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SCIENTIFIC RIGOUR OF ONLINE PLATFORMS FOR 3D VISUALISATION OF HERITAGE

RIGOR CIENTÍFICO DE LAS PLATAFORMAS EN LÍNEA PARA LA VISUALIZACIÓN 3D DEL PATRIMONIO

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Highlights:

- Online platforms for the 3D visualisation of heritage fail to disclose what type of reconstruction it is and its level of certainty, struggling to balance community engagement vs scientific rigour of their contents.
- ICOMOS and UNESCO recommendations regarding heritage are loosely followed on the reviewed platforms, and supporting documentation is often lacking.
- Scientific rigour on these platforms could be elevated with supporting textual fields to disclose further information about each visualisation.

Abstract:

3D visualisations –including 3D scans and 3D reconstructions– designed as part of larger archaeology, history or cultural heritage projects are commonly shared with the public through online platforms that were not necessarily designed to host heritage representations and often fail to contextualize them. This paper seeks to evaluate whether five online platforms commonly used today to share 3D visualisations of heritage (Google Arts & Culture, CyArk, 3DHOP, Sketchfab and game engines) offer features that facilitate their scientific rigour and community participation, based on guidelines from International Council on Monuments and Sites (ICOMOS) and United Nations Educational, Scientific, and Cultural Organization (UNESCO). The author starts by summarizing recommendations from 32 international guidelines that are relevant to the 3D visualisation of heritage, condensing them into nine key criteria: multi-disciplinary teams, objective-driven methodology and tools, careful documentation, type of reconstruction and level of certainty, authenticity, alternative hypotheses, multiple historical periods, respectful use of the heritage, and community engagement. The author proceeds to review the platforms above comparing their features with these nine recommendations and concludes that, while there are currently available features that could help to elevate the scientific rigour of the 3D visualisations and their contextualization to the public, they are not mandatory and are seldom used. The paper finishes with a recommendation for an information package to support 3D visualisations of heritage on public online platforms.

Keywords: cultural heritage; 3D visualisation; 3D reconstruction; ICOMOS; online platforms; community participation

Resumen:

Las visualizaciones 3D –incluyendo los escaneados 3D y las reconstrucciones 3D– desarrolladas como parte de proyectos más extensos de arqueología, historia o patrimonio cultural, comúnmente se comparten con el público a través de plataformas online que no necesariamente fueron diseñadas para alojar representaciones patrimoniales y que fallan frecuentemente al contextualizarlas. Este artículo busca evaluar si cinco plataformas en línea comúnmente utilizadas hoy para compartir visualizaciones 3D del patrimonio (Google Arts & Culture, CyArk, 3DHOP, Sketchfab y motores de juegos) ofrecen características que facilitan su rigor científico y participación comunitaria, basadas en recomendaciones de las directrices del Consejo Internacional de Monumentos y Sitios (ICOMOS) y de la Organización para la Educación, la Ciencia y la Cultura (UNESCO). La autora comienza resumiendo las recomendaciones de 32 directrices internacionales que son relevantes para la visualización 3D del patrimonio, agrupándolas en nueve criterios clave: equipos multidisciplinares, metodología basada en objetivos, documentación cuidadosa, tipo de reconstrucción y nivel de certeza, autenticidad, hipótesis alternativas, múltiples períodos históricos, uso respetuoso del patrimonio, y participación comunitaria. La autora procede a revisar las plataformas comparando sus características con estas nueve recomendaciones y concluye que si bien existen características actualmente disponibles que podrían ayudar a elevar el rigor científico de las visualizaciones 3D y contextualizarlas al público, tales no son obligatorias y rara vez se usan. El documento finaliza con recomendaciones que podrían acompañar las visualizaciones 3D del patrimonio en plataformas públicas en la red.

Palabras clave: patrimonio cultural; visualización 3D; reconstrucción 3D; ICOMOS; plataformas en la red; participación comunitaria

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1. Introduction

3D visualisation is an established, non-invasive tool for the study and documentation of historical sites and cultural heritage (Caro & Hansen, 2015; Grosman, 2016). Even though designed in the context of a larger study or research project, it is common for these visualisations to fall into the public domain through online platforms without reference to their original purpose or context, whether intentionally or not (Scopigno, Callieri, Dellepiane, Ponchio, & Potenzianiet, 2017).

