Analysing People's Movement in the Built Environment via Space Syntax, Objective Tracking and Gaze Data

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In this paper we use analysis tools from Space Syntax and objective observation of the human behaviour, to understand the impact of landmarks in the walking patterns of users of spaces. Our case study was a large exterior public open space (University Campus), in which participants could walk freely and simultaneously be tracked by several sensors. We carried Space Syntax analysis for this space, and then collected Global Positioning System (GPS) tracking information and used a mobile eye-tracking device to acquire eye gaze information. The collected data allowed us to map and analyse each subject behaviour in the public space. A more specific analysis was done to four selected landmarks that, according to the Space Syntax analysis, were the ones with higher integration values. Results indicate that landmarks with such higher integration values show also a larger count of fixations and saccades of gaze interaction.

Keywords: *Space perception, Human behaviour, Space syntax, Eye-tracking, Objective tracking*

INTRODUCTION

This paper focuses on how subjects perceive and move in architectural spaces, using analysis tools from Space Syntax and observation of human motion behaviour. In particular, this study aims to research the impact of landmarks shaping the way people perceive and move in a certain space.

Our premise is that mapping subjects' behaviour while moving in space, is vital to inform design so that buildings and public spaces answer to the real needs of future and present citizens. Our multidisciplinary research team investigates the influence of architecture elements and environmental variables (e.g. sound, light, thermal, wind, smell), in the human behavior while exploring space. In general, we examine these variables and compare them with results of Space Syntax analysis, in order to acquire more knowledge about human behaviour in space, towards complementing the standard Space Syntax analysis approach. The behavioral experiment we report in this paper, is then part of broader research initiatives in which we design experiments with participants either in real or virtual settings, where we take objective measurements of physiological data, such as heart beat, skin resistance activation or eye-tracking, kinematic data (trajectory and other kinematic measures of the subjects), as well as subjective data based on structured questionnaires collected from the participants. Our research hypothesis for this particular study is that landmarks are relevant in shaping the human movement behavior and that their presence can be objectively assessed by using both kinematic data acquired from GPS and data eye gaze information, calculated from collected eye-tracking data.

Physical environment influences people's behaviour via several psychological mechanisms such as sensory access, attention, memorability, behavioural affordance, affect and sociality (Montello 2007). On the other hand, Space Syntax theories state that patterns of behaviour in space can be recognized and measured through variables such as permeability, intelligibility, segregation and integration (Hillier & Hanson, 1984).

Our work follows Whyte's (1970) observations on people's behaviour in the city's public spaces, in which he described the public life in an objective and measurable way, highlighting spatial patterns of behaviour.

In this paper we present a study where results from space syntax analysis of a built environment, are examined together with data acquired from real behaviour of people in the same space. Therefore the study started with an analysis of a real space (the University Campus) according to Space Syntax methodologies. In this context, we have produced Visibility Graph Analysis and parameters such as integration, mean depth, control and intelligibility, in order to compare its outcomes with the results of the analysis of data collected in the real experiments, namely, human trajectories (collected through GPS) and gaze information (acquired through eye-tracking). Besides the objective measurements, we also applied post-experimental subjective data analysis using assessments reported from the subjects. The experiment design considered the space potentialities in terms of use and a comparison between the observed trajectory flows and the space syntax analysis.

The remaining sections of this paper are structured as follows: Section 2 summarizes related work in the areas of space syntax and objective measurement of data. Section 3 describes our experimental methodology. The results obtained with our study and its discussion are presented in Section 4. Finally, in Section 5, we extract some concluding remarks and discuss lines of future work.

RELATED WORK

In our day to day experience of space, we rely on a representation of the surrounding environment created by the conjugation of our senses and central nervous system (Loomis, 2003). This representation of our surroundings informs our decisions about the use of space. Being aware of the importance of our senses, asserts our capacity to determine the way a certain space is used.

The importance of landmarks on users' navigation have long been attested (Loomis, Klatzky, Golledge & Philbeck, 1999; Michon & Denis, 2001; Waller, Beall & Loomis, 2004). In order to evaluate their importance, several methods have been used along the years such as the capture of images and video of specific viewpoints that include the landmarks (e.g. Heitor et al 2013) , or Virtual Reality simulations (e.g Waller et al 2004). Although research of landmarks relevance on space perception has been done, the use of eye tracking data to assess real environment perception, namely, compared with Space Syntax analysis results, is novel.

