

Enhanced Interaction Experience for Holographic Visualization

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Abstract

Nowadays, holographic visualization pushes further the limits in exploring tri-dimensional digital content. 3D models typically displayed through a computer screen now enter the real world as holograms. The Hologram Table allows users to visualize and manipulate huge 3D models as if they were in the space in front of them. Its use has already proved helpful for the virtual fruition and presentation of complex cultural heritage buildings and their design interventions, but it surely can do more. The work aims at exploring the possibility of expanding the capabilities of the Hologram Table interaction by developing a custom-designed experience to interact with 3D point cloud data coming from survey activity. The test case was the interesting building of the Santa Maria delle Grazie (Milan, Italy) basilica. Initial results are encouraging and show that the point model can be enriched with associated information and additional content (images and texts) available for holographic visualization.

Keywords

cultural heritage, euclidean hologram technology, hologram table, point cloud, Unity.



Introduction

Holographic visualization allows you to overcome the limitations of the flat screen of a computer in the exploration of tri-dimensional digital content. Thanks to holographic devices (e.g. Microsoft HoloLens [Weinmann et al. 2021], Magic Leap [Wunder et al. 2020]), 3D point and mesh models now can enter the real world in the form of holograms [Kyung-Jin et al. 2020]. These seem to be the most futuristic way to view and intervene, even on large-scale or large-detail digital data. These visualization tools proved useful in many different applications ranging from industrial to medical [Fraga-Lamas et al. 2018; Brun et al. 2019]. In this ever-changing context, the world of Cultural Heritage (CH) strives to keep up with applications mainly relegated to tourism, dissemination and museums [Voinea et al. 2019]. In recent years, holographic visualization is entering the professional practice allowing for visualization and management of monumental heritage architectures [Teruggi, Fassi 2021]. Holograms could become an integral part of conservation procedures and virtual understanding of CH structures [Reaver 2019]. The difficulty lies in the production of the 3D content to be displayed. Indeed, if the modelling process is straightforward for industrial and standardized objects, it is not so for CH objects. In this field, similar elements are instead different in their geometry when considerable metric accuracy has to be maintained; besides, the complicated and time-consuming modelling phase usually introduces a certain degree of simplification, which depends on the subjective interpretation of the operator or specific software limits. However, thanks to the considerable advancement made in the survey techniques, nowadays, it is possible to have a complete and accurate description of even the most complex object in the form of point clouds. Architects, designers, historians, installers, and researchers could benefit from these accurate and precise representations. They could act as tools to collect and display digital models and their referenced information that can be accessed at any time and for any purpose. Having the possibility of tri-dimensionally enquiring and navigating through this data can undoubtedly enhance object understanding as well as communication exchange between all actors involved in the conservation/reuse/design process. Previous works investigated the possibility of using the Euclidean Hologram Table to visualize and manage complex and huge CH point clouds [Bolognesi et al. 2021]. The tested Euclidean proprietary software package allows setting up and displaying a dynamic 3D presentation where the users can navigate 3D models at different scales. This first experiment outlined a great potential in the holographic device and visualizations. Despite the high number of points to be managed, the navigation is incredibly fluid and lets to zoom in to see a high amount of detail. However, the standard interaction paradigm with the point model stops here; it is only possible to pan, orbit, zoom, and some basic annotations (e.g., labels, measures), but all basic information added during the navigation is lost when the device is turned off. Adding information and modification to the point clouds or the mesh models must be performed outside the holographic environment.

Recently, Euclidean Holographics released the Unity Toolkits (V0.5.62082), which are library integrations that allow developers of the Unity 3D game engine to interface with the hardware of the Euclidean Hologram Table. This new aspect opens a world of possibility, allowing it to enhance and expand user capabilities to interact with holographic models. In this work, the authors explore the possibility of broadening table device interaction capabilities by developing a custom-designed experience to interact with 3D point cloud data coming from survey activity. The test case was the basilica of Santa Maria delle Grazie (Milan, Italy).

