Virtual Tours and University Campuses: Proposal of a Model From the 360 Image and Photogrammetry in the age of Artificial Intelligence

Visitas virtuales y campus universitarios: Propuesta de un modelo a partir de la imagen 360 y la fotogrametría en la era de la Inteligencia Artificial

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Abstract

Traditionally, virtual tours that allow the user to visualise an environment have relied exclusively on one of the following methods: 360° photography and 3D restitution using laser scans or photogrammetry. Each of these methods has its own set of advantages and weaknesses. We propose a hybrid approach that offers the best of both worlds, designed specifically for use with head-mounted consumer virtual reality displays. Navigation has been one of the most important aspects of the app's development. The result is a natural, user-friendly virtual tour with improved navigation and high-quality images and videos. The model has been tested with a group of students with great results.

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Keywords

Augmented Reality. Technology. Journalism. Immersion.

Resumen

Tradicionalmente, las visitas virtuales que permiten al usuario visualizar un entorno se han basado exclusivamente en uno de los siguientes métodos: la fotografía de 360º y la restitución en 3D mediante escaneos láser o fotogrametría. Cada uno de estos métodos tiene su propio conjunto de ventajas y debilidades. Proponemos un enfoque híbrido que ofrece lo mejor de ambos mundos, diseñado específicamente para ser utilizado con pantallas de realidad virtual de consumo montadas en la cabeza. La navegación ha sido uno de los aspectos más importantes del desarrollo de la app. El resultado es una visita virtual natural y fácil de usar, con una mejor navegación e imágenes y vídeos de alta calidad. El modelo se ha probado con un grupo de estudiantes con grandes resultados.

Palabras clave

Realidad aumentada. Tecnología. Periodismo. Inmersión.

1. INTRODUCTION

We live in a technologised society in which, increasingly, the development of Artificial Intelligence is taking place globally, affecting all types of sectors. The field of communication is one of those that is taking most advantage of the benefits offered by technological progress, especially through virtual assistants and presenters developed for journalism because it allows many "possibilities to perfect, complete and complement the daily work of journalists" (Tejedor & Vila, 2021: 831). The media are gradually implementing AI-based technological tools. However, it is still in an "early stage of development" (Tejedor-Calvo et al., 2021:981).

Technology is seen as an ally, especially in the fight against disinformation through tools and strategies to mitigate its impact. Along these lines, studies are being developed, such as the project "IVERES: Identification, verification and response. El estado democrático ante el reto de la desinformación interesada" (PLEC2021-008176. Plan Estatal de Investigación Científica y técnica y de Innovación 2017-2020), carried out by Radio Televisión Española (RTVE) and the Autonomous University of Barcelona, which aims to develop an information verification system in Spanish against interested disinformation. The use of artificial intelligence in the field of communication is a step forward, above all, for automating complex or repetitive tasks in journalism. Automation is a challenge that "invites research, reflection and debate" to understand its application to journalism from an ethical perspective (Túñez & Tejedor, 2019: 166).

In recent years, academic research has been developed in the field of journalism and artificial intelligence. Tusa & Tejedor (2019) advocate expanding this research to consider AI as a "transversal discipline of public knowledge" (Tusa & Tejedor, 2019: 275). However, it is not only AI initiatives in communication and journalism that stand out. Since the home confinement due to Covid-19 and the restrictive measures derived from the pandemic have favoured the proliferation of projects and experiences of communication in cyberspace also from the level of leisure (Tejedor et al., 2020).

Virtual tours are a clear example of leisure projects in cyberspace. From monuments, cities, museums to natural enclaves, virtual tours of all kinds of places and destinations have been generated from image libraries, online videos, 360º content and other technological resources (Snow, 2020). Hatsune Miku, the virtual Japanese singer, has become a global trend for her "Hatsune Miku Expo 2020" tour that took her to London, Berlin, Paris, Amsterdam and Barcelona, among other places. This hologram is not the only one. The same technology resurrected Maria Callas at the London Coliseum 30 years after her death. For his part, James Dean, who died in 1955, will star in a film thanks to this digital development that has given life to Michael Jackson, Freddie Mercury or Tupac Shakur, among others. Virtuality has reached all areas of our life in its professional and daily facet (Cervi et al., 2020).

