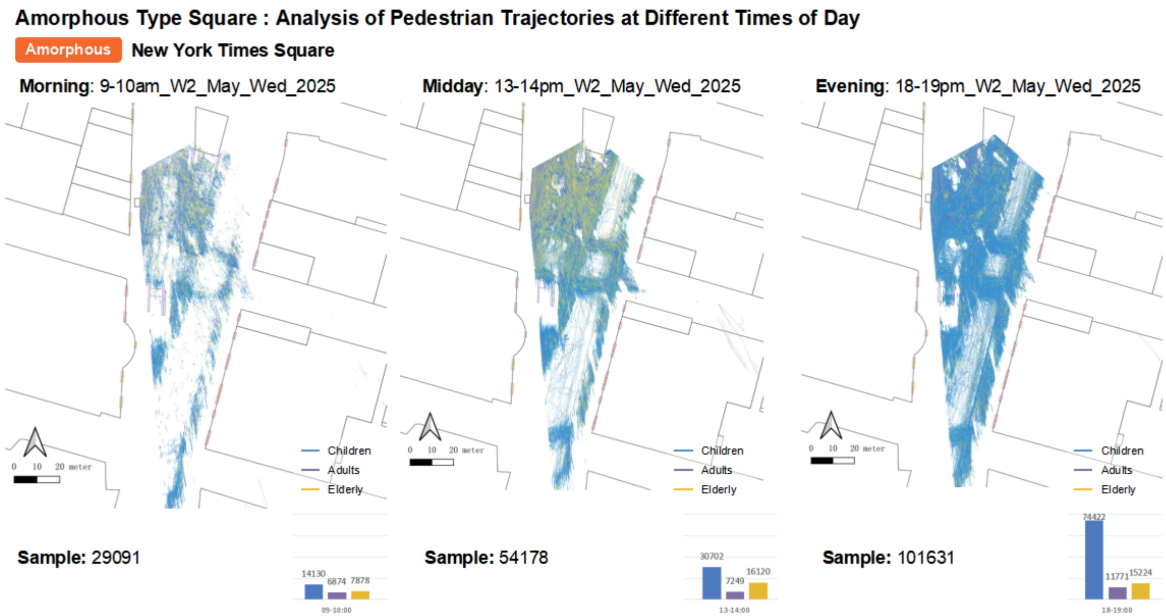


Figure 16. Amorphous Type Square: Analysis of Pedestrian Trajectories at Different Times of Day

The above time series show that people's movements in cities are influenced by different reasons and areas. As the number of pedestrians during the day has been rising, this is in line with the previous research on tourism-oriented public spaces, and the different spatial distributions also indicate that morphology affects how additional pedestrians are handled. Open Spaces can be organised across several areas, but enclosed spaces will have a high density of people in a small area.

Based on the above analysis, a time-varying and space-dependent plan for crowd management will be implemented. Open-plan public squares have a relatively open layout, so they need to distribute facilities and services for more visitors; enclosed squares should manage the central meeting area more strictly during peak hours. In short, based on the above results, both the time-changing aspects and the place-changing characteristics of pedestrian behaviour in urban public spaces should be considered together.

4.4. Effects of Spatial Variables on Different Age Groups

GLMs were employed to investigate how people of different ages react to their surroundings; therefore, three types of spatial variables were established in the analysis: Isotropic Area (IA), proximity to Points of Interest (POIs), and distance to public facilities, and their influence on pedestrian paths was examined. The results

