# From Reality to Augmented Reality: Rapid Strategies for Developing Marker-Based AR Content Using Image Capturing and Authoring Tools

Jorge D. Camba
Gerald D. Hines College of Architecture
University of Houston
Houston, TX
jdorribo@uh.edu

Manuel Contero
Instituto de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano (I3BH)
Universitat Politècnica de València
Valencia, Spain
mcontero@upv.es

***Abstract*— This paper builds on the authors' previous work with Augmented Reality (AR) technology, where interactive three-dimensional (3D) content was developed and combined with traditional printed materials to enhance the visualization and understanding of technical information. In this study, we describe a method to rapidly create custom marker-based AR content using 3D data from real objects and an authoring tool developed in-house. We present a two step process, where 3D geometry is generated automatically by capturing and processing a series of photographs of a real object and subsequently converted to an AR element that can be linked to a unique marker and used with a marker-based AR system. This system provides an opportunity for instructors to quickly and effortlessly create their own AR content to support their innovative teaching practices.**

***Keywords*— augmented reality; image-based modeling; 3D content creation**

## I. INTRODUCTION

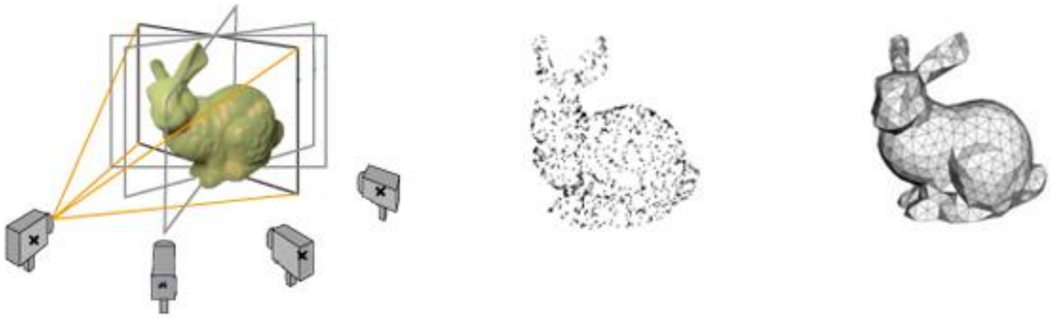
Although many instructors still rely primarily on lectures and traditional teaching practices and laboratory sessions, the growing body of empirical research shows that didactic lectures do not necessarily succeed in eliciting comprehension of complex concepts [1] and that learning can be improved when instructors incorporate teaching strategies that are interactive, student-centered, and take advantage of the existing technology [2, 3]. As stated by Millar [4], good teaching demands ongoing creative effort. In this regard, Augmented Reality (AR) technology provides an attractive and engaging resource to complement and enhance traditional teaching materials, usually based on pen and paper exercises, while promoting the development of visualization, self-assessment, and self-directed learning skills [5, 6].

The term "augmented reality" refers to the live direct or indirect view of a physical environment whose elements are augmented by computer-generated content (text, images, videos, 3D models, animations, etc.) [7]. Augmented worlds are generated in real-time and typically experienced via computer screens, projectors, or head mounted displays (HMD). The technology has been listed by the Horizon Report [8] as a key visualization tool that will be widespread in higher education in the near future. According to this report, the ability of AR to respond to user input confers significant potential for learning and assessment, as students build new knowledge based on visualizations and interactions with virtual models that bring underlying data to life [8].

AR systems have been used effectively as educational tools in various fields such as visualization and engineering graphics [9-11], architecture [12], and medicine [13, 14]. However, most educational applications focus on very specific subjects, the content is usually predefined by developers, and it is difficult for instructors to create or update existing content. This situation was described by Kerawalla et al. [15] who reported that teachers recognize the educational potential of AR, but demand more control and availability of the resources, so they can adapt them to the specific needs of their students.

In this regard, the development of AR content (a fundamental component of the system to ensure a truly engaging educational user experience) requires the creation of 3D computer models, which is a time consuming task and often involves a high level of proficiency in the use of 3D modeling packages such as Maya, SolidWorks, or SketchUp. While traditional geometry-based approaches such as polygonal and surface modeling enable the construction of highly realistic and sophisticated 3D shapes, they have a steep learning curve and require a significant amount of training and skill, which can make them unsuitable for non-expert users [16]. Such limitations can easily discourage educators from creating custom materials. Therefore, there is a need for efficient, cost effective, intuitive, and simple tools that allow instructors (who cannot be expected to be 3D experts) to author custom 3D models for augmented reality environments and applications.