The Basilica of *Santa Maria delle Grazie* Digital Survey

The basilica of Santa Maria delle Grazie has been digitally surveyed during several measurement campaigns due to its significant dimension and complex structure [Bolognesi, Fiorillo 2019]. The south side of the complex is occupied by the Solarian church (with three naves on the longitudinal layout and side chapels) with its Bramante tribune. The Chiostro dei Morti (post-war reconstruction after 1943 bombings) borders are on the south side with the

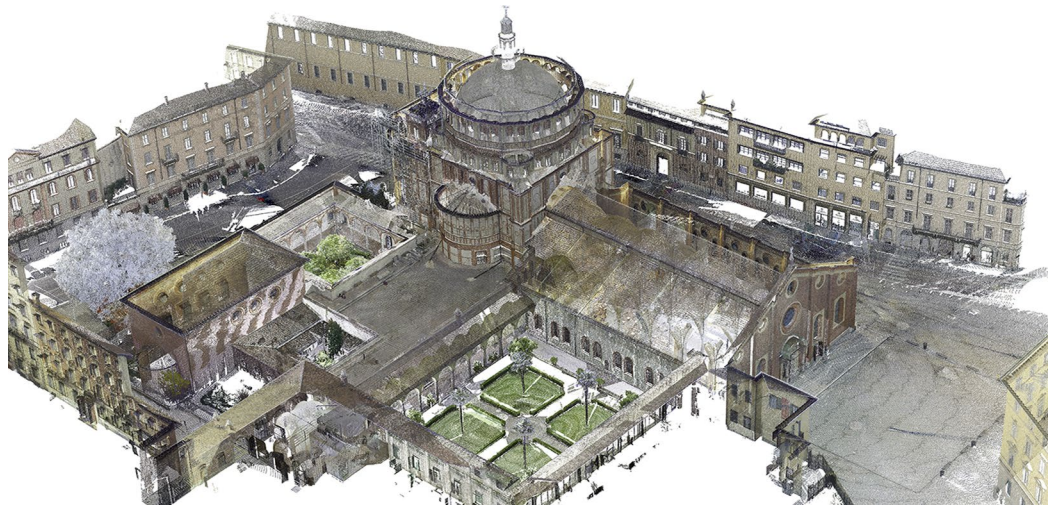


Fig. 1. The Basilica of Santa Maria delle Grazie, Milan, Italy (Point Cloud view).

church, on the east side the new sacristy of Ludovico il Moro and on the west side with the refectory (where the Last Supper fresco by Leonardo da Vinci is located). The old sacristy and the Chiostro delle Rane by Bramante and the small Chiostro del Rettore (also known as Chiostro del Priore) are located on the east side of the monastery complex. The church was included in the UNESCO World Heritage List in 1980 as an outstanding example of Renaissance art, together with the Cenacolo Vinciano.

The first survey activities conducted in 2019 interested the following areas: the Chiostro delle Rane (16 scans with Leica HDS7000), the Chiostro del Rettore the old and the new sacristy (36 scans with Leica P30). The final model output of these first surveys reaches more than 2 billion points. The most recent on-site campaigns (2020-21) were instead carried out with a Leica RTC360 for the 3D measurements of the tribune dome (internal and external surface) and the outer perimeter and indoors of the church. The latter 3D survey consists of 122 scans reaching about 4 billion points. Each TLS survey campaign is associated with a project where all the scans are referenced in a local coordinate system. All projects then were registered in a single absolute reference system working with cloud-to-cloud alignment algorithms (Leica Cyclone REGISTER 360). Once the registration step was completed, the scans were cleaned up by removing non-interesting objects in the scene (cars, people, etc.) and the noised points (far away, tangent to surfaces, edge effect points, etc.). The final cloud (Fig. 1) resulting from the merge of the 174 scans was sampled at a resolution of 5 mm, also removing the duplicated points due to the significant overlap among the scans (the latter is necessary above all for the target-less registration used).

The case study has undergone many structural transformations over time, offering interesting insights for our research. In the first place, the holographic visualization can help understand and represent this morphologically complex building and better design any interventions. Secondly, by customizing the hologram table interface, many historical, technical and technological data can be added that otherwise would be difficult to associate with the different areas involved quickly. In this way, the point cloud collects at the same time and in a single digital content the metric and geometric information of the current state and keeps track of the interventions and changes made to the building.

