Investigaciones
Geográficas
Interuniversity Institute of Geography
University of Alicante
ISSN: 0213-4691 | eISSN: 1989-9890
https://www.investigacionesgeograficas.com

Landscape through graphic representation: Augmented Reality as a tool for interpretation

El paisaje a través de la representación gráfica: la Realidad Aumentada como herramienta de interpretación

AUTHORSHIP

Felipe Fernández García
ARPE-Observatorio del Territorio Accredited Research Group. Department of Geography. University of Oviedo. Spain.

Daniel Herrera Arenas
ARPE-Observatorio del Territorio Accredited Research Group. Department of Geography. University of Oviedo. Spain.

Juan Sevilla Álvarez
ARPE-Observatorio del Territorio Accredited Research Group. Department of Geography. University of Oviedo. Spain.

DOI
https://doi.org/10.14198/INGEO.25511

CITATION
Fernández García, F., Herrera Arenas, D., & Sevilla Álvarez, J. (2024). Landscape through graphic representation: Augmented Reality as a tool for interpretation. *Investigaciones Geográficas*, (81), 33-50. https://doi.org/10.14198/INGEO.25511

CORRESPONDENCE
Juan Sevilla Álvarez (sevillajuan@uniovi.es)

HISTORY
Received: 2 July 2023
Accepted: 31 December 2023
Published: 26 January 2024

TERMS
© Felipe Fernández García, Daniel Herrera Arenas and Juan Sevilla Álvarez

This work is published under a license Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International

Abstract

Within a sociocultural context where visual components are becoming increasingly important and new technologies are spreading, geography must adapt to new demands, avoid trivialization in the use of images, and approach the task of creating graphic elements based on an effective and rigorous transmission of knowledge. Considering Augmented Reality as an advantageous technology due to the interactive, self-guided and dynamic nature of its tools, this research seeks to prove its effectiveness and determine the main benefits derived from its application in the representation of landscapes. The methodology takes as its starting point basic graphic materials, most of which are already known in landscape studies. Procedures based on new computer techniques are applied to these materials in order to obtain digital resources compatible with Augmented Reality and Virtual Reality. These resources can be integrated into more complex tools that help explain the composition and dynamics of landscapes. Thus, the figures presented in this article are accompanied by a web link and also incorporate a hyperlink, so that by clicking on them, the aforementioned resources are accessed. And those figures with the Observatorio del Territorio (OT) logo are image markers in themselves that allow Augmented Reality content to be opened on devices. The results are obtained by testing various forms of multimedia representation in the context of an R&D project with application in various urban, rural and natural areas of the Principality of Asturias. These are hosted on the server of the Observatorio del Territorio at the University of Oviedo. The conclusions indicate the beneficial use of dynamic sequences (animations, sliders…) for a better understanding of diachronic changes; the interactive third dimension for the representation of complex elements; or the general added value of combining information on media (audio, video, 360° panoramas, etc.) in the understanding of shapes and structures.

Keywords: landscape representation; Geographical Information Technologies (GIT); emerging tools; Augmented Reality; territorial culture; landscape awareness.

Resumen

En un contexto sociocultural donde los componentes visuales cobran cada vez más importancia y las nuevas tecnologías se difunden, la Geografía debe adaptarse a las nuevas exigencias, evitar la banalización en el uso de las imágenes y abordar la tarea de crear elementos gráficos que permitan una transmisión eficaz y rigurosa del conocimiento. Considerando la Realidad Aumentada como una tecnología ventajosa por el carácter interactivo, auto-guiado y dinámico de sus herramientas, esta investigación tiene como objetivo probar su efectividad y mostrar los principales beneficios derivados de su aplicación en la representación del paisaje. La metodología toma como punto de partida materiales gráficos de base, la mayor parte de los cuales son ya conocidos en los estudios del paisaje. Sobre estos materiales se aplican procedimientos basados en nuevas técnicas informáticas que permiten obtener recursos digitales compatibles con la Realidad Aumentada y la Realidad Virtual. Estos recursos pueden ser integrados en herramientas más complejas que ayudan a explicar la composición y dinámica de los paisajes. Así, las figuras presentadas en este artículo se acompañan de un enlace web e incorporan, además, un hipervínculo, de manera que al hacer clic sobre ellas se accede a los recursos mencionados. Aquellas figuras con el logo del Observatorio del Territorio (OT) constituyen marcadores de imagen en sí mismos que permiten abrir contenidos de Realidad Aumentada en los dispositivos. Los resultados provienen de probar varias formas de representación multimedia en el contexto de un proyecto de I+D con aplicación en diversas áreas urbanas, rurales y de dominante natural del Principado de Asturias. Estos se alojan en el servidor del Observatorio del Territorio de la Universidad de Oviedo. Las conclusiones subrayan el uso beneficioso de secuencias dinámicas (animaciones, comparadores de fechas con cortinilla deslizante...) para una mejor comprensión de los cambios; la tercera dimensión interactiva para la representación de elementos complejos; o el valor añadido general de combinar información de soportes (audio, vídeo, panorámicas 360º, etc.) en la comprensión de formas y estructuras.

Palabras clave: representación del paisaje; Tecnologías de la Información Geográfica (TIG); herramientas emergentes; Realidad Aumentada; cultura territorial; conciencia paisajística.

1. Introduction

The development and application of tools based on new technologies (Information and Communication Technologies) is becoming a resource with an extraordinary capacity to transmit information. Within these new technologies, Augmented Reality, understood as the combination of virtual elements in the real world, begins to be used in more and more areas such as Geography. In this sense, landscape studies constitute a field of great interest for a wide range of users, going from individuals, with the simple aspiration of enjoying landscapes or understanding the basic linked processes, to professionals, who need to know their composition and evolution in detail to carry out tasks related to their research and technical activities.

In a society with an overexposure to the visual (Mirzoeff, 2003), geography must avoid the trivialization in the use of images, giving them the importance that they deserve in the tasks of creation/selection of graphic elements, as a key to the academic process. In this process, it is essential to understand that "the production of any image involves tasks of a conceptual, technical and aesthetic order" (Hollman, 2008, 2016). In this sense, the visual perception lays the groundwork of concept formation (Arnheim, 1997). Therefore, the elaboration of graphic representations constitutes a fundamental mission within geographical science to which special attention should be paid, so that we can take advantage of all the opportunities that visual ability offers to improve teaching and research (Thornes, 2004). The development of Geovisualizacion, as result of linking cartography and scientific visualization (Dodge et al., 2008), increase the possibilities of geographical representations so they can be interactive, immersive and three-dimensional. In fact, it provides many Augmented Reality and Virtual reality possibilities to be exploited (Kraak 2020; Ortag 2012).

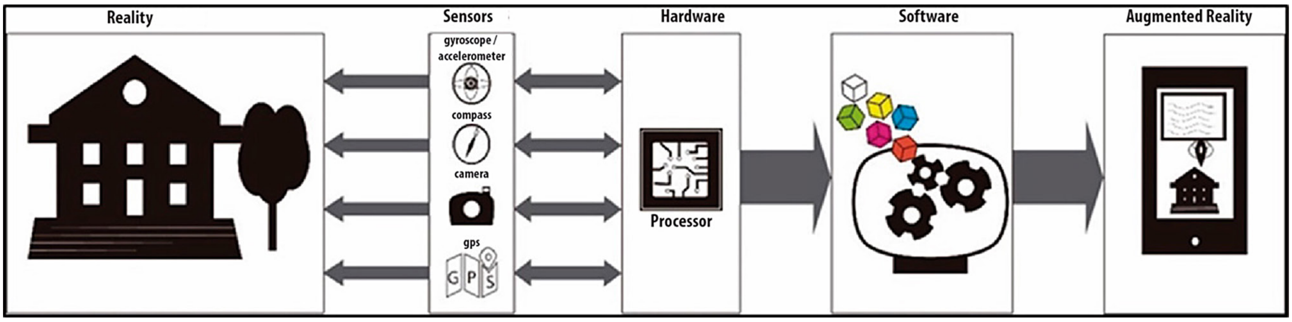
The combination of formats, the use of multimedia materials and three-dimensional elements, and interactivity constitute facts within today's society. Therefore, these are new communication formulas to be assumed, just as other representation techniques were incorporated in the past as a result of technological advances (Geographic Information Systems, automated mapping, etc.). However, it is necessary to adapt the visual language to the target audience and their new communication channels. Hence, application design based on Augmented Reality is among the technologies to test in order to offer new experiences of understanding the composition and transformations of landscape by digital information through devices. So tools can be downloaded and ran on mobile devices which are widely used, such as tablets or smartphones, allowing the combination of real and virtual elements through the use of markers, or by geopositioning, and benefiting from sensors available in these devices: GPS, cameras, compasses, gyroscopes, accelerometers, etc.

Faced with Virtual Reality technologies (whose spatial context is constructed with computerized procedures), this work opts for Augmented Reality to obtain advantages from the visualization of elements of the real world, either directly or indirectly, in combination with superimposed virtual elements through the use of devices (Carbonell

Carrera & Bermejo Asensio 2017a, 2017b; Chang et al., 2010; Cobo and Moravec, 2011). We wish to facilitate integrated knowledge, combining the environment of reality with enriching digital information in real time through the use of technological platforms that favour learning and understanding of concepts and processes.

