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A RECONSTRUCTIVE PROPOSAL OF DIOCLETIAN'S BATHS FOR THE 5G EXPERIMENTATION IN ROME

1. The role of 3D APIs: a short state-of-the art

There are many solutions for the virtual enjoyment of 3D scenarios, the most sophisticated ones make use of graphic engines in which the rendering is calculated in real time, and so also shadows, reflections, particle effects and more. All this has been available for some time now and it is made possible by the great computational capacity, not only for modern PCs, but also for consoles and portable devices. The evolution of graphic libraries such as WebGL, OpenGL and DirectX have decreed a real revolution that, thanks to the development of sophisticated APIs, have made Virtual Reality concrete for everyone.

But let's start from the beginning. Today DirectX is the reference system for 3D graphics, but this has not always been the standard. In the past decade we saw a real clash between Microsoft and Silicon Graphics, who were trying to impose their own 3D API: DirectX for Microsoft and OpenGL for SGI. The two companies tried to make their standards stand out and gain the trust of developers, Microsoft using its enormous financial power and SGI offering leadership based on the experience and reputation gained in the field of 3D. In this competition the smaller of the two, SGI, managed to gain an alliance with one of the most famous video game developers, John Carmack, a great pioneer and supporter of Open Source software. Meanwhile, Microsoft was starting the development of its API from scratch.

For several years, the potential of Direct3D had remained inadequate, also due to an interface that many programmers found less clear than the OpenGL one. However, Microsoft continued to invest in Direct3D, which had several positive upgrades over the years. The turning point was reached with DirectX 8, presented in 2001. For the first time, Microsoft APIs were bringing real innovations and not just offering OpenGL surrogates. The advent of Direct X 8 was a real problem for SGI, whose main profits came from the sale of expensive graphics workstations. Probably, the mistake of Silicon Graphics was not having understood that the explosion of the 3D graphics board market for gamers would have allowed ATI and nVidia to conquer important slices of the professional market, with extremely competitive prices, impossible to replicate for SGI.

The development of the OpenGL was also hindered by some disputes between the different supporters of the two technologies. With DirectX 9 Microsoft imposed its API on developers and the number of OpenGL supporters became increasingly small. When Khronos Group acquired OpenGL only a few years ago, everyone was anxiously awaiting news. The release of OpenGL 3 was announced, a revised version of the API that could compete with Microsoft, which meanwhile announced a future generation of API, DirectX 11. In short, a continuous race towards leadership, towards performance and market control. What is most interesting in our arguments, however, is the sense that, as content creators, we can give the 3D scenes inherent to the reconstruction of archaeological contexts. Indeed, OpenGL has not completely left the market, indeed a legacy of its own has greatly influenced the use of 3D scenarios on the web, i.e. WebGL, which is based on Khronos Group's OpenGL ES 2.0. Actually, OpenGL has not left the market completely also, indeed a legacy of its own has greatly influenced the use on the web of 3D scenarios, i.e. WebGL, which is based on Khronos Group's OpenGL ES 2.0. WebGL is a Web-based Graphics Library, integrated into the HTML language to provide a 3D graphics API within web browsers. This library is certainly a real revolution for the web, because it allows developers to insert explorable 3D objects into their pages, which do not require the installation of extra plug-ins or additional programs to work.

So by combining the latest version of the WebGL library and HTML5 language with JavaScript and CSS, you have the possibility to create animated 3D web projects. From an operational point of view, real time engines, such as Unity 3D and Unreal Engine allow to obtain the highest quality, but within a system that requires the presence of a more or less complex 3D model. The adoption of WebGL libraries allows you to manage only part of this potential, but offers very interesting alternatives for immersive navigation (Fig. 1).

2. Stereoscopy for immersivity

The main issue related to the use of high-end immersive applications, i.e. developed on the basis of complex 3D scenarios navigable in every direction in real time, is their management in museums. A first critical factor in this regard is the lack of specialised personnel. Such applications require the use of a PC and a start-up routine operation, necessary for calibration and control of the boot parameters. These operations are not critical at all, but require the presence of an experienced staff, who can also solve any application crashes if necessary. A second critical factor is the number of users who can simultaneously view the content. Virtual headsets such as HTC Vive or Oculus Rift, leader at the moment of VR systems, each one needs a connection to a single PC, so if you want to show your applications to a certain number of visitors, you will have to consider the necessary investments to purchase several complete systems.