The Future Today Institute, in its report Trends Report for Entertainment, Media & Technology, has pointed out the importance and projection that Augmented Reality (AR) will have in the coming years, especially with the emergence of 5G technology (FTI – Future Today Institute, 2020). The development of a whole series of techniques that allow the reproduction of real scenarios from a distance has made it possible, from anywhere, a virtual visit to another place. The main techniques and approaches to this type of development go through two types of solutions. On the one hand, the technique of creating 360º photos has allowed a

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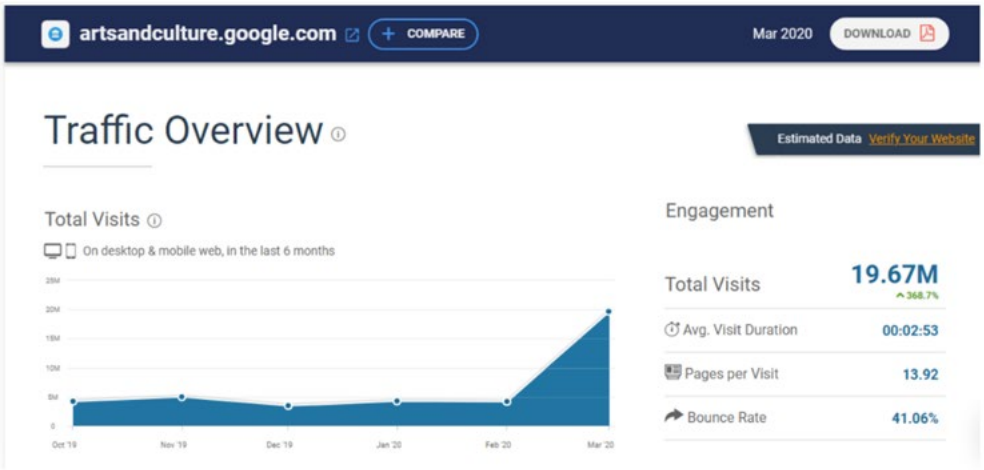
photorealistic quality, but limiting the virtual visit to a series of predefined locations. On the other, there are solutions based on photogrammetry or 3D space scanning.

Google's "artsandculture" platform (https://artsandculture.google.com/), which has the highest number of virtual visits to museums, indicates that, since March, a significant growth in its web traffic that had a global progression and by country. There is, therefore, an upward trend in so-called virtual visits or tours (see Fig. 1). The traditional format of these visits is based on the use of 360º photos and videos that can be viewed from the browser of a computer, mobile phone or other device connected to the Internet. It is the classic type of tour that, in the case of Google's "artsandculture" reaches more than 2,000 visits or tours to museums and other relevant monuments. Generally, it is a route to the museum rooms that usually incorporates wayfinding tools to support the user in their orientation and movement. This system uses arrows and hot spots. During the lockdown, a new virtual tour format has emerged that takes place on a live broadcast. Developed by the Pushkin Museum in Moscow, it is characterized by the fact that the visits are organized from 360 ° photos in groups (of 40 people for children and 80 for adults) that have a chat at their disposal to share doubts in real time (Grevtsova, 2020).

Figure 1. Data access to web 'artsandculture.google.com' during confinement



Source: data obtained from SimilarWeb.

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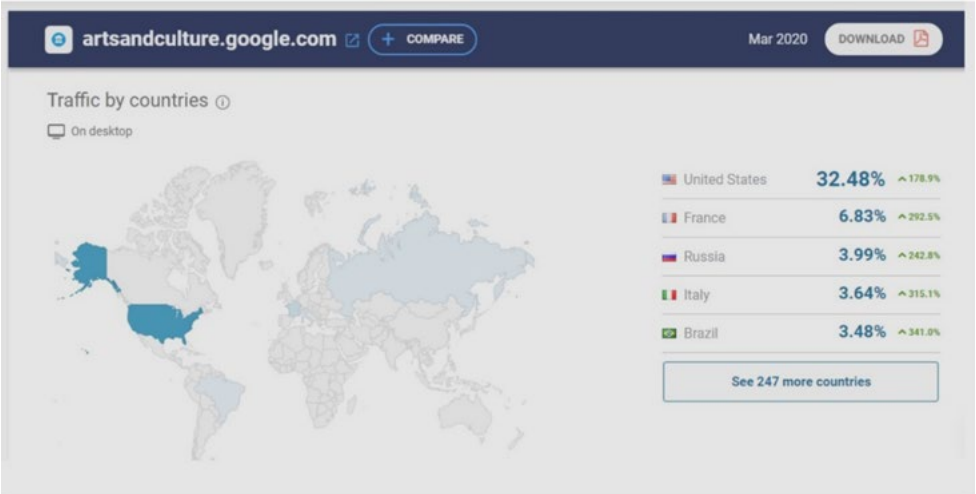
Figure 2. Data access to web 'artsandculture.google.com' by country during confinement



Source: data obtained from SimilarWeb.