In this paper, we present a rapid approach to AR content development that requires no 3D modeling skills and no expertise with CAD packages. Our approach comprises the use of a simple image-based modeling tool and a custom AR authoring application, which allows content designers to set up AR experiences in just a few minutes. All content is created automatically from real objects through a series of photographs that are processed as 3D geometry by the image-based modeling



(a) (b) (c)

Fig. 1. Image-based modeling sequence: (a) image capturing, (b) point cloud, (c) 3D mesh

tool. The conversion of the 3D model to an interactive AR element is performed by a separate authoring application developed in-house that links the 3D model to a two dimensional marker which can be physically manipulated by the user and works in conjunction with a software viewer that displays the content.

## II. IMAGE–BASED MODELING

The process of developing a three dimensional computer representation of an object using graphics software is known as 3D modeling. Requirements and strategies for the generation of 3D models depend on a variety of factors such as the desired level of detail, completeness, reliability, accuracy, data volume, costs, and operational aspects, among others [17].

Different techniques exist (both manual and automatic) for creating 3D models, depending on the application and purpose. In general, manual methods allow more control over the geometry during the modeling process, but require more knowledge and expertise of the tool. Popular methods to rapidly generate 3D models from existing data, such as 3D scanning or photogrammetry, often involve geometry reconstruction techniques. These methods have been used successfully in many specialty areas, including ancient architecture and cultural heritage reconstruction [18-20], dentistry [21], and large-scale scenes such as urban structures [22].

Recent advancements in specialized hardware such as laser scanners and structured lighting systems have made 3D reconstruction possible for non-experts. However, these tools are often costly, not portable or scalable, and constrained in terms of material properties (scanners cannot scan certain materials) and environmental conditions [16]. In recent years, personal digital cameras (and their seamless integration with smart phones) are providing real alternatives to more expensive systems. Compared with conventional geometry-based modeling and hardware-heavy approaches, these cameras, when combined with the appropriate software, provide an intuitive and increasingly attractive proposition for affordable 3D reconstruction [17].

The term “photogrammetry” refers to a wide range of techniques and algorithms by which 3D properties of an object are derived from a set of 2D images. Using triangulation, any feature seen in at least two photographs taken from known locations can be localized in 3D space. Furthermore, it is mathematically possible to solve for unknown camera positions when a sufficient number of corresponding points are available [23].

Digital close-range photogrammetry has been an active area of research for years and is used in many different fields and industries, such as architecture, engineering, mining, quality control, geology, and archeology [24, 25]. Recent technical developments include automatic orientation and measurement procedures, generation of 3D vector data, and digital surface models [26].

Digital photogrammetry techniques require the user to provide a group of images of an object acquired from different viewpoints (typically, at small increments around the object). The way in which photographs are acquired is a critical aspect of the process, as it greatly determines the quality of the final reconstruction [27].

The second step is computationally intensive, as it involves the generation of point cloud data from the source images. In this step, specialized algorithms identify points of interest in the image set and calculate the 3D coordinates of the surface of the object using the collinearity equation that defines the relationship between object and image coordinates [28].

Finally, a 3D mesh model is generated from this point cloud. Depending on the quality, the resulting mesh may contain gaps, so additional cleanup is sometimes necessary. The complete sequence is illustrated in Fig. 1.

Digital photogrammetry techniques have matured considerably to a point where a number of stable software tools have become widely available both as commercial products and as free and open source tools. Examples include programs and services such as Photoscan, Acute3D, or Autodesk’s 123D Catch and Memento, which was the tool used to create the examples shown in this paper.

## III. MARKER-BASED AUGMENTED REALITY

Augmented Reality is a visualization technology where virtual content is rendered in real time and seamlessly overlaid onto real live footage providing an enhanced or “augmented” view of reality [29].

In terms of hardware, augmented reality can be experienced through a regular desktop PC equipped with a Webcam (Desktop AR). The camera captures the real world view and specialized software generates the augmented content, which is positioned, oriented, and displayed on the computer screen as an augmented mirror. Early work of the authors with augmented reality books involves desktop AR experiences for teaching engineering design graphics [10], as shown in Fig. 2.

Handheld devices such as tablets and smart phones can work as see-through tools or “magic-lenses” to visualize AR content [30]. Previous work of the authors with augmented reality books includes AR experiences using this “magic lens” metaphor [9], as shown in Fig. 2.

