SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 6, Issue 1 (2016), 67-78
e-ISSN 2239-4303, DOI 10.2423/i22394303v6n1p67

PERSONAL HAND-HELD DEVICES AND VIRTUAL REALITY PASSIVE TECHNOLOGIES FOR DIGITAL HERITAGE BROWSING: LESSON LEARNT WITH THE KIVI PROJECT

*Violette Abergel, Renato Saleri, Laurent Bergerot, Livio De Luca**

*UMR 3495 MAP – Lyon - Marseille, France.

Abstract

A common issue for 3D real-time displaying concerns the amount of computing resources needed to perform smooth photorealistic sequences. Fast frame-rates and user-responsive interactions are hugely costly in terms of datasets workflows and digital effects processing: real-time cast-shadows, advanced lights effects, depth of view blurring and ambient-occlusion rendering are putting in severe strain the most recent rendering solutions. Certainly, the real-time rendering of architectural and digital heritage artifacts do not need advanced FX sets, commonly involved in multi-user role-games, but instead require very detailed 3D models to permit accurate surveying protocols and detailed scientific observations.
The recent (re)discovery of light immersive VR solutions brought to the front outdated problematics, revealed more than 20 years ago with the rise of former Virtual Reality experiments: early Nintendo Virtual Boy (1995) and the NASA's Incredible Helmet (mid 90's) explored personal immersive capabilities but without meeting at that time it's potential market.
Today, with the rise of low-cost smartphones mounts, we face similar issues : despite poor computing capabilities, reduced wireless bandwidths and low-polygons 3D models, the KIVI project explores technical and ergonomic opportunities that could today – with the use of personal hand-held technologies - ensure a rewarding experience in the virtual discovery of architectural and heritage artifacts.

Keywords

Virtual reality, multimedia databases, immersive visualization, 3D geometry optimization.

1. *Introduction*

Recently introduced within the International Congress on Digital Heritage 2015 – Expo (De Luca, Fischer, Guidi & Torres, 2015), KIVI is an immersive visualization kit for 3D object databases. The aim of KIVI is to simply make available the virtual reality paradigm to enhance the comprehension and the visualization experience of 3D objects.

As a matter of fact, recent technical breakthroughs in the domain of 3D surveying and modeling techniques and present challenges in digital heritage comprehension and preservation brought to life massive heterogeneous databases, containing lots of multi-purpose high-cultural value 3D objects. For instance, the CARARE (CARARE Project, 2013), 3DCOFORM (3D-COFORM project, 2013) and 3D ICONS (3D ICONS project, 2014) projects, carried out by some scientific international consortia in the last years collected thousands of 3D models (with complementary 2D media) today accessible in EUROPEANA (Europeana Foundation, 2008).

To support their broadcasting, Virtual Reality and more specifically immersive visualization appears today as a major vector and, somehow, an ideal solution.

KIVI, based upon current smartphone capabilities, has been tested within a 3D database developed by the MAP research team and was first introduced during the International Congress on Digital Heritage 2015 (Abergel, Saleri, Lequay, & De Luca, 2015b). First results were quite promising with specific 3D content although minor hardware limitations revealed some implementation issues which led - in fact – to a poor "ready to use" environment.

In this paper we will explain how the state of the art of present mobile technologies had an important influence upon our database management strategies and object displaying approaches.

2. Related Works

A common solution to manage, study and accompany the heritage conservation process consists in gathering and broadcasting digital content over the web through multimedia online databases. Yet, interesting approaches exist for sharing original and interactive visualizing contents to end-users (De Luca, Busarayat, Stefani, Veron, & Florenzano, 2011; Jiménez Fernandez-Palacios, Remondino, Stefani, Lombardo, & De Luca, 2013), with the aim of optimizing the diffusion targets – regardless of their complexity or their structure (D'Andrea, Niccolucci, Bassett, & Fernie, 2012). This approach mostly involves sustainable software environments and standardized and intuitive manipulation sets for cross-platform "plug-in free" solutions (Webel, Olbrich, Franke, & Keil, 2013).