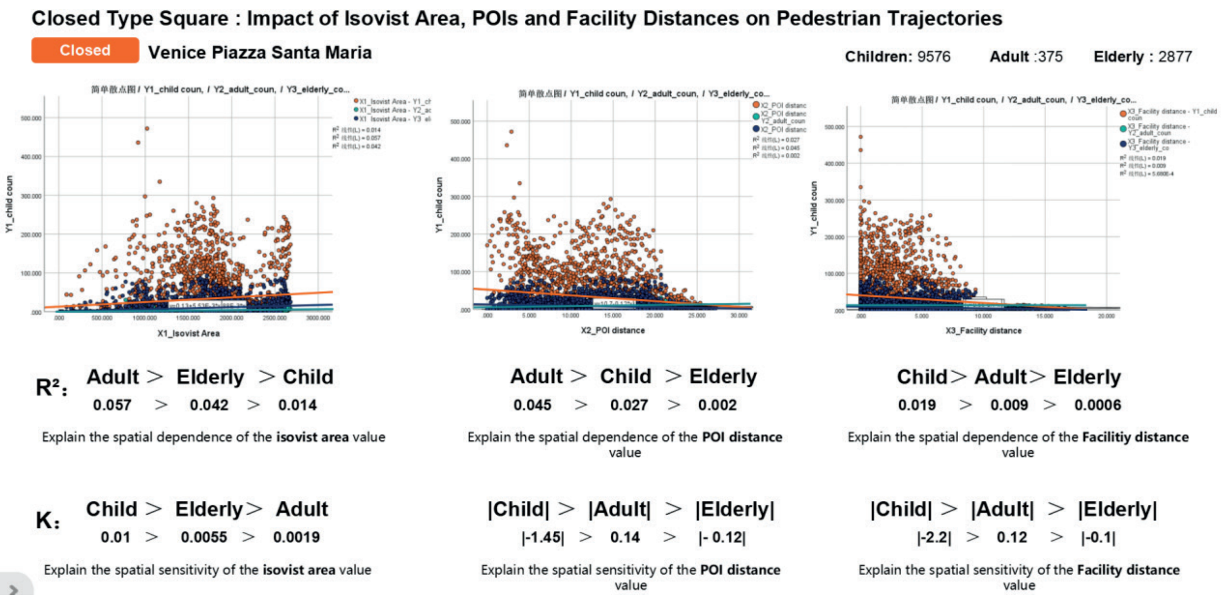


Figure 17. Closed Type Square: Impact of Isovist Area, POIs and Facility Distances on Trajectories

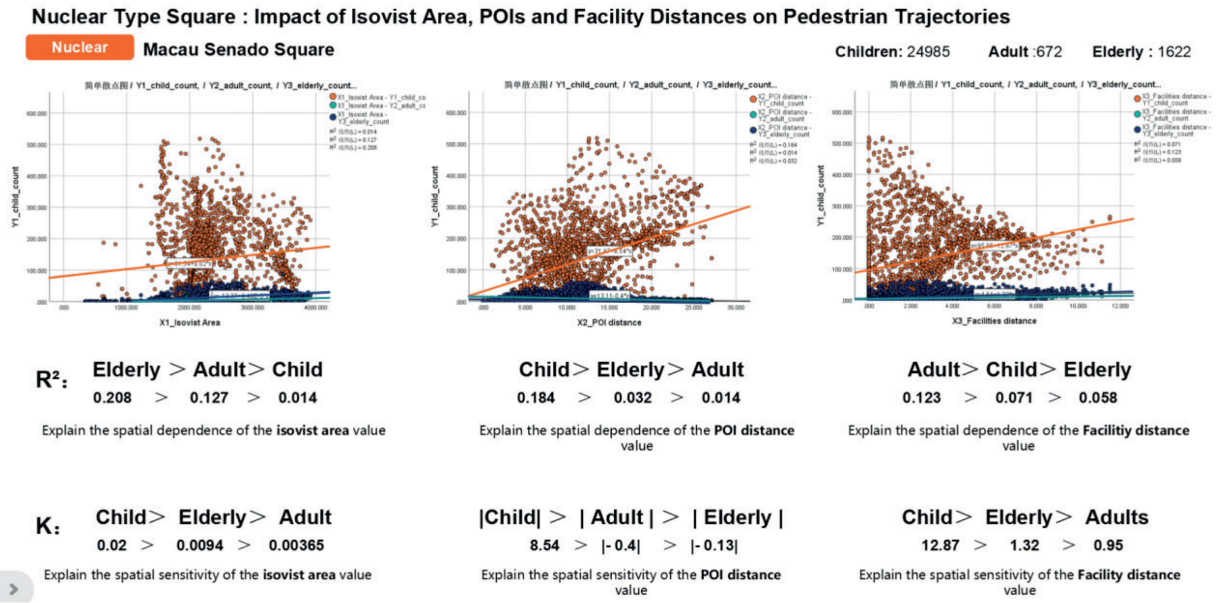


Figure 18. Nuclear Type Square: Impact of Isovist Area, POIs and Facility Distances on Trajectories