Finally, special displays and eyeglasses, such as the popular Google Glass, can also be used to experience AR. These devices integrate a series of cameras that capture real world images and combine it with the virtual content, which is displayed directly on the transparent lenses. Other visualization technology includes virtual retinal displays [31] and special head-worn displays (HWDs) [32].

There are many tools to develop augmented reality content, some of which require technical and programming skills. A common technology is based on markers. In this technology, fiducial 2D images are used to recognize the three dimensional space seen by the camera and correctly position and orient the virtual content on the screen. Because of their simplicity, markers can be easily integrated in printed lecture notes and assignments, allowing instructors to enhance educational materials, and students to visualize the contents being described on paper in full 3D [9].

Two different elements can be used: black and white patterns and regular images. Black and white markers are the most recognizable, reliable, and widely used type of augmented reality. They are typically square shapes with unique black and white patterns inside. This unique pattern allows the AR software to select the correct AR content that is linked to the marker.

Alternatively, regular images provide a “markerless” interaction, which is a more ubiquitous and user friendly approach [33]. Any image can be used to trigger AR content but a high level of contrast and detail in the image, as well as more processing power, are required. Examples of both black and white markers and image-based markers are shown in Fig. 3. A comparison of both approaches is described in Table 1.

In this paper, we use a custom authoring tool called *Aumentaty Author* (available at http://author.aumentaty.com) to develop AR content from 3D models generated through image-based modeling techniques. The tool was designed with simplicity in mind and no prior programming experience is required to use it.


Fig. 2. Desktop AR (top) and "Magic lens" (bottom)

Fig. 3. Sample AR elements: black and white markers (top) and regular images (bottom)

TABLE I. MARKER (BLACK AND WHITE) VS. MARKERLESS (IMAGES) AUGMENTED REALITY

| Marker | Advantages | Disadvantages |
|---|---|---|
| Black and white markers | Common and easy to find and create.<br>Relatively low computer requirements.<br>Efficient tracking. | Intrusive and Invasive.<br>Marker similarity. All markers are combinations of black and white patterns, which can be confusing for the user.<br>If part of the marker is covered the virtual model is lost. |
| Markerless (Images) | Any image with sufficient level of detail can be used as a marker.<br>Ubiquitous. There are no intrusive markers which are not part of the environment.<br>They allow occlusion and virtual buttons. | The image must have significant details and proper contrast.<br>More complex image tracking.<br>More hardware demanding. |

## IV. METHODOLOGY

We present a simple and intuitive approach to AR content creation that comprises two steps: creation of 3D models from real objects using an image-based modeling tool (*Autodesk Memento*, in our case), and conversion of the 3D model into an interactive AR element using an AR authoring tool (*Aumentaty Author*, in our study). The proposed methodology is illustrated in Fig. 4.

### A. Creation of 3D Models

The first step requires the acquisition of 3D information of the object that needs to be modeled. Because of the nature of image-based modeling software, objects with plain, transparent, glossy, or reflective surfaces will not work correctly. Similar problems occur when underexposed or overexposed photographs are used.

Multiple pictures will be taken by shooting at least a loop of sequential photographs about the subject (two loops at different heights are usually recommended). For better results, the same lighting conditions must be used for all photographs, and the object being photographed must not move. Additionally, to facilitate the 3D reconstruction, it is also recommended that the object being photographed occupies at least 70% or more of the pixels in the images and that the sequence of pictures has some overlap.

The set of photographs can now be processed by an image-based modeling tool. In this paper, we used *Autodesk Memento Beta*, a solution for converting captured reality input into high definition meshes that can be fixed and optimized.

Depending on the quality of the resulting 3D model, additional cleanup may be required to eliminate unnecessary noise or busy surroundings. Basic fixing/cleanup can be performed by smart selection and clean up tools available in *Autodesk Memento*.

Finally, the textured 3D model reconstructed by *Autodesk Memento* can be exported to several formats: OBJ, STL, PLY, and FBX. Because of the formats supported by our AR authoring tool and based on *Aumentaty* recommendations, models are exported to FBX so they can be processed successfully.

### B. Creation of AR Content

Creating an interactive AR element with *Aumentaty Author* is a visual and intuitive process. First, a marker is selected from the marker ID menu and printed, so the scene can be visualized interactively as it is being created.

