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SPATIAL PERCEPTION OF LANDMARKS ASSESSED BY OBJECTIVE TRACKING OF PEOPLE AND SPACE SYNTAX TECHNIQUES

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ABSTRACT

This paper focuses on space perception and how visual cues, such as landmarks, may influence the way people move in a given space. Our main goal with this research is to compare people's movement in the real world with their movement in a replicated virtual world and study how landmarks influence their choices when deciding among different paths.

The studied area was a university campus and three spatial analysis techniques were used: space syntax; an analysis of a Real Environment (RE) experiment; and an analysis of a Virtual Reality (VR) environment replicating the real experiment. The outcome data was compared and analysed in terms of finding the similarities and differences, between the observed motion flows in both RE and VR and also with the flows predicted by space syntax analysis. We found a statistically significant positive correlation between the real and virtual experiments, considering the number of passages in each segment line and considering fixations and saccades at the identified landmarks (with higher visual Integration). A statistically significant positive correlation, was also found between both RE and VR and syntactic measures. The obtained data enabled us to conclude that: i) the level of visual importance of landmarks, given by visual integration, can be captured by eye tracking data ii) our virtual environment setup is able to simulate the real world, when performing experiments on spatial perception.

KEYWORDS

Virtual Environments, Behaviour, Space Syntax, Eye tracking, Objective Tracking

1. INTRODUCTION

Physical environment influences people's behaviour via several psychological mechanisms such as sensory access, attention, memorability, behavioural affordance, affect and sociality (Montello 2007). Research on the users' perception of space has been carried on for several decades in order to understand patterns of behaviour and then predict and design according to them. Our work follows Whyte's (1980) 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 complement to Whyte's analysis, 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). Studies observing people behaviour in virtual reality and the real world can complement space syntax analysis by introducing other variables in the outcomes of the analysis as landmarks (Lyu et al. 2015), light (Gochenour 2014) and land-use (Do et al. 2013). The perception of space is dominated by the distant senses (vision and hearing), while proximal ones (smell, touch and taste) give information about elements that are in direct contact with people.

The large goal of our research aims at studying how auditory, kinaesthetic and olfactory senses and visual elements like light and colour influence people's reactions to space. The study now presented follows our team´s prior research on space perception via analysis of real environments and virtual reality settings that simulate real spaces (Dias, Eloy, Carreiro, Proença, et al. 2014; Dias, Eloy, Carreiro, Marques, et al. 2014; Eloy et al. 2015). On those studies, either in real or virtual settings, we designed experiments with participants and collected objective measurements of physiological data, such as heart beat, skin resistance activation, gaze (via eye-tracking), kinematic data (trajectory and other kinematic measures of the subjects), as well as subjective data based on structured questionnaires. In Eloy et al (2015), we showed that the presence of landmarks can be objectively identified and assessed by collecting data with GPS and eye-tracking devices, from people's movement while walking in a real space, in a simple space exploration task.

In this paper, we raise four new hypothesis in line with our previous research:

Hypothesis 1: The presence of landmarks in virtual space can be objectively assessed by using gaze data acquired from an eye-tracking device;

Hypothesis 2: There is a positive correlation between people's walking paths in both real and virtual spaces;

Hypothesis 3: There is a positive correlation between people's walking paths in the real space and the paths predicted by space syntax analysis;

Hypothesis 4: There is a positive correlation between people's walking paths in the virtual space and the paths predicted by space syntax analysis.

This paper is divided in six sections. We start by describing related work in the literature that is in line with our research, both in the fields of space syntax and of assessment of space perception using virtual environments and objective measurements. In section three, we explain our research methodology and all the experimental settings. In this section, we also describe how syntactic measures were calculated to assess the potential of human motion associated with the space, and how experiments in both real and virtual spaces were designed to observe the way people move. Section four presents the obtained results and in section five, we discuss those results vis-à-vis the hypothesis raised for the research. The paper ends with conclusions and topics of further research, both drawn in section six.

2. RELATED WORK

Space Syntax theory, introduced in 1976 by Hillier and his colleagues at University College of London, 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 et al. 1976; Hillier & Hanson 1984). By analysing a series of spatial characteristics, space syntax helps designers understanding the role of spatial configurations in shaping patterns of human behaviour and to estimate the social effects of their designs. This analysis model enables us to study the causal relationships between the form of architectural and/or urban spaces and its modalities of use and occupation.