Virtual Reality (with the use of sensorial immersion and depth perception) can enhance the recognition of complex 3D scenes for non-expert users (Ibrahim, Ali, & Yatim, 2015; Livatino, Cuciti, & Wojciechowski, 2006; Callieri, Leoni, Dellepiane, & Scopigno, 2013). The potential of 3D data display offers a renewed interactive experience and an effective mediation overall quality. However, main present issues concern the specific data-transformation process, necessary to broadcast 3D contents on the web (low-bandwidth, online 3D display standards...) (Congote, Segura, Kabongo, Moreno, Posada, & Ruiz, 2011), but also interaction ergonomy, in order to provide simple and intuitive connections between the 3D models and the final-user.

Recent breakthroughs brought exciting tech-solutions to even enhance real-time interactions with immersive devices: amongst others, the Kinect© and the Leap Motion© certainly are today the most known motion-based game controllers. However, we believe that they tend to become a major obstacle for sustainable cultural dissemination as they tend to affect the optimal compromise between efficiency, durability, convenience and accessibility.

Next to the HTC Vive© or the OSVR©, the Oculus Rift©* is today certainly the most common and widely known immersive interface (Oculus VR©, 2015). Its side-by-side stereoscopic mount combined with a real-time rendering processed by a remote computer, offers a twin-biconvex lens system focusing on a unique 5.7" diagonal screen with a 1920x1080 pixels resolution. The Oculus Rift© features internal gyroscopes, accelerometers and magnetometers, and sends through a 1000 Hz USB outgoing signal the user-position parameters to a nearby computer. According to this spatial information, the computer's GPU sends back - within a 60-75 Hz refresh rate - the stereoscopic view port of the observed 3D immersive scene. The indisputable efficiency of such a system depends on:

1) The efficiency of the stereoscopic display, which provides a significant depth perception,

2) The ability of the sensors to provide accurate position measurements with a high refresh rate, in order to instantly match the user viewing direction and thus, the orientation of the virtual cameras,

3) The effectiveness of the GPU, the more affected component in this configuration.

Besides the effectiveness of such a system, it needs to be connected to a strong external GPU able to provide at least a constant 75Hz frame-rate 1080p display. Former tests also revealed a noticeable screen-door effect caused by a low 386 dpi screen-resolution. We believe that this present version, lacking some evolutive features, doesn't ensure a sufficient technological sustainability. Besides the twin wires heavy connection, upcoming releases of the OR© will certainly need to provide a higher resolution display with the consequence of enhanced graphics processing capabilities and, thus, heavier connection interfaces between the head-mount and the processing unit. For common users this will probably lead to periodical expensive computer graphics and processing unit replacement, and to complex software upgrade, which could be in time both expensive and disheartening.

Recent light-weight - low cost solutions flooded the market with the intent to provide simple VR experiences, with the use of integrated sensing devices of personal smartphones. The Archos©, the Homido© mount or the very cheap Google Cardboard are very effective "universal headsets", ready-to-play the increasing offer of immersive games or interactive contents (Google, 2015).

The increasing computation power of such personal devices creates new and interesting VR opportunities. Present mid and high-range smartphones offer leading-edge capabilities, provided with gyroscopes, accelerometers and magnetometers, high definition 4,5“ to 5,7“ HD, fullHD, WQHD, or even 4K displays. We think that the success stories of recent passive head-sets are due to the rate of evolutivity of personal communication devices combined with their overall capacity and the exponential growth of the offer in terms of downloadable VR applications, providing ready-to use immersive solutions and even more sophisticated content. Hardware periodical revisions and a quick range turnover improve the overall accessibility and significantly lowers its obsolescence, improving by the way the sustainability of the entire system[1].

Manufacturers all over the world rushed through these opportunities and developed specific solutions to meet the needs of users: we must here distinguish “active” and “passive” VR headsets:

“Active headsets” are integrated solutions - like the Samsung Gear VR mount (Samsung, Presentation of the Samsung Gear VR, 2015) - embedding high-rate movement-sensors (accelerometers, gyroscopes, magnetometers, proximity and presences sensors…) freeing the smartphone overall activity which will be able to focus on computing and displaying processes. They offer versatile and lightweight immersive solutions, often with higher screen resolutions and, thanks to their wireless status, easier user movements.

Nevertheless, on-board smartphone GPU’s are still weaker than remote computing solutions - like the OR© environment - and need to load, in order to achieve higher frame-rate renderings, pre-processed low-polygons 3D scenes.