Next, the camera needs to be activated and pointed to the printed marker. On the computer screen, the marker will turn orange, indicating that the AR software is recognizing the marker. At this point, the user can browse for the model that was created in the previous step and drag and drop it from the models library part of the interface to the icon that corresponds with the

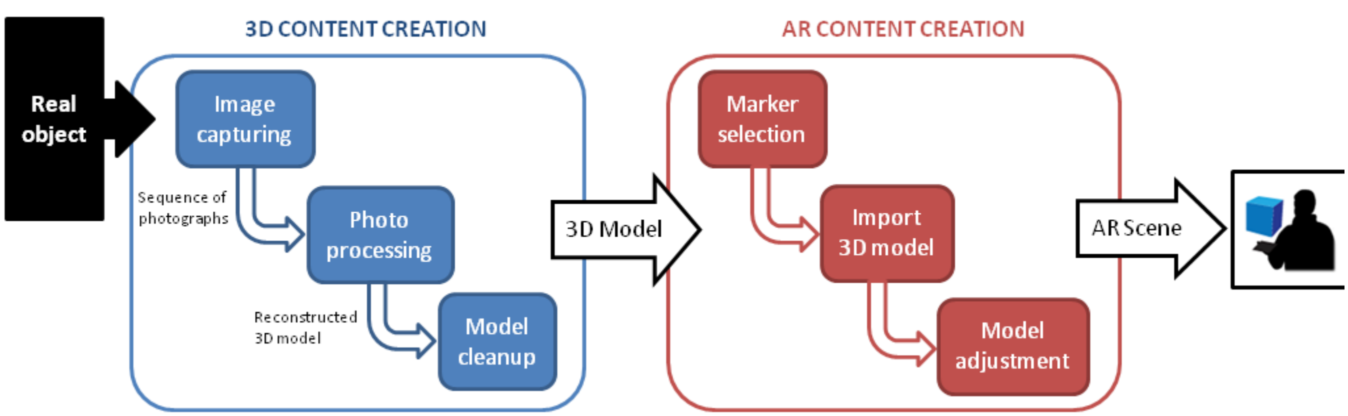
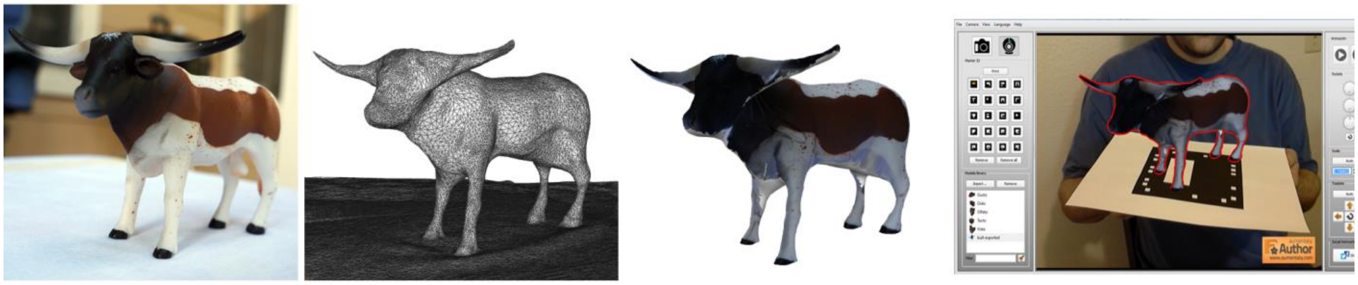



Fig. 4. Proposed methodology for creating Augmented Reality (AR) content



(a) (b) (c) (d)

Fig. 5. AR creation process : (a) real object, (b) reconstructed mesh (low quality), (c) cleaned textured model, (d) augmented reality content

marker that was printed in the first step. The 3D model will be placed over the marker in the software interface to provide a visual cue of the link that was created. The tool can use 3D models in the following formats: FBX, DAE, and OBJ. If textures are used, they must be included as part of the 3D file. If animations are included in the model, they will be played repeatedly when the scene is exported and visualized with *Aumentaty Viewer*.

The controllers located on the main panel can be used to move, scale, and rotate the 3D with respect to the marker. This allows for basic adjustments in the scene, which are useful in many situations such as when the model has a different vertical orientation from the marker's scene or the 3D model is too large with respect to the marker. This basic process will be repeated as many times as models and markers are used in the application. A maximum of 12 models can be included in a single scene.