The theory has been extensively tested and high correlation between Integration, motion flows and space use, has been demonstrated by several authors (Hillier et al. 1976; Penn et al. 1998; Conroy-Dalton et al. 2010; Serdoura 2006). Since then, studies have broaden their use of syntactic measures, showing that other measures yield higher correlations with pedestrian flows (Freeman et al. 1991; Kivimäki et al. 2016; Newman 2005). Regarding Wayfinding and Spatial Configuration Emo et al. (2012) demonstrated how various syntactic measures are correlated with human behaviour on pedestrian route choice. In particular, this study revealed the existence of a higher correlation among the measure of Betweenness or Choice and pedestrian counts, than the one registered between the measure of Integration and pedestrian counts.

As mentioned, this work follows on our prior research on space perception and use. We previously investigated on people's navigation and visual attention in real environments (Eloy et al. 2015) and the current research aims at replicating a real experiment in a Virtual Reality environment and extracting conclusions brought forth by the comparison of results.

Our experience of space relies on a representation of the environment generated through a conjugation of our senses, that is compiled by our central nervous system (Loomis 2003). This representation informs our decisions on space use and therefore, by studying our senses we can aim at predicting how people make use of space. One of the main senses that influences our decisions is vision. Landmarks and their importance on users' navigation have long been shown in literature (Loomis et al. 1999; Michon & Denis 2001; Waller et al. 2004). In order to evaluate their importance, several methodologies and tools have been used as, e.g. the capture of images and video at specific viewpoints that include the landmarks (e.g. (Heitor et al. 2013)), and Virtual Reality simulations (e.g. (Waller et al. 2004)).

According to the "strong eye-mind" assumption, what a person sees can be an indication of what he/she is currently thinking or is predominant in his/her cognitive process (Just & Carpenter 1976). This means that by registering an individual's eye movement, we have access to data about where, on a given visual field, such individual's attention is being focused on. The individual's visual attention can be analysed through fixations (breaks between the informative regions of interest) and saccades (rapid eye movements between the fixations), allowing us to better understand how space is seen from the individual's point of view (Salvucci & Goldberg 2000). Moreover, it helps us to identify which are the areas that most attract the gaze of the users. This information is an important contribution to study the decisions undertaken by people when walking through a given space. In fact, according to Benedikt (1979), the visual information a pedestrian acquires when he/she is experiencing a certain space, influences his/her behaviour.

The eye-tracking concept refers to a set of technologies which allows tracking and measuring an individual's eye movements, when exposed to a visual stimulus in a real or controlled environment. This makes it possible to determine where, for how long and in which order, in his/her visual span, was the individual focusing his/her attention the most (Poole & Ball 2006). The use of eye tracking data to study objective environmental perception, compared also with Space Syntax analysis results, is a novel development in this area, particularly when combining field data collection with Virtual Reality data collection.

3. EXPERIMENTAL METHODOLOGY

3.1 CONDITIONS

The methodology used in this study encompassed the analysis of three conditions of use of the same physical territory, namely, the exterior area of ISCTE-IUL's University Campus shown in Figure 1. The three conditions were the following: i) Condition 1 – computer assisted automatic space analysis performed by space syntax DepthmapX and Space Syntax Toolkit for QGIS; ii) Condition 2 - real space analysed by direct observation of people and data collection; iii) Condition 3 - virtual space analysed in a semi-immersive virtual environment by direct observation of people and data collection.

In Condition 1, we have performed a Visibility Graph Analysis (VGA) and a Segments Analysis. For VGA a map of the area in study was drawn. This map included not only the buildings and trees at eye level but also other elements at knee level that restrict walking. The map was then imported to DepthmapX and a VGA analysis performed utilizing a grid of 1x1 meter. This analysis aimed at obtaining standard control, integration, depth and intelligibility measures. For the Segment Analysis, a second map was drawn based on the longest line, and minor corrections were performed where three or more lines intercepted, to reduce unnecessary segmentation. With this Segment Analysis, we obtaining NACH (normalised angular choice) and NAIN (normalised angular integration) measures. (Hillier et al. 2012)

Condition 2 consisted of an analysis of how people walk in the real space. The experiment was done in the campus area, exactly the same location that was subject to space syntax analysis in Condition 1 (Figure 2 and Figure 4). For condition 3 a virtual model of the ISCTE-IULs' campus was modelled and experiment participants navigated through it in a semi-immersive virtual environment (Figure 3 and Figure 5).