Augmented Reality requires at least 4 components (Kipper & Rampolla, 2013) that make possible to combine digital resources on a real image or element: on the one hand, the sensors that allow to capture data from the environment and the position of the device (camera, gyroscope, accelerometer, compass, GPS ...); second, a system for storing and processing information; third, a software that combines the information; and, finally, a display device, either the device's own screen or others such as the Head Mounted Display type (HMD) (Figure 1). In order for the augmented virtual information to be activated on the display device, a marker is required to trigger the digital resources. Then, taking into account a utility linked to the explanation of landscape, texts, images, animations, videos, audios, 3D elements and links to applications or external resources, etc. constitute basic elements to enrich information.

Figure 1. Components of Augmented Reality



Source: Olay Varillas et al. (2019)

Due to the speed at which these technologies evolve, it is difficult to establish a classification that encompasses all the varieties and possibilities. However, we can use the one established by Lens-Fitzgeral (2009) in which four types of Augmented Reality (Peddie, 2017) are differentiated according to interactivity, complexity and the type of activator. They indeed have distinct advantages for landscape experiences.

The first type is based on hyperlinks activated by barcodes or QR (Quick Response) markers detected by the sensor (camera), this type being characterized by low interactivity, since its function is limited to linking to a website where the extended information is hosted. Such triggers are useful because of their widespread use, especially in outdoor environments, but they have the disadvantage of weak integration between digital and real elements.

The second type is based on the use of image markers or 3D objects, the activation also being carried out by the sensor; this type implies a greater degree of interaction, since there is a link between the activator and the virtual information integrated and superimposed on reality[1]. They are particularly useful to complement the information available in brochures or printed items, but they could require a specific application or webAR.

In the third type, markers are not used, but the activation is carried out with various sensors integrated in mobile devices (GPS, compass, accelerometer, gyroscope ...). It may present difficulties depending on the sensitivity and precision of the devices, but it allows for self-guidance in open spaces, offering additional information based on the user's position. By means of these activators it is possible to carry out itineraries in which the explanation is directly linked to our position so it is therefore spatially contextualised.

There is a fourth type in which Augmented Reality no longer depends on a screen but it becomes an immersive vision through glasses or other HMD devices (*Head Mounted Display*). However, this type is not sufficiently developed today to offer comfort and safety in open spaces and therefore the use in explaining landscape does not seem relevant to us.

These types can be used in a complementary way integrating them in the same application. For example, in the case of designing a route or itinerary (Sánchez Verdú et al., 2014) where it is included: a guide (in a digital or paper format) that would contain markers; the location of QR codes or image markers through posts or beacons that would serve as links to high-capacity alphanumeric information; and, finally, geolocation (through geopositioning or activated by beacons) that would grant access to information at certain points along the route.

1 The quality of the image that triggers Augmented Reality as a marker is important. Quality implies not only a good resolution, but also aspects such as contrast, the number of lines, changes in texture, etc. Thus, the more visual details a marker has, the better its performance.

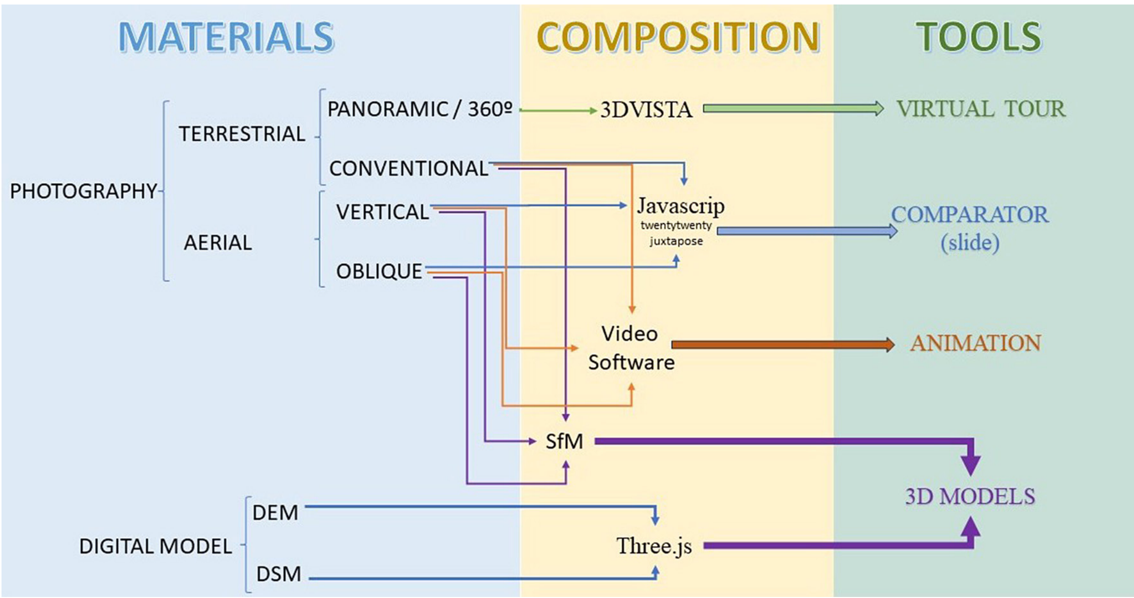
All these characteristics making Augmented Reality a tool with significant potential in the field of Geography, however it is necessary "that future research also provide a better knowledge for its effective application" (Akçayır & Akçayır, 2017; Chiang et al., 2014; Cheng & Tsai, 2013; Falk & Chatel 2017). Some authors have analysed the possibilities of Augmented Reality especially in the educational field. In most cases, their studies have proposed applications for specific purposes in Geography teaching: composition of specific itineraries for understanding the evolution of landscapes (Sánchez Verdú et al., 2014), 360º images for experience locations (Prisille & Ellerbrake, 2020; Stojšić et al., 2016) or three-dimensional models to improve learners' orientation skills and understanding of structures (Carbonell Carrera & Bermejo Asensio, 2017a; Pratama et al., 2021). Besides, Stintzing et al. (2020) have tested gamified environmental experiences using an Augmented Reality geo-localised application.

Based on this research axis, our work proposes the following hypothesis: the interactive, auto-guided and dynamic character of Augmented Reality tools is beneficial for representing the distinctive features of landscapes due to the nature of the source materials, the form of activation and the dynamic effects (Damala et al., 2008; Marques et al., 2019); it facilitates the interpretation of forms and structures as well as shows their dynamics, underlining the diachronic dimension, by showing the action over time of the underlying natural and human processes. This vision underlined in our work is related to the postulates of the European Landscape Convention (signed in Florence, 2000), which has been of vital importance for the approach, understanding and enjoyment of landscapes by the population. Landscape analysis must matter as an object of interest in the learning process about geographical space and its cultural values (Alomar-Garau & Gómez Sotano, 2022; Olcina Cantos et al., 2022); what Ortega y Gasset (1906) expressively called landscape pedagogy, being present in the fields of humanities, social sciences or the environment (Busquets, 2010; García, 2011; Hernández 2010; Liceras, 2013). Consequently, the objective of the research is designing and proving the effectiveness of a repertoire of tools that could articulate landscape interpretation experiences. It is estimated that these tools could support an increase in effectiveness related to the visual component or interactivity due to more direct and intuitive intervention; note those cases with greater possibilities of handling by including buttons and labels that trigger other processes with pop-up information. They are conceived to obtain information that is not accessible with the same immediacy in other media formats (Eve, 2012).

2. Methodology

The methodology of our research is based on conceiving the sequence materials - techniques – applications (Figure 2). It involves the detailed and in-depth knowledge of the characteristics of materials or sources that can be used. Likewise, attention is paid to the adaptation of representation forms in order to achieve the most of the capabilities provided by new graphic techniques. Besides, interest is directed to the conception of applications in which the interpretation of landscapes is adapted to the media and demands of current users.

Figure 2. Workflow scheme showing procedure for composition of tools based on Augmented Reality



Own elaboration

2.1. The choice of graphic materials

There are many graphic materials that can be used for the development of Augmented Reality applications. As it has been pointed out previously, the options have been multiplying (videos, audios, photographs, maps, three-dimensional models, diagram blocks, etc.); however, the focus here is on the use of photography and the creation of slider comparators, three-dimensional models and virtual tours[2], trying to illustrate their importance as geographic documents and how to use them as Augmented Reality resources.

Terrestrial photography was early in countries such as France or the United States, where the method of repeated photography was used to analyse transformations in landscape[3]; a task that French foresters began at the end of the 19th century, and which North American researchers continued from the sixties of the last century (Carré & Metailié, 2008; Rogers & Malde, 1984). The use of terrestrial photography in Spanish geography has, on the contrary, been late and less systematic, which has surely had to do with the fact that the available photographic collections were not abundant until recent years. And its usefulness in the analysis of the dynamics of landscapes contrasts, however, with their limited application. They do allow in many cases to make diachronic analyses, using the method of repeated photography (Carré & Metailié, 2008). In this method, while not keeping exactly the same point of view between the contrasting images, they show the perspectives of the same landscape at different dates, with very interesting results when a good photo interpretation task is done.