Virtual tours as an object of study were introduced in 2002 by researchers from the University of Texas (USA) at a time when virtual tours were very new and limited by the scarce bandwidth and power of the computers of the time. After analyzing some experiences, always based on photography, the researchers concluded that the objective was to achieve a three-dimensional and immersive representation with photorealistic quality. The exposure and future projection of the authors is especially relevant:

> "Imagine a system that would allow visitors to experience a truly immersive 3D experience. Their experience would feel as if they were actually visiting the museum in person. A visitor to a new virtual museum could walk into a replica of the museum building and then select how halls might be configured based on previous exhibits. With a more advanced system, the museum patron could perform a metasearch on the collection (s) and have a virtual space tailored to their visit" (Jones & Christal, 2002).

Today, this objective has been achieved both when creating and visualizing these experiences, although under very specific conditions that prevent their popularization.

A framework for usability evaluations of websites that include virtual environments and follow Nielsen's (1993) recommendations for expert evaluation has been proposed by Sutcliffe and Gault (2004). Sylaiou et al. (2014), on the other hand, conclude that five quality criteria are required for evaluating virtual museums in general: "Imageability", "Interactivity", "Navigability", "Virtual Spatiality" and "Narration". However, the main problem that occurs with heuristic evaluation experiments, in general, is that all heuristics are equally important in the evaluation process. Therefore, the research question that occurs is how the heuristics could be combined in the evaluation process of museum virtual tours.

Based on the above, the research seeks to answer the following three research questions:

1. Is a hybrid virtual reality tour app that combines high quality 360º photography and video with a low-resolution 3D restitution feasible and practical?
2. Does the hybrid approach provide better navigation and orientation for the user compared to a 360º only solution?

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3. Does the hybrid approach improve on the visual quality and features such as 360º video compared to a 3D restitution only?

Objectives:

- Design and create a virtual reality tour app that allows the users to visualize an environment simultaneously through a series of 360º images and a low-resolution 3D model of the same environment obtained via 3D restitution.
- Test the ease of navigation on the virtual environment of the app with a group of students.
- Implement a system that combines both 360º photography and video seamlessly, so that both media types can be used to represent a point of view.

2. THEORETICAL BACKGROUND

Web-based virtual tour applications built with 360° panoramic images are widely used around the world. The main element of such a tour is a viewing window that the user can control. Another technological possibility is the use of augmented reality (AR), which is considered a tool with "great potential" to "give users a leading role" (Tejedor et al., 2020: 10).

Augmented human technologies" are one of the five emerging technology trends of 2020, according to the Gartner Hype Cycle for Emerging Technologies (Panetta, 2019). Since Milgram and Kishino built the concept of "virtual continuum", Augmented Reality has been a permanent object of study in recent years (Milgram & Kishino, 1994). Research and technological development have made the founding concept evolve towards three dimensions: virtual reality, augmented reality, and mixed reality. The first refers to artificial environments in which the user immerses himself as one more member of the same. For its part, augmented reality places artificial creations on a real environment. For its part, the mixed media offers an amalgam between created content, interactive holograms, and real scenarios. The works of the pioneering works of Azuma (2017) and Raskar et al. (1998), among others, inaugurated an explosion of research and publications on the representation of virtual visual information in real contexts. The works of Prendes (2015), Meneses and Martín (2015), Azuma (2015), Parra et al. (2017), Maquillón Sánchez et al. (2017), Montoya (2018), Benítez and Herrera (2018), Webb (2018; 2019), Maña et al. (2020) or Tejedor et al. (2020), among others, have delved into the potentialities, especially communicative, of these augmented technologies.

