METHODOLOGICAL BASES FOR A NEW PLATFORM FOR THE MEASUREMENT OF HUMAN BEHAVIOUR IN VIRTUAL ENVIRONMENTS

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ABSTRACT:

Human behaviour is analyzed to evaluate the functionality and performance of a public space. It has been traditionally measured by surveys and observation with some limitations since they are subjective valuations and they are influenced by the interviewer and/or the observer. In addition, the observation obliges us to make that evaluation subsequently, when the project has been executed. Nowadays, virtual reality resolves these problems as consequence of its capacity to represent scenarios in a realistic, immersive and interactive way. It allows us to analyse human behaviour before the execution of projects and in a cost-effective and controlled way.

This article presents the methodological bases for a new platform to measure human behaviour in virtual environments. It will assist in the decision-making process through the pre-evaluation of different spaces before being executed. An applicable methodology is explained from which metrics are created and it allows to optimise functionality and performance of a new construction or remodelling. This is a cross-cutting platform since it can be applied to any project in which the people transit is a pivotal element for commercial, cultural or leisure spaces. Furthermore, different examples of practical application are presented.

Keywords: data intelligence, human behaviour, virtual reality, tracking, neuroarchitecture, decision-making

RESUMEN:

Para evaluar la funcionalidad y el rendimiento de un espacio se analiza el comportamiento de sus usuarios. Este se ha medido tradicionalmente a partir de encuestas y observación, con las limitaciones de tratarse de valoraciones subjetivas, influenciadas por el entrevistador y/o observador, y, en el caso de la observación, evaluar el espacio a posteriori, una vez ejecutado el proyecto. Hoy en día, la realidad virtual solventa estos problemas, al ser capaz de representar escenarios de forma realista, inmersiva e interactiva, permitiendo analizar con un bajo coste el comportamiento de los usuarios antes de que se ejecuten los proyectos, en un entorno controlado.

El presente artículo presenta las bases metodológicas para una nueva plataforma de medida del comportamiento humano en entornos virtuales, que ayudará en la toma de decisiones a través de la pre-evaluación de los espacios antes de ser ejecutados. Se define una metodología aplicable con la tecnología actual, a partir de la cual se obtendrán métricas con las que optimizar la funcionalidad y el rendimiento de espacios de futura construcción o remodelación de los ya existentes. La herramienta es transversal ya que puede aplicarse a cualquier proyecto que tenga como elemento fundamental el tránsito de personas, ya sean espacios comerciales, culturales, dotacionales o de ocio, y se presentan diferentes ejemplos de aplicación práctica.

Palabras clave: data intelligence, comportamiento humano, seguimiento, realidad virtual, neuroarquitectura, toma de decisiones

1. INTRODUCTION

Human behaviour is the main source of information to evaluate the functionality of an area which has been designed for human use such as a shop, a museum or a park. This information has been traditionally collected by means of surveys and observation.

Surveys show subjective assessments about a person's experience when visiting someplace. However, they reveal significant deficiencies owing to the own conditioning of human beings when measuring or expressing ourselves. It is necessary to go beyond subjective measurements [1] since most cognitive states occur at the unconscious level [2].

On the other hand, observation has been used to evaluate human behaviour. These studies have been carried out by direct observation [3], video recordings and, recently, by GPS or Bluetooth [4]. Nevertheless, the major limitation of these tools is that they cannot be used for the pre-evaluation and the optimization of a zone before being built.

To solve this problem, Virtual Reality (VR) is promoted as a tool capable of representing three-dimensional scenes in a realistic, immersive and interactive way, making it possible to stimulate and to evaluate spatial environments under controlled laboratory conditions [5]. It enables variables to be isolated or modified quickly and cost-effectively in the same space, something which is unfeasible in the real space [6].

Studies which have made use of VR have already been carried out to recreate spaces in order to help project designers with the decision-making process. On the one hand, some studies have been based on showing the virtualized space to new users as well as obtaining their assessments through surveys [7]. On the other hand, there are studies which have developed techniques to evaluate the space on the basis of behavioural data navigation, interaction and visual exploration [8]. However, these studies have been based on submitting the results using graphic representations and any metrics have been defined to analyse the performance.