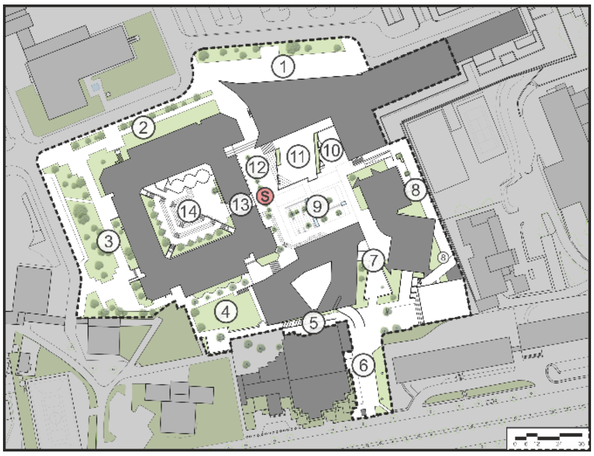

Figure 1 – Main areas of the ISCTE-IUL campus and starting point (S)

3.2 EXPERIMENTAL SETTINGS

The experiments undertaken for Conditions 2 and 3 included the participation of volunteers that freely explored the campus for a period of 10 minutes. Since both studies were based in observing people walking, several decisions where taken in order to define how to perform the experimentations. Our prior Space Syntax analysis, helped us selecting a location in the Campus to start the experimentation. To that aim, we selected the place with higher integration value measured in Condition 1 as the start location (indicated with an "S" in Figure 1). In fact, from this chosen point all possible trajectories could be followed by participants, enabling them to choose freely from a large variety of options.

3.3 DATA COLLECTION

During this study, particularly for both Condition 2 and 3, we collected both objective and subjective data from the participants' activities namely, objective data regarding the paths chosen to explore the campus area, and subjective questionnaire data regarding their attachment to the space. The objective data consisted of the 3D positions along the trajectory taken, the speed of the motion and the gaze of participants during the entire experiment.

Trajectories followed by the participants in Condition 2, were captured by means of a Garmin Forerunner 310XT GPS tracking system. This system is unobtrusive and has an acceptable 4 m accuracy which is sometimes degraded by reflections in buildings and vegetation. Location data consisted on a time-series of latitude, longitude and elevation geodesic coordinates in spherical coordinates. Since the quality of the elevation data from GPS is known to be 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 Mat Lab 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. In Condition 3, the path followed by each participant was collected automatically by a specific functionality of the virtual reality system. Among other variables, the XYZ position in the virtual environment was collected in relation to the virtual world reference frame. The data collection system outputs a set of samples with timestamped entries, with an average delta of 31.73 milliseconds (ms) and a standard deviation of 10.85 ms. The walking speed for the virtual experience was fixed and defined using the average speed of the participants of Condition 2. This value was constant for the whole experiment, so that the subject could only either be standing still or moving in the virtual environment at this fixed speed.

To collect gaze information, we used a head-mounted eye tracker from Ergoneers (Dikablis model). In Condition 2, participants wore a backpack which stored a Surface Pro 2 that was collecting the data from the eye tracking device. From the collection of gaze information, we extracted 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 Salvucci and 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.

Literature on the topic of users' perceptions of environmental conditions, tend to analyse the attachment users have to the places they are assessing. Kyle et al (2004) even states that users with the strongest attachment are also the most sensitive to environmental conditions existent within the setting. We´ve followed a similar approach by collecting subjective data by means of a questionnaire that participants answered at the end of each experiment. The goal of using this type of analysis was to obtain more information about user's assessment on space potentialities and affordances, as well as to gather extra knowledge about their preferences and level of self-identification with the campus.

Figure 2 – (left) Participant of condition 2 using the instruments for data collection in the real space of the ISCTE-IULs' campus.

Figure 3 – (right) Participant of condition 3 using the instruments for data collection in the semi-immersive virtual environment.

Figure 4 – ISCTE-IULs' campus used in the experiment of Condition 2.

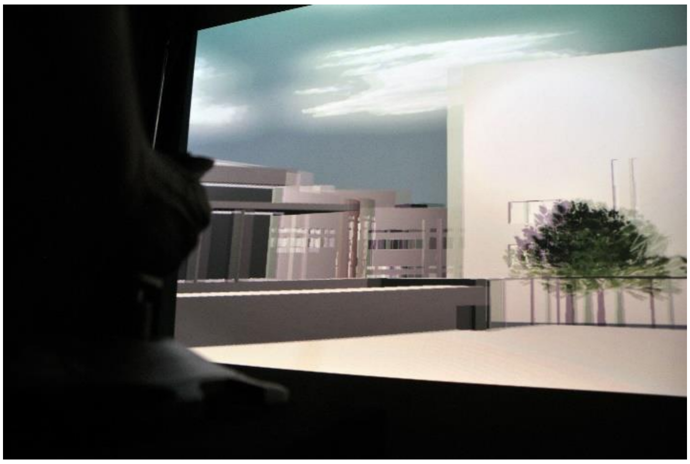

Figure 5 – A snapshot of ISCTE-IULs' virtual campus used in the experiment of Condition 3.