As for the aerial photography, whose origin dates back to the central years of the 19th century, its true documentary value is reached from the moment in which flights are carried out systematically and with coverage of wide sectors of the territory. This means that, in the photographic archives, public and private, there is an important volume of vertical and oblique aerial images for working with the techniques of photointerpretation (Fernández García, 1998; Fernández García & Quirós Linares, 1997).

For the use of vertical aerial images in the historical analysis of the landscape, it is convenient to identify the temporal perspective with which the analysis is going to be made. On the one hand, there are aerial images to analyse those processes that were developed before the birth of aerial photography, but that have left some mark on the landscape and, therefore, can be recognized and interpreted in the photographs or, at least, in a part of them; and, on the other hand, we can distinguish the images that illustrate “contemporary” historical processes, those that were developed over the last decades and, therefore, are documented photographically in their different stages of evolution.

Oblique aerial photographs, old or new, are another interesting material in photointerpretation tasks, as well as an important complement to vertical aerial photography. Oblique aerial imaging had a great development in the early days of air navigation (both in the ballooning stage and in the early stages of aviation). Afterwards, oblique views have been taken throughout the 20th century (although to a lesser extent than vertical aerial photographs). In this way, there are photographic archives, also public and private, that have extremely useful content for studies of landscapes and their dynamics.

Another kind of base materials are 3 dimensional models. Among these, there are Digital Elevation Models (DEM) and Digital Surface Models (DSM), specially those provided by the Spanish National Geographic Institute-CNIG (models with different resolutions, ranging from 200 to 2 meters mesh, being also possible to have 2x2 km Lidar data, with a density of 0.5 points per square meter, with which very precise digital models can be elaborated). On the other hand, there are photogrammetric models obtained from ground and/or aerial photography.

2.2. Composing dynamic figures

One of our main methodological purposes has been the integration of photography in new processes that improve graphic quality and generate new forms of dynamic and interactive representation. However, these new forms of representation also have certain requirements.

2 Although it is closer to what we know as Virtual Reality, we use it because the virtual tour can be deployed using Augmented Reality technology, with markers or positioning. And it is a suitable complement to other graphic resources.

3 As opposed to repeated photography, for which a reliable methodological support is available (Carré & Metailié, 2008), and which essentially consists of the use of historical terrestrial photographs from archives and current photographs taken expressly from a point of view as close as possible to the old photo, comparative photography is considered to be the procedure consisting of making a comparison between aerial, vertical or oblique photographs taken on different dates, obtained in all cases in photo libraries.

Regarding a first type of composite tools, that of comparators (Figures 3 and 4), historical photographs can be used to create series. Traditionally, the analysis of photographs was done by contrasting one with the other in the form of a static image. Today, devices allow us to compare more than two images dynamically and interactively. However, it is necessary to eliminate the deformations of the photographs (due to the type of projection, among other aspects), obtaining rectified historical images or historical orthophotomaps. Thus, it is feasible to insert them into Geographic Information Systems (GIS) and combine and compare them with the series of recent and current orthoimages.

When using aerial photography, a difficulty derives from the fact that, in order to have current images with the same point of view as the historical ones, it is necessary to perform specific flights for this purpose. This involves very high costs, which can only be reduced in some cases by using Unmanned Aerial Vehicles (Commonly known as DRONES). However, in some areas it is not possible to use these vehicles; which is why we have explored the possibility of resorting to the Google Earth three-dimensional visualization system. In this case, by superimposing on the historical photograph, the aim is to obtain the current image with the same point of view, with which to generate animations (Figure 5).

In the case of oblique aerial photography and terrestrial photography, the level of precision in the overlay is lower. This is because the adjustment process has to be done manually, looking for the same framing and point of view to obtain a current replica of the historical photograph. Once we have two or more photographs with the same framing, by adapting a Javascrip[4], it is possible to superimpose and integrate the images in a comparator. For repeated photography, regarding the technical part, it does not differ, in essence, from that already mentioned for the elaboration of comparators with vertical or oblique aerial photography (Figure 6).

Another technique implemented has been the construction of block diagrams, since it interests to provide interactivity when manipulating three-dimensional models. GIS software has incorporated tools for the analysis and visualization of these models in 2.5 D or 3D. Thus, QuantumGis allows these models to be viewed and exported for publication on the web, thanks to a specific plug-in that converts the model into a web page, compatible with any browser that supports WebGL, using a Javascrip library called Three.js. Additionally, it is possible to export in GLTF format which constitutes an 3D element. This model can also be exported and uploaded to the sketchfab platform, where it is possible to configure its display, incorporate views, images, explanations and audios. It is also compatible with Virtual Reality vision glasses.

Besides, the Structure from Motion (SfM) algorithms that are used for the elaboration of historical orthophotomaps have other applications, among which is the elaboration of three-dimensional photogrammetric models obtained from ground photography and/or aerial photography taken from unmanned vehicles. In this case, it is necessary to carry out a total photographic coating of the study area, and with a high percentage of overlap between consecutive photographs. It will be precisely such overlapping of the photographs that will allow the software to calculate the position of the camera and its orientation, as well as the geometry and 3D structure of the object[5]. The final result is a three-dimensional photogrammetric model with photographic texture, which can be shared through online platforms such as sketchfab or directly in specific Virtual Reality or Augmented Reality software (Figure 7).

Another form of representation has to do with the capacity of 360° cameras to achieve a sensation of immersion, that is to say, to generate the feeling of being inside the photograph. In virtual tours we are not limited to a single point of view or framing but to a spherical view where incorporating a wide range of explanatory elements is possible. To develop virtual tours based on 360° spherical photos or 360° panoramas, free software available on the Internet can be used, such as Kuula, which is easy to use; or professional software (we use 3D-Vista), which offer much more possibilities (Figure 11), but whose handling, on the other hand, requires a specific learning process.

3. Results. Landscape analysis with Augmented Reality Tools

Regarding the activation of the tools, access to Augmented Reality in this paper can be done in different ways: in the case of desktops and laptops, by using the web link at the bottom of the figure; and for mobile devices (tablets and smartphones), by using the icon, downloading the Observatorio del Territorio app (https://observatoriodelterritorio.onirix.com/daabb928ea9b4c519285e9f5ffb4966a), enabling "unknown sources" and

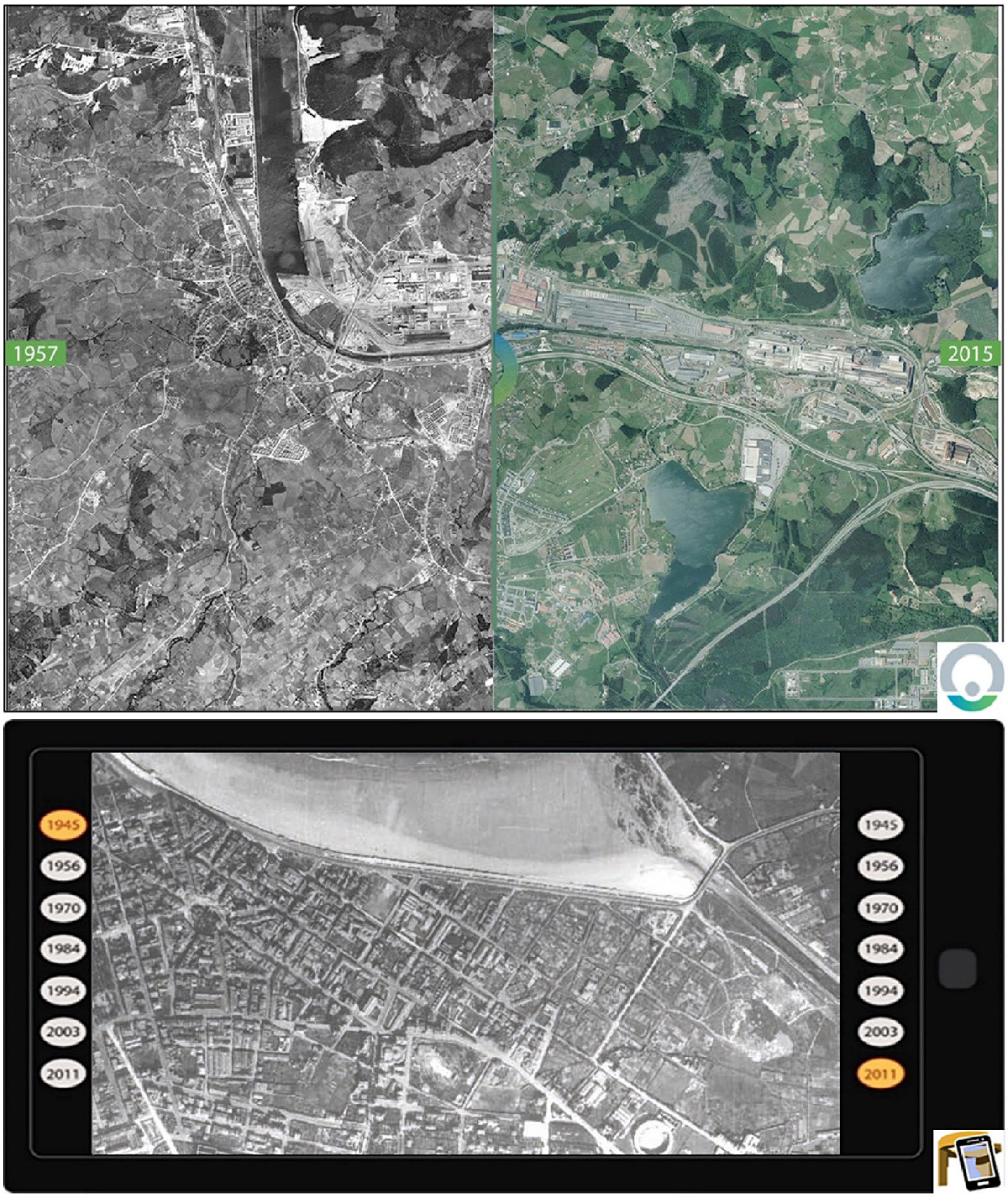
4 JuxtaposeJS or TwentyTwenty are examples of these java libraries that allow to program these comparators. It can even be done automatically in https://juxtapose.knightlab.com/