The Space Syntax theory is founded on the concept that the physical and spatial configuration of the built environment, informs us how space is experienced, explored and apprehended. (Hillier & Hanson, 1984) Space Syntax combines a range of spatial characteristics with the observed user activities within a given space, in order to highlight the causal relationships between the form of architectural and/or urban space and its patterns of use and occupation (Serdoura, 2006).

Space Syntax aims to create a unified description of the relationships between society and space, being directly applicable to architecture, urban design and territorial planning as an interpretative tool for existing and proposed spaces. (Hillier, Leaman, Stansall & Bedford. 1976). Space Syntax theory uses a set of methodologies and analysis techniques that enable a quantitative description of complex patterns of spatial organization at various scales.

The theory has been extensively tested and high correlation between the various syntactic measures and the users' perception of space has been demonstrated (Davies, Mora, & Peebles, 2006; Meilinger, Franz, & Bülthoff, 2012). Likewise, the same high correlation has been verified between the same measures and the way users move in space (Conroy-Dalton, Hoelscher, Peck, & Pawar, 2010; Kalf, Kühner, Senk, Conroy-Dalton, Strube & Hölscher, 2010; Mavridou, 2006).

The work we now present follows on our research on space perception (Dias, Eloy, Carreiro, Vilar, Marques & Moural, 2013; Dias, Eloy, Carreiro, Proença, Moural, Pedro et al., 2014). The previous work reported experiments performed in virtual reality settings and focused on objectively and subjectively capturing adverse reactions of users to extreme architectonic spaces and/or architectonic elements. The work now reported focuses primarily on people's navigation and visual attention in real environments.

METHODOLOGY AND EXPERIMENTAL DESIGN

Space Syntax analysis

For the purposed of this study, a preliminary analysis of the space was performed using Space Syntax theory. A base CAD design was prepared with the area to be studied. This drawing was updated with details of elements that could induce changes in the users' movement such as street furniture, trees, litter bins and water fountain features.

The analysis domain included only the area where people could walk during the experiment so that the analysis focused only on the navigable spaces, instead of all the exterior area.

A Visibility Graph Analysis (VGA) was performed following the methodology proposed by Alistair Turner (2004), which considers the navigable area and incorporates not only the elements that bloc vision at eye level (eye-sovist) but also every element that restricts or obstructs the visual permeability of the space, such as benches, bushes and trees (knee-sovist). The resulting VGAs analysis focused on the integration, depth, control and intelligibility measures of the ISCTE-IUL Campus. The resulting measures were used to determine the most relevant landmarks in the campus and determine the starting position of our experiment.

Analysis in the real space

Participants. The participants were recruited as volunteers. The following admission criteria was considered when choosing the participants: i) Not having an architectural background, due to architects' space perception trained skills that could bias the experiment (only students from the 1st year of graduation were admitted); ii) Not having motion constraints or physical disabilities, that could turn urban elements into obstacles that otherwise wouldn't present a challenge; iii) Studying, working or having another activity at the University Campus; iv) Not suffering from cardiovascular problems or diseases. The total sample collected consisted on 10 male and 8 female participants ranging from 18 to 45 years old, with a mean age of 25 and a standard deviation of 7.24.

Experimental settings. The experiment took place at the ISCTE-IUL's Campus within an area defined in Figure 1. From the outcome of Space Syntax analysis, namely from the integration measure in the VGA, one of the most integrated spaces in the campus was chosen as the starting position for all users in the experiment. From this central position all types of paths could be followed. All participants received the same instructions and ten-minute time frame to perform the task. Participants were asked to explore the University Campus during a pre-defined time while being observed and objectively measured by several devices.

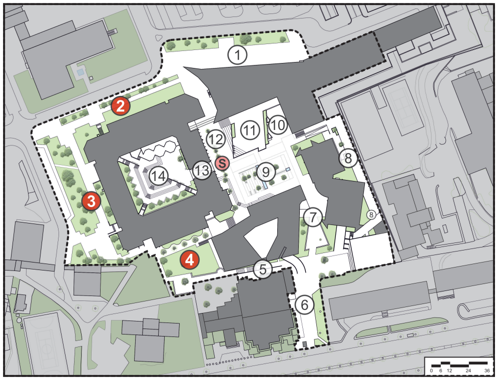


Figure 1
Sub-areas of the ISCTE-IUL Campus and Users Start Position (S)