3.4 PARTICIPANTS

Participants were recruited from the ones who: i) don't have an architecture background, ii) have good prior knowledge of the university campus, iii) don't have motion constrains or physical disabilities, iv) don't suffer from cardiovascular diseases. For Condition 2, 18 volunteer's participants were selected, ranging from 18 to 45 years old, with a mean age of 25 and a standard deviation of 7.24. Condition 3, engaged 20 volunteer participants, ranging from 18 to 31 years old, with a mean age for 22 and a standard deviation of 4.09.

3.5 PROTOCOL

The experiment included two parts: a prospecting one during which volunteers were survey to check selection criteria; and the experiment proper, where participants were asked to explore the prescribed area of the university campus. All participants engaged in experiments of Conditions 2 and 3, received the same instructions to accomplish the campus exploration. Before the experiment started participants were briefed about the task to be performed and the data collection equipment they would carry. Participants were told to freely explore the area the best that they could during ten minutes. At the end, they answered a questionnaire about their experiment

4. RESULTS

4.1 SPACE SYNTAX (CONDITION 1)

As mentioned, we conducted a first analysis of the university campus by means of Space Syntax in order to study the potential of human motion that theoretically could occur in that space. For that analysis we conducted a segment analysis for calculating NACH and NAIN and a VGA analysis for acquiring global integration, intelligibility, control and mean depth measures. The main aims of this analysis were: i) to find the more integrated areas to contribute to the definition of the landmarks that will be focus of study and ii) to have data on peoples' potential motion flows to compare with the results of Condition 2 and 3.

From a qualitative analysis twenty-two landmarks were identified in campus, based on special architectonic elements (e.g. prominent doors, unusual shape) and audio sources (e.g. water falls), as depicted in Figure 6. Based on a VGA analysis (Table 1) we chose the four most integrated landmarks - V02, V04, V09 and M01 – to perform the gaze (based in eye-tracking) analysis in Conditions 2 and 3 explained later in this section.

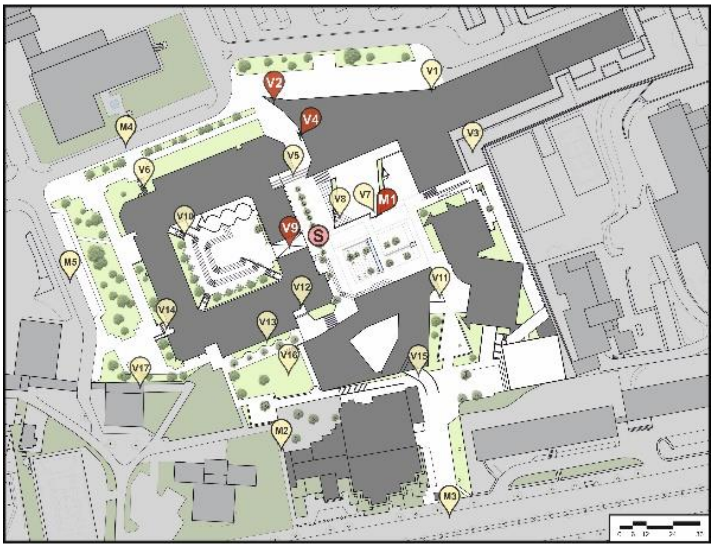

Figure 6 - Full set of identified landmarks (yellow), analysed landmarks (red) and starting point (S) of the experiment.

Landmark	V2	M1	V9	V4	V3	V5	M4	V1	M3	V13	V11	V7	V12	V6	V17	V15	V8	M2	V16	V14	M5
Integration value	7.1	6.2	5.6	5.5	5.3	4.7	4.7	4.6	4.4	4.1	4.1	3.5	3.4	3.4	3.3	3.3	3.1	3.0	2.8	2.8	2.2

Table 1 - Integration values calculated on VGA analysis (isovist at knee-level) for each Landmark in decreasing order

The VGA analysis presented in Figure 7, shows that areas 9, 12, 14 and the transition zone between areas 1 and 2 have high values of Global Integration, Intelligibility and Control and low values of Mean Depth, indicating that, in the context of the studied area, those areas are very central, easily reachable and are areas where the whole system is visually controlled and easily understood. More peripheral areas like 2, 3, 4 and 5 present the opposite values and constitute areas where users more rarely access and are not part of the regular flow.