By comparing the features offered by these platforms with guidelines from ICOMOS and UNESCO on heritage management, the author seeks to heuristically evaluate whether five online platforms commonly used today to share 3D visualisations of heritage with the general public offer the necessary scientific rigour to contextualize these visualisations. The platforms examined are: Google Arts & Culture, CyArk, 3DHOP, Sketchfab and game engines; they were selected based on two items: a) being commonly used to share 3D visualisations of heritage online with the general public; and b) being actively supported by their developers as of the writing of this article.

Section 2 defines what the scope of 3D visualisations of heritage is. Section 3 summarizes the key ICOMOS and UNESCO documents relevant to the 3D visualisation of heritage. Section 4 presents the five online platforms. Section 5 compares the platforms and evaluates them according to the recommendations of Section 3. The paper finishes with a discussion and recommendations for improving the scientific rigour of 3D visualisations of heritage publicly shared via online platforms.

2. 3D visualisation of heritage

Encompasses any 3D visualisation that features a heritage object or practice, whether officially recognized heritage or not, as well as historical and archaeological sites. 3D visualisations tend to focus on tangible heritage, but intangible heritage can also be displayed through motion capture (Grau & de Gruyter, 2017) and simulations, such as digital battle re-enactments (McCall, 2016). For the sake of this evaluation, visualisations that focus on archaeological, historical and heritage subjects will be collectively classed under the umbrella of *heritage* and the analysis will focus on the 3D visualisation of tangible heritage only.

The first type of 3D visualisations of heritage includes 3D scans of objects, monuments and sites via laser scanning, photogrammetry or a combination of both (Caro & Hansen, 2015), where large outdoor spaces benefit from aerial photogrammetry (Sabina, Valle, Ruiz, García, & Laguna, 2015). They can be combined with Geographic Information System (GIS), Ground Penetrating Radar (GPR) and other traditional topography techniques to create a digital version of the heritage in its current state, being especially popular with archaeological studies. The high level of fidelity of 3D scans allows researchers to study a site or objects remotely, inspect areas that are dangerous or hard to reach (Esclapés, Tejerina, Esquembre, Bolufer, 2013), and aids in the management of complex heritage sites (Brunetaud, De Luca, Janvier-Badosa, Beck, Al-Mukhtar, 2012). Another benefit is the accumulation of a digital memory bank, which is especially meaningful for heritage sites that are deemed at risk (Kacyra, 2009).

The second type of visualisations includes 3D reconstructions, which can be based or not on an initial 3D scans. When scanning is possible, the first step is to digitize the site or object in its current state as a starting point for the reconstruction (Manferdini, Gasperoni, Guidi, & Marchesi, 2016); this also enables virtual anastylosis (anastylosis refers to the archaeological practice of reassembling pieces of an object of building that were originally connected) (International Forum of Virtual Archaeology, 2011). Next, a virtual reconstruction is built using 3D modelling software geared towards engineering or computer graphics, depending on the objective of the project (Lužnik & Klein, 2015). Extra elements such as decorative objects, vegetation, characters, animals, ambient sounds, dialogue and music can be added to the reconstruction (Caro & Hansen, 2015).

3. Scientific guidelines for heritage studies

There are two documents that deal exclusively with digital visualisation of heritage: 1) the London Charter (Denard, 2009), and 2) the Seville Principles (International Forum of Virtual Archaeology, 2011). While they act as primary guidelines for the 3D visualisation of heritage, they do not override other documents that address physical heritage; therefore, for a more holistic overview of the guidelines governing heritage studies, 32 relevant ICOMOS and UNESCO documents with worldwide mandate have been analysed, starting with the Charter of Athens from 1931 (for a full list, see Table 1).

A network analysis reveals two key influencers: the 1964 Charter of Venice (ICOMOS, 1964) and the 1972 UNESCO Convention (UNESCO, 1972). A first level thematic analysis indicates that the primary concern of the 32 documents is the preservation and conservation of heritage, which accounts for roughly a third of the papers. Next follow matters of safeguarding, management and restoration. Finally, specific issues are handled in dedicated documents, as is the case of both The London Charter and The Seville Principles.