For those who want to create VR rooms with multiple workstations, there are collaborative environments where different users can live together a collective experience, such as the Facebook Spaces application, or the rooms

Fig. 1 – A fragment of trabeation (a) and a basis of a Corinthian column (b).

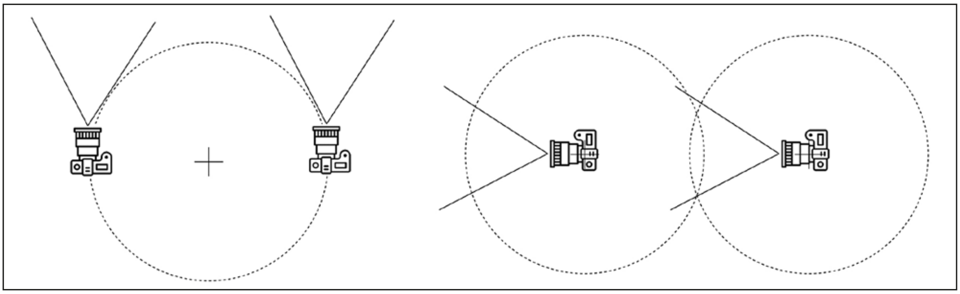

Fig. 2 – Example of typical stereoscopy error. The axis rotation on a single camera produces errors in interocular separation. The rotation around the axis of the camera pair produces parallax error.

available on Samsung and Oculus platforms, which are very interesting for possible social sharing and interactions. This kind of experience, of course in a reduced form, can be achieved even without major investments, using your smartphone or the new Oculus Go viewers, i.e. all the standalone virtual reality headsets. The use of these viewers does not require any particular computer skills or user skills, and focuses on the quality of 3D stereoscopic vision (Fig. 2). The scenes will not be navigable in real time as in PC-based systems, and the visitor can only "jump" from one viewpoint to another. But the representation, being pre-calculated, i.e. based on rendered panoramas, has no limitations on the number of polygons and algorithms, and is equally effective for the end user.

In fact, perhaps the most incisive element in the VR visit experience is the ability to develop an immersive navigation, where the user has the real feeling of being in the reconstructed space. The "sense of presence", the feeling of making the object "graspable", its almost real perception, are part of an emotional participation that creates more empathy and therefore greater understanding of the message communicated.

3. Basic requirements

In order for this important result to be achieved, every specialist in virtual archaeology must best meet certain indispensable prerequisites. The first requirement is the scientific reliability of the reconstruction, i.e. its "credibility" both on a technical-constructive and historical-aesthetic level, its adherence to the scientific data coming from the available documentation, to the principles of good building and to those documented in a given historical period, in a specific civilization. The second requirement is its verisimilitude. This is again about "credibility" or "plausibility". Materials and objects must correspond to their references in the real world, and the rendering algorithm must be able to represent them with the correct physical characteristics of roughness, reflection, refraction, etc.

Finally, the lighting must be able to emphasize a particular setting, a mood with recognizable, personal, strongly expressive characteristics. Quoting Le Corbusier: «Architecture is the masterly, correct and magnificent play of masses brought together in light. Our eyes are made to see forms in light; light and shade reveal these forms». Light is therefore the element that generates the shading necessary to understand the morphology of an object, but also a way to represent aspects that would otherwise be difficult to perceive. Just think of the "raking light" lighting techniques, useful to the restorer to highlight the surface roughness; or of the artistic productions that great masters like Caravaggio have left us.

All this will have to be enjoyed in stereoscopic mode, which is, in my opinion, the fundamental prerequisite for satisfying immersion. In the new generation headsets, the stereoscopic enjoyment is very comfortable and the user has the clear impression of being inside a real scene. An interesting case study, in order to obtain a comfortable immersive vision, was recently tested in the reconstruction of the Baths of Diocletian in Rome, as part of a project to test and launch 5G technology in Rome.

4. The Baths of Diocletian in VR

The 5G technology, which is a fifth generation network, will be officially available from 2020 and will connect millions of devices worldwide at high speed and low latency, allowing the realization of advanced projects in the fields of smart technologies, internet of things, smart cities and next generation smart homes. The use of this new high-speed connection will also positively involve, in the near future, the enjoyment of cultural heritage, offering new and more powerful solutions, especially in the field of immersive VR/AR visualization.