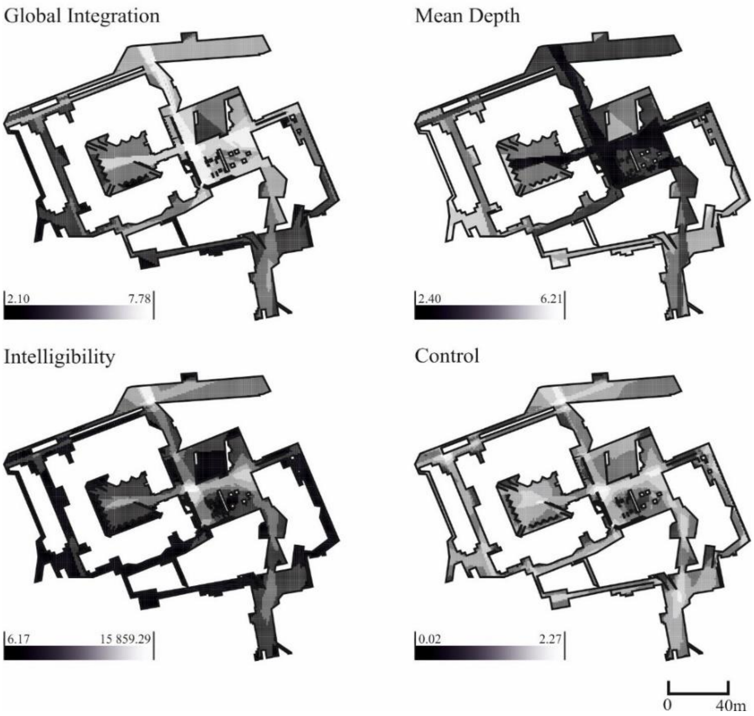

Figure 7 – VGA Analysis of the ISCTE-IUL's university exterior campus, measures of Global Integration, Mean Depth, Intelligibility and Control

For our segment analysis of the space, a wide range of radii were applied – 50m, 100m, 200m, 300m, 500m and N (or unrestricted) – to allow a broader range of study. The values acquired for the various measures plateaued on radii larger than 300 meters, which revealed to have no significant difference from the ones of N, indicating this radius as the maximum for this case study. Thus, we have opted to use radii N and another in between - radii 100 meters - to perform the various correlations between the various experimental conditions. Figure 8 shows NACH and NAIN measures for radii 100m and N. NACH value is the division of total choice by total depth for each segment in the system, therefore adjusting choice values per the depth of each segment in the system (otp.spacesyntax.net). NAIN measures how close each segment is to all others in terms of the sum of angular changes that are made on each route (Glossary of space syntax, ucldigitalpress.co.uk).

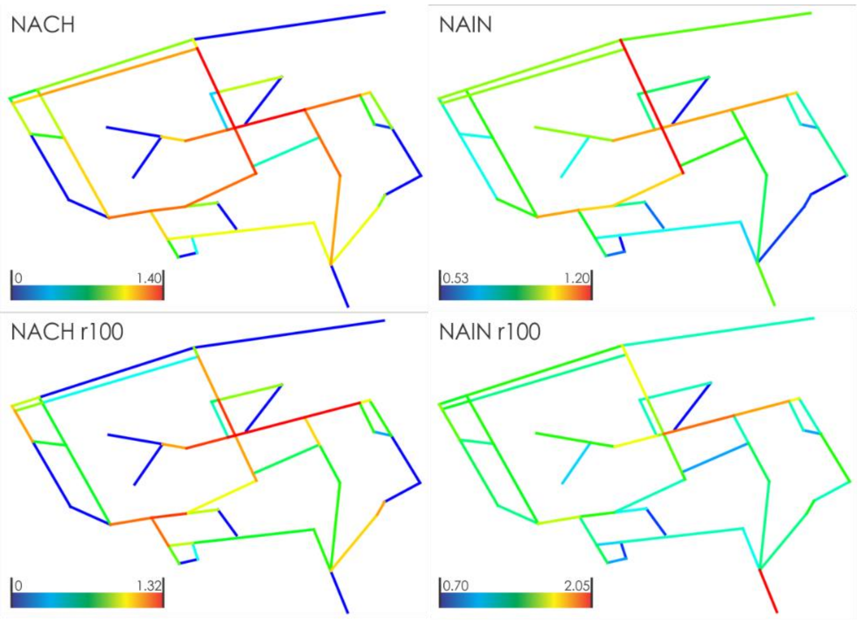

Figure 8 – NACH and NAIN Segment Analysis Radii 100 meters and N

4.2 REAL ENVIRONMENT (CONDITION 2) AND VIRTUAL REALITY (CONDITION 3)

In Conditions 2 and 3 we collected data regarding the trajectories followed by the participants and to where they were looking when near the selected landmarks.