5 The use of targets to align the photographs is also of great help. At the same time, they will serve as control points to scale and geolocate the model.

selecting “LandscapeGraphics” (once the app has started, it is necessary to scan the figure with the marker so that Augmented Reality is activated). Or by using the icon , downloading the Gijón Aumentado app in Google Play and scanning the corresponding figure. But it should be marked that tools in this research could be integrated in various ways to deploy an Augmented Reality experience. the same element can be used with different levels: QR codes activatable on site, real objects as markers, or geopositioning.

Using historical photography collections, we have firstly developed a simple Augmented Reality tool aimed at allowing the user to see the transformations suffered by a landscape; all this through the comparison between aerial photographs taken on two different dates. By dividing the screen into two halves and having buttons referring to the dates in each of them, it allows the user to choose the corresponding image to make the comparison. In this way, the transformations that occurred in a previously defined time interval can be observed. Comparison is facilitated by a sliding touch curtain (Figure 3).

Figure 3. Examples of aerial photography comparators. Above, Avilés (1956-2011); down, Gijón (1945, 1956, 1970, 1984, 1994, 2003 and 2011)



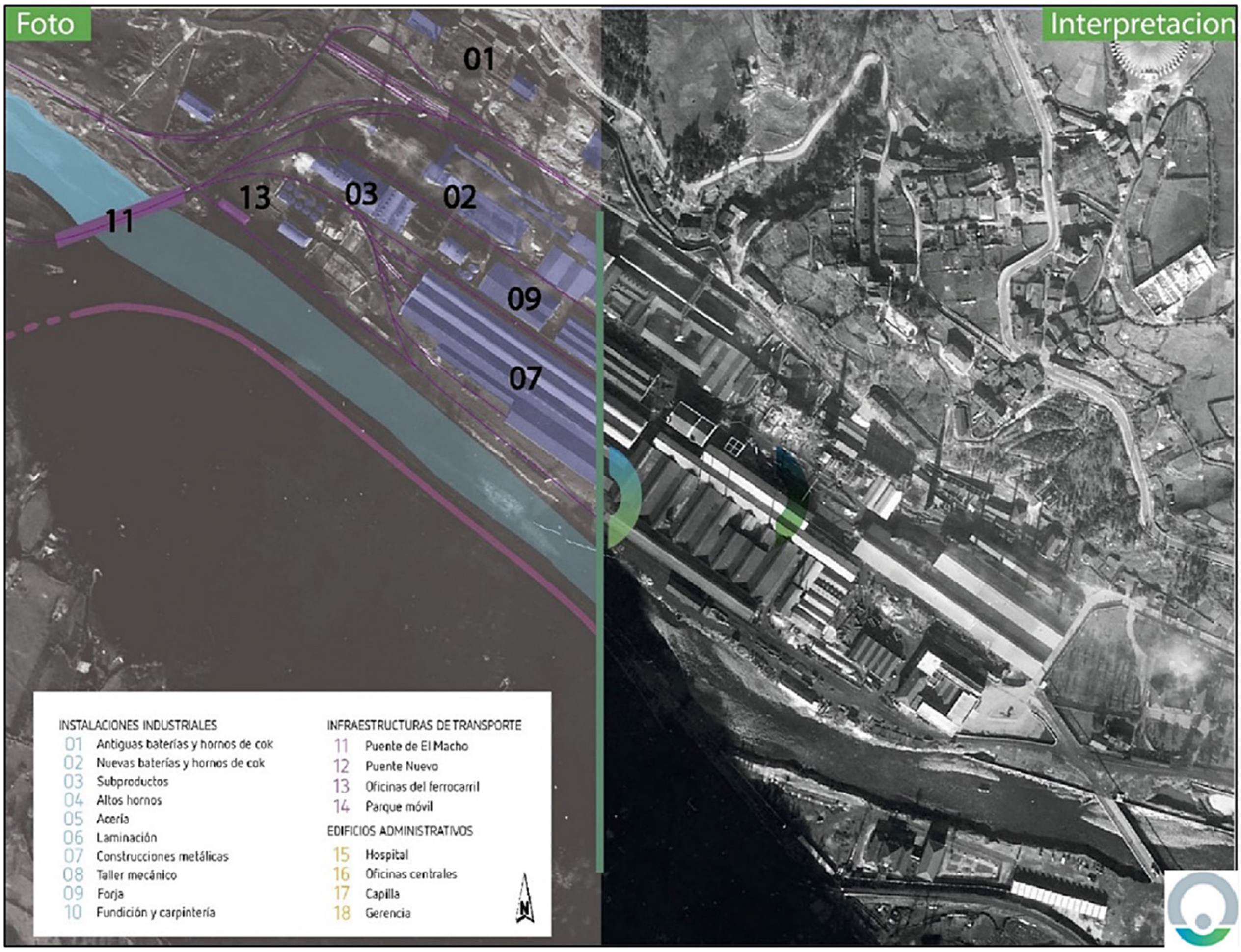
Own elaboration. Available at: Observatorio del Territorio (Avilés) and Gijón Aumentado.
Una guía del Gijón histórico basada en técnicas de Realidad Aumentada http://www.observatoriodelterritorio.es/expo/urbe3/aviles.html

A variant of this would be oriented to the exploitation of oblique, both historical and current aerial photography, on which to carry out works of location, identification and analysis of the structural elements of landscape.

The results that can be obtained are more satisfactory when vertical aerial photography is used to document the landscape transformations that took place throughout the 20th century, especially those that occurred in the second half, or during the last two decades. On the other hand, oblique images can be used in landscape studies, both in the timeless aspect and in the analysis of their dynamics; but the best results are achieved when they are used simultaneously and in addition to vertical aerial photographs and cartography. In fact, oblique aerial photography offers us a view of the surface elements that is more familiar to us and, consequently, interpretation tasks are substantially facilitated. However, despite the general overview that they provide, it is still true that interpretation is sometimes limited by the perspective of oblique vision; then the complementary use of oblique photographs with verticals and maps promotes a better understanding of landscape organization.

As it has been exposed, this way of combining graphic materials to compose dynamic images allows an interesting reading of inherited landscapes. This will be more fruitful the greater the knowledge of the historical processes that shaped landscapes (Figure 4). The repertoire of phenomena that can be studied using aerial photography is considerable, by analysing the morphology, structure and use of different elements that make up the landscape. The logic of some of these elements can be found in past historical contexts and they have endured, fossilized in the landscape, even changing their use but keeping its shape. It is possible to link some with the Roman era (parcels, roads, mining, etc.), to the medieval period (abandoned urban settlements, roads, cattle ravines, hydraulic works, parcels ...), to the modern age (canals and irrigation works, dams, breakages, maritime ports ...) or to the 19th and first half of the 20th centuries (hydraulic works, ports, airfields and airports, railways and roads, mining, industrialization, etc.).