A more in-depth thematic analysis reveals recurring concerns relevant to the 3D visualisation of heritage, which is discussed in Sections 3.1 to 3.4. These can be grouped under the following items: (1) authenticity, preservation, restoration and reconstruction (where both preservation and conservation are grouped under *preservation*); (2) methodology, team and community; (3) documentation; (4) issues specific to the digital visualisation of heritage.

Due to the focus of this study, issues not directly pertinent such as the definition of heritage, legislation, professional training, archaeological site management and intangible heritage are for the most part omitted.

3.1. Authenticity, preservation, restoration and reconstruction

Starting with the Charter of Venice of 1964 (ICOMOS, 1964), preserving authenticity as well as the physical heritage itself is a recurring concern, featured in 26 out of the 32 documents analysed, including the dedicated 1994 Nara Document on Authenticity (ICOMOS, 1994) and the 2008 Québec Declaration on the Preservation of the Spirit of the Place (ICOMOS, 2008b). Although the definition of authenticity itself is flexible, there is a

consensus that preservation should extend beyond the object or building and also encompass the surrounding area, its context, values and use. Recent documents express concern that touristic exploitation might trivialize cultural practices and cause loss of authenticity (ICOMOS, 1999; ICOMOS, 2008a; ICOMOS, 2011; ICOMOS, 2014). Similarly, inhabited historical areas must strive for the delicate balance between preserving their authenticity with the on-going pressures of urban expansion, modernization, as well as the community's socio-economic sustainability (The Charter of Krakow, 2000; ICOMOS, 2011a; ICOMOS, 2011b).

Preservation plans should favour preservation over restoration, and limit physical reconstruction to a minimum (ICOMOS 1964, ICOMOS 1982, ICAHM 1990, The Charter of Krakow, 2000; ICOMOS, 2003; ICOMOS, 2003a); whenever possible heritage should be preserved in situ and in context, including interior and decorative elements as well as meaningful green spaces (ICOMOS, 1982; ICOMOS, 2003a). Documents dealing with restoration distinguish between restoration based on historical evidence and restoration based on hypothesis, where the latter should only be applied where absolutely necessary to prevent structural damage or ensure the safety of the site. While most guidelines recommend visual distinction between original and restored areas, in the case of inhabited heritage there is greater flexibility.

In general there is higher tolerance towards restoring heritage that is mostly intact, while destroyed heritage should not be restored except in extraordinary circumstances where the destruction is recent (due to armed conflict or natural disaster) and the site has exceptionally high cultural, spiritual or historical value (ICOMOS, 1982a; The Charter of Krakow, 2000; Lima Declaration, 2010; UNESCO 2016). Archaeological sites should not be restored except for anastylosis (ICOMOS, 1964), and reconstructions to test archaeological hypothesis should be conducted off-site (ICAHM, 1990).

3.2. Methodology, team and community

Guidelines recommend choosing a methodology that reflects each project's specific needs and objectives; there are general recommendations such as detailed documentation and favouring non-invasive techniques, but there is no clear preference for one universal methodological approach.

There is an increasing concern with scientific rigour: the first charters recommend a healthy measure of good sense and respect towards the community; the following 1970s-1990s period focuses on methodologies that favour academic research and scientific publications; the period of the 2000s onwards focus on the continuous management of (large) heritage sites and favour flexible methodologies that are periodically revised to reflect changes in the circumstances of the heritage itself as well as the community, surrounding area, and its socio-economic context. Methodological steps should be well documented and published in scientific circles.

The organization of research teams reflects the evolution in the approach and priorities of heritage studies: The Athens Charter (1931) debates the legality of international teams, an aspect that in recent guidelines is considered a positive means of exchanging ideas and valuing international heritage and culture, as well as providing support between researchers. Multi-disciplinary teams are widely regarded as a necessary component of any heritage study, emphasizing the collaboration between archaeologists, historians, heritage specialists, architects and engineers. Where destroyed heritage must be reconstructed, supervision by a qualified archaeologist or historian is recommended.