In this context, the aim of this article is to show a new technology platform to measure human behaviour to support the decision-making process through the pre-evaluation of architectural places before being developed. It will use a cross-cutting methodology from which metrics are obtained in order to evaluate and optimize the functionality and the performance of projects in different fields: commercial, cultural, healthcare and so on.

2. METHODOLOGY

2.1. HUMAN BEHAVIOUR TRACKING

Human Behaviour Tracking (HBT), which is the assigned name for this platform, is a technology to analyse human behaviour which is based on monitoring navigation, interaction and visual exploration of a group of users in a space. The information flow of HBT system in VR encompasses three phases (*Figure 1*).

Experimental phase: firstly, the RV space is modelled and a sequence of experimental studies is carried out on *n* users. They can be either within the same space or separately and they can have or not a task to be carried out depending on the selected characteristics to be evaluated.

Processing phase: once the experimental studies have been carried out, there will be a data set which can be divided into three groups: user's navigation or time position, interactions with the space and visual exploration. This article focuses on the processing of navigation and interaction data without taking into account visual exploration. Moreover, it is also necessary to draw the contextual variables on which the experiment has been conducted. This information will be processed by a software developed for this purpose resulting in a whole series of innovative metrics stored in a database.

Assessment phase: on the basis of a set of metrics contained in the database, it is feasible to analyse the space performance according to diverse variables. Applying statistical analyses, a final assessment on the alternative to be

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studied will be carried out. Furthermore, it is crucial to develop new types of graphic representations facilitating the interpretation of the results obtained to the professional.

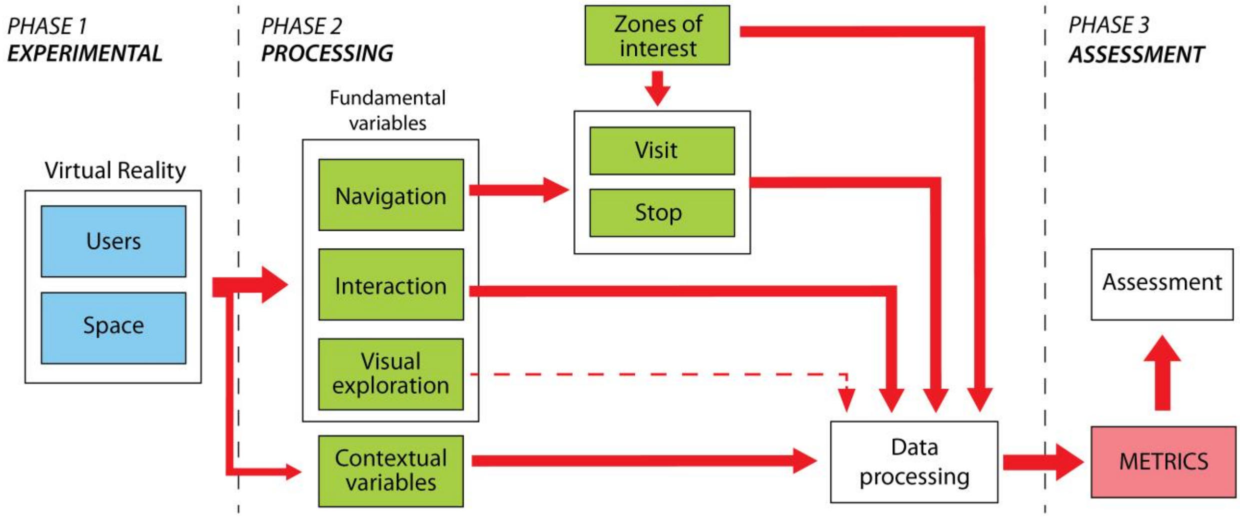

Figure 1*: Information flow diagram in a HBT system in VR*

2.2. EXPERIMENTAL PHASE

The main advantage of VR is that enables the replication of the space to be evaluated with a great degree of realism, allowing us to alter the design elements as well as those ones of sensory experience in a controlled way through specific characteristics or variables. New developments in computer design make it possible to produce sophisticated images which not only are capable of transmitting the characteristics of a future space, but they also evoke in the observers feelings and emotions which may be provoked by the space [9].