The possibilities of 360º communication have been studied by different authors who, such as De la Peña et al. (2019), Domínguez (2012; 2015), Kool (2016), Guizzo da Rocha (2016), Aronson-Rath et al. (2017) or Vaz and Tejedor (2019), have investigated the new journalistic formats and possibilities that derive from the process of convergence between technology and communication. Immersion as a narrative resource has also been investigated from different approaches, highlighting the studies by Vázquez-Herrero and López-García (2016), Pérez-Seijo (2017) and Watson (2017).

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Interactive virtual tours improve the visual presentation and spatial understanding of the place being visited. Day by day, providing such tours is becoming crucial for the websites that present a place having visual importance. It is also an effective tool for advertising the galleries, shopping centers etc. Therefore, evaluating the usability of these virtual tours is meaningful and findings are important to designers of similar applications.

The realization of a virtual tour has been based on two predominant processes. The most widely used approach, due to its quality, low bandwidth, and ease of creation, consists of taking 360º photos and videos, using 360º cameras, creating panoramic images with a traditional camera or using sets of simultaneous photographs with multiple cameras (known as a rig). 360º photography tours are a type of virtual visit widely used due to their relative ease of creation, good visual quality and contained size (Koehl et al., 2013). The other approach is technically superior, but it is more expensive and requires much higher bandwidth consumption. It involves the realization of a 3D model of the space to be recreated, either through the use of 3D laser scanner techniques, photogrammetric restitution from multiple photographs or a combination of both techniques (Pulcrano et al., 2019). This technology, in addition to allowing a three-dimensional recreation of the environment through which users can move, has many other uses such as documentation, restoration and conservation of architectural heritage. Having an accurate 3D model of a building is an invaluable tool that offers far more possibilities than a collection of panoramic photographs. For example, after the Notre Dame de Paris cathedral fire on April 15, 2019, the precise and detailed 3D model made by Professor Andrew Tallon using laser scanning techniques was of great help in the reconstruction (Tallon, 2013).

In the university environment, there are different experiences that have opted for Virtual Reality (VR) such as the project of the University of Seville (Spain) or UDIMA (Distance University of Madrid, Spain) in Second Life (see Fig. 3) or the commitment of the Universidad del Desarrollo de Concepción (Chile) for Augmented Reality (AR) through a project based on 360º photography (see Fig. 4).

Figure 3. Universidad de Sevilla (Spain) project at Second Life

Source: Universidad de Sevilla.

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Figure 4. Universidad del Desarrollo de Concepción (Chile) Project

Source: Universidad del Desarrollo de Concepción (Chile).

3. METHODS

Based on these findings, the possible solutions were defined. For functional requirements, a virtual campus tour that is based off panoramic videos were selected as the technology to be used because it offers dynamic 360 degree experience while watching it, as compared to traditional photo-stitching based virtual tour.

Usability issues of these virtual tours are hardly studied. Villanueva et al. (2004) performed a study with virtual tours using 360º panoramic photos, which they call photorealistic virtual environments. They investigated the proper usability evaluation methodology for this kind of application. Two qualitative methods are compared: think-aloud protocol and heuristics. Their conclusion was that think-aloud protocol is more convenient. They also proposed to group the usability issues into four categories: Functionality, Interaction, Appearance and extra Comments/Suggestions by the user. Pinhanez et al. (2001) conducted research for design concerns of web tour interfaces. They worked with cultural information tours rather than spatial navigation tours. They proposed to design those kinds of applications with a "less clicking, more watching" approach.

This research takes as a case study the Autonomous University of Barcelona (Spain) with the aim of taking a virtual tour of its campus. The research, developed over 12 months of work, has generated a proposal for a hybrid solution, conceived to try to overcome the limitations inherent in each of the two techniques most applied in the development of virtual tours (visit based on 360 photography and Photogrammetry). The generated prototype is specifically designed to be experienced through Virtual Reality viewers. It is based on the simultaneous use of images and 360 video with a 3D model of the UAB campus, made using

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photogrammetry with a low medium level of detail, which is shown to the user as a scale model of approximately 2 by 3 meters. It has been developed using the Unity development environment, one of the most widely used for creating interactive 3D experiences in real time.

