FROM THEORY TO PRACTICE: DIGITAL RECONSTRUCTION AND VIRTUAL REALITY IN ARCHAEOLOGY

Abstract: The paper presents a digital restoration methodology of a historical monument starting from the results of a terrestrial scan done in situ. The paper describes the steps to be followed to achieve a digital restoration whose results can be validated in the virtual environment and then used in an interactive virtual reality application.
Keywords: *digital reconstruction, terrestrial laser scan, virtual reality*

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DOI: 10.14795/j.v4i4.287
ISSN 2360 – 266X
ISSN–L 2360 – 266X

INTRODUCTION

As our society continues to develop and evolve it becomes more and more aware about the importance of preserving cultural heritage sites and monuments. Such sites undergo the natural degradation process (due to their age), hence the need to preserve them as best as possible. A solution in this sense is digitizing and transposing all information about them and their elements into the virtual environment, thus creating a "virtual reality". By doing so the heritage site is not only preserved, but it is also available to the general public without risking further degradation. By definition, virtual reality (VR) employs "the use of a computer-generated 3D environment – called a virtual environment (VE) – that one can navigate and possibly interact with, resulting in real-time simulation of one or more of the user's five senses."[1]

Recent developments in the Information and Communication Technologies (ICTs) have enabled the creation of advanced virtual reality hardware equipment. As these technologies continue to evolve, they are being used in other fields such as archaeology. A VR experience provides immersion within a virtual reality environment. This immersion is defined by the capability of the user to be isolated from the real world and transferred into the virtual world.

In this paper the authors propose a methodology and present the result of the digital reconstruction of the large round temple from Sarmizegetusa Regia (Fig. 1). The second round temple, measuring 29,4 m in diameter, is the largest of all the circular edifices identified in Dacia. Its surface is confined by two stone circles, the first one made of 104 massive andesite blocks, the second, which is placed inside, by 30 groups of 7 pillars (6 higher plus one lower), also made of andesite. Inside the temple a circular room made of a wooden pole structure was built, which supported a clay wall, and approximately in the middle, there was another room built in the same technique, but shaped like an apse. The temple's roof was conical (or almost conical) and was covered with shingles. An exterior limestone block platform

1 GUTTENTAG 2010.

Fig. 1. The large round temple from Sarmizegetusa Regia.

was the entrance, which had a tile roof. The total height of the edifice was estimated as having between 10 m and 15 m.

The results presented in this paper are obtained based on archaeological data and on the architects' and engineers' sketches and calculations, all 3D models are only reconstruction proposals (hypothetical models of the missing structures). It's well known that for documenting cultural heritage sites and/or monuments, because of the interdisciplinary nature of this task, professionals from different knowledge areas are required, "which implies not only a huge amount of information and requirements, but also a very heterogeneous set of sources, data structures, content and formats."[2]

3D reconstruction, refers to capturing and reproducing the shape and appearance of an arbitrary object or scene given depth and color information. Main motivations are: (1) to ensure that the information of the shape and appearance of an object is not lost in case of damage by natural or accidental causes; (2) to allow the dissemination of digital media collections for a large audience via virtual museums; (3) to create replicas; (4) to identify art forgery; (5) and to allow the collection of specific geometric or texture information when difficult to obtain from the real object[3].

Virtual reality was used for 3D virtual reconstruction and visualisation of the archaeological site, for independent architectural monuments like Roma Theatre from Byblos or even an entire ancient city Rome or Palmyra[4].

WORK METHODOLOGY

The digital reconstruction of a historical monument implies an interdisciplinary approach and the use of tools from diverse fields, such as topography, engineering or entertainment/video game industry.

Complete recording of Cultural Heritage is a multidimensional process. It addresses not only the problem of three-dimensional (3D) digitization of objects and monuments but involves all the aspects of this new digital content management, representation and reproduction. It addresses issues affecting the whole life cycle of the digital cultural content[5].

The result of the digital reconstruction process is a 3D model that has to respect the historical and archaeological information. This kind of model can be used both in research and in cultural heritage dissemination using electronic technologies.

Fig. 2 illustrates a digital reconstruction methodology used by the authors in the process of reconstruction and promotion of historical monuments in the Orăștie Mountains area and the large round temple.