These solutions are moreover quite expensive, only accessible to advanced users and are often built for a small range of compatible devices: the Samsung Gear VR is only compatible with two specific smartphones and costs up to 200€.

“Passive headsets” are simple hardware mounts, versatile enough to dock-in a wide variety of existing devices. They only provide a stereoscopic headset, which leads the smartphone to perform both sensing and computing tasks. Their simplicity and ease of manufacture, in conjunction with the rapid technological improvement of smartphones capabilities, are the reason of their recent massive surge. No matter the brand or the inner qualities of the handset, the only issue depends on the presence of specific sensing devices. Experience fidelity is based on the specific type of smartphone involved. Starting with the inexpensive Google Cardboard mount to the more sophisticated Archos or Homido headset, and generally priced between 1€ and 70€.

The accessibility and the simplicity of such a technology is certainly a huge advantage for digital multimedia dissemination of architectural and cultural heritage knowledge, and besides, the main reason of our interest in developing our own integrated VR solution: the KIVI project.

3. *Innovation*

3.1 KIVI: System overview

At this stage of our research, our strategy was to achieve the convergence of these fields of interest, in order to provide accessible immersive visualization tools to everyone for a wide variety of highly valuable cultural heritage 3D models. To do this, we considered existing virtual reality modalities compared with prevalent smartphones and tablets emerging technologies offering both easy-to-use adaptive mounts and cross-platform/cross-connected applications providing user-centered sets of informations and realistic immersive 3D scenes.

To do so, we presumed that most connected users owned a state-of-the-art portable device, powerful enough to take advantage of such new cultural learning and diffusion paths, and that the ergonomy of our environment didn’t require specific learning or even an additional piece of

---

[1] Statistical data from Mediametrie, concerning the use and implementation of media in France, point out the extensive smartphone distribution as high as 50% of the French population, with a peak of 79.2% for those under the age of 25 (Mediametrie, Statistics on media behavior in France (2015)). GFK anticipates an overall world-wide distribution close to 70% within 3 years (Gesellschaft Für Konsumforschung, 2014). Besides, the handset upgrade cycle is estimated at 18 months in 2014 (Mediametrie 2015) due to the rapid rise of technological capabilities and the variety of available supply.

hardware. Overall ergonomy of our system had to provide a sufficient generic interaction level to fit sparse and complex databases, while offering embracive gestural tools to fulfil the user's manipulation needs.

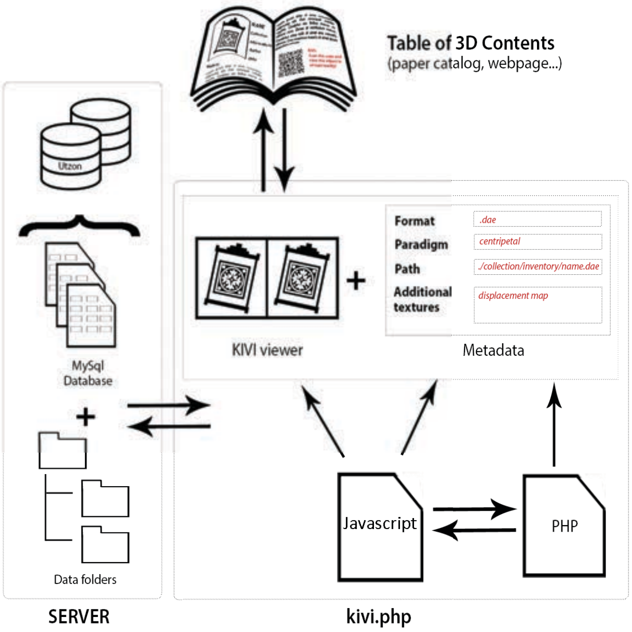

Fig. 1: KIVI's architecture

3.2 KIVI: Hardware and software

In concrete terms, KIVI is made of two elements: 1) the software environment for immersive visualization of 3D models collections, and 2) the custom headset, designed specifically for all 4'' to 6'' smartphones screens.