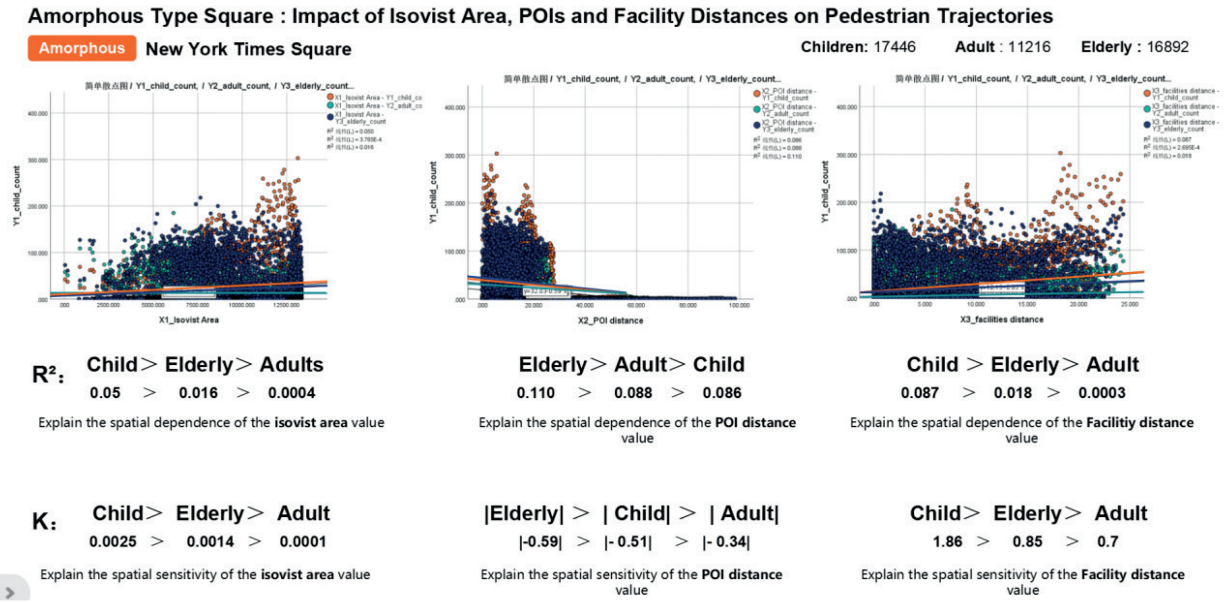


Figure 19. Amorphous Type Square: Impact of Isovist Area, POIs and Facility Distances on Trajectories

show that children, adults and older people are all different; therefore, the effect of the built environment is not the same for all age groups.

The distance from a public facility had the strongest effect on the children. In all three squares, a higher number of pedestrians was consistently observed near the facilities; thus, it can be inferred that these places offer attractions and activities that appeal more to younger people. The Distance to a POI also affected children's mobility, but generally had a weaker impact than public facilities. IA was relatively far from affecting the children's paths. Therefore, function-oriented areas are more influential on how children use public space than a wide distribution of these areas.

Adults had a different distribution. The effects of IA, POI distance and facility distance were generally weaker and more evenly distributed than those for the other two age groups. Thus, the areas where people live are not their primary focus for travel and movement. The paths of these groups were relatively unchanged in different squares; therefore, adults were less affected by changes in their surrounding areas.