With these premises, a project was born that aims to virtualize some spaces of the Baths of Diocletian through innovative, immersive, emotional

Fig. 3 – The Baths nowadays.

and persuasive solutions (Fig. 3). The solution is based on pano and VR video, i.e. 360° spherical panoramas that allow the stereoscopic vision and, above all, the animation of the scene, thus increasing the "sense of presence" of the observer and the immersion in the ancient space. This is populated with life, with human figures and elements that increase the spatiality of the reconstruction (sense of scale, presence, verisimilitude). The virtualization concerns the spaces connected to the gym: the open porch, the side rooms and the Aula Ottagona, transformed in 1928 into a Planetarium, of which an extraordinary umbrella dome is still intact. From a methodological point of view, the reconstructed spaces represent an example of "typological reconstruction", where fragmentary and incomplete information, extremely important and precious on the scientific level, is continuously weighed on the technological-functional and historical-aesthetic level, in an attempt to find a plausible reconstructive solution.

In spite of the many information gaps, especially on the decorative apparatus, the 3D restitution shows us again the monumentality of the ancient spaces, with the mosaic carpets reconstructed on the basis of the preserved remains and a compositional articulation closely connected to the peculiar construction logic of the Roman baths (Fig. 4). Noteworthy are the marble columns and the large barrel-shaped vaults, that intersect and design crosses on which the thermal windows open, large semi-circular openings that originally appear in the Baths of Diocletian and then will become typical of the architecture of Palladio and many architects of Italian Renaissance. Many

Fig. 4 – The virtual restoration of the mosaic located in via Cernaia.

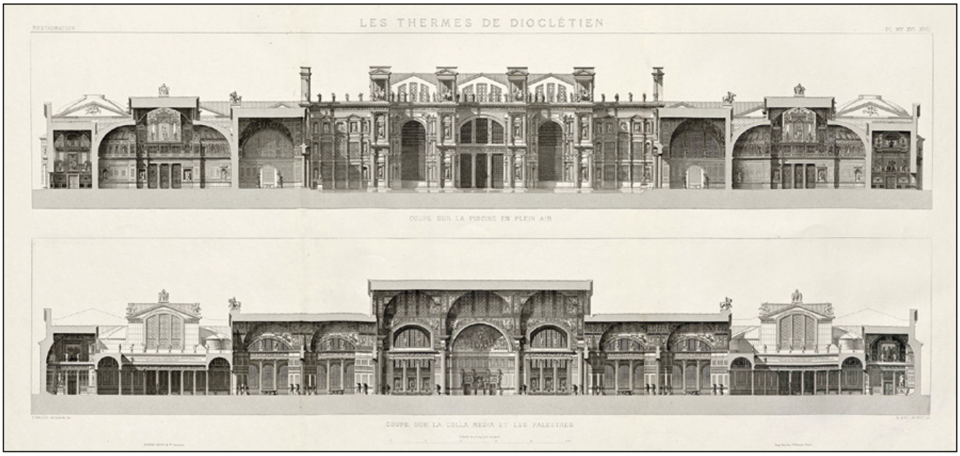

Fig. 5 – Paulin's reconstructive drawing.

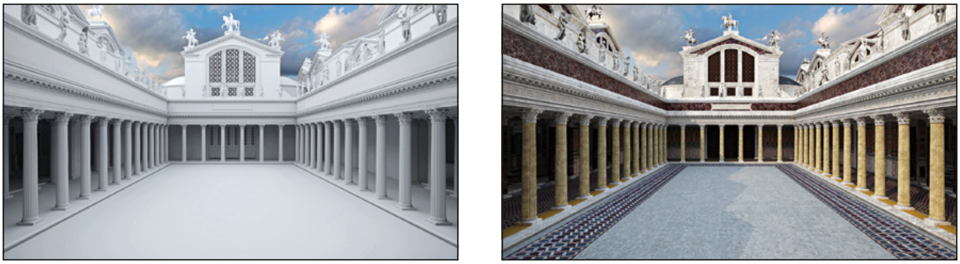

Fig. 6 – a) 3D model without textures of the palestra. See at the top-left of Paulin's reconstruction for a comparison; b) 3D reconstruction of the palestra with mosaic floor restoration and reconstituted fragments.