The software environment (Fig. 1) consists of:

- The remote database which contains the 3D objects and their metadata; Light-weight development and maintenance operations can be easily remotely accessed. Moreover, every new 3D model dropped on the database is immediately accessible to the community through the KIVI portal, according to a set of internal rules.
- An HTML5 page which provides the user access to remote data assets and establishes secured gateways between the database and the 3D scene. This very page provides a bimonoscopic flashcode decoder. This decoder, specially designed to ease a "hands-free" access to online resources within a virtual reality mount, allows users to quickly choose and import 3D objects to the viewer.
- The PHP page with the Javascript viewer, which embeds an empty 3D scene and displays the incoming 3D model. This empty 3D environment is a built-in empty shell for the immersive display and 3D data interaction. Developed with the WebGL API, and more specifically with the THREE.JS library, it provides a pre-formatted void document, invoking when desired an external 3D file (often in Collada format) and providing the default ambient light set, the stereoscopic display asset, and the spatial sensors interface, able to adjust the stereo viewport orientation in sequence with user head movements.

The other element of KIVI is the passive headset, easily reproducible with 3D printing, laser cutting, and simple assembly rules (Fig. 2).

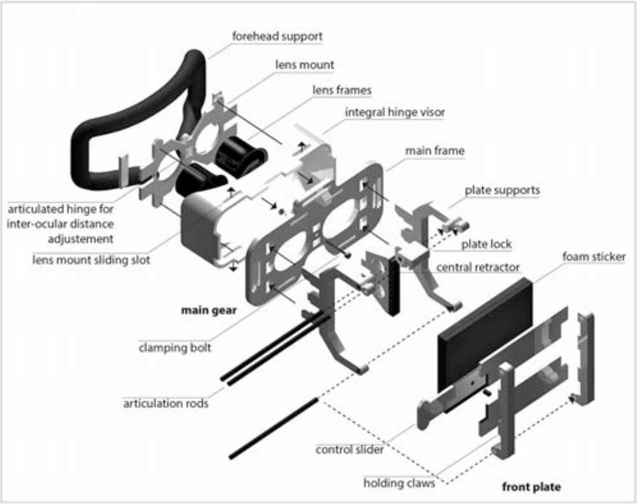

Fig. 2: KIVI's headset : exploded diagram

It consists in a side-by-side stereoscopic main-frame, made of two bi-convex lenses which eye-fit is adjustable within a 45 to 65 mm range, corresponding to the average human interocular distance. The rear part of the headset is the smartphone holder, bringing the phone screen on the lenses' focal plane. Finally, the headset supplies auxiliary functions for data interactions, like a bicolor slider for various interactive adjustments (Fig. 3) (Fig. 4).

Thus, this system is certainly similar to the Google Cardboard solution but we needed more flexibility in the use of built-in smartphone components, to explore interaction capabilities that did not require specific game-controllers.

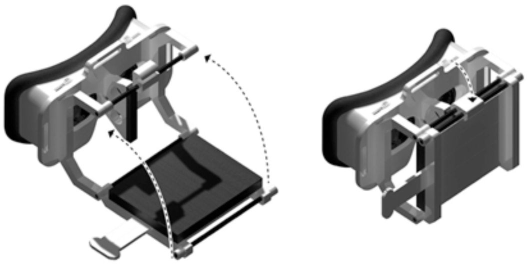

Fig. 3: KIVI's headset : assembly diagram

Depending on the smartphone type, it is possible to adjust the slider position relative to the front camera placement. We must say that some configurations – e.g. smartphones with a centred camera - are still incompatible with the present slider design and thus the peculiar hardware interaction permitted with KIVI. A very next release should solve this drawback.

3.3 Interface

KIVI needs neither prior installation nor plug-in, just a fast Internet connection. To access the immersive visualization of a 3D object from the database, the user simply needs to access the KIVI home-page within his usual mobile browser and enclose his smartphone into the headset. From this moment, no further direct contact with the smartphone screen is needed. The user observes the real environment through the bimonoscopic image from the smartphone's rear camera, and looks for the specific flashcode associated with an object from the database. Three seconds of immobility triggers the flashcode decoder program and routes the browser to the 3D scene. This operation allows quick and hands-free access to items from a potentially very large database. In terms of maintenance, adding a new model in the database solely implies the creation of a new flashcode set.