Community engagement, on the other hand, is a far more complex topic, where guidelines differ the most, often reflecting the local political and economic context. While there is a universal mantra that "one must value heritage in order to preserve it" and 23 out of the 32 charters analysed explicitly recommend increasing public awareness towards heritage, there is nonetheless a distinct lack of consensus about just how to involve the community. Generally speaking, the period of 1970-80s, including the 1972 UNESCO Convention (UNESCO, 1972), reflects a rather paternalistic approach where specialists and government agencies take on the role of managing heritage for the benefit of the local community, which is generally kept at arm's length as regards day to day activities and the decision-making process. The subsequent reframing of heritage as a touristic-economic resource renewed the role of the community, now as active partners in the preservation and promotion of local heritage.

Despite clear interest in engaging the local community, there remains a disagreement regarding the community's level of participation: in the one extreme there are guidelines that frame the community as guardians of the local heritage and place upon them both the right and the responsibility to define and preserve their heritage (ICOMOS, 1999; ICOMOS, 2008b; ICOMOS, 2014; ICOMOS, 2017); in the other extreme there are guidelines that reduce the community's role into educating them about avoiding intentional destruction and vandalism of heritage sites (UNESCO, 1972; ICOMOS 2003a). Furthermore, some fear that, unintentionally, visitors and the community, in general, may damage the heritage or resort to inappropriate preservation techniques.

3.3. Documentation

While there is a universal agreement in favour of documentation, papers that focus on restoration and archaeology emphasize most strongly the need for careful documentation and publication of results. At a minimum, documentation must cover the restoration process, historical sources consulted and the overall project methodology, while guidelines dealing with archaeology and heritage management also recommend careful documentation of the heritage itself through non-invasive means. This need is further emphasized for sites that are at risk or are of difficult access.

Results must be published and made easily accessible to researchers, legislators and government institutions. While public access to results is encouraged, only four out of the 32 documents consulted recommends publication in popular media.

Table 1: List of documents consulted and their summarized recommendations (marked as X when recommended).

	Multi-disciplinary teams	*Objective-driven methodology and tools*	*Careful documentation*	*Authenticity*	*Type of reconstruction and level of certainty*	*Alternative hypotheses*	*Multiple historical periods*	*Respectful use of the heritage*	*Community engagement*
The Athens Charter 1931	X	X	X		X		X		X
The Venice Charter 1964	X	X	X	X	X				
UNESCO Convention 1972	X		X						
The Florence Charter 1981	X	X		X			X		
Declaration of Dresden 1982	X	X	X	X	X		X	X	X
Washington Charter 1987	X	X	X	X			X	X	X
Lausanne Charter 1990		X	X	X	X			X	X
The Nara Document of Authenticity 1994	X		X	X				X	X
Sofia Charter 1996	X	X	X						X
Sofia Principles 1996	X	X	X						
Stockholm Declaration 1998	X								X
International Cultural Tourism Charter 1999	X	X		X			X	X	X
Charter on the Built Vernacular Heritage 1999	X	X	X				X	X	X
Mexico Principles 1999	X	X	X	X	X				
The Charter of Krakow 2000	X	X	X	X			X		X
UNESCO Convention: 30th Anniversary 2002	X		X						X
Victoria Falls Charter 2003	X	X	X	X			X		
Victoria Falls Principles 2003	X	X	X	X	X				
Xi'an Declaration 2005	X	X	X	X				X	X
Charter on Cultural Routes 2008	X	X	X	X				X	X
Québec Charter 2008	X	X	X	X	X	X	X	X	X
Québec Declaration 2008	X	X	X	X				X	X
UNESCO World Heritage Information Kit 2008	X	X		X					X
The London Charter 2009	X	X	X		X				
Lima Declaration 2010	X	X		X					X
The Paris Declaration 2011	X	X		X				X	X
The Dublin Principles 2011	X		X	X				X	X
The Valletta Principles 2011	X	X	X	X			X	X	X
The Seville Principles 2011	X	X	X	X	X	X	X	X	
The Florence Declaration 2014	X	X	X	X				X	X
UNESCO Operation Guidelines 2016	X	X	X	X				X	X
Delhi Declaration 2017	X		X	X				X	X

3.4. Issues specific to virtual heritage

There are only two guidelines that specifically address the digital visualisation of heritage: the 2009 Charter of London (Denard, 2009), about the digital visualisation of heritage; and the 2011 Principles of Seville (International Forum of Virtual Archaeology, 2011), that focuses on virtual archaeology. Besides them, both the Québec Charter 2008 (ICOMOS, 2008a) and the Québec Declaration 2008 (ICOMOS, 2008b) make recommendations regarding the digital visualisation of heritage and all four are summarized in this section.