In the first step, using several specific tools, the current state of the site is digitized, with the purpose of using the data and further processing it in the 3D modeling

2 SOLER/ MELERO/ LUZÓN 2017
3 GOMES/BELLON/SILVA 2015
4 PORTALÉS/ALONSO-MONASTERIO/VIÑALS 2017, PIERDICCA *et alii* 2016, YOUNES *et alii* 2017, DENKER 2017
5 PAVLIDIS *et alii* 2007

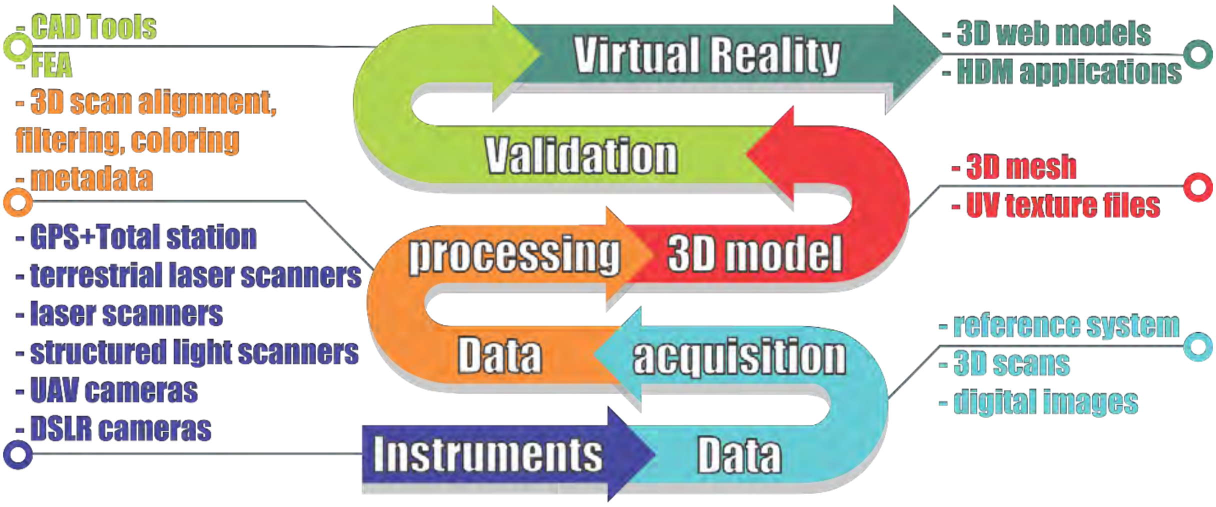

Fig. 2. Work methodology.

stage.

The use of modern equipment and instruments for documenting the tangible cultural heritage, improved the way in which archaeological intra-site surveys and records are done[6].

Modern archaeology makes use of conventional and advanced measurement systems, such as total stations and GPS units. These systems offer greater accuracy, automatic registration and the data is stored in an electronic form, which can be imported and processed in different software environments. Geographic Information Systems (GIS) have been used in the archaeology field extensively in the last decade, for excavations, to annotate and document monuments. 3D terrestrial laser scanning represents a technology that adds another layer of information regarding the 3D data of the tangible cultural heritage.