3.4 Interactions

Basic interactions respond to primary needs and provide generic interaction modalities for any kind of database-related 3D model. We pointed out the fact that the user should have a global environment sight freedom but also, depending on the type of observed object, be able to roam in the scene or adjust the focal length. To ensure a consistent visualization experience for every single 3D object we split the 3D database in two distinct sub-classes : small objects on one side, handled with a "centripetal" paradigm and wide objects (architecture, landscapes, wide dimension scenes...) on the other, more compatible with "centrifugal" interactions. In both cases, KIVI brings three rotation degrees of freedom with the use of internal gyroscopes and a custom zoom-action, performed with the plastic two-color slider interacting with the rear camera of the smartphone.

For instance, to walk-through the scene, the rear camera of the enclosed smartphone is involved: whether the user places his hand or the slider coloured test-card in front of the view frustum, a random pixel pattern is tracked through a WebRTC API, every 500 milliseconds: if more than 80% of measured pixels are below a given colour threshold, the movement starts, and the virtual camera translates in the direction of its point of view. This movement can be stopped when moving the slider - or the hand - away from the lens: although stopped, the user can freely examine the surrounding 3D scene.

This interaction seems quite interesting to explore further: we considered yet only a simple black to white gradient and we could imagine others colour gradients with different possible interactions; we will see, however, that such a feature could seriously detriment the display frame-rates.

Fig. 4: KIVI's headset

To grant an optimal compatibility over the entire database contents, we had to ensure, within the KIVI viewer, an instant paradigm swapping, depending on the scalar dimension of the loaded scene. To do so, we embedded in the URL variables some specific informations that will force the script to handle such 3D scenes correctly. Thus, the PHP component considers the model metadata and launches the generation of the specific content-based 3D viewer by triggering the correct available interactions.

4. Performances and limits

Needless to say, this environment requires lots of computational resources; first of all, because the use of ThreeJS environment forces the download of the entire model prior to its visualization, but also because we process the 3D displaying within the smartphones inner processors capabilities, unable yet to fluently display non-optimal 3D models. Finally, WebRTC-based interactions (especially used for rear-camera triggering) also require huge amounts of data processing, probably more than needed within our bandwidth specific needs: on idle, the process monitors the full camera-stream, but only uses a sparse pixel-count every 500 milliseconds. These specific issues have been closely benchmarked below.

4.1 Benchmarks

The present kit was submitted to early performance tests, highlighting the operational potentials and limits. KIVI was tested with many representative samples of third party 3D databases, for example, we picked these two representative ones: a piece of furniture sourced from the Petit Trianon in Versailles, dating back to the 18th century and an interior 3D model of the Saint-Michel de Cuxa abbey (fig. 5) (tab. 1).

Fig. 5: Left: Piece of furniture from the Petit Trianon. Right: Interior of the Saint-Michel de Cuxa abbey

We submitted two versions of the script environment: one was only 3D viewing enabled, the other implemented the WebRTC API for the video-stream pixel surveying.

Tab. 1: Test-files properties

3D Object	Piece of furniture from the Petit Trianon	Interior of the Saint-Michel de Cuxa abbey
Size of the Collada file	0.99 Mo	8.91 Mo
Total size of the texture files	20.4 Mo	29.6 Mo
Number of faces	7816	43 985
Number of edges	12 180	26 262
Paradigm	Centripetal	Centrifugal

Two different smartphones were tested, both based upon an Android architecture but built with different technical specifications (tab. 2). We also tested KIVI on an iPhone 6, which is not already compatible with WebRTC API.

Tab. 2: Test-devices properties

Device	Sony Xperia Z3	Samsung Galaxy Note 4	iPhone 6
CPU	Qualcomm Snapdragon 801; 2.46 GHz	Qualcomm Snapdragon 805; 2.65 GHz	Apple A8, 1.4 GHz
GPU	Adreno 330; 578 MHz	Adreno 420; 600 MHz	PowerVR GX6450, 43 MHz
Screen	5.2” IPS triluminos display 1920 x 1080 px 424 ppi	5.7” Super AMOLED display 2560 x 1440 px 515 ppi	4.7” IPS display 1334 x 750 px 321 ppi

Every testbed was benchmarked by running both scenes; an accurate frame-count was performed for each configuration (tab. 3).