The observed motion flows are shown in Figure 9 regarding Condition 2 and Figure 10 for Condition 3. A visual analysis of these flows shows a more diverse exploration of space in Condition 2 where most subjects moved through all the campus in a similar way. Condition 3 shows a higher concentration of movement in areas 11, 12, 13 and 14. It should be noted that there the method used to record trajectories in Condition 2, a fitness GPS watch, has several meters of error due to satellite signal degradation. Ongoing evolution of the devices and of the satellite network, with the addition of a large number of satellites by Russia, Europe and China's own systems (GLONASS, Galileo and BeiDou), will provide greater accuracy in the coming 2-4 years.

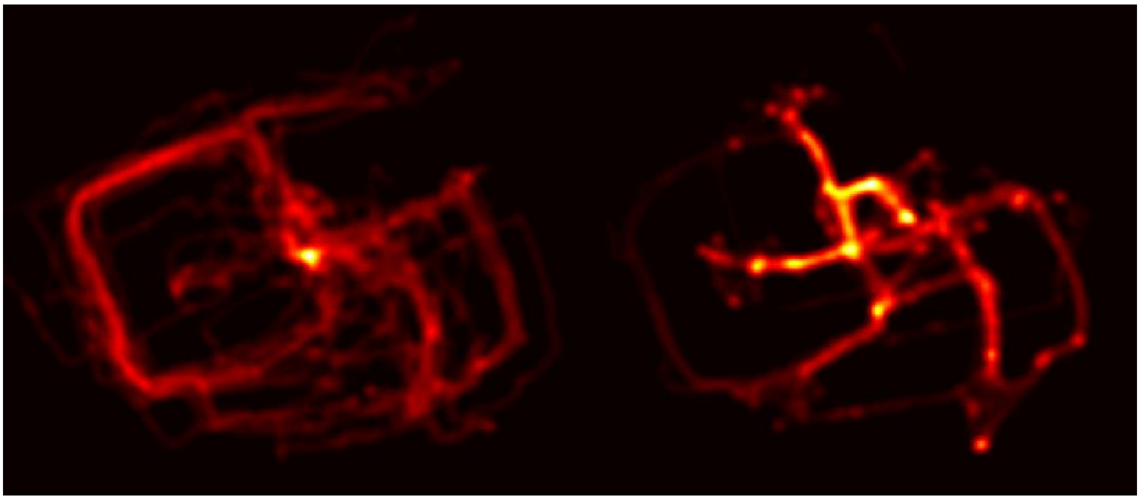

Figure 9 – Motion flows in Condition 2 (RE)

Figure 10 – Motion flows in Condition 3 (VR)

Table 2 shows the fixations and saccades occurred for each landmark per subject, both in Conditions 2 and 3. V9 is the landmark that in both Conditions has higher values with V2 being the second one. The differences obtained in the values will be discussed in the Discussion section.

From the questionnaires, we obtained the level of identification of the participants with ISCTE-IUL as well as a personal assessment on what were their preferred spaces (Table 3).

To measure the level of identification with ISCTE-IUL we computed an index composed by 4 items (e.g., "I identify myself with ISCTE-IUL", "I like ISCTE-IUL very much"; Chronbach alpha = .60). The analysis of the means revealed a high level of identification with ISCTE-IUL both in the real (M = 5.12; SD = 0.90), t (19) = 25.42, p < 0.001, and in the virtual scenarios (M = 4.75; SD = 1.02), t (15) = 18.54, p < 0.001. Furthermore, there were no significant differences in the level of identification between these two scenarios, t (34) = 1.16, p = 0.251.

Relating to the preferred areas (Table 3), we verified a low correlation (0.48) between Condition 2 (RE) and 3 (VR). In Condition 2, the subjects tended to prefer areas dominated by vegetation (areas 2, 3 and 4), and in Condition 3 subjects preferred the areas that, in the real environment, have the most social life of the campus (areas 9, 11, 14). The low correlation between the two conditions, although all participants showed a high level of identification with the campus, drives us to conduct further studies on this subject in the future. A preliminary hypothesis for such a correlation, that requires further experimental validation, is that participants of the virtual experiment were first curious and then satisfied by the virtual representation of places they like. For the real experiment, participants might have learned better the campus and discovered places they did not knew well.