It is possible to find different VR devices which can be classified in non-immersive systems, semi-immersive systems and immersive systems [10]. Each one of these systems has advantages and disadvantages which imply the choice of a platform according to the characteristics to be evaluated. In addition, it will be necessary to take into account the navigation metaphor chosen because this will influence on the user's behaviour. The implication of these choices is complex and it is beyond the scope of this article.

Once the platform and the navigation metaphor have been defined, it is essential to model the future space. If it is attempted to analyse a set of alternatives, it is necessary to design them, to develop the whole process for each one of them and, finally, to compare the assessments. These solutions, which combine the CAD modelling in 3D, the navigation metaphors, the interactivity in the scene and the potential variations in the space, are developed making use of a graphic engine such as Unity (Unity Technologies, EEUU).

The experimental studies will also be designed according to the characteristics to be assessed, being possible to implement tasks for this purpose. For example, if it seeks to study why an exhibition room is little visited in a museum regardless of the content on display, individuals would be required to search for it and it would be assessed what layout reduces the time that users need to find it. However, if it is supposed to study the natural sequence of visits made by users to the supermarket, the task would be an open purchase with a limited budget allocated for that purpose or without it.

2.3. PROCESSING PHASE

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2.3.1. Fundamental and contextual variables

It is possible to divide the information related to users' behaviour into two groups: fundamental variables and contextual ones. **Fundamental variables** are related to navigation, interaction and visual exploration. In order to collect these variables, it is essential to have a measurement layer in the background of the VR system to extract relevant information from each personal session in the VR space to be subsequently processed. This layer will be inserted in the graphic engine using scripts.

Navigation will be defined by the user's position and orientation over time on the basis of a Cartesian reference system through its X and Y coordinates. To simplify the subsequent analysis, the HBT system only analyses navigation in floor plans. In the event that the project has different floors, each one of them will be evaluated separately. From this position, the visits and the stops are obtained to assess the project.

The user's **interaction** with the space is another fundamental variable to assess the space performance and it will depend on the project to be analysed. For example, it could be the purchase of an item in a supermarket or when the user presses the information button of a work of art in a museum. Nevertheless, according to the requirements of the study, it could enable diverse and more complex interactions within the zone such as allowing the user to change different parameters of the project.

Visual exploration describes how and where the user is looking at. In order to measure it, the VR platform has to include eye-tracking systems which follow the pupil of the user to establish where the gaze is directed. In this article, we are focusing on navigation and interaction.

On the other hand, **contextual variables** contain the information about the sample as well as he experimental conditions. The profile of users is the most important data when dividing the sample in accordance with age, gender or personality. These variables will be obtained from a previous questionnaire in which the questions vary depending on the project. It is also fundamental to maintain control over the experimental conditions since the same alternative may be evaluated using different characteristics such as a range of colours, and over the environmental conditions like temperature, lighting or sound.

2.3.2. Interest zones

In order to analyse the space comprehensively, it is crucial to divide it in zones which have an analytical interest for the study. Different metrics are obtained for each one of them, allowing us to evaluate the performance in minute detail. Thus, we will, for instance, divide a supermarket in diverse zones according to the product which is offered and to assess the functionality of each zone (*Figure 2*).