Tab. 3: Average frame rate depending on device

3D Object	**Piece of furniture from the Petit Trianon**			**Interior of the Saint-Michel de Cuxa abbey**		
Device **Viewer**	Sony Xperia Z3	Samsung Galaxy Note 4	iPhone 6	Sony Xperia Z3	Samsung Galaxy Note 4	iPhone 6
Light (WebGL only)	55 FPS	37 FPS	58 FPS	10 FPS	9 FPS	15 FPS
Full (WebGL + WebRTC)	20 FPS (minimal zoom) 15 FPS (maximal zoom)	18 FPS (minimal zoom) 13 FPS (maximal zoom)	/	6 FPS	6 FPS	/

Best frame-rates are achieved with less resource-consuming FullHD smartphones but with the drawback of a more visible screen-door effect through a head-mounted gear. For instance, the Samsung Galaxy Note 4 WQHD display slightly slows down inner processor cycles but offers a leading-edge display for Virtual Reality purposes.

Moreover, we must say that using WebRTC significantly reduces the system performance: this quite recent API is not optimally supported by tested browsers and our code may still be improved. Despite some structural weaknesses, WebRTC looks quite promising in terms of ergonomic and intuitive interaction potentials, especially in the domain of mediation (or even in augmented reality).

These first results identified interesting aspects of our approach. Depending on the involved resources, we can see that some 3D scenes were displayed with acceptable frame-rates (up to 58 fps), which makes this system very suitable for mobile lightweight immersive solutions, especially for cultural mediation purposes which can be, in some cases, comparable to Oculus Rift© performances. But the tested 3D objects were all low-poly sets, which most of the 3D database elements are not!

4.2 Possible lag consequences

Immersive devices could lead to sensory or induced behaviour issues; cyber-sickness occurs when visual and inner ear perception differs, especially with equilibroception. It is often manifested by fatigue, nausea or dizziness. Slow frame-rates could be responsible for such symptoms, especially below 25 Hz where the movement is not fluid enough to ensure an optimal visual experience. During DH2015 exhibition, visitors felt rather comfortable with the KIVI mount, probably because of the hollow-frame structure of the head mount, which allowed users to stay connected to real environment. Low frame-rates (display lag) tend to have a negative effect upon the user's experience; to counter-balance this peculiar drawback we pointed out many possible solutions.

5. Lag preventing : setting the database

Obviously, we should first examine the data-type of 3D objects contained within the database. Early benchmarks were not able to point out a significant incidence of object's format and the scene framerate. Besides, some formats provide simpler descriptive routines leading to faster download rates; so far we prefer the Collada format which is a standard 3D format, supported by the Khronos consortium group (Khronos group, 2015), widely compatible with most of the current 3D software, and adopted by ISO as a publicly available specification. However, KIVI deals also with OBJ, STL and PLY standards.

Polygon decimation could also help to enhance framerate on mobile devices: the lighter the poly-count, the faster the scene rendering. Low-poly 3D models were submitted to KIVI interface during Digital Heritage 2015 Exhibition (Abergel, Saleri, Lequay, & De Luca, 2015b) and, to even enhance the immersive experience, the lighting was embedded within the texture set: a plain ambient light is then sufficient to provide appropriate volume and detail comprehension.

Moreover, enhancing the display frame-rate doesn't have to impact the global aesthetic: some visual special effects are introduced in the computation loop to ensure a pleasant visual experience, like texture improving, in order to decrease the polygon count and therefore optimize the rendering process itself. Every single object used for testing and benchmarking purposes was part of the "Petit Trianon" furniture collection (Renaudin, Rondot, De Luca 2011a; Renaudin, Rondot, & De Luca, 2011b); to speed-up frame-rates, actual models were photographed in their historical position within the palace chambers or rendered with a texture-baking process, thus including direct and ambient light information within the object's texture layer.

According to the usual strategies for improving the visualization through the use of a 3D polygonal model as light as possible (Remondino, 2001), we introduce a multi-layer approach that will permit the displaying of a satisfying visual experience with a reduced set of polygons: as stated above, with a simple ambient light we can enhance the visual appeal of downloaded scenes by stacking a bump, normal or displacement map to simulate very accurate surface aspects depending on the presence and the position of a virtual light source (fig. 6)

These are well-known strategies that are less crucial today, according to the increasing power of graphic-processing outputs. Nevertheless, digital contents for passive VR headsets require today to turn again towards those early optimization strategies because of the weakness of hand-held devices processing capabilities.