Subject/Landmark	V2 (%)	V4 (%)	V9 (%)	M1 (%)
RE02	12.22	6.20	59.03	18.15
RE03	32.12	10.69	52.62	-
RE04	-	5.13	4.17	30.43
RE05	30.15	4.95	8.75	-
RE06	5.83	9.09	2.86	2.70
RE08	13.95	14.15	12.44	9.65
RE10	5.84	-	-	8.48
Average ± SD	14.30 ± 11.47	7.17 ± 4.25	19.98 ± 23.04	9.92 ± 10.28
Confidence interval	8.50	3.15	17.07	7.61
VR03	39.63	26.83	15.79	15.25
VR04	2.33	20.79	15.44	0
VR05	19.81	19.31	21.35	12.67
VR07	3.2	33.67	17.65	0
VR08	-	0	13.07	0
VR09	16.06	8.65	22.49	4.68
VR11	-	-	26.87	0.38
VR14	26.87	26.96	13.91	25.92
VR15	18.09	22.04	17.99	15.4
VR16	-	-	11.97	1.91
VR17	13.65	0	21.11	7.42
VR18	5.71	31.03	4.41	8.21
VR19	47.67	0	30.71	4.59
Average ± SD	19.30 ± 14.32	17.21 ± 12.25	17.9 ± 6.53	7.42 ± 7.63
Confidence interval	8.88	7.24	3.55	4.15

Table 2 - Fixations and saccades for each landmark, per subject (Condition 2 subjects RE02 to RE10, and Condition 3 subjects VR03 to VR19). The values shown represent the percentage of time that the participant looked at the landmark when it was on his/her field of view. Only 7 from the 18 experiments of Condition 2 and 13 from the 20 experiments of Condition 3 were considered valid for the eye-tracking analysis. "-" means that the subject did not pass through the landmarks and "0" means that the subject did not look at the landmark.

Areas/% of likes	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Condition 2 (RE)	3.9%	15.7%	19.6%	25.5%	0%	0%	9.8%	2%	13.7%	0%	7.8%	0%	0%	2%
Condition 3 (VR)	2.1%	2.1%	8.3%	8.3%	2.1%	2.1%	2.1%	4.2%	25%	0%	18.8%	4.2%	2.1%	18.8%

Table 3 – Number of times participants said that areas were the ones they preferred.

4.3 CORRELATIONS BETWEEN THE THREE EXPERIMENTAL CONDITIONS

Data resulting from the analysis performed with space syntax (Condition 1) was correlated with data collected in Condition 2 (RE) and Condition 3 (VR), regarding the paths taken by the participants. For that correlation, we considered, in Conditions 2 and 3, the number of subjects that passed through each segment (Sub) and the total number of passages for each individual segment (Pas). Regarding Condition 1 we used the values of NACH, NAIN in radii N (rN) and 100m (r100m), for each segment.

With such data, a wide range of correlations were performed as shown in Table 4. Both number of subjects and total passages revealed a high correlation, respectively 0.825 and 0.827, between Condition 2 and 3. The correlations performed revealed to be higher between Condition 1 and Condition 2 (RE) than between Condition 1 and Condition 3 (VR). This higher correlation was higher with rN than with radius r100m. Additionally NACH obtained a higher correlation with Condition 2 and 3 than NAIN.

	VR-Sub (Condition 3)	VR-Pas (Condition 3)	RE-Sub (Condition 2)	RE-Pas (Condition 2)
RE-Sub (Cond. 2)	0.825 / p=2.857E-15	-	-	-
RE-Pas (Cond. 2)	-	0.827 / p=2.196E-15	-	-
NACH rN (Cond. 1)	0.657 /p=2.787E-8	0.596 / p=1.009E-6	0.743 / p=3.483E-11	0.730 / p=1.201E-10
NAIN rN (Cond. 1)	0.536 / p=0.000017	0.563 / p=5.158E-6	0.478 / p=0.00017	0.513 / p=0.000044
NACH r100m (Cond.1)	0.460 / p=0.000316	0.430 / p=0.000853	0.485 / p=0.000129	0.485 / p=0.000129
NAIN r100m (Cond.1)	0.314 / p=0.0173	0.327 / p=0.013	0.329 / p=0.0123	0.337 / p=0.0103

Table 4 - Correlations between the experiments of Condition 2 (Real Environment) and Condition 3 (Virtual Reality) calculated using Spearman's rank order correlation. RE: Condition 2; VR: Condition 3; Sub: Number of Subjects passing on the landmarks; Pas: Individual Passages on the landmarks.

5. DISCUSSION

The results obtained from the questionnaires shown that that all subjects, both in Conditions 2 and 3, have a high place attachment and constitute a homogenous sample on that matter. This result also indicates that subjects have a positive perception about the place they are accessing (Bernardo & Palma-Oliveira 2012) and their attitudinal anchor relating to environmental conditions is set notably lower than the ones who have lower attachment (Kyle et al. 2004). Situations less interesting of the environment as e.g. lower aesthetics or less qualified spaces are therefore not taken as a critic subject. With this results we can therefore assure that the experiments were not biased by characteristics of space that are not the morphological ones.