3.1. Tool development and adaptation

In May 2019 Oculus launched the Oculus Quest, a mobile device with all the advantages of connected headsets. It was a 6 degrees of freedom system with motion controllers that included 4 cameras for inside-out tracking and its own CPU, memory and graphics processor. All this, together with a very affordable price compared to other proposals, turned this viewer into a Virtual Reality device for all audiences. In this way, the rebirth of Virtual Reality initiated by the Oculus Rift in 2013 was confirmed (Saker & Frith, 2020).

Oculus Quest is probably the most versatile Virtual Reality platform in existence at the time of writing this article, and the constant updates it has received represent improvements so important that, in fact, it has de facto replaced the rest of the brand's viewers: the possibility of connecting the Quests to a PC via a USB C cable and using them as an HMD connected very similar to the Oculus Rift S, and more recently hand tracking through image recognition based on machine learning, which allows the use of the HMD without controllers , only by gesture control. Obtaining a simple and intuitive user experience that this work has pursued has been based on this tool.

Gesture control of Virtual Reality was introduced through the Leap Motion sensor in 2014, a peripheral equipped with infrared cameras that allows highly accurate monitoring of the position and gestures of the user's hands. This sensor has been used with great success in visualization projects such as the one carried out at the Archaeological Museum of Milan in 2015 (Gonizzi Barsanti et al., 2015). In this study, the authors mentioned the main advantages of gesture-based control: an almost zero learning curve, a very high level of immersion, and a precise and intuitive control system. They also commented on the limitations they found with the use of such hardware, mainly the complexity of the configuration process. Added to this was the limitation of having two devices (the Oculus Rift DK2 viewer and the Leap Motion controller) connected to a personal computer using two cables.

This set of limitations is overcome by integrating gesture control into the Oculus Quest hardware itself, allowing simple and natural gesture control. The control of the application was based on a single, very simple gesture that represents the main selection system in the Quest hand tracking system: the "pinch" or pinch gesture, that is, bringing the thumb and index finger together:

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Figure 5. Photogrammetric 3D Model of the UAB Campus

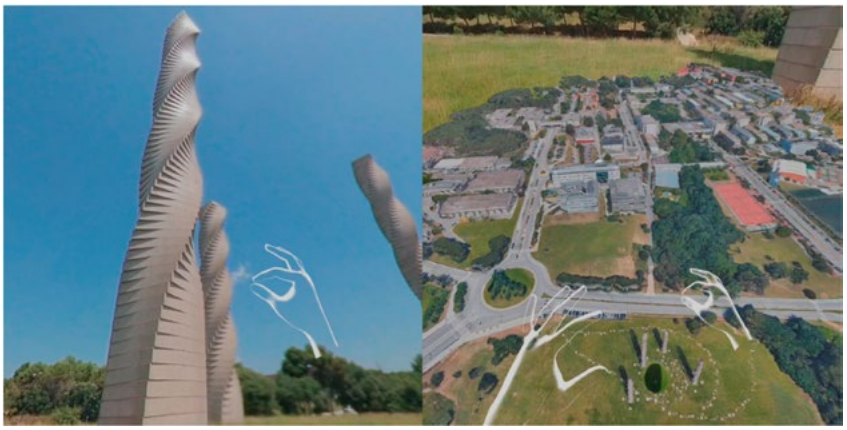
Source: elaborated by the authors.

Regarding the hardware used, it was decided to use the Oculus Quest Virtual Reality viewer. Since the irruption of the first commercial Virtual Reality devices, two types of devices have been consolidated. On the one hand, the high-quality ones, with six degrees of freedom and designed to be connected to a PC or other device that performs the calculation and representation of the experience. On the other, mobile devices, in which the technical characteristics were limited, generally conditioning the tracking of movement to three degrees of freedom.

4. RESULTS AND DISCUSSION

In this way, as we mentioned, it is possible to create an experience that includes the main advantages of both approaches: on the one hand, a simple-scale 3D model, with a reduced level of detail and file size, which provides a clear sense of the user's location at all times and represents a reference point at all times; and on the other hand, a series of images and 360 video of great quality and realism, which surround the user with the real environment of the visit.

Figure 6. 360 viewpoints represented on the three-dimensional model



Source: elaborated by the authors.