Hardware Setup for the Holographic Visualization

The Euclidean Hologram Business Table belongs to the equipment of the LaborA physical and virtual modelling laboratory (Politecnico di Milano) and is arranged in a dedicated dark-room. The device (2.1 m x 2.1 m x 0.6 m) is formed by a flat-screen (1.2 m x 1.2 m) and an embedded projection system (Fig. 2). The latter enables to appear 3D models in the table screen centre up to a height of about 70 cm in a hemispherical volume. The holographic

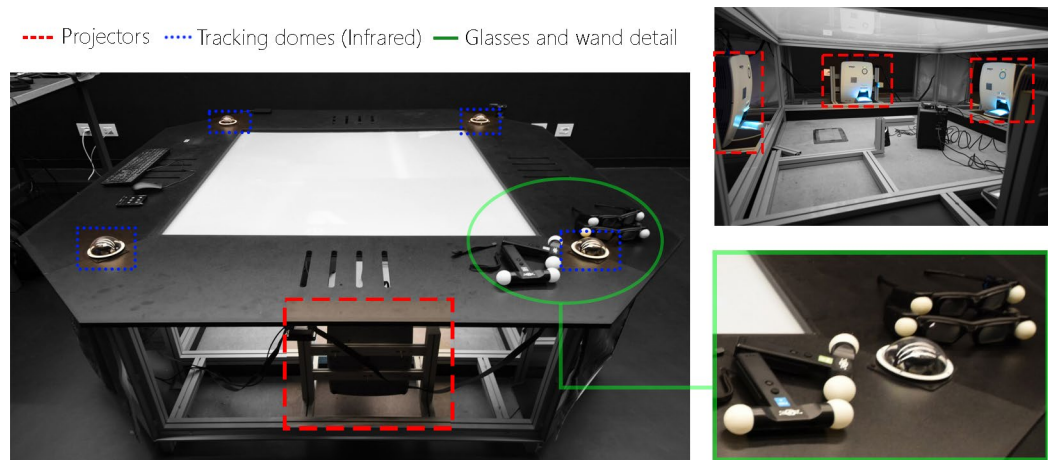


Fig. 2. Euclidean Hologram Table hardware.

device is managed through a workstation (5820 Dell Precision Tower) equipped with two graphics cards (AMD Radeon Pro WX5100). One is dedicated to rendering an external secondary screen (a traditional projector) that allows the model visualization even without glasses. At the same time, the other receives the images to be displayed on the glass surface in the centre of the table through four projectors (Vivitek D757WT with a maximum resolution of 1920 × 1200 at 60 Hz).

A specially designed wand and glasses allow immersive interaction with the holograms, both of which use an infrared tracking system to calculate their position and orientation in space. The tracking equipment consists of four tracking domes arranged in the four corners of the table and controllers, Radio Frequency Dongle and Sync Emitter, connected via USB to the PC. The spheres on the wand and the glasses allow their correct position determination. Indeed, the sync emitter takes light from glasses and wands and sync all devices to work together. Two primary users (equipped with a wand and glasses) can together view and interact with the hologram. A secondary user (fitted with the glasses only) can be added for each primary user, who must be on the same side of the table as the primary user. Thanks to the innovative Multi-User Hologram Technology, two people or two groups can see object projections on the table from different sides. In addition, a supplementary group of users without immersive devices can still participate by looking at the screen or external secondary monitor.

Software and 3D Model Setup

The proposed holographic experience has been developed inside Unity 3D software, a game engine that allows developers to create content for a wide range of devices. Ranging from desktops to virtual and augmented reality applications, software capabilities are limited only by the availability of libraries to interface with the targeted device. The latest Unity Toolkit libraries (V0.5.62082) released by Euclidean have to be imported to interface with the hardware of the holographic table. They contain all necessary functions and methods to access and use sensor streams coming from the device (e.g., wand position, button trigger, wand ray).

The up-to-date HoloTray software has to be installed on the Holographic Table workstation, which is in charge of all background processes necessary to have a correct holographic visualization.