Older adults had stronger responses to the spatial characteristics in the nuclear square. Both IA and POI distance had a stronger effect on the paths of children than on those of adults. Areas with better visual openness and easier access to destinations attracted more elderly pedestrians; thus, visibility and environmental legibility may be affecting people's choice of way. Based on the above, it can be inferred that older people are more accustomed to well-lit areas and easy-to-use outdoor spaces.

The results generally support the previous studies on age-friendly urban environments. Earlier studies have shown that children need activity venues more urgently, and older people have relatively higher demands for accessibility and the environment. Combine the age-classified pedestrian trajectories with a quantitative indicator of spatial visibility to extend the above results. A continuously recorded behavioural data system will not require manual observation and will enable the comparison of different age groups in the same area at the same time.

The above results will help design public spaces better. Areas for children need to have easy-to-access facilities and activity spaces, and areas for older adults should prioritise visual openness, simple spatial organisation and comfortable walking conditions. Based on the above analysis, a single design approach is unlikely to meet the diverse needs of all people, and age-sensitive design should be incorporated into the planning of public spaces.

4.5. General Discussion

As shown by the three case studies, a different arrangement of plazas will look quite different. Amorphous-type plazas have good visual connections and can be arranged in many dispersed ways; closed plazas generally contain pedestrians in an enclosed space, whereas nuclear plazas are located in the centre and use central landmarks to organise pedestrian flow and social activities. The above differences can be seen in behaviour and show that the arrange-

Summary : The impact of Isovist area, POIs and facility distances on pedestrian trajectories

Population	Most Sensitive Variable	Most Sensitive Square Type	R^2 Performance Across Squares	K Performance Across Squares	Conclusion
Children	Facility > POI > Isovist	Nuclear	Nuclear(0.184) > Amorphous(0.110) > Closed(0.027)	Nuclear(12.87) > Closed(2.20) > Amorphous(1.86)	Most sensitive; Especially reactive to facility proximity
Adults	Isovist / Facility	Nuclear / Closed	Nuclear(0.127) > Closed(0.057) > Amorphous(0.086)	Nuclear(0.95) > Amophous(0.70) > Closed(0.14)	Flattest response; Least affected by spatial variables
Elderly	Isovist / POI	Nuclear / Amorphous	Nuclear(0.208) > Amorphous(0.088) > Closed(0.042)	Nuclear(1.32) > Amorphous(0.85) > Closed(0.12)	In open spaces, more attentive to POI; In nuclear spaces, most affected by Isovist area

Table 3. Impact of Isovist Area, POIs and Facility Distances on Pedestrian Trajectories

ment of space is directly related to how people move in the street.

In Times Square, additional visitors spread across many areas, whereas in Piazza Santa Maria they stay concentrated in the centre.

Compared with previous studies, the first innovation of this paper is a joint-analysis system that combines computer vision and Isovist. Previous studies have mainly focused on either pedestrian detection or spatial layout analysis, but this paper integrates automatically extracted movement trajectories with quantitative metrics of spatial visibility to study the influence of urban form on pedestrian behaviour more directly. It is also a relatively easy-to-operate system and can be extended to cover more public places with real-time video data.

5. Conclusion and Limitations

5.1. Summary

This study combines computer vision and Isovist analysis to study pedestrian behaviour in three typical urban squares: Times Square in New York, Senado Square in Macau, and Piazza Santa Maria in Venice. Publicly available webcam footage was used to extract pedestrian trajectories and isovist analysis to quantify spatial visibility; then, Generalised Linear Models (GLM) were employed to study how spatial features related to changes in pedestrian behaviour.