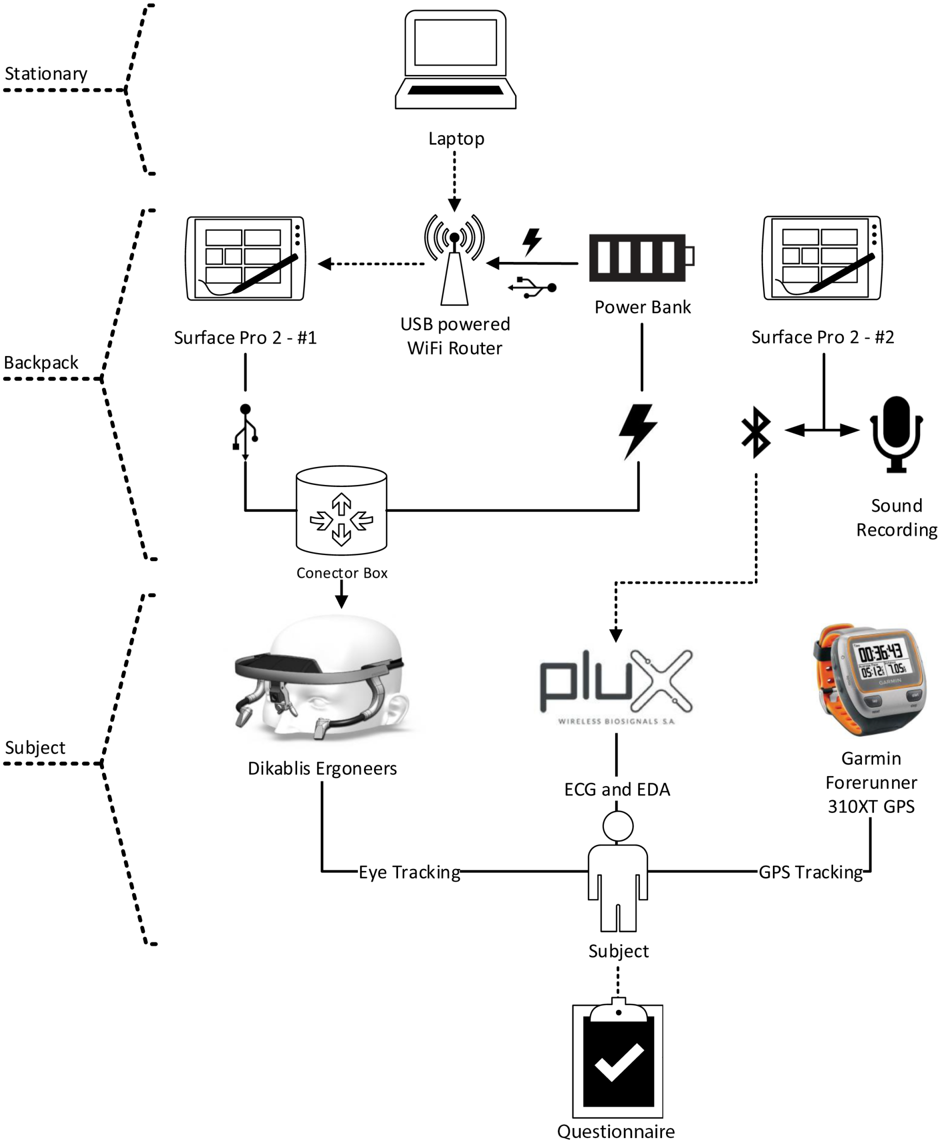
Instruments for objective data collection and analysis methodology. Data for this experiment was collected using GPS and eye tracking sensing, this one used to acquire gaze information. For this last data modality acquisition, we used the head-mounted Dikablis Eye Tracker from Ergoneers. The setup (Figure 2) consisted of the eye tracking glasses, a connector box, a power bank, a wireless router, a Surface 2 Pro tablet and a laptop. The Eye Tracker was connected to the connecter box which, as well as the wireless router, was powered by the power bank and stored data in real-time in the Surface Pro 2. The Surface 2 Pro and the laptop were connected via the wireless router. The Eye Tracker glasses has one RGB field camera with a 90º aperture angle lens attached and two IR eye cameras (one for each eye). From this setup we were able to extract several primitives for each timestamp, such as X and Y gaze location on each video source, eye saccade movement, fixation state and pupil area (height and width). We used a fixation duration metric, according to the principles of Dario D. Salvucci and Joseph H. Goldberg (Salvucci & Goldberg, 2000). The methodology used to evaluate landmark influence was based on an analysis of events which describe the presence of a landmark on the field video. Fast-head movements and fixations lower than 50ms were not considered for analysis.