While non-invasive digital documentation tools such as, photogrammetry, laser scanning/Light Detection and Ranging (LIDAR) and Geographic Information System (GIS) are highly valued, there is, however, an underlying concern that digital visualisations of heritage may be misinterpreted by the public. In particular is the danger that their high level of visual realism might be erroneously mistaken for historical truth, a concern that is exacerbated with 3D reconstructions. To contravene this problem, extreme transparency and detailed documentation are urged, including all historical sources consulted, clearly identifying the type of digital

representation and its level of certainty. Where possible, alternative hypotheses as well as representation of multiple historical periods must be made available.

Technological decisions and the choice of tools must reflect the objectives of the research project and favour solutions that offer longer-term use at lower maintenance costs, with all steps of the development of the visualisation clearly documented. There is a difference of opinion regarding the objective of the visualisation itself: while the Charter of London (Denard, 2009) recommends maximizing the number of outputs, the Québec Charter (ICOMOS, 2008a) favours educational applications while the Principles of Seville (International Forum of Virtual Archaeology, 2011) recommend that the visualisation must correspond to the objectives, noting that there are technical differences regarding resolution, style and methodology between visualisations aimed at researching, preservation or dissemination.

3.5. Overview/Summary

3D visualisations of heritage must respect the Charter of London and Principles of Seville, but also incorporate recommendations regarding physical heritage that enhance the scientific rigour and authenticity of the 3D visualisation. The following list presents a summary of the points presented in Sections 3.1 to 3.4 that combined have the potential to enhance the scientific rigour of 3D visualisations of heritage; while this list is an interpretation of the author and does not attempt to override official guidelines, it does condense the consulted guidelines. A full list of the 32 documents consulted and their summarized recommendations are available in Table 1.

- **Multi-disciplinary teams:** are fundamental to ensure quality, and in the case of 3D visualisations should take place under the supervision of an archaeologist, historian or similar to ensure historical rigour. International partnerships can be advantageous and are encouraged for transnational heritage.
- **Objective-driven methodology and tools**: clear objectives are fundamental to guide the choice of digital tools, platform and the overarching methodology. The visualisation's level of detail, visual fidelity and visual style may vary depending on the objective: e.g. 3D reconstructions for structural testing might look cruder when compared with those for touristic purposes, and reconstructions for virtual reality (VR) and augmented reality (AR) must follow strict development guidelines. When choosing the tools and platform it is also important to consider future maintenance costs.
- **Careful documentation:** 3D visualisations require extensive documentation of the historical sources, developmental steps and methodological decisions. Results must be published and accessible to the scientific community, legislators and to guide future work. It is also recommended the digitization of heritage deemed at risk, of high cultural value, and of archaeological sites.
- **Type of reconstruction and level of certainty**: 3D visualisations must explicitly declare what is represented between: a) findings preserved in situ, b) findings returned to their original position, c) physical reconstructions, or d) virtual reconstructions. Reconstructions should furthermore specify if they are based on historical evidence or hypothesis, what are their level of certainty and the source of the historical evidence and/or hypothesis. Scales of historical evidence such as that of Figueiredo (2014) help to codify this information visually, as shown in Figure 1 where the scale is presented and applied to a 3D reconstruction of heritage, allowing viewers to quickly distinguish between areas where there is higher or lower level of certainty.
- **Authenticity**: 3D visualisations must respect the context, historical period(s) and intangible practices, incorporating where adequate elements that enhance its authenticity such as soundtracks and ambient sounds that reflect the culture and historical period, depict the heritage in use, accurately represent inhabitants, animals and vegetation. Accurately incorporating these elements is particularly important for projects aimed at the general public and should be done under the supervision of a qualified historian or similar.
- **Alternative hypotheses**: when possible, multiple hypotheses must be tested and visualised.
- **Multiple historical periods**: when possible, multiple historical periods must be depicted without favouring a single period.
- **Respectful use of the heritage**: interactive and immersive 3D visualisations must encourage meaningful and respectful exploration of the heritage, avoiding situations where the 3D heritage might be misappropriated or disrespected.
- **Community engagement**: whenever possible 3D visualisations of heritage must educate the public and promote awareness. It is important to incorporate participatory tools that engage the community in creating meaning and value around their cultural practices, contributing to cultural convergence around their heritage.