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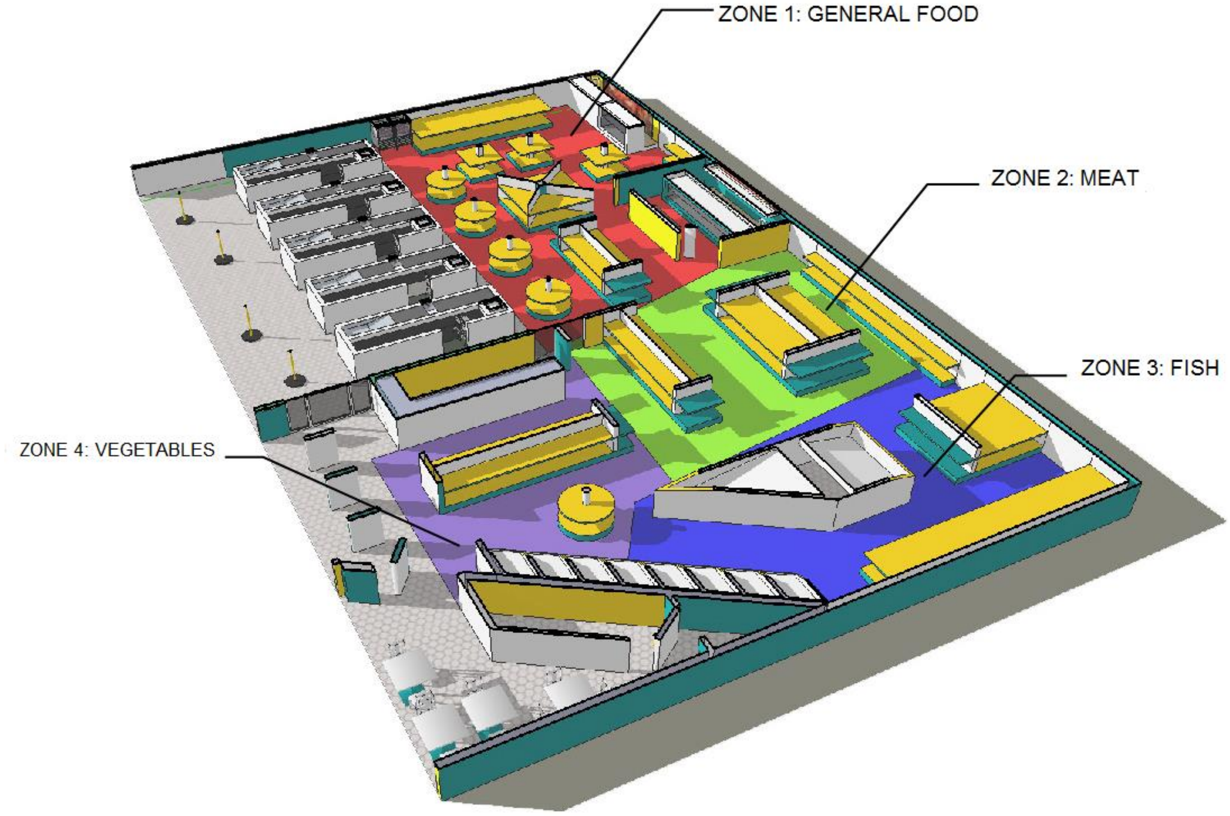

Figure 2: *Example of a zoning diagram in a supermarket with four interest zones*

Moreover, different levels can appear which will vary depending on the project. For example, in a supermarket, three levels are proposed, based on the zone concerned, the type of article and the sales area/direct display.

In the example of a textile store (*Figure 3*), a first layout would be made in large sales zones (men, women, kids …). On a second level, these zones would be organised according to the items offered (trousers, shirts, suits …). The third level would consist in dividing the space as much as possible in order to study the performance of each rack. Thus, we would be able to study what the performance is in rack no. 2 in the men trousers zone. Similarly, in a museum, it would be possible to study the performance of the work of art no. 3 whose author is participating in the exhibition no. 1.

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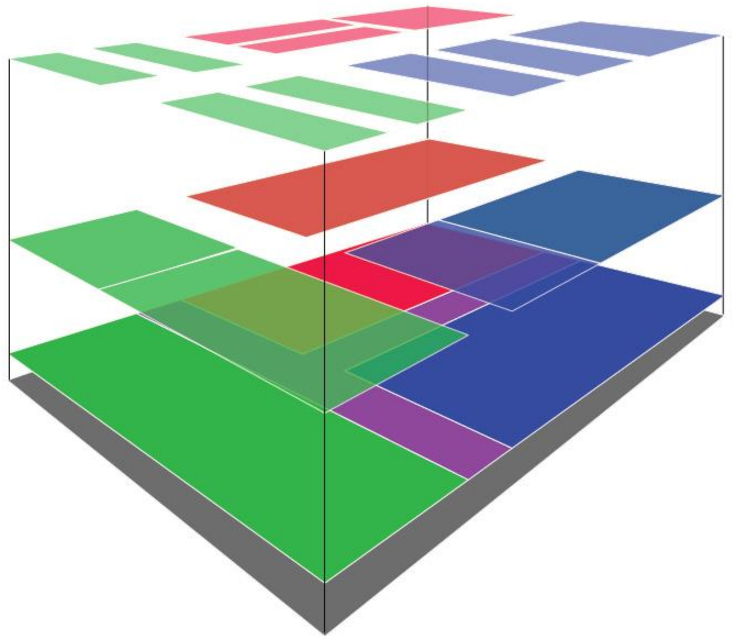