For human trajectory collection, a Garmin Forerunner 310XT GPS tracking system was employed. Being a sports watch, the 310XT is unobtrusive while yielding an acceptable 4 m accuracy at 1 Hz of data recording frequency. The major disadvantage is that its accuracy deteriorates in cloudy weather and in places with limited sky vision i.e. near high rise buildings, bellow dense vegetation or in interior or covered spaces. Location data consisted on a time-series of latitude, longitude and elevation geodesic coordinates. Since the quality of the elevation data from GPS is very poor, the original elevation was replaced by values from an available digital terrain model of the same space. The spherical coordinates were then converted to a regional rectangular grid using the Transcoord Pro v 2.0 software (*http://www.dgterritorio.pt*) and exported to the Matlab system for post-processing. Walking speed time-series for individual tests were calculated, as well as individual and global average values. Smoothing of the peaks corresponding to poor satellite reception was performed, but no correction of location errors was done.

Instruments for subjective data collection. In addition to objective measurement, subjective data collection was also applied by means of a structured questionnaire answered by participants at the end of the experiment, aiming at collecting their preferences about the spaces they have walked through. The outcome data considered space potentialities in terms of use and the similarities and differences between the observed motion flows and the space syntax analysis.

Experiment protocol. The experimental session was divided in two parts: prospecting and experimenting. For the prospecting part, performed some days before the experiment, volunteers were surveyed about their heart condition, education level and mo-

Figure 2
Data Collection
Setup



bility state. Participants were neither informed about the goal of the experiment, nor about the nature of their tasks on the day of the experiment, other than the fact that they would have to be in the Campus of the University. At the time of the experiment, all participants, one at each time, arrive at the research centre, signed the term of consent and were briefed about their task and the data collection equipment they would carry. The same explanation was given to all subjects: that their task was to explore freely the ISCTE-IUL campus the best they could in 10 minutes, and that at the end they would need to answer a questionnaire about the campus' space details, to encourage them to explore the space. One researcher followed the participants throughout the exploration task, at a safe distance so that the participant would not be disturbed (Figure 3).

Figure 3
(1) Instrument calibration process; (2) User with eyetracker and Instrument backpack; (3) Subject exploring the space

RESULTS AND DISCUSSION

Space Syntax and GPS tracking analysis

Space Syntax measures of Global integration, Mean depth, Intelligibility and Control depicted in Figure 4, show which spaces have more potential of use within the system. Spaces 9, 12, 14 and space between 1 and 2 (Figure 1) have high values of all four measures meaning that those places are very central in the context the studied area, easily reachable and areas where the whole system is visually controlled and understandable.

For the GPS tracking analysis the sample consisted of 15 participants, 7 male and 8 female (mean age of 25 and a standard deviation of 7.93). A map displaying the locations were higher concentration of location points from all experiments with valid GPS data was produced (Figure 5). Through comparison, we are able to verify that there is a correlation between the paths taken by the subjects and the areas indicated by Space Syntax analysis as having more potential of use.

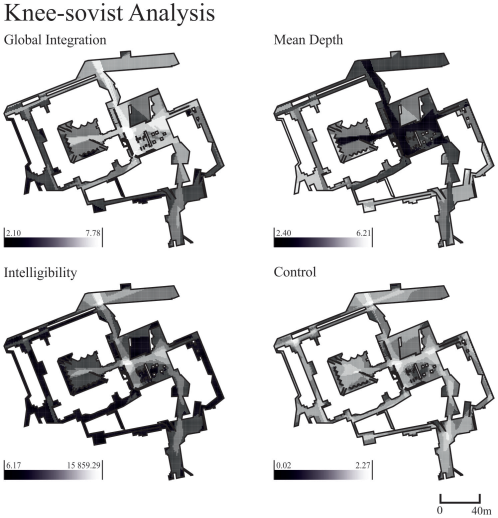


Figure 4
Space Syntax VGA analysis of the studied area: visual global integration, visual mean depth, global Intelligibility and visual control