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In test phase, a heuristic evaluation was done with experts to evaluate the features and functionality of the system, in which they can check the system whether it is perfectly functioning based on requirement and design specifications. This evaluation is important to ensure that the system works effectively and smoothly. Five experts participated in evaluating the system. The experts were university lecturers who have 10 to 25 years of professional experience in the computer science field. Heuristic evaluation contains several criteria that need to be evaluated by the experts. The criteria are visibility of system status, match between system and real world, user control and freedom, consistency and standard, flexibility and minimalist design, aesthetic and minimalist design, help and documentation, and error control. Each criteria can be rated using 5-point Likert Scale ranging from Strongly Disagree (1) to Strongly Agree (5).

The research has made it possible to identify a series of criteria to evaluate the pros and cons of the two virtual tour creation methodologies used. Regarding the technical difficulty in data collection, in the case of 360º photography a few years ago it was essential to use specialized equipment such as reflex cameras and panoramic heads. This aspect meant a great investment in time and money and required the collaboration of experts. Today the process has been greatly simplified thanks to the existence of a large catalog of compact 360º cameras, which allow the panoramic view to be captured automatically with a single shot in a matter of seconds and with hardly any prior knowledge required (Reddy & Ghouse, 2017). In contrast, photogrammetric restitution remains an enormously complex process that involves the use of multiple technological equipment of high complexity and price. For example, laser scanners or, recently, the use of drones for aerial photography. These requirements demand the participation of specialized technicians.

360º photography allows access to suitable equipment at affordable prices. The collection and processing of data is practically instantaneous. This aspect means that for many projects in which cost is a limitation, 360 photography is used Napolitano et al. (2017). In contrast, both the taking of photogrammetric data and the processing of said data until obtaining a three-dimensional model that can be used in a realistic virtual visit, are slow and complex processes with an enormous number of phases. Among them: the cleaning of the data, the virtual alignment of the points of view used for each of the photographs, the creation of the cloud of millions of points and its simplification, the triangulation of the faces to obtain a surface constant and texturing of the 3D model from the photographs taken, among others. All this involves a huge amount of human work that, in most cases, has to present a highly specialized profile. In addition, it implies a high number of hours on the part of the computer equipment (Evagorou et al., 2019).

When it comes to image quality, 360º photography is also superior, although with a significant limitation. 360º photography has, in general, a very high level of quality as long as the photographic equipment used is correct. If there are no artifacts that degrade the visual quality, this technique is totally realistic. It is, in short, a photographic copy of reality. The only potential limitation is resolution. Nowadays, rigs or automatic 360º cameras are usually used for their ease of use and speed, but traditionally 360º panoramas were made by joining multiple photographs (stitching). In fact, currently, if the union is done properly, it is the solution that provides the highest quality and resolution (Aznoora et al., 2009).

The quality of a 360º photo is generally superior in realism to that of a 3D scan. It is also potentially unlimited. With the sufficient number of photographs it would be possible

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to achieve a practically perfect quality in most situations. In fact, the resolution of a photographic panorama is exponential, as has been shown in photographs of more than one billion pixels of resolution (gigapixel images), using automatic photo-taking equipment (Kopf et al., 2007).

This increase in the resolution of the panoramic image comes at the cost of exponentially increasing the weight of the files. In general terms, comparing examples with an equivalent level of resolution, the file size is much smaller in solutions based on 360º photography. This aspect is logical, since photogrammetric restitution stores visual information (textures) and spatial information (three-dimensional meshes). In addition, it should be noted that, in the three-dimensional model, the image information must be uniform from all points of view, which greatly increases the number and size of the necessary textures. Therefore, a photogrammetric restitution generally occupies much more than a 360º tour, so the download time increases considerably (Wessels et al., 2014).

With regard to progressive loading, that is, the minimum download necessary for the user to start the virtual visit, 360º photography also has an important advantage: the content is clearly divided into independent units (the 360 photographs themselves). This element has multiple advantages. On the one hand, downloading the first image is enough to start the visit with high quality, while the rest of the images are downloaded in the background. On the other hand, if the user decides to jump to any other point of view, the download can be interrupted in the background and, instead, quickly downloaded that particular point. All this is not possible in a photogrammetric restitution, at least a priori, because all or a good part of the 3D model must be downloaded to start the visit. Although there are solutions, such as downloading the three-dimensional model in parts or resorting to multiple models of variable resolution, the study allows us to point out that a 360º photo tour has an initial load much faster than a photogrammetric restitution (Bonacini, 2015).