For huge or complex scenes we must switch the displayed models with the use of a LOD (Levels of Detail) function. The viewer will automatically swap between actual size and low poly versions of the same object depending on the distance to the user. This is certainly a time consuming approach as 3D models (especially complex digital heritage scenes) will often resist to automated polygon-decimation routines and most of the fine shape-tuning for optimal visual results will be - needless to say - manual. So, manual and semi-automated routines do exist to create quality visual models for mobile immersive environments but as said above, they will first need time-consuming manual handling procedures but also the writing of informational connections to an existing SQL database which will permit the quick and pertinent browsing in the depth of huge 3D data-sets. Whether a single model should be carrying a normal-map texture layer, the metadata header will inform the PHP script in time to load a THREE.JS viewer that will be able to handle this specific rendering routine. If not, the preload of a THREE.JS viewer would wastefully slow down the frame-rate.

Fig. 6: Enhancing the display with additional textures: the same low-poly 3D model of a stone wall, displayed in wireframe, flat-shading and with a normal map.

As a consequence, initial user-reactions were certainly positive and led to many promising interactions, but we must put in perspective these very first feelings because of the poor implementation -so far- of automated pre-processing routines. KIVI is not yet an actual "plug and play" interface and will certainly need further improvements to bring its hardware and software to an optimal level.

6. Conclusion and perspectives

Present limits of our system lay on current on-board GPU and CPU performances. With the quick increase of technological improvements, this will hopefully not be an issue in a very short time. Meanwhile, to increase the frame rate and the feedback delay we should - when possible and necessary –lower the polygon number and the texture size of on-line resources, implying time-consuming 3D models post-processing. So far, our system is not as “ready to use” as we wish.

An interesting approach would consist of creating a general workflow or protocol designed to normalize the organization and the taxonomy of heritage 3D object databases: within similar data-sets and data-structures we could easily implement and commoditize a way more versatile and fast version of KIVI software.

However, KIVI is still in progress but points out some interesting upcoming potentials if crossed with ultra-portable or - better – the next generation of wearable electronic devices. We will certainly soon witness the explosive growth of exciting new technologies such as WebGL and moreover WebRTC API's, getting free of third party software, although presently very effective. We believe that these solutions will very soon bring increasing sustainable and easy-to-support cultural content able to widen the offer of free-access knowledge and maybe bring fresh and unexpected opportunities for everyone.

REFERENCES

3D-COFORM project (2013). Tools & Expertise for 3D Collection Information. In *D.1.5 Project Final Report*, p. 189. Retrieved from http://www.3d-coform.eu.

3D ICONS project (2014). *3D-ICONS Guidelines*. 1st ed, Ireland, p. 53. Retrieved from http://3dicons-project.eu.

Abergel, V., Saleri, R., Lequay, H., & De Luca, L. (2015a). An immersive visualization kit for online 3D objects databases. In *2015 Digital Heritage International Congress (2015 Digital Heritage)*, 28 Sep - 2 Oct 2015 Granada (Spain), Vol.1, (pp 305-308). Denver, USA: IEEE.

Abergel, V., Saleri, R., Lequay, H., & De Luca, L. (2015b). KIVI: Bring Virtual Reality to online 3D objects databases. In *International Congress on Digital Heritage - EXPO*, 28 Sep - 2 Oct 2015 Granada (Spain), Vol. 2. Geneve, Switzerland: Eurographics DL. Retrieved from: https://diglib.eg.org/handle/10.2312/14479

Callieri, M., Leoni, C., Dellepiane, M., & Scopigno, R. (2013). Artworks narrating a story: a modular framework for the integrated presentation of three-dimensional and textual contents. In *ACM WEB3D – 18th International Conference on 3D Web Technology*, (pp 167-175). San Sebastian, Spain: ACM.

CARARE Project (2013). Connecting ARchaeology and ARchitecture in Europeana. In *D1_8 Final Report*, p. 13. Retrieved from http://www.carare.eu.

Congote, J., Segura, A., Kabongo, L., Moreno, A., Posada, J., & Ruiz, O. (2011). Interactive visualization of volumetric data with webgl in real-time. In *Proceedings of the ACM Web3D' 11 – 16th International Conference on 3D Web Technology*, (pp 137-146). Paris, France: ACM.