By default, Unity 3D software is able to work and import tri-dimension models in FBX (Film-Box) format. However, this file format is not compatible with point cloud models coming from survey activities. Therefore, it is necessary to use the PCX [PCX 2021] libraries to import and render point cloud data in PLY – Polygonal File Format inside the Unity game engine. Their most basic function is reading all points that make up the model allowing the

software to treat them as a unique 3D mesh model composed only of vertexes (with no sides). Each vertex brings the (R, G, B) data associated with the corresponding point. Nevertheless, the most common file for point cloud exchange among different digital survey software is E57 [Huber 2011], a compact, vendor-neutral format for storing together with the point coordinates the images and metadata produced by 3D imaging systems. Therefore, file conversion and more processing actions (e.g. point cloud decimation, orientation and so on) are needed to import the model inside the developing environment. In this work, all point cloud elaboration have been performed using CloudCompare software, an open-source GNU General Public Licence (GPL) software that can manage/edit both 3D point and mesh models.

The whole point model of the Santa Maria delle Grazie complex is comprised of around 6 bln points at an average resolution of 5 mm. Due to the enormous number of points, the point cloud was subsampled at 5 cm resolution with a final PLY of 14,985,027 points and a dimension of 214 Mb. This point reduction allows i) to ease computational requirements on the hardware during both processing and navigation phases and ii) to retain a good visualization quality when the point cloud is holographically displayed on the Hologram Table. For the correct visualization of the point cloud in Unity3D, it is necessary to flip the Y axis with the Z when saving to the PLY file because the software, like most game engines, works with a left-handed reference system. Only (R, G, B) data are read inside the game engine. Depending on the instruments, survey data could include other attributes (e.g., normal vectors and reflectance). To visualize this additional information in Unity, they must be converted into a corresponding to the (R, G, B) data type associated with each point. This process overwrites the default radiometric information. It is thus necessary to create a different version of the same model to visualize different types of data acquired. For this work purposes, only the authentic (R, G, B) colours of the basilica of Santa Maria delle Grazie have been taken into account.

In summary, the work pipeline that allows employing the survey data in the Unity environment includes the following steps (Fig. 3): 1) scan alignments and point cloud editing (the output file format is generally the E57); 2) point cloud setup for holographic display (model decimation and orientation); 3) model export in a PLY file format compatible with PCX libraries to finally arrived at using Unity Toolkits for the Hologram Table.

Enhanced Interaction Experience

The research aims to transform the point cloud of the complex of Santa Maria delle Grazie into an informative model with associated other relevant information: e.g., pictures, historical photos, textual information, survey data, and technical drawings. Every part of the holographic experience must be programmed using the Unity Toolkits available functions to reach this goal (Fig. 4). From an operative point of view, inside the Unity scene, it is necessary to add the point cloud model and the asset of the Hologram Table present inside the toolkits. This allows to i) have a 3D virtual model of the device and all its sensors inside the unity scene and ii) have all necessary background scripts that will stream the holograms through the table four projectors. All virtual models that have to be displayed on the Hologram Table surface must be positioned referred to the model of the Unity Toolkits asset that can be moved or

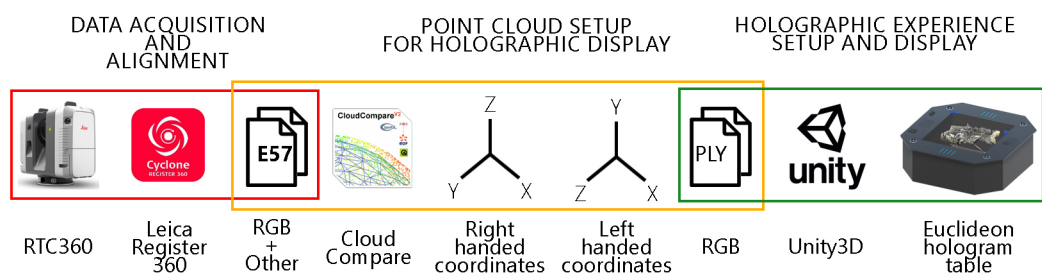


Fig. 3. 3D model setup pipeline.