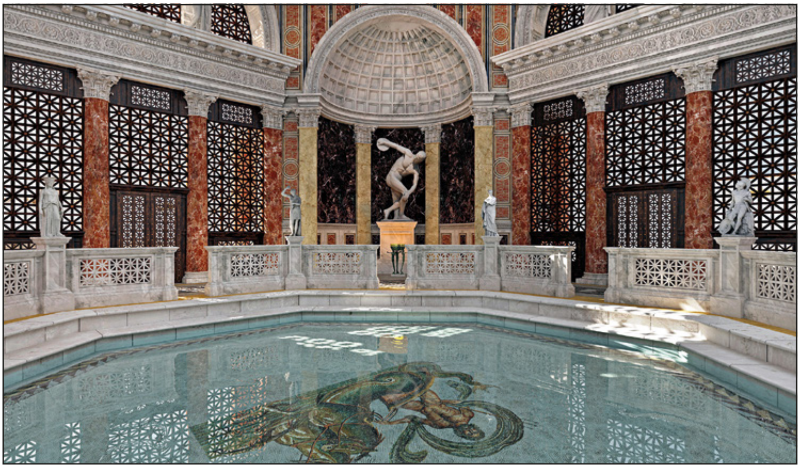

Fig. 7 – 3D reconstruction of the Sala Ottagona (little *frigidarium*).

Fig. 8 – Interiors 3D reconstruction.

architectural elements have been restored starting from the preserved ones, but the aim of the project is to offer a reconstructive proposal with a double purpose: to provide the visitor with tools for a knowledge of the good in line with the potential of modern technologies, and to represent the thermal complex with a complete re-enactment solution.

An interesting solution, to this end, is offered by the study of Edmond Jean-Baptiste Paulin (1848-1915), a *pensionnaire* of the French School in

Rome, who in 1880 published an in-depth study of the Baths of Diocletian, with surveys, restoration proposals and a very detailed reconstruction (Fig. 5). His drawings are very interesting, not for the reliability of the reconstruction, which is fanciful in some parts, but for the adherence to shapes, colours and architectural detail solutions, which he has been able to document in other contexts or to deduce from logical observations (Fig. 6). The result in this project is an updated vision of his reflections, combined with the observations and deductions peculiar to the 3D study, but with the added value of immersive vision. An integrated headset (Oculus Go) has been used for the 3D view, with which the 5G bandwidth allows the display of very high resolution scenes, with 6K VR video and 8K multi resolution scenes. This is a low cost technological solution that focuses on the quality of the reconstruction, within a simplified visit logic (Figs. 7-8).

5. Hardware related issues

The software part has been developed exploiting the potential offered by WebGL libraries, which allow an optimal management of stereoscopic resources also on mobile devices. But why take an interest in stereoscopic viewing when all major TV manufacturers have long since abandoned the development of home stereoscopic products? The blockage of the commercial diffusion of this technology does not demonstrate the irrelevance of 3D in the vision, but rather a bad management of SW and HW resources connected to 3D. The effects of motion-sickness, the main culprit for the abandonment of this technology in the home environment, is often due to the production of low quality content, poor vision systems, or viewing difficulties experienced by a significant group of users. Very often the use of an integrated approach between software development and the management of dedicated hardware, necessary to ensure the highest levels of visual comfort, has been neglected. As a result, 3D enjoyment has been moved exclusively to a professional environment, where all these factors need to be carefully weighed to reduce vision problems. In the specific case dealt with here, some problems related to the production and viewing of stereoscopic panoramas have been detected, which can be completely eliminated with small expedients.

This does not prove that immersive technologies are winning, but that simple expedients, often overlooked in the past, can solve problems that are considered an unavoidable part of the technology itself. A first problem to avoid is the correspondence between the stereo channels. When calculating the rendering with GI algorithms, the different rendering of the right and left channel must be taken into account, due to the stochastic approach of the light samples. If not corrected, this calculation feature leads to obvious differences in the two channels, with inconsistent colour spots in the stereoscopic pair, this causes motion-sickness. An effective solution is to calculate the GI for only one channel, saving the Irradiance Map to file. In this way the right and left channel will share the same Global Illumination, with the total disappearance of the problems just described. This, combined with camera target control and interocular separation (fixed at 6.5 cm), produces almost perfect stereoscopic panoramas.

A further control of the Mip Mapping, managed with cubemap of 2048 pixels per face (power of 2) and a frame buffer parameter set to 2 pixels, has completely eliminated flickering in the viewer, contributing to the almost total elimination of motion-sickness due to the software. The hardware component is very effective in itself and provides excellent visual comfort when supported by quality content. This kind of methodology is applicable on stereoscopic panoramas obtained from scenes completely generated on the computer, then from virtual reconstructions or 3D modelling of elements, and 3D scenes of various types. In real footage, on the other hand, the 360° stereoscopic vision has recently been resolved by several manufacturers who, with similar principles, have put dedicated hardware on the market. The various solutions available are distinguished by the functional characteristics offered and by the quality of the stitching, but the distinctive element is certainly the quality of the optics, which make these devices slide into high price ranges, out of the consumer market.