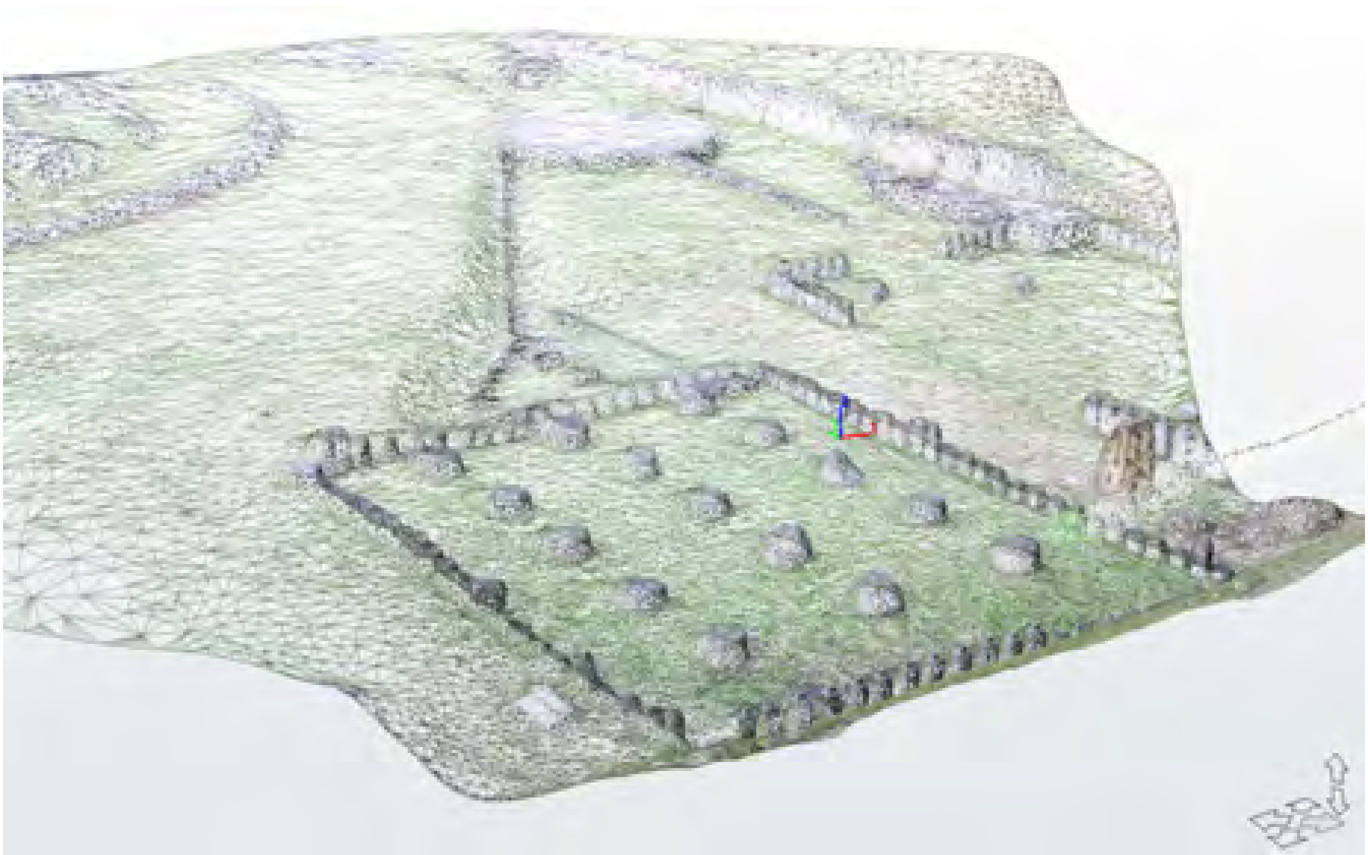

Fig. 3. Digitizing the sacred area of Sarmizegetuza Regia using photogrammetry (data set from 2010).

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Fig. 4. Digitization of the large round temple.

The digitization process can be done using various methods and techniques such as photogrammetry, laser scanning, LIDAR, etc.[7]. Currently it is possible to create 3D reconstruction of cultural heritage sites using open data from social media, a vast amount of open data is now available on social media, which are posted every day on the internet, the 3D model is generated using Structure from Motion (SFM)[8].

It is now possible to use video imaging from social media such as YouTube, Facebook and Twitter to create 3D reality-based models of cultural heritage architectures and monuments 3D images can be incorporated into a BIM model[9].

The acquired data is processed to obtain the preliminary 3D model. Preliminary models are usually characterized by large amounts of information. This model can be used as the starting point of the digital reconstruction process.

In digital reconstruction, the authors recommend the use of the engineering modeling solution, specifically, because the created models are compatible with software solutions that can be used to validate the reconstruction proposals. The validation of the 3D model should be done using a multi-criteria approach and it should be validated at least from a historical and engineering / architectural viewpoint, information and tools from other fields can also be used. After the 3D model has been validated, it can be used in virtual and augmented reality applications, in dedicated databases such as Europeana or other socio-educational purposes.

RESULTS

For the 3D digitization of the current state of the Dacian circular temple, the Z+F Imager 5010X laser scanner has been deployed in multiple scanning stations to capture the position of the in-situ stone blocks.