Therefore, the following were determined. Firstly, the three kinds of squares have different spatial visibility characteristics: Amorphous squares are relatively open to the eye; Nuclear squares have a stable visual system centred

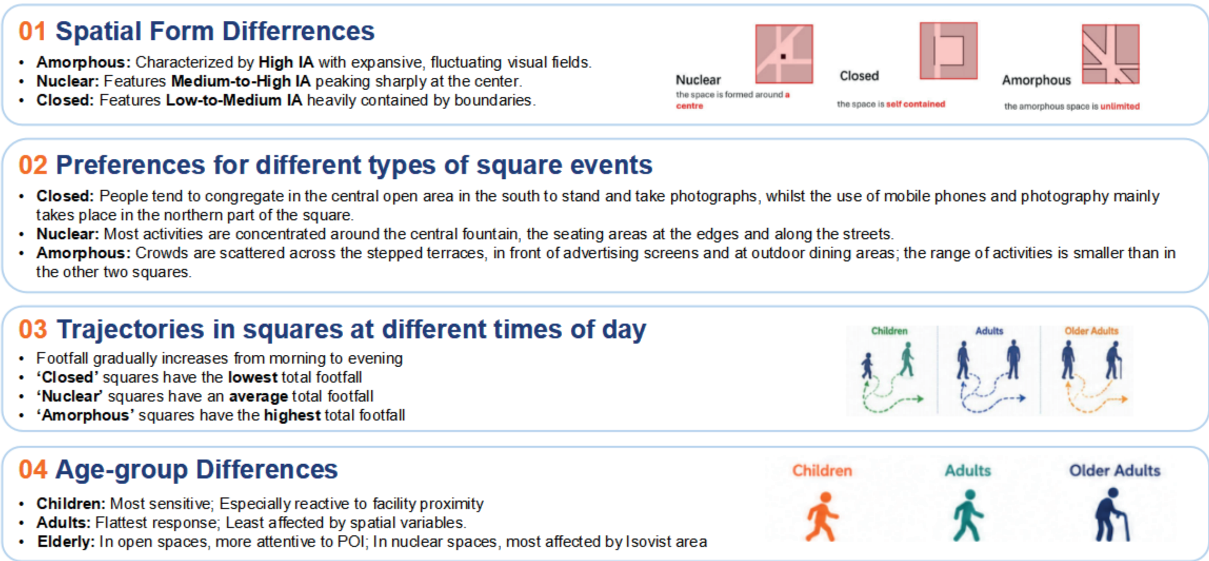


Figure 20. Summary

around a key feature; and closed squares, due to their enclosed form, have low visibility. Second, pedestrian behaviour differs in amorphous squares: in amorphous squares, activity is relatively spread out; in closed squares, pedestrians gather in the central open area; nuclear squares are a combination of the two, with activity concentrated around a central fountain. Third, although the pedestrian volume in the morning and evening was gradually rising across all three cases, the distribution patterns among the three types of squares varied. Finally, the different groups showed varying behaviours; older people moved relatively normally and responded more strongly to how far away or visible their destinations were.

Therefore, the above studies have provided some methodological and practical support for future research. Computer Vision and Isovist analysis will be used to map the space and fluctuations of people. Research has shown that different kinds of plazas need to be designed in different ways in practice, and the needs of people of different ages should be taken into account in the planning of public spaces. Increase the visibility of space, add suitable public facilities, and enhance the connection among key activity areas to build more inclusive and age-friendly urban public spaces.

5.2. Limitations

First, pedestrian data were collected from publicly available webcam videos over one week in both summer and winter. Although the above datasets show typical characteristics of daily life, to build an all-encompassing view of long-term changes in the behaviour of pedestrians, it would be necessary to expand the observation period to include all seasons, weekdays and holidays, etc. Age classification also uses computer vision algorithms; there are still errors in densely crowded areas or in poor light.

Second, a Generalised Linear Model (GLM) was used in this paper to study the effect of location on walking behaviour. Although GLMs are simple in operation and interpretation, the behaviour of pedestrians is often the result of complex non-linear interactions among space, society and environment. In the future, high-end models will be used to investigate the connection among these factors more accurately, such as spatial regression models and machine learning algorithms.

Finally, the above three representative tourist plazas were selected for analysis. Although the three types of plazas in the above cases are representative, they do not cover all kinds of urban public areas. Future research will consider a larger number of cities and public areas with different cultures, climates, functions, etc., to determine whether the behaviour patterns observed here can be generalised to other urban areas. Weather, land-use intensity and perceived walkability could also be included.

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