Figure 4. Photointerpretation work using a comparator (slide). In the image, the missing nineteenth-century steel factory Fábrica de Mieres, located on the right bank of the Caudal River



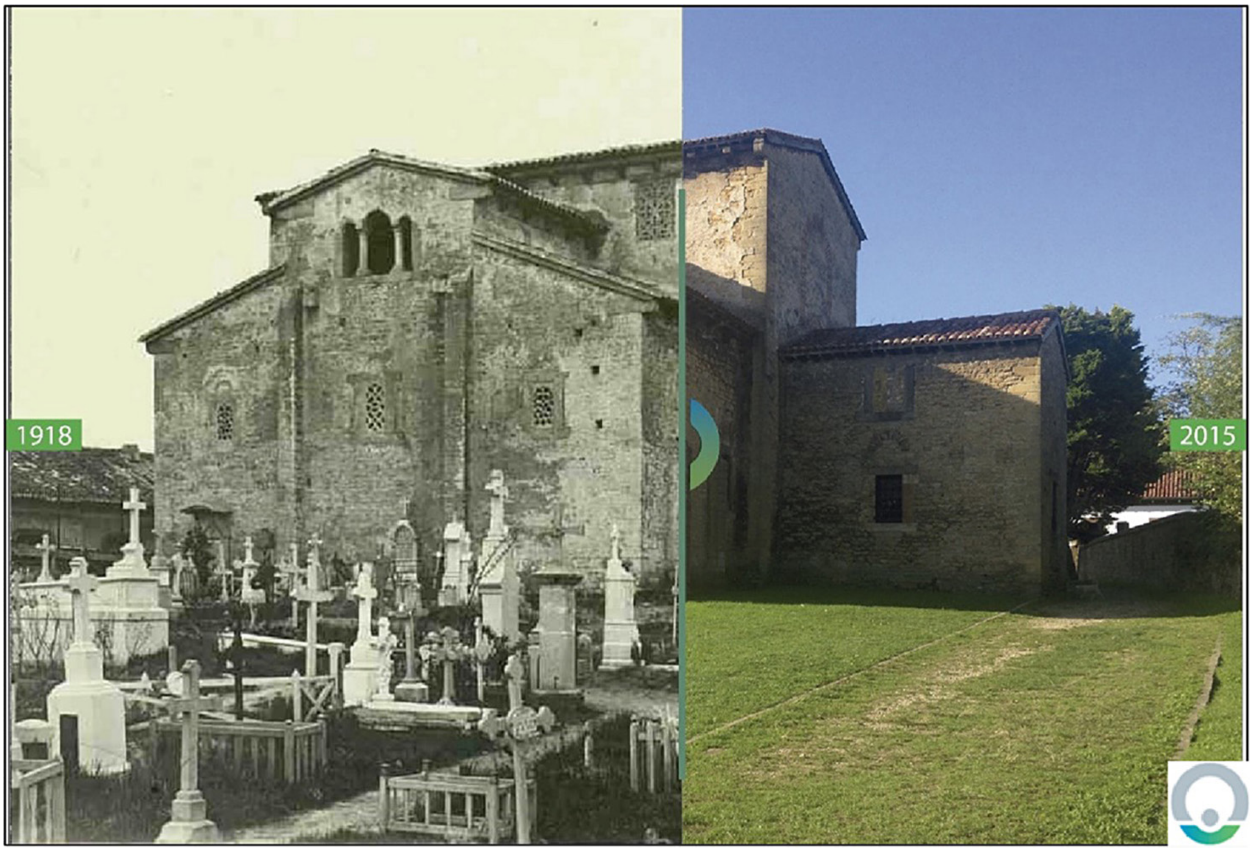
Source: Asturias Railway Museum (the image) and own elaboration (photointerpretation) http://www.observatoriodelterritorio.es/rarv/foto/fabrica.html

Figure 5. Avilés, sequence of oblique aerial images

Own elaboration. Available at: Observatorio del Territorio http://www.observatoriodelterritorio.es/expo/urbe3/img/intro.gif

Repeated photography can also help to understand landscape transformations when they are not perceptible in other graphic representations, such as cartographic ones (Figure 6). Following the methodological proposal by Carré and Metailié (2008) and experiences accumulated so far[6], our tool tries to systematize the process of making the repeated photograph, basing it on the location of the historical images that can be used and, secondly, on exposing the current image from the same, or similar, point of view and angle.

Figure 6. Terrestrial photograph comparator by using slide: Santullano Pre-Romanesque Church, Oviedo (1918, 2018)

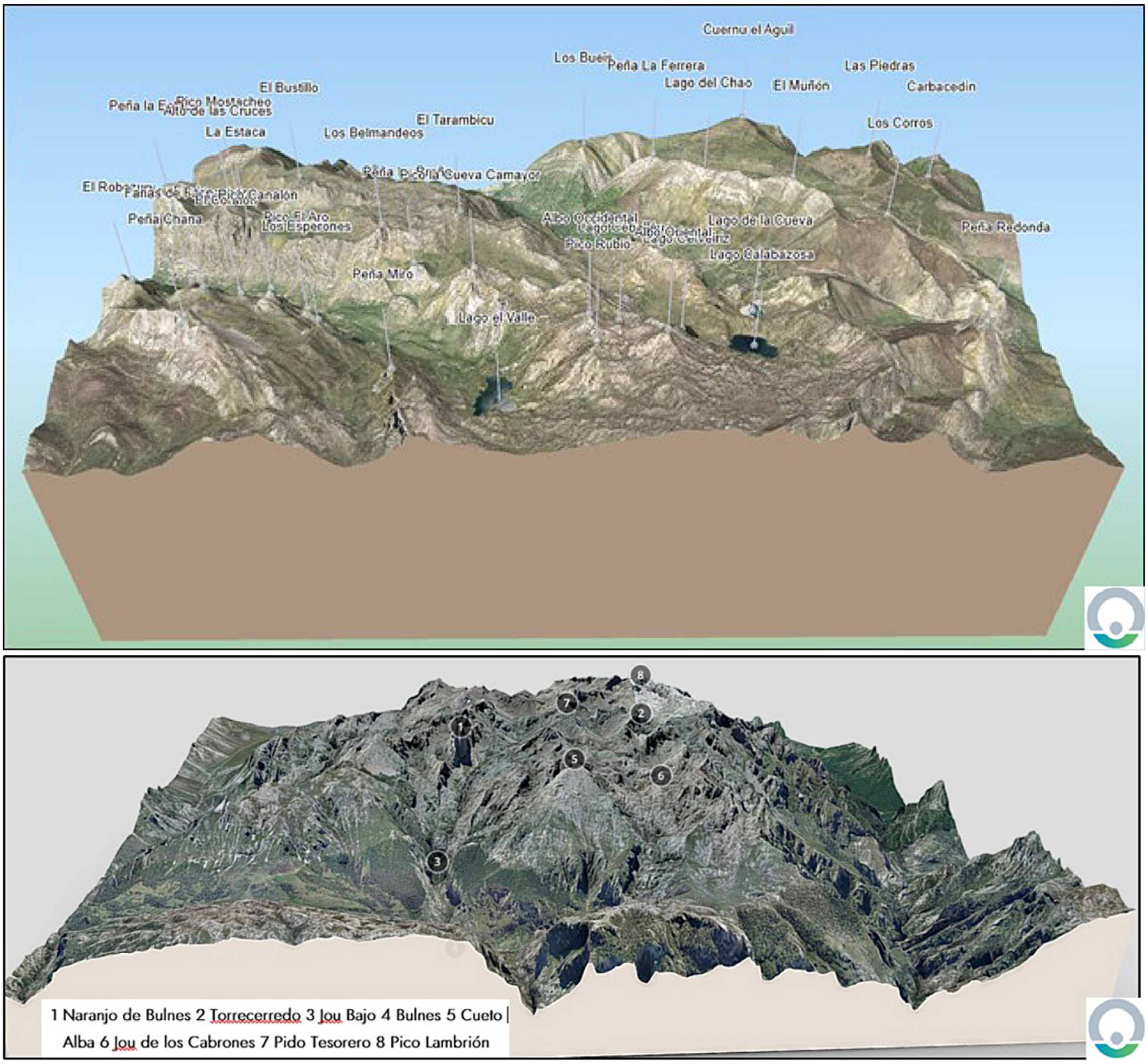


Own elaboration. Available at: Observatorio del Territorio http://www.observatoriodelterritorio.es/expo/urbe2/Prerromanico/SanJulian2.html

Among the tools designed, there are also three-dimensional blocks (Figure 7), which have a long tradition in geographic analysis, particularly in the field of physical geography. They also offer new possibilities for the study of landscapes in their digital and interactive aspects, and constitute an Augmented Reality resource with singular utility when rotating is possible to recognize forms and structures from different angles (Carbonell Carrera & Bermejo Asensio, 2017a; Priestnall, 2009).

6 Notable in this regard are the French experiences of L 'Observatoire Photographique du Paysage, the Parc National des Pyrénées, or L'Observatoire Homme-Milieu Pyrénées Haut Vicdessos; as well as the work carried out by the Andalusian Landscapes Observatory and Archive (OAPA) (González Díaz, 2019).

Figure 7. Above, three-dimensional block of the Somiedo Lakes (Asturias);
below, photogrammetric block of the Picos de Europa (Asturias-Cantabria-León) made with sketchfab



Own elaboration. Available at: Observatorio del Territorio. http://www.observatoriodelterritorio.es/expo/modelos3d/hipsometrico2.html and https://sketchfab.com/3d-models/picos-de-europa-39226cfef18d4ef3851c8f40e7bcaf0a

Through the combined use of the tools exposed in the previous section, it is possible to perform landscape analysis with Augmented Reality as an element that provides added value to geographic analysis. This combination is very effective in the preparation of publications (research or dissemination articles, tourist brochures, educational guides, books) in which, by incorporating markers (QR codes and image markers), the reader can trigger actions of Augmented Reality: animations, comparators, 3D blocks, three-dimensional models, audios, videos, etc. that complement the explanations or add information (Figures 8 and 9).