For the digitization of the large circular temple, 64 scanning stations were used. The result of this operation can be seen in Fig. 5. The alignment of the point clouds and their processing was done using the Z+F Laser Control software Fig. 6.

After aligning the point-clouds, resulted from the scans, they were filtered and processed to obtain a 3D mesh. In the case of the sacred area of Sarmizegetuza, for scanning the entire area 64 scanning stations were used, their placement are shown in Fig. 7. The volume of the collected data is about 84 GB and their use in software other than those dedicated to terrestrial scanning is almost impossible. Thus, the area of interest was cropped, (Fig. 5) after which reduction filters were applied, the areas with vegetation and other sources considered as "noise" in the scan (e.g. tourists) were removed and then the resulting point-cloud could be imported into CATIA V5, where the digital reconstruction of the large circular temple (Fig. 8) was carried out.

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8 KYRIACOS 2016
9 ALSADIK/GERKE/VOSSELMAN 2015

Fig. 5. The result of the terrestrial scan of the large round temple.

The digital restoration comprised of the independent modeling of each element of the temple and their assembling into a model that later entered the validation stage. The digital reconstruction process can lead to a unique or to multiple results (3D models), but these must be obtained strictly based on historical-archaeological information and existing analogies. The validation of a digital restoration proposal can be completed with the help of various engineering solutions, such as finite element analysis, used in our case for checking the wood structure Fig. 9.

Fig. 6. Aligning point clouds using Z+F laser control software.

Fig. 7. Placement of stations for scanning the sacred area from Sarmizegetuza Regia.

After validating the reconstitution proposal, the 3D model must be converted to a geometry compatible with virtual reality applications. For these applications, only the visible geometry is needed that will be endowed with various specific properties such as collision / collider, and to which a texture should be applied that is as close as possible to the real one, using various effects (reflexive, shadows, etc.) to create a realistic photographic virtual environment. Most of the time, engineering software does not offer the same rendering quality as those used in the gaming or movie industry. For creating the virtual reality application as a "virtual tour" through the large circular temple, it was chosen to optimize the 3D model in 3ds Max and to develop the application in Unreal Engine. In 3DS Max every visible element was virtually remodeled using the 3D model made in CATIA and the laser scanning, both considered as standards Fig. 10. In order to import the point cloud into 3ds Max, a supplementary processing of the 3D scans was necessary in Autodesk Recap Pro, from where they were exported in *.rcp format and later imported into 3ds Max.

Virtual and augmented reality technologies promise to alleviate some of the difficulties caused by lack of contextual clues about the functions of their various spatial elements and significance of their architectural features by providing

Fig. 8. The intermediary 3D model of the reconstruction proposal and the superimposed 3D scan.