Finally, the AR scene with all markers and models will be exported to *Aumentaty Viewer*, so it can be visualized on any device (desktop or mobile) equipped with a camera. *Aumentaty Viewer* is a 3D content viewer that can open AR scenes created with *Aumentaty Author*. Content can also be exported to portable devices and shared via email and various social networks. An example of the process is illustrated in Fig. 5.

## V. CONCLUSIONS AND FUTURE WORK

Augmented reality has the potential to become an effective tool to enhance traditional teaching materials and deliver instruction. In previous research, we studied the educational value of both mobile and desktop-based AR in the area of engineering design graphics. However, the creation of content for these applications remains a time consuming task that requires a significant level of technical expertise.

The methodology we discussed in this paper was designed to be simple and easy to implement, as no 3D modeling experience is required to develop content. Unless there are problems with the photographs, the image-based modeling part is mostly an automated process. The 3D reconstruction is live, which means that results can be refined by taking more pictures of the object in the region where it failed.

We noticed that not all meshes come out of the reconstruction process perfectly. Although many require additional cleanup work, specialized tools in Memento, such as slice and fill or smart selection are usually sufficient in most situations.

In terms of AR authoring, we propose a tool that is easy to use by teachers. *Aumentaty Author* provides a graphical environment that does not require any scripting or programming and content is created by experiencing the augmented reality content as it is being created. Users learn to work with the authoring tool almost immediately and the interaction with the markers becomes natural very rapidly.

Despite its simplicity, the proposed methodology still relies on users having access to the real object that needs to be modeled (so photographs can be taken), which may not be easy depending on the content. In addition, the computational resources involved in reconstructing the 3D mesh are significant, which makes time an important factor in the process.

Long term plans include collaborations with K-12 educators in the creation and integration of custom AR materials in the classrooms. We plan to perform a study at different levels, examining both the use and limitations of the proposed methodology in terms of content development and usability, and also the impact of such contents in the students' understanding of the material. As a technical challenge, we are interested in building hardware for mounting multiple cameras so we can speed up the image capturing step.

## REFERENCES


[1] Terenzini, P.T., and Pascarell, E.T. Living with myths: Undergraduate education in America. Change, 1994, 26(1), pp. 28-32.

[2] Levin, D. and S. Arafeh, The Digital Disconnect: The Widening Gap between Internet-Savvy Students and Their Schools. 2002.

[3] Kolb, D.A., Experiential learning: Experience as the source of learning and development. Vol. 1. 1984: Prentice-Hall Englewood Cliffs, NJ.

[4] Millar, S. B. Effecting faculty change by starting with effective faculty: Characteristics of successful STEM education innovators. In National Research Council, Improving Undergraduate instruction in science, technology, engineering, and mathematics: Report of a workshop, 2003, pp. 101-117.

[5] Chen, Y., et al., Use of Tangible and Augmented Reality Models in Engineering Graphics Courses. Journal of Professional Issues in Engineering Education and Practice, 2011. 137(4): p. 267-276.

[6] Martín-Gutiérrez, J., M. Contero, and M. Alcañiz, Evaluating the Usability of an Augmented Reality Based Educational Application, in Intelligent Tutoring Systems, V. Aleven, J. Kay, and J. Mostow, Editors. 2010, Springer Berlin Heidelberg. p. 296-306

[7] Azuma, R.T., A survey of augmented reality. Presence-Teleoperators and Virtual Environments, 1997. 6(4): p. 355-385.

[8] Johnson, L., Adams Becker, S., Estrada, V., Freeman, A. (2015). NMC Horizon Report: 2015 Higher Education Edition. Austin, Texas: The New Media Consortium.

[9] Camba, J., Contero, M., and Salvador-Herranz, G. Desktop vs. mobile: A comparative study of augmented reality systems for engineering visualizations in education. 2014 IEEE Frontiers in Education Conference (FIE), pp. 1-8.

[10] Dorribo-Camba, J., Contero, M., Incorporating augmented reality content in Engineering Design Graphics materials, 2013 IEEE Frontiers in Education Conference (FIE), pp. 35-40.

[11] Dünser, A., et al. Virtual and augmented reality as spatial ability training tools. in Proceedings of the 7th ACM SIGCHI New Zealand chapter's international conference on Computer-human interaction: design centered HCI. 2006. ACM.

[12] Webster, A., et al. Augmented reality in architectural construction, inspection and renovation. in Proc. ASCE Third Congress on Computing in Civil Engineering. 1996.

[13] Sielhorst, T., et al. An augmented reality delivery simulator for medical training. in International Workshop on Augmented Environments for Medical Imaging-MICCAI Satellite Workshop. 2004.