Figure 3: Example of a zoning diagram for a shopping centre and a museum on three levels

2.3.3. Navigation variables

The fundamental navigation variables need a pre-processing to be calculated. The first of them is the **visit**. It will be counted every time that the subject enters within zone of interest and leaves it. In this way, we will be able to analyse quantitatively how they behave and which sequence the users will follow in the future area. Figure 4 shows the itinerary followed by a user within a space, taking into account that the user has visited zone 2 five times.

The **stop** completes the navigation variables. It is understood as the amount of time during which a user is at a standstill observing the space or interacting with it. The definition poses technical issues, given the fact that two types of stops in which the user is technically stopped can be found, but they do not fit into the given definition.

The first one that we find is caused by the realization of small moves within the same stop (one step forward to carry out an interaction, one step right to turn the head, etc.). In this way, several stops could be detected due to these small moves but only one has in fact been realized. The other one is the one which takes place within a short time frame in the movement process, when the user has stopped for milliseconds, but no detention has been made to observe or interact within the space. If we did not have into account these two events, countless false positive results would be obtained which would undermine the analysis.

For this reason, it is essential to calibrate the standstill detection algorithm. Firstly, it will be necessary to indicate the minimum speed under which the stops are considered and in this way small displacements are discarded. A minimum time threshold in which the user is at standstill will also be calibrated from which a stop will be considered and thus exclude the second type ones. These parameters will depend on the VR system employed and on the navigation metaphor.

Thus, a stop will occur when a user is over x seconds at standstill, taking into account that the user has no movement when he is under speed y.

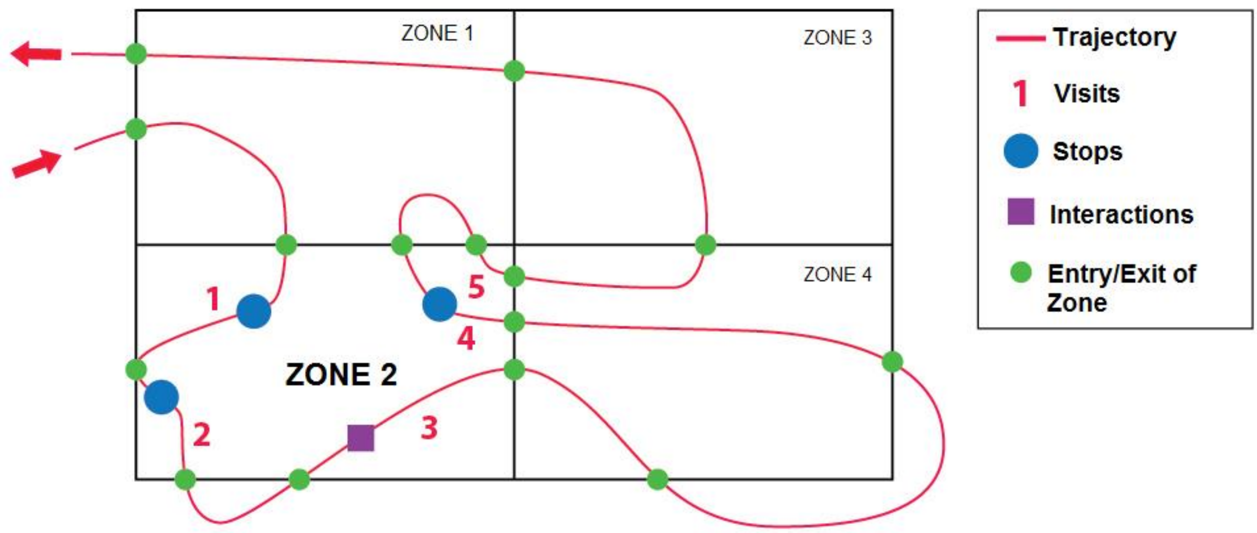

Figure 4: Diagram of the visits and stops made by a user within Zone 2.