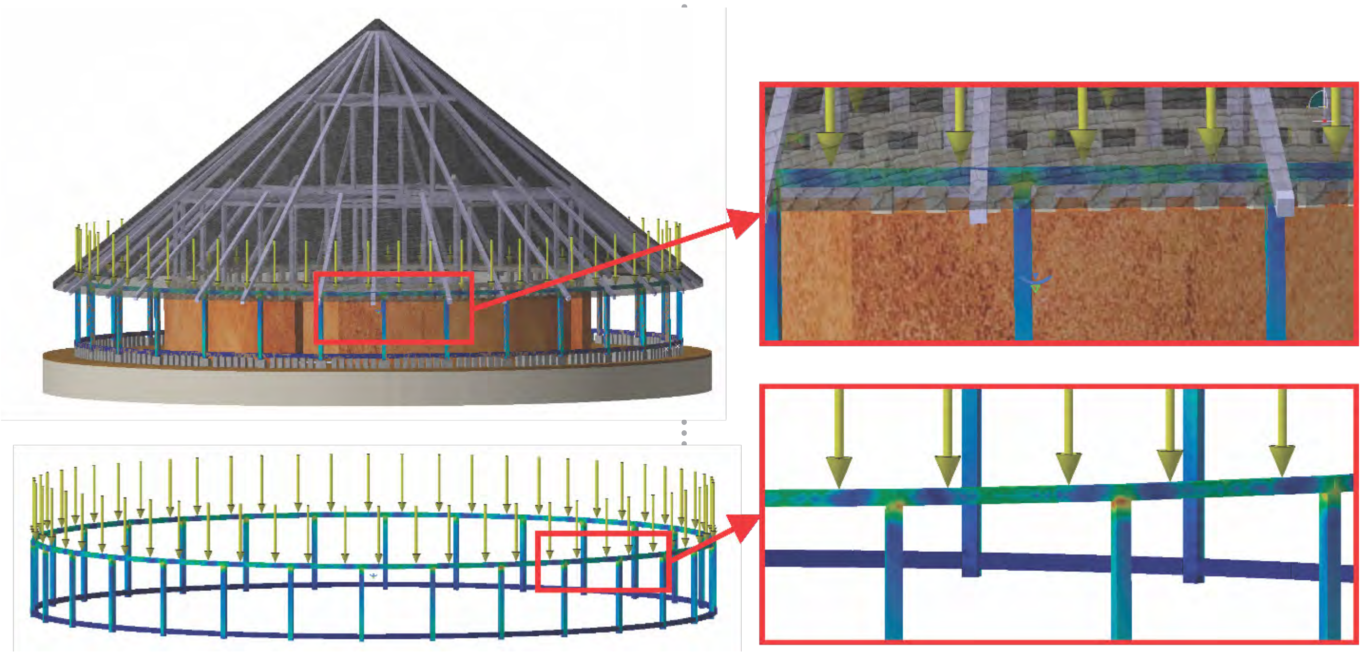

Fig. 9. Validating the wooden structure using fininte element analysis.

historically accurate reconstructions and relevant contextual information to allow for a richer and more impactful visitor experience[10]. Users wear 3D stereo viewers and headphones, and optionally hold a control pad, to be immersed in a realistic, interactive, and much enhanced environment.

The virtual environment was developed using the Unreal Engine, which represents a platform that can develop virtual reality environments for a wide variety of devices such as PC, consoles, mobile devices. The scene created for the round Dacian temple allows users to visualize and interact with the virtual environments. The user has the possibility to move around in the environment either by walking in the HTC camera range or by using the walkthrough system based on the teleporting system that allows the user to select a place within their view range and navigate towards it Fig. 11.