D'Andrea, A., Niccolucci, F., Bassett, S., & Fernie, K. (2012). 3D-ICONS: World Heritage Sites for Europeana: Making Complex 3D Models Available to Everyone. In Proceedings of *Virtual Systems and Multimedia (VSMM), 2012 18th International Conference on*, 2-5 Sept. 2012 Milan (Italy), (pp. 517-520). Denver, USA: IEEE.

De Luca, L., Busarayat, C., Stefani, C., Veron, P., & Florenzano, M. (2011). A semantic-based platform for the digital analysis of the architectural heritage. *Computers & Graphics*, 35(2), 227-241.

De Luca, L., Fischer, L., Guidi, G., & Torres,J.C. (Eds.) (2015). *2015 Digital Heritage International Congress (2015 Digital Heritage)*, 28 Sep - 2 Oct 2015 Granada (Spain).

Europeana Foundation (2008), [Online] Retrieved from: http://www.europeana.eu, 2008, Netherlands.

GFK (Gesellschaft Für Konsumforschung) (2014). *Smartphones: la croissance à tout Prix* [Online], Retrieved from: http://www.afjv.com/news/4329_smartphones-la-croissance-a-toutprix-etude-gfk.htm

Guidi, G., Scopigno, R., Torres, J. C., & Graf, H. (2015). *2015 Digital Heritage International Congress (2015 Digital Heritage)*, 28 Sep - 2 Oct 2015 Granada (Spain), Vol. 2 "Special Sessions". Denver, USA: IEEE.

Google (2015). *Google Cardboard, Experience virtual reality in a simple, fun, and inexpensive way*. [online] Retrieved from: https://www.google.com/get/cardboard/

Khronos group (2015). *Collada™, 3D Asset Exchange Schema*. [Online] Retrieved from: https://www.khronos.org/collada/

Ibrahim, N., Ali, N., & Yatim, N. (2015). Factors Facilitating Cultural Learning in Virtual Architectural Heritage Environments: End User Perspective. *Journal on Computing and Cultural Heritage (JOCCH)*, 8(2). Article No. 8

Jiménez Fernandez-Palacios, B., Remondino, F., Stefani, C., Lombardo, J., & De Luca L. (2013). Web Visualization of Complex Reality-Based 3D Models with NUBES. In *Proceedings of 2013 Digital Heritage International Congress (DigitalHeritage)*, 28 Oct – 1 Nov 2013 - Marseille (France), Vol. 1 : (pp. 701-704). Denver, USA: IEEE.

Livatino, S., Cuciti, D., & Wojciechowski, A. (2006). Virtual Reality an Stereo Visualization in Artistic Heritage Reproduction. In M. Ioannides, D. Arnold, F. Niccolucci & K. Mania (Eds.), *Proceedings of 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST)*, Geneve, Switzerland: Eurographics Association

Mediametrie, Statistics on media behavior in France (2015). *Comportements médias*. [Online] Retrieved from: http://www.mediametrie.fr/comportements/communiques/

Oculus VR© (2015). *Oculus Rift, next-gen Virtual Reality*. [online], Retrieved from: https://www.oculus.com/rift/

Remondino, F., (2001). From point cloud to surface: the modeling and visualisation problem. In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol XXXIV- 5/W10.

Renaudin, N., Rondot, B., & De Luca L. (2011a). The Petit Trianon in Versailles: The Virtual, an Historic Reality. In *Proceedings of VAST: 12th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage*, Prato, Italy.

Renaudin, N., Rondot, B., & De Luca L. (2011b). 3D Virtual Reconstruction and Visualization of the Petit Trianon in Versailles. In *Leuven Workshop Virtual Palaces, Part I*, Leuven, Belgium.

Samsung, Presentation of the Samsung Gear VR (2015), *Samsung Gear VR Innovator Edition* [online] Retrieved from: http://www.samsung.com/us/mobile/wearable-tech/SMR320NPWSXAR

Webel, S., Olbrich, M., Franke, T., & Keil, J. (2013). Immersive experience of current and ancient reconstructed cultural attractions. In A. Addison, L. De Luca, G. Guidi, & S. Pescarin (Eds.), *Digital Heritage International Congress (DigitalHeritage)*, Vol. 2. Denver, CO, USA: IEEE.

(DigitalHeritage), 28 *Oct – 1 Nov 2013 - Marseille (France)*, Vol. 1, pp. 395 - 398 , IEEE, Danvers USA.