2.4. EVALUATION PHASE

2.4.1. Software

Once the inputs are defined, it is necessary to carry out a procedure of data treatment to obtain the metrics. To this end, a computer software in octave-matlab has been designed (Figure 5). It carries out the process in an automated manner until the export of the final data base with which the assessment of the project is undertaken. In the following sections, the types and blocks of metrics which have been designed are being described, as well as different examples are given and some of them are explained. Depending on the available space, the designer should analyse which are the best ones to explain the performance to be optimized.

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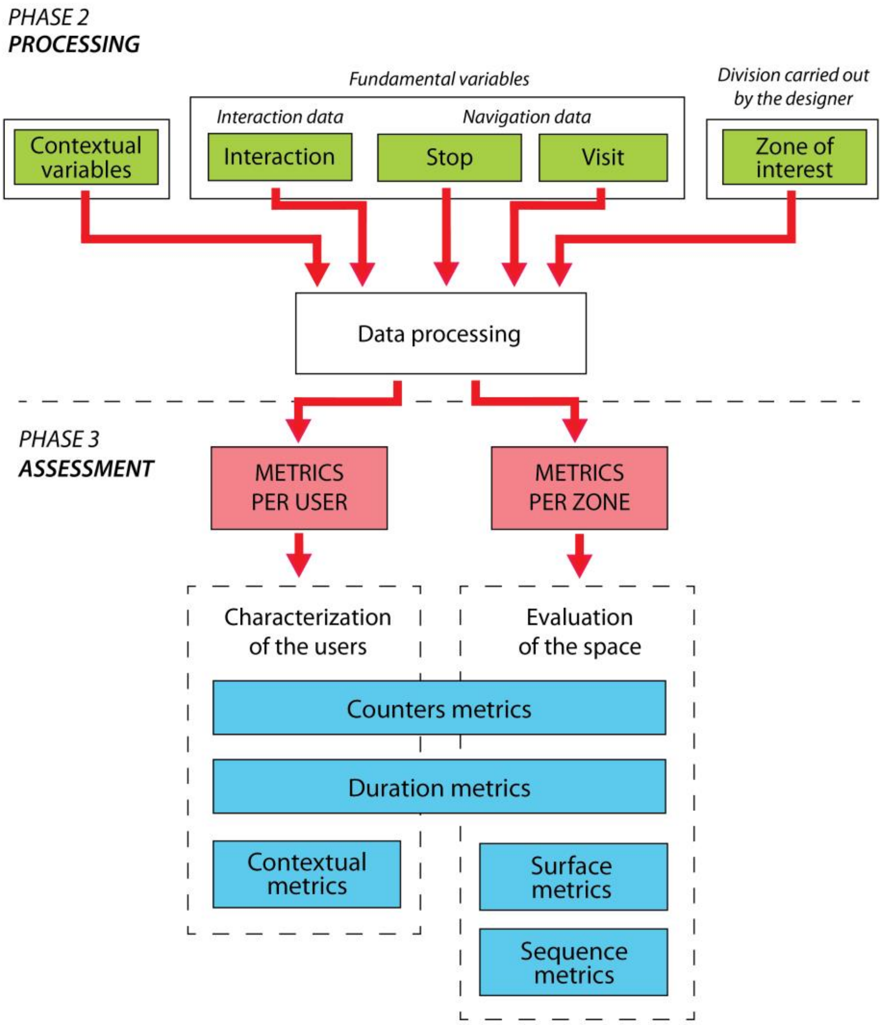

Figure 5: Diagram of the metric collection software.

2.4.2. Counter metrics

Within this block, we include the metrics referring to the number of times that a visit, a stop or an interaction is made. A distinction can be drawn between user metrics and zone metrics.