Our analysis on the data obtained in the conducted experiments, allowed us to assess the hypothesis raised for this research.

Hypothesis 1: The presence of landmarks in virtual space can be objectively assessed by using eye gaze data acquired from an eye-tracking device.

Our data collection approach, showed that the presence of landmarks in the virtual reality environment can be objectively assessed by using eye gaze data acquired from an eye-tracking sensor, proving hypothesis 1. Indeed fixations and saccades for each landmark were calculated and show high values.

The large standard deviation was obtained in the results from Condition 2 and 3 regarding the fixations and saccades of the four landmarks (Table 2, e.g. for V9) can be explained due to the architectural characteristic of the space. In fact, V9 is a wide and long tunnel where participants registered high values of fixation and saccades when they cross it and a very small value when they just pass in front of it. In other landmarks in which the architectonical characteristics are more confined (e.g. the vertical stairs in the façade in V04), the observed values are more constant.

Hypothesis 2: There is a positive correlation between people's walking paths in both real and virtual spaces.

Considering hypothesis 2, the data confirms a positive high correlation between people's movement in the real and in the virtual space. Data obtained confirms the premise with a high correlation on both number of subjects that pass through an area and total number of passages by area, with 0.825 and 0.827 respectively, and a p-value under 2E-15.

This result enables us to perform studies on people's movement in virtual reality environments simulating the real environments in ISCTE-IUL VR-Lab.

Hypothesis 3: There is a positive correlation between people's walking paths in the real space and the paths predicted by space syntax analysis.

We verified a high positive correlation between people's walking paths in the real space and the measure NACH rN and a moderate positive correlation with NAIN rN, confirming, in essence, our hypothesis 3. An eventual bias occurred by the fact participants had to walk using visible equipment was already discussed in Eloy (2015) . Without this bias the correlation could have been higher.

Hypothesis 4: There is a positive correlation between people's walking paths in the virtual space and the paths predicted by space syntax analysis.

We have also verified a moderate positive correlation between people's movement in the virtual space and the syntactic measure NACH rN and NAIN rN, proving our hypothesis 4.

It is important to emphasize that the correlations obtained between the syntactic measures and RV were slightly inferior then the ones verified between syntactic measures and RE. These results need further research but it is interesting to observe that even though the real environment contains distracting elements as people walking, greenery, and so one, the correlation with the syntactic measures was higher than the one with between syntactic measures and virtual environment. Besides the confirmation of hypothesis 2, other studies with our virtual reality environment showed that it enables high levels of presence therefore simulating well the real environment (Dias, Eloy, Carreiro, Marques, et al. 2014). One possible interpretation is that a more realistic virtual environment, e.g. incorporating active walking, greater field of vision, more realistic greenery or further modelling of the surrounding area, would increase the correlation between virtual reality and syntactic measures.

6. CONCLUSIONS AND FUTURE WORK

The research presented in this paper aimed at assessing the spatial perception of landmarks, by collecting and analysing objective and subjective data from users participating in real and virtual reality experiments.

It was hypothesised that the presence of landmarks in virtual space could be objectively assessed by using gaze data acquired from an eye-tracking device and that a positive correlation would exist between people's walking paths in three conditions – space syntax simulation, real environment and virtual environment.

The obtained results have shown, on one hand, that eye-tracking data collection enabled us to assess the relevance of the presence of landmarks when a subject navigates in a virtual reality environment. On the other hand, our experiments have revealed that there is not just a high positive correlation between people's movement in the real space and space syntax measures, but also, between people's movement in the virtual space and space syntax measures. Differences between this two correlations were discussed in the previous section.This result reinsures the predictive capabilities of segment analysis and, in particular, the use of NACH over NAIN measures, for pedestrian traffic. We have also shown that there is a positive correlation between people's movement in the real space and in the virtual space. With this finding we have an evidence of the applicability of our semi-immersive virtual environment to replicate real environments with sufficient accuracy, when evaluating space perception and use.

Future work involves a fourth condition of study with 3D sound (ambisonics and binaural) scape in virtual reality. The aim of such a study is to verify if 3D sound effects in virtual reality have a significant effect in increasing the sense of presence and immersion of the subjects and positively impact the correlations between the Virtual Reality environment, the Real Environment and the Space Syntax theoretical measures.

Furthermore, performing additional experiments with a sample of participants that bear no prior knowledge of the University Campus, would most likely enable observation of lower attachment values (of participants to the space), that could then be compared with the results now presented in this study. According to the literature (Kyle et al. 2004), we would in fact expect that this new sample would respond in a different way to the exploration challenge introduced in this study, and thus explore other facets of the interaction between users and space.

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