Table 1
Number of "likes" per Space

Space	1	2	3	4	5	6	7	8	9	10	11	12	13	14
No. of likes	2	8	10	13	0	0	5	1	7	0	4	0	0	1

Table 2
Percentage values of fixations and saccades for each landmark, per subject

	V02	V04	V09	M01
Subject/Event	**% of fixations and saccades**	**% of fixations and saccades**	**% of fixations and saccades**	**% of fixations and saccades**
T01	12.22	6.20	59.03	18.15
T02	32.12	10.69	52.62	0.00
T03	0.00	5.13	4.17	30.43
T04	30.15	4.95	8.75	0.00
T05	5.83	9.09	2.86	2.70
T06	13.95	14.15	12.44	9.65
T07	5.84	0.00	0.00	8.48
Average	14.30	7.17	19.98	9.92
Confidence interval	8.50	3.15	17.07	7.61

Table 3
Integration values calculated on VGA analysis (knee-sovist) for each Landmark in decreasing order

Landmark	V02	M01	V09	V04	V03	V05	M04	V01	M03	V13	V11
Integration Value	7.1	6.2	5.6	5.5	5.3	4.7	4.7	4.6	4.4	4.1	4.1

Landmark	V10	V07	V12	V06	V17	V15	V08	M02	V16	V14	M05
Integration Value	4.0	3.5	3.4	3.4	3.3	3.3	3.1	3.0	2.8	2.8	2.2

Table 4
Values of Integration, Mean Depth, Intelligibility and Control for the analyzed Landmarks

Landmark	V02	V04	V09	M01
Integration	7.1	5.5	5.6	6.2
Mean Depth	2.54	2.99	2.95	2.71
Inteligibility	15364.5	3469.82	4584.87	8097.24
Control	2.08	0.75	0.99	1.54

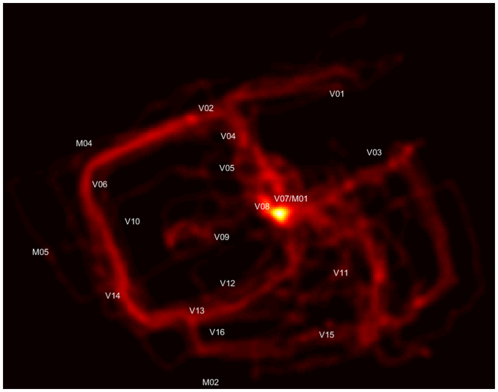


Figure 5
Heatmap with GPS data from 15 tests performed in the campus.
Correlation between reported measures and GPS data

Reported measures and GPS data acquired analysis

Participants were asked in a questionnaire, to point out the three spaces in the campus they liked the most. The goal was to compare the reported feedback with the results coming from the paths followed by the subjects in their experiment. Participants declared that spaces 4, 3 and 2 were the ones they most liked throughout the area of the ISCTE-IUL campus they explored (Figure 1 and Table 1). These spaces are in the borders of the campus and the main element that distinguishes them from the remaining spaces, is the more abundant presence of natural elements such as grass and trees.

Based on the knowledge about users' preferences, we then analysed their movement in those places in order to find an association between the reported perception and the real behaviour. The average walking speed of the 15 tests was 4.4 km/h. In the areas referred in the previous paragraph, participants walked faster: in zone 3, the average velocity was 4.6 km/h, whereas in zone 2 and 4 it was 4.7 km/h, approximately 5% more than the average. This may be due to the fact that those are just passing by areas without much path decision possibilities and therefore users decided to speed up to fulfil the task. Space Syntax depth measures show that those spaces are deep in the system and their values of integration are in the average among the area, meaning that their potential of use is low (Figure 4). Nevertheless, the fact that users' reported liking those places lead us to believe that other qualities rather than the morphological ones seems to indicate that they are of great relevance for users and therefore those need to be analysed in future research.