Another option, with similar results, is the elaboration of itineraries supported by plans or maps with markers, in which, as in the previous assumption, it is the QR codes or image markers that allow the user to access the Augmented Reality actions (Figure 10).

Itineraries based on markers located on the routes have similar characteristics: these markers can be QR codes and image markers installed on panels along the route; or be made up of landscape elements (when the mobile device detects them, they trigger the Augmented Reality elements). Furthemore, the combination of Augmented Reality resources can be based on the geolocation of the pre-set points of interest (POI) in which the dynamic components should be triggered.

Figure 8. Didactic brochure with Gijón urban history[7]

Own elaboration. Available at: Observatorio del Territorio (Fernández García et al., 2018). Download the PDF brochure http://www.observatoriodelterritorio.es/wp-content/uploads/2018/06/GijonAumentado.pdf or the mobile app https://play.google.com/store/apps/details?id=org.fundacionctic.GijonAumentado

Figure 9. Example of the use of image markers in the educational brochure that collects the urban history of Gijón

Own elaboration. Available at: Observatorio del Territorio http://www.observatoriodelterritorio.es/wp-content/uploads/2018/06/GijonAumentado.pdf

7 The Gijón Augmentado proposal arises from an agreement with the city council and Fundación CTIC for the preparation of a mobile application (Android system) and a guide brochure. These were conceived for the dissemination of knowledge of the Gijón urban landscape with a tourist and educational purpose, through the multimedia explanation of its fundamental pieces, including heritage assets. The user only needs a copy of the guide booklet and download the app from the operating system's virtual store to start the interactive experience. The emerging and dynamic graphic resources that house the "augmented" textual and graphic information (animations, sliders, 3D blocks, etc.) are displayed when the camera is focused on the brochure images, once the mobile application is opened. It also contains a virtual tour composed of a combination of spherical photographs which are nourished by additional materials (historical photographs, documents, audios…).

Figure 10. Didactic-tourist map showing a tour in Gijón's historic centre

Own elaboration. Available at: Observatorio del Territorio. Download the PDF plan http://www.observatoriodelterritorio.es/wp-content/uploads/2020/04/PlanoItinerio_Gijon_r.pdf or the mobile app https://play.google.com/store/apps/details?id=org.fundacionctic.GijonAumentado

Figure 11. Avilés virtual tour generated by using 3dVista

Own elaboration. Available at: Observatorio del territorio http://www.observatoriodelterritorio.es/rarv/aviles/

Finally, virtual itineraries made up of 360° spherical photos or 360° panoramas (both indoor and outdoor spaces) are based on the relationship between Points of Interest (POI), as landmarks in scenic viewpoints (Figure 11). In each POI, all relevant "augmented" information is linked.

4. Discussion

Learning to observe and interpret landscapes is relevant since the territory, and the values it treasures, constitute an essential area for the construction of a solid citizenship, in relation to cultural learning and awareness with the environment; and this, taking the analysis and valuation of landscape to meet the foundations of a renewed management of territorial heritage (Gómez, 2013; Martínez de Pisón, 2010). In this sense, it is relevant not only institutional expert-based approaches but also local (place-based), participatory and inclusive ones (Dakin, 2003; Marques et al., 2019).

The interest in landscapes from various areas of society as educational, research, cultural, social, even health (McIntosh et al., 2019) stands as one of the main objectives to be achieved, in such a way that it contributes to its maintenance and conservation, as well as to the increase of social awareness towards heritage. Thus, the efforts in this research have been directed towards the development of tools that stimulate the approach, knowledge and enjoyment of landscape by a wider public in several activities (tourism, common leisure, environmental education, etc.); but also, for those who may be interested in the study and analysis of its dynamics in higher education, research or spatial planning.

As noted above, in a society where the visual component is becoming increasingly important, in which new technologies are spreading and the spatial dimension has come to occupy an essential place, technologies have great potential to facilitate the interpretation of landscape dynamics from an innovative perspective (Squire, 2010; Olay Varillas et al., 2019) different from traditional methods. In this context, the incorporation of Augmented Reality acquires interest as long as it represents a new step in the process of continuous adaptation between forms of representation / valuation and technical advances. It must be taken into account that in a situation of constant technological evolution, proposals for the transmission of knowledge have to adapt to the new needs and habits of society (Prensky, 2001; Ramón, 2017; Fernández García & Herrera Arenas, 2022).

Although there has been much debate about whether Geography is a visual discipline (Driver, 2003; Thornes, 2004; Lois, 2009) or not (Rose, 2003, 2016), the importance of the representation of landscapes as demonstrated in this work seems clear. Indeed, geographers have endeavoured to represent the territory and explain the landscape through various procedures that involve a process of synthesis or abstraction. Of these procedures, the difficulty of representing reality in a static and two-dimensional format must be appreciated, as well as the value of semiology for setting the bases for the legibility of graphic representations (with principles mainly established by Jacques Bertin at the end of the 60s of last century). In addition, we must consider the ability of geographical science to incorporate new techniques that have made it possible to fine-tune new representation variables adapted to new demands, from Humboldt's paintings of nature, to the early introduction of photography (Garrido et al., 2016), both terrestrial and aerial; or the irruption of Geographic Information Systems (Moya et al., 2012) without neglecting the semiological rigor. On this line, this work has intended to give way to more intuitive visualizations in which the new expectations of 21st century users are present, such as interaction, dynamic character, autoguiding and multitemporal representation. It is understandable that due to these new user demands, the role of virtual and augmented realities takes on special relevance (Çöltekin et al., 2020). Virtual and augmented realities technologies offer us the possibility of including new forms of representation which, in combination with the classic ones, can update the way of presenting and modelling geographic information about processes, forms, structures…. Thus, our research contributes to these tools being perceived as suitable for a new dynamic way of knowledge transmission and dissemination of scientific content.

Despite the fact that these techniques have not been sufficiently treated from academic Geography (Bos, 2021), Augmented Reality techniques, besides the Virtual Reality ones, allow the incorporation of 360º integrated views, three-dimensional and interactive elements (Bos et al., 2022; Carrera et al., 2018; Delgado Peña, 2017) which help a more complete understanding of landscapes and some of their most prominent components, as exposed in this research. Moreover, they facilitate new possibilities in the consideration of the temporal dimension, a key point to explain the dynamism of landscapes; and, finally, they allow the insertion of complementary information that has no place in the classic representations of landscapes. Hence the interest in conceiving formulas for the use of Augmented Reality to progress in a field of knowledge with high socio-cultural, economic and environmental interest. In this sense, the main challenge has been to achieve more or less complex combinations of texts and various graphic materials in figures with dynamic effects and emerging elements. Hence the need to delve deeper into the balance between communicative efficiency of geographical information and technological possibilities; and to make this line of studies evolve, continuous testing of existing and future computer programs is necessary. This suggestive tool can be especially suitable as long as it is correctly supported by the technological pillars (appropriate and accessible technical solutions) and the contents (scientific quality, correct formats, adapted knowledge level) so that it is effective for users (Olay Varillas et al., 2019; Beato et al., 2020). In this vein, some academic and scientific works linked to our project or others have included RA and RV for landscape representation with the purpose that governs our research (Ghadirian & Bishop, 2008; Carbonell Carrera & Bermejo Asensio, 2017a; Martínez-Graña et al. 2017; Delgado Álvarez, 2022; Beato et al., 2020; Marino et al., 2021; Rodrigues et al., 2018; Stintzing et al., 2020).

5. Conclusions

The research has led to reflection on a set of tools composed and used in educational, tourist and research contexts and disseminated in scientific meetings or publications. The results of these works have encouraged us to consolidate some proposals with materials already used in geography, such as photography or digital models, but applying new representation techniques (until now these did not have a wide place in the classic publication media). These proposals offer new possibilities for the study of landscapes and for the dissemination of their characteristics. The gear of this triad, materials, techniques and applications, through current Augmented Reality technology opens a new path that allows new ways of approaching landscape knowledge by researchers and teaching staff (and also by other kind of public: technical staff in public entities, tourist agents…).

This sequence of materials-techniques-applications must be based on a rigorous geographical and landscape analysis and on careful exposition or didactic planning. Only in this way can appropriate and quality content be conceived. In any case, it is possible to conclude that approaching the study of landscape with the use of Augmented Reality techniques will mean an improvement in the understanding of the evolution and configuration processes of landscapes due, among other things, to the possibilities of interaction and dynamism.

Undoubtedly, the visual and graphic component have always played a very important role in geography, opening in recent years a certain debate about the weight that this component should have. The results of this research show that the graphic treatment of information, as a source of analysis, or as a result of research, has had, and should continue to have, a really important weight in geographical science. In this sense, Augmented Reality can offer the possibility of incorporating new formats and applications to research. And it can become a powerful tool for the transmission of knowledge. To do this, it is necessary to develop and adapt geographic content to materials suitable for new modes of communication.