The **user** ones characterize the particular behaviour of one subject, for example, the number of visits made by user, the number of revisits, the percentage of visited zones, the average of stops or the total number of interactions made by each user. This information will be extremely valuable to assess how the sample has responded to space. For example, a high number of visits will indicate that the users have greatly explored the space.

On the other hand, the **zone** metrics define the behaviour of the fixed zones and they will be prominently used for the evaluation of the space. With them, we will be able to later assess the performance of each zone of the space, for example, through the number of visits to each zone, the percentage of people who has visited them, the number of stops per zone, the percentage of individuals who have been at standstill or the number of interactions in each zone. With these metrics, we will be able to analyse in detail the performance of each zone. If a zone has a high number of visits, but a low percentage of individuals who have been at standstill, this could be due to its good situation in space but its low interest for the user. On the contrary, a zone with few visits but with a high level of interactions would indicate a high performance but its accessibility should be improved.

In order to be able to analyse more precisely when visits, stops or interactions are carried out, these counters will also be exported assigning the time at which the action has been carried out so as to be able to analyse, for example, if the interactions are concentrated at the beginning or the end of a user's route and the ratio of visits or stops per hour.

2.4.3. Duration metrics

This block is focused on analysing the fundamental navigation variables, but taking into account its total duration. They can also be classified according to the user and the zone.

Within the **user** ones, we can find the average duration of a user's visits or the total time that he has been at standstill. With them, we will analyse the users' general behaviour, for example, if a lot of stops have been made but of short duration or few stops of long duration. The first case implies that the users have explored the space a lot, but they have not been really interested whereas the second one could be due to very selective users who make few stops but they have found interesting contents.

With the **zone** metrics, we evaluate the performance of each zone of the space. This will be explained with metrics such as the total duration of the visits in each zone, the percentage of time in revisiting or the total duration of the stops in the zone. They become central since, for example, a zone may have obtained a lot of visits but its total duration is very short because it is a transit area.

2.4.4. Other metrics

In this section, three new blocks are described: contextual, surface and sequence metrics.

Contextual metrics contain all the necessary information to characterize intrinsically the users. In general, this information is collected by means of surveys and it includes age, gender and other variables according to the project. The information referring to the environmental conditions such as humidity or luminosity is incorporated too. Finally, experimental variables associated to experimental conditions of the study are included, as for example, if the store had reduced prices.

Surface metrics include the main metrics within the counters and duration blocks, but weighted according to the surface of the zone. It is important to take into account that the zones can have a different surface, what can determine the difference on the final number of interactions. For this reason, performances per square metre will be analysed.

Sequence metrics analyze the order in which visits, stops and interactions have been carried out. With these data, we can observe the pattern followed by the users when moving and interacting with the space. The block will be of special relevance in the spaces where the designer wants to encourage specific routes, as in cultural exhibitions or stores like IKEA.

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3. CONCLUSIONS

The present work proposes the methodological basis of a technological platform which allows us to evaluate projects before their implementation. In order to do this, a sequence of metrics is defined using VR systems and HBT techniques so as to analyse and to evaluate human behaviour in the space taking into account three fundamental variables: visit, stop and interaction.

With this transversal contribution to different sectors, together with the foreseeable expansion of VR devices, a new window of opportunities is opened in the field of decision making, as we count on more information about the different alternatives, allowing us to choose the one which maximises performance, optimizing the functionality and the cost/benefit of the future space. The results will be of great interest for any kind of space which has as fundamental the flow of people, whether it is commercial, cultural, gastronomic or leisure.

This methodological basis poses different challenges that will be developed in future publications. Firstly, it is necessary to apply it to a specific case study to evaluate the scope of the technology, and to include visual exploration to the platform. Furthermore, it is necessary to analyse how the RV platform, the navigation metaphor and the simultaneous users through avatars influence the metrics. It is also important to improve and strengthen the stop detection algorithm, proposing a particular calibration for each platform and navigation metaphor and to continue increasing the metrics associated to each zone.

At the same time, two possible research lines are considered: combining this technology with neurophysiological signals and personality features to increase the understanding of human behaviour in the space and developing a final global metric able to evaluate in a global and quantitative way the performance of a space.

4. ACKNOWLEDGEMENTS

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