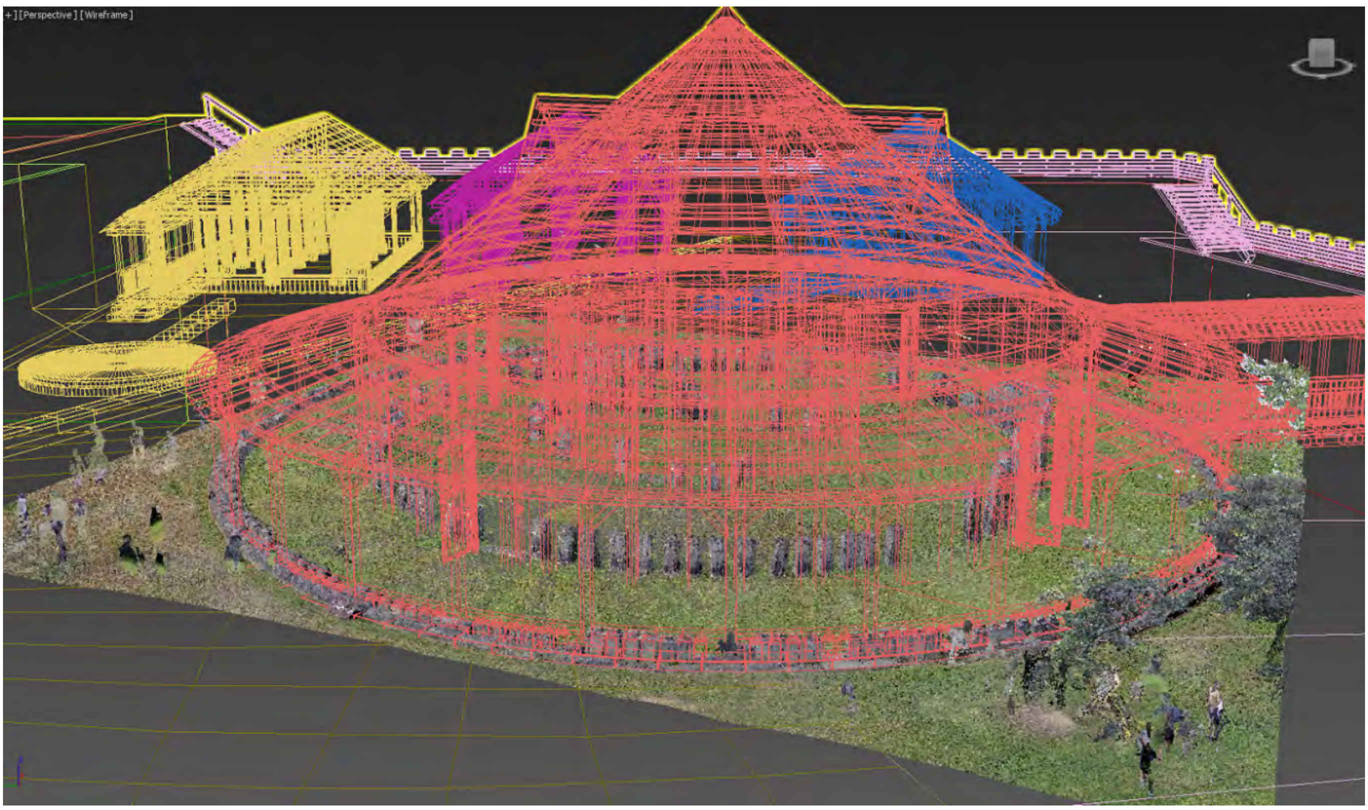

Fig. 10. Modeling the large circular temple in 3ds Max.

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Fig. 11. Testing the VR enviroment.

The teleporting systems based on the HTC Arc Pointer enables users to explore larger areas then the standard predefined square base environment. The virtual reality navigation systems use an intuitive parabolic curve rendered in the view port, which enables an interactive destination selection done by the user in real time.

The user experience was enhanced by adding some 3D objects inside of the 3D reconstructed model of the large circular temple. The artefacts have been digitized using the VIUScan 3D laser scanner and the Go!Scan 50 3D structured light scanner Fig. 12. The user can manipulate the artefacts using the two controllers, he can inspect features on them, or he can rearrange them in the virtual environment.

Considering the size of the monument, in the virtual reality application a virtual flight function was also implemented, enabling the user to inspect the large circular temple using a flight-type navigation as well. The created virtual reality environment displays the temple in real size, so it can be virtually visited using the teleportation function, and then, in a space of 3 by 4m the user can move freely, the correlation with the virtual reality environment being made based on the data received by the tracking system. After each teleportation, the tracking in the 3 by 4 m space is synchronized with the user's real-life position by processing the information obtained from the "eyesight" of the tracking system.

CONCLUSIONS

Using 3D modeling and engineering software, the authors were able to "rebuild the past", in a form that

Fig. 12. Digitizing the artifacts.

combines existing elements from the actual archaeological site with the hypothetical model of the missing structure. Using 3D models and virtual reality applications information can be provided and/or disseminated to the average audience, that otherwise is hard to access and difficult to understand and which is normally reserved for specialists. The reconstruction is and interdisciplinary task and involves the use of several instruments, specific to related fields, such as engineering, architecture, or even the game industry. The validation of the restoration proposals can only be completed in the virtual environment, using tools from Computer Aided Engineering. The tools used to digitize the current state of some monuments or artifacts generally produce a large amount of data that can often be used only in highly specialized software solutions and to which public access is restricted. Creating 3D reconstructions from laser scans of the site's current state can lead to the attainment of faithful models, whose dimensional deviation can be considered insignificant in relation with the dimensions of the monument. The paper presents a validated 3D reconstruction methodology and a validation of the models obtained in virtual reality applications. The case study presented in this paper (the large circular temple from Sarmizegetuza Regia) was digitized using a laser scanning technology that provides a dimensional accuracy of ± 1mm at 180 m. The 3D modeling was completed in CATIA V5 and the virtual reality application model was created in 3dStudio Max. The initial data was reduced by about 80%, the user's visual perception remaining the same. The virtual reality application was developed in Unreal Engine, and some scanned Dacian artifacts were also introduced. The user can walk around inside the monument, scaled at a 1:1 ratio, having a real perception of its size and shape.

ACKNOWLEDGEMENT

The research presented in this paper was partially supported by EEA Grants LP10-PA16/RO12.

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