Finally, the use of the Augmented Reality techniques does not imply a physical distancing from the study object. On the contrary, direct contact with study areas and with landscapes, through field trips and excursions, may preserve a fundamental weight. Augmented Reality, far from replacing them, can be an enriching complement, capable of providing new content that is superimposed on reality, thus contributing to ubiquitous interpretation and learning. To achieve these advantages, it is necessary to focus the effort on the prior step of treating graphic materials and designing tools that will contribute to enrich experiences. It is about elements that can be activated in situ in a way that another type of media cannot make; what allows a greater degree of self-guide.

The development of more advanced and complex graphic resources combining a greater variety of audiovisual and textual materials is a challenge to take into account in the future development of this research axe. Furthermore, given the vigor with which geographic information technologies are evolving, other challenges may be directed towards the generation of fully virtual itineraries for a greater expansion of non-face-to-face landscape experiences. Indeed, for situations where traveling and observation *in situ* are not possible, we pose the challenge of taking Virtual Reality techniques in the immediate future studies, following Griffon et al. (2011), Kitchen (2020) or Stojšić et al. (2016). These Virtual Reality techniques hold the advantage of integrating three-dimensional and interactive elements in an immersive way and without direct contact with the represented territory, which also satisfy a wide range of utilities and situations.

Funding

This work was supported by Spanish *Ministerio de Economía y Competitividad* under Grant CSO2017-84623-R. It is part of the results from the research project *La Realidad Aumentada como herramienta para la explicación del paisaje. Aplicaciones a la docencia y al turismo*.

References

Akçayır, M. & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*, 1-11. https://doi.org/10.1016/j.edurev.2016.11.002

Alomar-Garau, G. & Gómez-Zotano, J. (2022). Del paisaje en la geografía: Perspectivas y actividades del Grupo de Paisaje de la Asociación Española de Geografía. *Cuadernos de Geografía de la Universitat de València*, (108-9), 857-874. https://doi.org/10.7203/CGUV.108-9.24067

Arnheim, R. (1997). *Visual thinking*. Univ. of California Press.

Beato, S., Poblete, M. A., Mariano, J. L., Herrera, D., & Fernández, F. (2020). Carreteras paisajísticas y realidad aumentada en la Sierra del Aramo (Macizo Central Asturiano). *Ería*, *40*(2), 145-166. https://doi.org/10.17811/er.2.2020.145-166.

Bos, D. (2021). Geography and virtual reality. *Geography Compass, 15*(9), e12590. https://doi.org/10.1111/gec3.12590

Bos, D., Miller, S., & Bull, E. (2022). Using virtual reality (VR) for teaching and learning in geography: fieldwork, analytical skills, and employability. *Journal of Geography in Higher Education*, *46*(3), 479-488. https://doi.org/10.1080/03098265.2021.1901867

Busquets, J. (2010). La educación en paisaje: una oportunidad para la escuela. *Íber. Didáctica de las Ciencias Sociales, Geografía e Historia*, *65*, 7-16.

Carbonell Carrera, C. & Bermejo Asensio, L. A. (2017a). Landscape interpretation with augmented reality and maps to improve spatial orientation skill. *Journal of Geography in Higher Education*, *41*(1), 119-133. https://doi.org/10.1080/03098265.2016.1260530

Carbonell Carrera, C. & Bermejo Asensio, L. A. (2017b). Augmented reality as a digital teaching environment to develop spatial thinking. *Cartography and Geographic Information Science*, *44*(3), 259-270. https://doi.org/10.1080/15230406.2016.1145556

Carré, J. & Metailié, J.-P. (2008). De los paisajes de ayer a los paisajes de mañana. Metodología de un observatorio fotográfico para el análisis de las dinámicas paisajísticas: El valle de Vicdessos, Pirineos de Ariége (Francia). *Cuadernos geográficos de la Universidad de Granada*, *43*(2), 123-150.

Carrera, C. C., Perez, J. L. S., & Cantero, J. de la T. (2018). Teaching with AR as a tool for relief visualization: Usability and motivation study. *International Research in Geographical and Environmental Education*, *27*(1), 69-84. https://doi.org/10.1080/10382046.2017.1285135

Chang, G., Morreale, P., & Medicherla, P. (2010). Applications of Augmented Reality Systems in Education. In D. Gibson & B. Dodge (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference 2010* (pp. 1380-1385). Association for the Advancement of Computing in Education (AACE).

Cheng, K.-H. & Tsai, C.-C. (2013). Affordances of Augmented Reality in Science Learning: Suggestions for Future Research. *Journal of Science Education and Technology*, *22*(4), 449-462. https://doi.org/10.1007/s10956-012-9405-9

Chiang, T. H. C., Yang, S. J. H., & Hwang, G.-J. (2014). An Augmented Reality-based Mobile Learning System to Improve Students' Learning Achievements and Motivations in Natural Science Inquiry Activities. *Journal of Educational Technology & Society*, *17*(4), 352-365.

Çöltekin, A., Lochhead, I., Madden,M., Christophe, S., Devaux, A., Pettit, C., Lock, O., Shukla, S., Herman, L., Stachoň, Z., Kubíček, P., Snopková, D., Bernardes, S., & Hedley, N. (2020). Extended Reality in Spatial Sciences: A Review of Research Challenges and Future Directions. *ISPRS International Journal of Geo-Information*, *9*(7), 439. https://doi.org/10.3390/ijgi9070439

Cobo Romaní, C., & Moravec, J. W. (2011). *Aprendizaje invisible hacia una nueva ecología de la educación*. Universitat de Barcelona.

Dakin, S. (2003). There's more to landscape than meets the eye: Towards inclusive landscape assessment in resource and environmental management. *The Canadian Geographer/Le Géographe canadien*, *47*, 185–200. https://doi.org./10.1111/1541-0064.t01-1-00003

Damala, A., Cubaud, P., Bationo, A., Houlier, P., & Marchal, I. (2008). Bridging the gap between the digital and the physical: Design and evaluation of a mobile augmented reality guide for the museum visit. In *DIMEA'08 Proceedings of 3rd International Conference on Digital Interactive Media in Entertainment and Arts* (pp. 120-127). https://doi.org/10.1145/1413634.1413660

Delgado Álvarez, R. (2022). Realidad aumentada y contenidos geográficos en los itinerarios didácticos. Propuesta didáctica para su puesta en valor en la formación de docentes de Educación Primaria: el paisaje de Las Villuercas. *Ería, 42*(2), 191-207. https://doi.org/10.17811/er.42.2022.191-207

Delgado Peña, J.J. (2017). Enseñanza virtual y actividades digitales para la adquisición de competencias geoespaciales. In *Actas VIII Congreso Ibérico de Didáctica de Geografía* (pp. 12-24).

Dodge, M., McDerby, M., & Turner, M. (Ed.). (2008). *Geographic Visualization*. https://doi.org/10.1002/9780470987643

Driver, F. (2003). On Geography as a Visual Discipline. *Antipode*, *35*(2), 227-231. https://doi.org/10.1111/1467-8330.00319

Eve, S. (2012). Augmenting phenomenology: Using augmented reality to aid archaeological phenomenology in the landscape. *Journal of Archaeological Method and Theory*, 19, 582–600. https://doi.org/10.1007/S10816-012-9142-7

Falk, G. & Chatel, A. (2017). Smartgeo - mobile learning in geography education. *European Journal of Geography,* 8, 153-165.

Fernández García, F. (1998). Las primeras aplicaciones civiles de la fotografía aérea en España. 1: El Catastro y las Confederaciones Hidrográficas. *Ería*, *46*, 117-130. https://doi.org/10.17811/er.0.1998.117-130

Fernández García, F. & Quirós Linares (1997). El vuelo fotográfico de la «Serie A». *Ería*, *43*, 190-198. https://doi.org/10.17811/er.0.1997.190-198

Fernández García, F., Herrera Arenas, D., Olay Varillas, D., & Fernández Bustamante, C. (2018). *Gijón aumentado. Una guía del Gijón histórico basada en técnicas de realidad aumentada.* Ministerio de Economía, Industria y Competitividad, CTIC, Universidad de Oviedo. https://www.observatoriodelterritorio.es/wp-content/uploads/2018/06/GijonAumentado.pdf

Fernández García, F. & Herrera Arenas, D. (2022). Territorio, paisaje, turismo y TIC. La realidad aumentada y la realidad virtual como herramientas para la promoción del turismo. *Estudios Turísticos* (224), 43-57. https://doi.org/10.61520/et.2242022.13

García, A. (2011). El paisaje: un desafío curricular y didáctico. *Didácticas Específicas*, *14*, 1-19.

Garrido, E., Rebok, S., & Puig-Samper, M. Á. (2016). El arte al servicio de la ciencia: Antecedentes artísticos para la impresión total del paisaje en Alexander von Humboldt. *Dynamis*, *36*(2), 363-390.