Landmarks and eye tracking data analysis

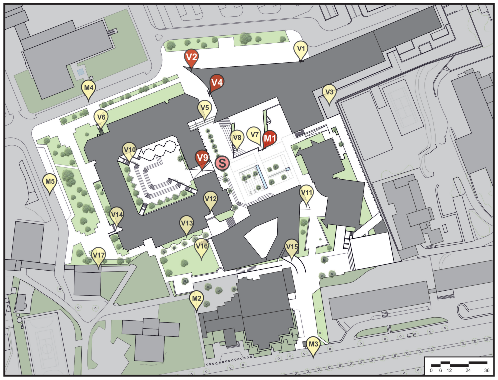


Figure 6
Landmarks identified, Analyses landmarks in Red/Deep Grey and Starting Point (S)

Twenty-two landmarks where identified by our group within the campus, based on specific characteristics: special architectonic elements (e.g. special doors, unusual shapes on the buildings, prominent group of stairs) and audio sources (e.g. water falls), as depicted in Figure 6. To focus our study of the impact of landmarks in users' behaviour, we choose the four more relevant ones according to the integration values previously calculated by the VGA kneesovists analysis (see Table 3). Therefore landmarks V02, V04, V09 and M01 were chosen as a focus of our study, since their integration value is the highest of the overall sample of landmarks (see Table 2). The adopted strategy was to study the outcomes from eye tracking data, while participants were looking to landmarks V02, V04, V09 and M01.

We chose to consider both fixations and eye saccade movements that would target the landmark, since some of them are large enough to allow people to perform saccade movements on them. There are two levels of events considered for the analysis, 1) time windows defined by the presence of a landmark on the field camera feed and 2) within the previous time windows, smaller time windows defined by when the user has its gaze (being fixation or saccade) on the landmark. For the eye-tracking analysis, the sample consisted of 7 participants, 6 male and 1 female (mean age of 27 and a standard deviation of 8.25), which shows a decrease of the sample size due to eye-tracking software and hardware instability occurred throughout the data collection.

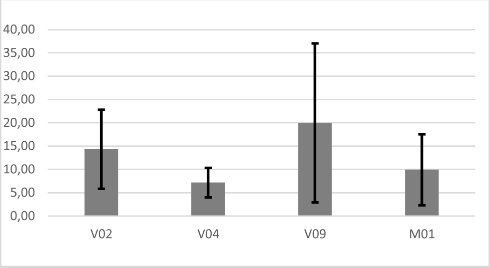


Figure 7
Average and confidence values, of fixations and saccades per landmark

Figure 7 depicts all participant's average number of fixations and saccades that reached each one of the landmarks, whereas Table 4 lists the percentage values of fixation and saccade for each landmark, per subject. The calculations of integration value, obtained from Space Syntax analysis and of fixation/saccades computed for each landmark, place the Landmarks in the same ranking order in both studies, except for V09.

During the analysis, we noticed that landmark V09 had much higher values of fixations and saccades due to its different nature, since it is the only one that could be crossed through (this landmark is a small tunnel). Regarding participant T04, we have noticed that, compared to the others, he had an unusual tendency to look to the floor, except when he was in presence of M01, the only landmark that is both visual and audio (this landmark is a fountain). Excluding V04, all landmarks showed a high Standard Deviation and Confidence Intervals, i.e., their influence were highly dependent on the subject and on which paths they chose which led them to the landmarks from different perspectives. Due to the small sample no statistical relevant analysis is possible and therefore we opted to perform a qualitative analysis to inform the lines of future research. In fact, the small sample of this landmark attention via gaze, does not allow us to extract strong conclusions, but to give some evidence on the reported facts.

SUMMARY AND FUTURE WORK

The exploratory research presented in this paper, is based on an experiment which aimed at studying the influence of architecture elements and environmental variables in human motion behavior. We was hypothesized that landmarks are relevant in shaping the human motion behavior and their presence can be objectively assessed by using both kinematic data acquired from GPS and eye gaze information, namely the number of fixations and saccades, computed from captured eye-tracking data. To verify this hypothesis, objective and subjective assessments were conducted in an experimental setting. The results described in section 4 showed us that landmarks may be identified by a qualitative assessment, based e.g., on its visual and audio characteristics, and can be verified by a space syntax analysis. Eye-tracking data collection enabled us to assess the relevance of the presence of landmarks within the overall system, and supported the calculation of gaze data (number of fixations and saccades that concur on a given landmark). The comparative analysis between integration value and gaze data, considered the landmarks whose integration values were the highest, gave an indication that those values are somewhat correlated and that landmarks with higher integration values showed also a higher number of fixations and saccades. Future work involves extension of the analysis of the eye-tracking data during the complete path of each participant, so that we will be able to compare integration and gaze data for other landmarks, which were not considered in the current study.

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