[14] Tang, S.-L., et al., Augmented reality systems for medical applications. Engineering in Medicine and Biology Magazine, IEEE, 1998. 17(3): p. 49-58.

[15] Kerawalla, L., Luckin, R., Seljeflot, S., and Woolard, A. “Making it real”: exploring the potential of augmented reality for teaching primary school science. Virtual Reality, 2006, vol. 10, pp. 163-174.

[16] Nguyen, M.H., Wunsche, B.C., Delmas, P., and Lutteroth, C. 3D models from the black box: Investigating the current state of image-based modeling. Communication Proceedings, Pilsen, Czech Republic, Union Agency, pages 25--28, 2012.

[17] Kersten, T.P., and Lindstaedt, M. Potential of automatic 3D object reconstruction from multiple images for applications in architecture, cultural heritage and archaeology. International Journal of Heritage in the Digital Era, 2012. 1(3), pp. 399-420.

[18] Gaiani, M., Gamberini, E. and Tonelli, G. VR as work tool for architectural & archaeological restoration: the ancient Appian way 3D web virtual GIS, Proceedings of Seventh International Conference on Virtual Systems and Multimedia, 2001. pp. 86.

[19] Lu, S.Z. Virtual Reconstruction of FouGuang Temple Based on Virtual Reality, International Conference on Management of e-Commerce and e-Government ICMECG '08, 2008.

[20] Yao, J., Zhang, H. and She, F. Research on Method of 3D Reconstruction of Ancient Architecture (Nanputuo Temple), International Conference on Cyberworlds, 2008.

[21] Martorelli, M and Ausiello, P. A novel approach for a complete 3D tooth reconstruction using only 3D crown data, International Journal on Interactive Design and Manufacturing, ISSN 1955-2513, June 2012.

[22] Yao, J., Ruggeri, M.R., Taddei, P., Sequeira, V. Automatic Scan Registration Using 3D Linear and Planar Features, 3D Research, 2010, Vol. 1, No. 3, pp. 2-18.

[23] Debevec, P.E. Image-based modeling and lighting. ACM SIGGRAPH Computer Graphics, 1999, 33(4), pp. 46-50.

[24] Barazzetti, L. Remondino, F., Scaioni, M.: Combined use of photogrammetric and computer vision techniques for fully automated and accurate 3D modeling of terrestrial objects. Proceedings of SPIE Optics+Photonics, Vol. 7447, 2-3 August, San Diego, CA, USA, 2009

[25] Opitz, R., Simon, K., Barnes, A., Fisher, K., Lippiello, L.: Close-range photogrammetry vs. 3D scanning: Comparing data capture, processing and model generation in the field and the lab. The Computer Applications and Quantitative Methods in Archaeology (CAA) 2012 conference, 2012.

[26] Yastikli, N. Documentation of cultural heritage using digital photogrammetry and laser scanning. Journal of Cultural Heritage, 2007, 8(4), 423-427.

[27] Butnariu, S., Gîrbacia, F., and Orman, A. Methodology for 3D reconstruction of objects for teaching virtual restoration. International Journal of Computer Science, 2013, 3(01), 16-21.

[28] McGlone, J.C. Manual of Photogrammetry, 5th Edition, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, 2004.

[29] Azuma, R.T., A survey of augmented reality. Presence-Teleoperators and Virtual Environments, 1997. 6(4): p. 355-385.

[30] Rohs, M. Oulasvitra.A. Target acquisition with camera phones when used as magic lens. In Proceedings of the 26th International Conference on Human Factors in Computing Systems, CHI ’08, pp. 1409–1418. ACM, 2008.

[31] Pryor, H.L., Furness, T.A., and Viirre, E., The Virtual Retinal Display: A New Display Technology Using Scanned Laser Light. In Proceedings of the 42nd Human Factors Ergonomics Society, Santa Monica, CA. 1998, pp. 1570-1574.

[32] Hua, H., Gao, C., Biocca, F., and Rolland, J. P. An ultra-light and compact design and implementation of head-mounted projective displays. In Virtual Reality, 2001. Proceedings. IEEE. pp. 175-182.

[33] Puyuelo,M., Higón,J.L., Merino,L., Contero,M. Experiencing Augmented Reality as an Accessibility Resource in the UNESCO Heritage Site Called “La Lonja”. Procedia Computer Science, 2013, vol. 25, pp. 171-178.