Ghadirian, P. & Bishop, I. (2008). Integration of Augmented Reality and GIS: A New Approach to Realistic Landscape Visualisation. *Landscape and Urban Planning, 86*(3), 226-232. https://doi.org/10.1016/j.landurbplan.2008.03.004

Gómez, J. (2013). Del patrimonio paisaje a los paisajes patrimonio. *Documents d' Anàlisi Geogràfica*, *59/1*, 5-20. https://doi.org/10.5565/rev/dag.48

González Díaz, J.A. (2019). *Modelos de gestión del territorio, paisaje y biodiversidad en un espacio de montaña: la Reserva de la Biosfera de Redes* [Doctoral thesis, Universidad de Oviedo]. Repositorio Institucional de la Universidad de Oviedo. http://hdl.handle.net/10651/52834

Griffon, S., Nespoulous, A., Cheylan, J. P., Marty, P., & Auclair, D. (2011). Virtual reality for cultural landscape visualization. *Virtual Reality*, *15*(4), 279-294. https://doi.org/10.1007/s10055-010-0160-z

Hernández, A.M. (2010). El valor del paisaje cultural como estrategia didáctica. *Tejuelo, 9*, 162-178.

Hollman, V. (2008). Geografía y cultura visual: Apuntes para la discusión de una agenda de indagación. *Estudios Socioterritoriales. Revista de Geografía*, (7), 120-135.

Hollman, V. C. (2016). Ante las imágenes: Los desafíos del giro visual para la Geografía. *GEOUSP: Espaço e Tempo (Online)*, *20*(3), 518. https://doi.org/10.11606/issn.2179-0892.geousp.2016.121485

Kraak, M. (2020). Geovisualization. In A. Kobayashi (Ed.), *International Encyclopedia of Human Geography (Second Edition)* (pp. 141-51). Elsevier. https://doi.org/10.1016/B978-0-08-102295-5.10552-9

Kipper, G. & Rampolla, J. (2013). *Augmented reality: An emerging technologies guide to AR*. Syngress/Elsevier.

Kitchen, R. (2020). Using mobile virtual reality to enhance fieldwork experiences in school geography. *Geography Education in the Digital World: Linking Theory and Practice*, chapter 12. https://doi.org/10.4324/9780429274909-12

Lens-Fitzgeral, M. (2009). *Sprxmobile, Augmented Reality Hype Cycle*.

Liceras, A. (2013). Didáctica del paisaje. Lo que es, lo que representa, cómo se vive. *Íber. Didáctica de las Ciencias Sociales, Geografía e Historia*, *74*, 85-93.

Lois, C. M. (2009). Imagen cartográfica e imaginarios geográficos. Los lugares y las formas de los mapas en nuestra cultura visual. *Scripta Nova. Revista Electrónica de Geografía y Ciencias Sociales*, *13*(0).

Martínez-Graña, A. M., Legoinha, P., González-Delgado, J. A., Dabrio, C. J., Pais, J., Goy, J. L., Zazo, C., Civis, J., Armenteros, I., Alonso-Gavilan, G., Dias, R., & Cunha, T. (2017). Augmented Reality in a Hiking Tour of the Miocene Geoheritage of the Central Algarve Cliffs (Portugal). *Geoheritage, 9*(1),121-131. https://doi.org/10.1007/s12371-016-0182-3

Martínez de Pisón, E. (2010). Saber ver el paisaje. *Estudios Geográficos*, *269*, 395-414. https://doi.org/10.3989/estgeogr.201013

Marino, J.L., Poblete, M.Á., Beato, S., & Herrera, D. (2021). Geotourism Itineraries and Augmented Reality in the Geomorphosites of the Arribes del Duero Natural Park (Zamora Sector, Spain). *Geoheritage, 13*, 16 https://doi.org/10.1007/s12371-021-00539-x

Marques, B., McIntosh, J., & Carson, H. (2019). Whispering tales: using augmented reality to enhance cultural landscapes and indigenous values. *AlterNative: An International Journal of Indigenous Peoples*, *15*(3), 193-204. https://doi.org/10.1177/1177180119860266

McIntosh, J., Rodgers, M., Marques, B., & Gibbard, A. (2019). The use of VR for creating therapeutic environments for the health and wellbeing of military personnel, their families and their communities. *Journal of Digital Landscape Architecture*, *4*, 185-194. https://doi.org/10.14627/537663020

Mirzoeff, N. & García Segura, P. (2003). *Una introducción a la cultura visual*. Paidós.

Moya Honduvilla, J., Bernabe Poveda, M. A., & Escobar, F. J. (2012). La representación de la información geográfica. In M. Á. Bernabé Poveda & C. M. López Vázquez (Eds.), *Fundamentos de las Infraestructuras de Datos Espaciales* (pp. 109-121).

Olay Varillas, D., Herrera Arenas, D. H., & Fernández García, F. (2019). La Realidad Aumentada como instrumento para el estudio de la dinámica del paisaje mediante el empleo de fotografía. *ArtyHum Revista Digital de Artes y Humanidades*, *Monográfico: Desafíos epistemológicos, técnicos y educativos para las Humanidades Digitales,* (1), 11-29.

Olcina Cantos, J., González Pérez, J. M., & López Estébanez, N. (2022). Un panorama general de la evolución de la geografía española (1992-2022). In *La geografía española actual. Estado de la cuestión: Aportación española al congreso de la UGI. París 2022. El tiempo de los geógrafos* (ANTE y USC, pp. 9-27). Asociación Española de Geografía.

Ortag, F. (2012). Geovisualization and visual analytics. *International Cartographic Association*. https://icaci.org/research-agenda/geovisualization-and-visual-analytics/

Ortega y Gasset, J. (1906, september 17th). La pedagogía del paisaje. *El Imparcial*.

Peddie, J. (2017). *Augmented reality: Where we will all live*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-319-54502-8

Pratama, H., Azman, M. N. A., Kenzhaliyev, O. B., Wijaya, H., & Kassymova, G.K. (2021). Application of augmented reality technology as an interactive learning medium in geography subjects. *Series of geology and technical sciences,* 4, 21-29. https://doi.org/10.32014/2021.2518-170X.77

Prensky, M. (2001). Digital Natives, Digital Immigrants. *On the Horizon, 9*(5), 1-20. https://doi.org/10.1108/10748120110424816

Priestnall, G. (2009). Landscape Visualization in Fieldwork. *Journal of Geography in Higher Education*, *33*(sup1), S104-S112. https://doi.org/10.1080/03098260903034020

Prisille, C. & Ellerbrake, M. (2020). Virtual Reality (VR) and Geography Education: Potentials of 360° 'Experiences' in Secondary Schools. In D. Edler, C. Jenal & O. Kühne. (Eds), *Modern Approaches to the Visualization of Landscapes*, *RaumFragen: Stadt – Region – Landschaft* (pp. 321-332). Springer Fachmedien. https://doi.org/10.1007/978-3-658-30956-5_18

Ramón, A. (2017). Tecnologías de la Información Geográfica, un recurso para el aprendizaje de la vida cotidiana. In R. Sebastià & E. M. Tonda (Eds.), *Enseñanza y aprendizaje de la Geografía para el siglo XXI* (pp. 151-173). Universidad de Alicante.

Rodrigues, J. M. F., Ramos, C. M. Q., Cardoso, P. J. S., & Henriques, C. (eds.) (2018). *Handbook of Research on Technological Developments for Cultural Heritage and eTourism Applications.* IGI Global. https://doi.org/10.4018/978-1-5225-2927-9

Rogers, G.F. & Malde, H.E. (1984). *Bibliography of Repeat Photography for Evaluating Landscape Change*. University of Utah Press.

Rose, G. (2003). On the Need to Ask How, Exactly, Is Geography «Visual»? *Antipode*, *35*(2), 212-221. https://doi.org/10.1111/1467-8330.00317

Rose, G. (2016). *Visual methodologies: An introduction to researching with visual materials*. SAGE Publications Ltd.

Sánchez Verdú, R. & Sebastiá-Alcaraz, R. (2014). *Realidad aumentada. Recurso para el aprendizaje de la geografía: Geoalcoi*. http://rua.ua.es/dspace/handle/10045/46773

Squire, K. (2010). From information to experience: Place-based augmented reality games as a model for learning in a globally networked society. *Teachers College Record*, *112*, 2565–2602. https://doi.org/10.1177/016146811011201001

Stintzing, M., Pietsch, S., & Wardenga, U. (2020). How to Teach "Landscape" Through Games?. In D. Edler, C. Jenal, y O. Kühne (Eds.), *Modern Approaches to the Visualization of Landscapes*, *RaumFragen: Stadt – Region – Landschaft* (pp. 333-349). Springer Fachmedien. https://doi.org/10.1007/978-3-658-30956-5_19

Stojšić, I., Džigurski, A. I., Maričić, O., Bibić, L. I., & Vučković, S. Đ. (2016). Possible application of virtual reality in geography teaching. *Journal of Subject Didactics*, *1*(2), 83-96.

Thornes, J. E. (2004). The Visual Turn and Geography (Response to Rose 2003 Intervention). *Antipode*, *36*(5), 787-794. https://doi.org/10.1111/j.1467-8330.2004.00452.x