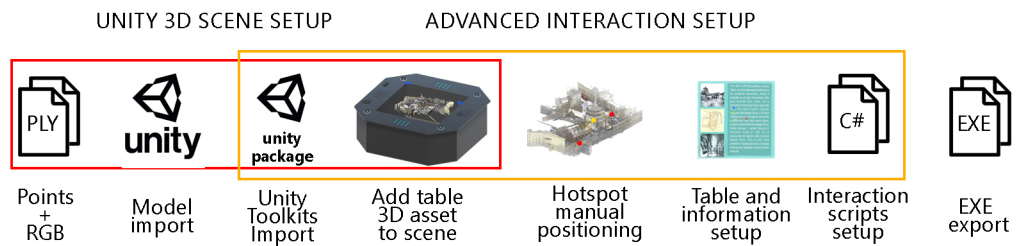


Fig. 4. Unity3D scene setup pipeline.

scaled as necessary. Each object that does not fall into the flat display of the device will fail to show up when running the application. The point model positioning can be aided by simulating the user first point of view (FPV); it gives a rough idea of how holograms will result on the physical device. Alternatively, it is possible to connect the developer computer to the same network of the Hologram Table through an Ethernet cable. In this way, it is possible to live test the application before final deployment making all necessary adjustments.

Specific scripts of the toolkits must be attached to the unity game objects that must react to interactions. These allow each 3D model to be responsive to different actions performed by the user. For example, the toolkits give access to the wand controller ray cast. This is a ray that projects forward from the virtual model of the wand controller and indicates the direction to which this is pointed. Every object looks for an intersection with this ray before allowing interactions. Furthermore, it is possible to access wand signals through specific functions when a particular button is triggered. This allows the development of a conditional system for which a specific task is performed when the 3D object is pointed with the wand and a determined button is pressed. For the basilica holographic project, pointing it with the wand and holding down the secondary button of the wand allows translation 3D content according to the wand position.

The basic setup of the experience presented foresees four different elements that constitute the scene:

1. The Santa Maria delle Grazie point model.
2. 3D red sphere corresponding to each informative hotspot.
3. Planes and text objects that represent the informative table (and its relative information).
4. A contextual menu with info and control buttons.

The hologram model is placed at the centre of the device flat display as the main object of visualization. When the experience is started, only this model with the associated hotspots is visible and responsive to interactions (Fig. 5). Red spheres are manually placed at the position of the correct hotspot and cannot be moved independently from the model. Both objects are responsive to wand interaction; the basilica model can be moved and zoomed, and clicking on the hotspots will turn on the relative table, which is invisible by default. The hotspot table is composed of three-square planes on its left side and a text field on the right part. A single solid colour plane acts as a background for better text readability. While the text field is associated with historic relevant information, a specific picture is associated with each square plane as its texture. Clicking on these last objects will turn on another plane associated with a full-resolution version of the corresponding image. It is important that the tables (and all relevant user interface elements) are placed almost parallel to the device display area. This alignment allows for better readability of the content that can be contained inside the 70 cm height dome rendering areas above the table. Specific, close buttons associated with plane objects allow the full resolution image or the whole table to turn off. The contextual menu is used to access information regarding the survey activity performed. Clicking on the central button allows displaying a table with all relevant point cloud details. Instead, the side buttons allow rotating the model of the basilica displayed. During the development stage, it is necessary to fill in all data contained inside the table and all hotspots associated with the point cloud. Once the setup is finished, it is possible to build the final solution that can run and be displayed on the Hologram Table.