The minimum resolution for fixed, non-animated scenes is 8K, but many devices now reach 12K and 8K in stereoscopic animation. These hardware solutions are the result of years of experimentation, during which the most varied expedients have been used. A first valid solution was proposed a few years ago, following an optimization of the stitching composed of many pieces. In practice, the overall anamorphic image is generated by a very high series of footage with a very narrow focal length, which makes the parallax-induced error negligible. For the system to work, in fact, the two stereoscopic cameras must rotate around the same axis, as is the case with human binocular vision. This means that the two cameras do not rotate around their axis, but around an eccentric axis which, as is well known, produces significant stitching problems induced by its own parallax.

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Francesco Gabellone
NANOTEC – CNR
Campus Universitario Ecotekne - Lecce
francesco.gabellone@cnr.it

REFERENCES

Abdul Rahim E.E. 2013, *Exploring a Desktop Virtual Reality Application for Education*, PhD Thesis, Department of Informatics and Enabling Technologies, Lincoln University.

Ben-Ezra M., Pritch Y., Peleg S. 2001, *Omnistereo: Panoramic Stereo. Imagine*, «IEEE Transactions on Pattern Analysis and Machine Intelligence», 23, 3, 279-290.

Bourke P.D. 2008, *Omni-directional stereoscopic fisheye images for immersive hemispherical dome environments*, in E. Prakash (ed.), *Proceedings of the Computer Games & Allied Technology 09 (CGAT09)*, Singapore, Research Publishing Services, 136-143.

Gabellone F. 2015, *Digital technologies and communication: Prospects and expectations*, «Open Archaeology», 1, 1 (https://doi.org/10.1515/opar-2015-0005).

Gabellone F. 2017, *The reconstruction of archaeological contexts: A dialectical relationship between historical-aesthetic values and principles of architecture*, in N. Masini, F. Soldovieri (eds.), *Sensing the Past*, 1128 Springer International Publishing AG 2017, Vol. 16.

Gabellone F., Giannotta M.T., Ferrari I. 2014, *La valorizzazione di contesti inaccessibili nella necropoli greca di Taranto: un modello di fruizione multimodale basato su interfacce naturali*, «Arkos Scienza Restauro e Valorizzazione», 2.

Gluckman J., Nayar S., Thoresz K. 1998, *Real-time omnidirectional and panoramic stereo*, in *Proceedings of the DARPA Image Understanding Workshop*, *IUW'98 (Monterey, CA,1998),* Monterey, CA, 299-303.

Huang H.C., Hung Y.P. 1996, *Panoramic stereo imaging system with automatic disparity warping and seaming*, in *Proceedings of International Conference on Image Processing and Character Recognition, ICS'96 (Taiwan 1996)*,Taiwan, ROC, 48-55.

Parisi T. 2015, *Learning Virtual Reality: Developing Immersive Experiences and Applications*, O' Reilly Media.

Peleg S., Ben-Ezra M. 1999, *Stereo panorama with a single camera*, in *Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition, San Juan (Porto Rico 1997)*, Los Alamitos, CA, IEEE, 395-401.

Tzavidas S., Katsaggelos A.K. 2002, *Multicamera setup for generating stereo panoramic video*, in *Proceeding of the 2002 SPIE Conference on Visial Communicatins and Image Processing (VCIP)*, San Jose, CA.

ABSTRACT

The 5G is the fifth generation of networks. It will officially arrive from 2020 to connect millions of devices all over the world with high speed and low latency, to enable advanced projects based on smart technologies, Internet of Things, smart cities and a new generation of smart houses. The use of this new high-speed connection will positively involve, in the near future, the virtual enjoyment of cultural heritage, allowing to offer new and more powerful solutions, especially in the field of immersive VR/AR visualization. On these premises we have carried out a project that aims to virtualize some spaces within the Diocletian Baths through innovative, immersive, emotional and persuasive solutions. The results are based on simple panoramas and 360° VR videos. However, they are enhanced with the stereoscopic vision and, above all, the animation of the scene, thus increasing the "sense of presence" of the user. The immersive visit within ancient spaces is populated with life, human figures and elements that increase the spatiality of reconstruction (sense of scale, presence, verisimilitude).