There is one more advantage that we must point out in the case of the 360º image. Both the panoramic cameras that we currently have, as well as numerous video services, allow the creation and distribution of photographs, but also 360º video. Like traditional video, 360º video represents a huge quantum leap from photography. In addition, it allows you to add much more information and offer a much more complete experience (Benítez de Gracia & Damas, 2018). The possibilities are virtually limitless, as many as those offered by traditional film and video formats. They range from showing an environment including sound to incorporating real people, performances, conversations, and so on. In the case of 3D scanning, incorporating video is not generally possible, although it can be partially incorporated. For example, in the form of a person engraved on a chroma background or on a screen. However, these solutions do not have as much quality or possibilities as a 360º video.

Research has established that in many aspects tours based on 360º photography are superior to 3D restitution (capture time, processing time, size, etc.). However, there is an advantage in photogrammetric restitution that is fundamental: the possibility of changing our point of view which, especially in Virtual Reality (VR), provides a deep sense of immersion far superior to that of 360º photography. This is, along with its value as a document and measurement tool, the main advantage of photogrammetry. It is a scanned three-dimensional space that allows the user to walk through it, crouch down to look at a detail or perceive the depth of objects. It provides a feeling of immersive realism far superior to that of a 360 photograph,

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limiting the user to a single position and giving a very unnatural feeling in a VR experience when the user moves their head and does not perceive any change in the image (Shults et al., 2019).

In this sense, navigation is also an important advantage for 3D models obtained from photogrammetry or laser scanning: navigation is continuous. The user can, with the right VR hardware, literally walk through the virtual model, teleport to different locations, or even fly from one location to another. All this is also produced in a continuous way, without jumps and from a more natural perception. With enough data collection, the quality can be practically indistinguishable from reality, as demonstrated by the "Replica" study conducted by Facebook researchers (Straub et al., 2019).

360º photography, on the other hand, uses a collection of fixed points, with high quality, but without the possibility for the user to navigate beyond the preset points of view (Mazzoleni et al., 2006). These jumps are not always continuous or obvious, giving the user a momentary sense of confusion when moving from one point to another. This aspect, however, is solved in many virtual tours with a list of the points that can be visited or with a location map. It is an effective solution so that the user can orient himself, but still presents abruptness in the passage from one point to another. The previous reflections are summarized in the following table:

Table 1. Synthesis

Attribute	Image	Photogramettry
Data collection operator	Minimum training	Expert
Data collection speed	Quick (minutes)	Very slow (hours)
Processing speed	Quick (minutes)	Very slow (hours and days)
Image quality	Always very high	Depending on the viewpoint
Data volume	Low (only image) High (Image + Video 360)	Very High (3D Model, textures)
Starting downloading	Low (First image, streaming video)	High (Model low resolution)
Video compabilty	Yes	Partially
Presence	Good	Excellent
Free movement	No	Yes

Source: elaborated by the authors.

5. CONCLUSION

As has been pointed out, the two most used solutions for virtual visits (360º photography and 3D restitution) have advantages and disadvantages. After experimenting and analyzing both solutions in the pilot experience developed on the UAB campus, we propose a solution

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that combines the advantages of both methods and minimizes their drawbacks. It is about combining 360º photography and video with a polygonal 3D model. The proposal consists of using a 3D scale model of the space to be visited that serves, on the one hand, as a virtual model with valuable information about the space to be visited and, at the same time, that acts as a reference system to locate in it the positions of the photographs and 3D videos made.

Regarding the navigation method, the team experimented with multiple solutions, including being able to interact at different points to show 360º photos. This system worked well, but did not take advantage of the possibilities of movement around the stage. Finally, a combination of two possibilities was chosen: that of interacting at different points and that of walking through the virtual model through a system that detects and displays the closest panorama at any time. The main characteristics of this approach are the following:

1. Maximum quality and realism in 360º image.
2. Ease of data acquisition and processing.
3. Support for both photography and 360 video.
4. Smooth transition between positions, providing a sense of continuity.
5. Possibility of viewing the set to visit in model mode.
6. Ability to preview panoramic images.
7. Simple 3D model to make, adaptable to any space.
8. Minimum size of the 3D model. Virtually instant initial download.

The research also concludes that there is a need for academia to carry out more studies and research into the development of artificial intelligence in the communication and education sectors. This will help to identify more possibilities for implementation from different perspectives.

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