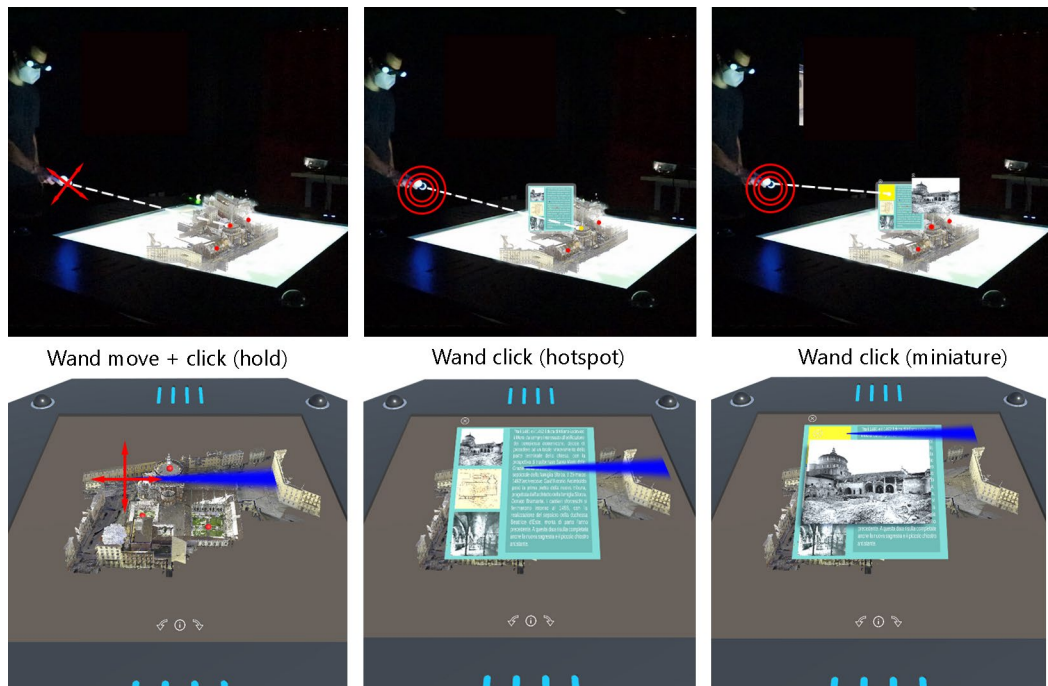


Fig. 5. Holographic experience sequence with first and third-person views.

Conclusions and Future Works

Euclidean Hologram Table, used in its native standard modality, proved to be a powerful point cloud visualization tool and digital model presentation. The advantages of using the standard proprietary software package (Presenter) are different: the management of high numbers of points thanks to the Euclidean Unlimited Detail technology [Euclidean 2013]; no restriction about the point cloud file format; no developer skills need (beginner level of user). However, interaction with the 3D content is basic: pan, zoom, orbit and essential measuring functions.

However, Unity 3D software, expanded with the recently released Euclidean Unity Toolkits libraries, let us transform raw survey data into a powerful, informative holographic model to explore and enquire about different types of knowledge associated with complex heritage geometries. The test experience allowed building a final application where the user can interact with hotspots and virtual information regarding different parts of the CH building. Therefore, the most significant benefit is that both the user interface and digital content are 100% fully customizable. On the other hand, this aspect implies the need for advanced programming and developer skills. One should consider unfavourable aspects to take into account: the restriction about the point cloud file format and the related need to use PCX plugins; and the current impossibility to exploit the Euclidean UD tech to render points using the Unity Toolkits for the Hologram Table. Therefore, it poses a strong limit on the number of points that can be displayed. It is necessary to subsample the point models to an acceptable resolution to retain a good visualization quality while lowering the strain on the device. The last open question that can be developed and improved is whether all associated information to the point cloud is decided a priori. The data embedded in the application during the development process are stored locally on the device. Hotspot position, table fields, and images cannot change during the hologram runtime. The final user can only access types of information and hotspots decided during development. A new version of the application has to be exported each time digital content is added or changed, including user interfaces (UI). For example, hologram visibility is strongly tied to the height of the user. If the application is set for good readability with a certain user height, it may be possible that a lower height user will not see all UI elements due to a high incidence angle of its field of view with the table. Therefore, this change has to be during the UI development in Unity.

In conclusion, this first experiment opens a wide path for future directions. Providing the user with the possibility i) to load/modify/add content (e.g. live section) and hotspots during runtime of the hologram display or ii) to download it through an online connection with a reference database would enhance the information exchange process. Furthermore, adding the possibility to save preferences in different sessions and enabling UI elements to adapt to different users heights would certainly boost both the usability of the product and the overall quality of the holographic visualization experience.

A short video of the presented work is available at the following link: <https://youtu.be/hLP9U3XRVM>

References

- Bolognesi Cecilia Maria, Fiorillo Fausta (2019). Digital Survey in Bramante's Masterpieces. In *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-2/W15, 2019, pp. 193-200.
- Bolognesi Cecilia Maria, Teruggi Simone, Fiorillo Fausta (2021). Holographic Visualization and Management of Big Point Cloud. In *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVI-M-1-2021, 2021, pp. 71-78.
- Brun Henrik et al. (2019). Mixed reality holograms for heart surgery planning: First user experience in congenital heart disease. In *European Heart Journal Cardiovascular Imaging*, 20 (8), 2019, pp. 883-888.
- Euclidean (2013). Understanding UD Technology. <https://web.archive.org/web/20160823095235/http://www.euclidean.com/technology-2> (10 February 2022).
- Fraga-Lamas Paula, Fernández-Caramés Tiago, Blanco-Novo Oscar, Vilar-Montesinos Miguel (2018). A Review on Industrial Augmented Reality Systems for the Industry 4.0 Shipyard. In *IEEE ACCESS*, (6), 2018, pp. 13358-13375.
- Huber Daniel (2011). The ASTM E57 file format for 3D Imaging Data Exchange. In Beraldin Jean-Angelo, Cheok Geraldine, McCarthy Michael, Neuschaefer-Rube Ulrich, McDowallan, Dolinsky Margaret, Baskurt Atilla(eds.). *Three-Dimensional Imaging, Interaction, and Measurement. Proceedings of SPIE Electronics Imaging Science and Technology Conference (IS&T)*, 7864. San Francisco: SPIE, pp. 88-96.
- Kim Kyung-Jin, Park Byung-Seo, Kim Jin-Kyum, Kim Dong-Wook, Seo Young-Ho(2020). Holographic augmented reality based on three-dimensional volumetric imaging for a photorealistic scene. In *Opt. Express*, 28 (24), 2020, pp. 35972-35985.
- PCX, 2021. GitHub – Keijiro, PCX. <https://github.com/keijiro/Pcx>. (10 February 2022).
- Reaver Kai (2019). Three case studies in virtual preservation. Applying virtual reality to Cultural Heritage AGATHÓN. In *International Journal of Architecture, Art and Design*, 6, 2019, pp. 210-217.
- Teruggi Simone, Fassi Francesco (2021). Machines Learning for Mixed Reality: The Milan Cathedral from Survey to Holograms. In Del Bimbo Alberto, Cucchiara Rita, Sclaroff Stan, Farinella Giovanni Maria, Mei Tao, Bertini Marco, Escalante Hugo Jair, Vezzani Roberto (eds.). *Pattern Recognition. ICPR International Workshops and Challenges. ICPR 2021. Lecture Notes in Computer Science*. Cham: Springer, pp. 613-617.
- Voinea Gheorghe-Daniel, Girbacia Florin, Postelnicu Cristian Cezar, Marto Anabela (2019). Exploring Cultural Heritage Using Augmented Reality Through Google's Project Tango and ARCore. In Duguleană Mihai, Carrozzino Marcello, Gams Matjaz, Tanea Iulian (eds.). *VR Technologies in Cultural Heritage. VRTCH 2018. Communications in Computer and Information Science*. Cham: Springer, pp. 93-106.
- Weinmann Martin, Wursthorn Sven, Weinmann Michael, Hübner Patrick (2021). Efficient 3D Mapping and Modelling of Indoor Scenes with the Microsoft HoloLens: A Survey. In *PFG*, 89 (4), 2021, pp. 319-333.
- Wunder Linda, Gonzaga Gomez Nicole, Gonzalez Juan, Mitzova-Vladinova Greta, Cacchione Max, Mato Jampierre, Foronda Cynthia, Groom Jeffrey (2020). Fire in the Operating Room: Use of Mixed Reality Simulation with Nurse Anesthesia Students. In *Informatics*, 7 (40), 2020, pp. 1-13.

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