4. Online platforms for the 3D visualisation of heritage

Online platforms allow easy and interactive access to 3D visualisations of heritage: users can easily manipulate the visualisation, inspect details, obtain more information or take a virtual tour. Not all platforms offer the same functionalities or level of popularity (size of the audience), and more relevant for their scientific rigour, they offer different features, structure and interface that facilitates –or hinder– following the scientific recommendations summarized in Section 3.5.

This section reviews five online platforms commonly used today for the 3D visualisation of heritage; while this list is not exhaustive, it includes representatives both scientific and popular: Google Arts & Culture, CyArk, 3DHOP, Sketchfab and game engines. First, each platform will be presented with a description of its main features. In Section 5, these features will then be compared between the five platforms and also against Section 3.5, providing an overview of how they support or not the scientific recommendations. To facilitate the discussion, content developers will be referred to as author(s), whether they are individuals, teams or institutions, whereas the public that interacts with these contents will be referred to as user(s).

(a)

(b)

Figure 1: Scale of historical evidence by Figueiredo; a) Scale applied to the 3D visualisation of Domus Braga; b) Scale codification charter. Source: Figueiredo (2014).

4.1. Google Arts & Culture (GAC)

Hosted by Google, this platform allows museums, universities and cultural institutions to share their collections and projects with the public. With a traditional webpage format, the platform allows authors to share text, images and videos both standard and 360 via web and mobile apps (Android and iOS). While GAC does not provide interactive support of 3D content, visualisations can be rendered as video 360 for VR tours, such as the example in Figure 2, which features a partnership between CyArk and GAC depicting a virtual tour of Bagan, Myanmar, that includes 3D scans of the location with added textual and narrative content.

GAC's content is controlled by Google, which assumes the role of gatekeeper. Before uploading any project, authors must either be invited by the platform or register an authorship request upon proving their association with an established museum, gallery, research institution, cultural institution or similar. GAC only allows publishing of content that is copyright-free or copyright-cleared and recommends the use of Google's proprietary hardware to capture photos and video 360.

One of GAC's unique features are themed collections featuring cross-author content, providing users with a selection that is broader and deeper than any single collection or institution alone can provide. Highlighted collections often reflect current events as well as user preferences based on their profile, previous interactions with the platform and with other Google services (Wilson-Barnao, 2017).

As regards user interaction, the platform follows a model of mass communication, where users can create accounts for a more personalized experience but are limited to a passive role: they can mark favourites, create personal collections and share links, but they cannot comment, discuss, expand upon, add or re-appropriate contents.

4.2. CyArk

CyArk is a non-profit organization founded in 2003 with the goal of documenting world heritage sites and facilitating (virtual) access to these sites (Kacyra, 2009). Its platform features a large collection that combines interactive 3D visualisations, images, virtual tours with the aid of mini-maps, 360 photos and textual information, as can be seen in the example on Figure 3, featuring the temple of Xochicalco, Mexico. All content is created, published and managed by the CyArk team.

Each heritage site is visualised independently and can be chosen based on culture, country, map or timeline, as depicted in Figure 4. While most examples offer interactive tools and detailed information about each heritage site, others are still under development and there is no clear distinction between the different types of features available until the user chooses a specific example. As well as documentation of the heritage sites, the platform also offers educational resources aimed at the classroom.

There are no tools for user interaction, whether passive or active: users cannot create accounts to customize their experience, it is not possible to mark favourites, create personal collections, ask questions, make comments, nor expand upon, add or re-appropriate contents.

4.3. 3DHOP (3D Heritage Online Presenter)

Developed by the Visual Computing Lab of ISTI-CNR as an interactive platform to visualise 3D heritage, 3DHOP does not offer content hosting but is instead a plugin that authors can add to their own websites and online platforms (Scopigno et al., 2017). Figure 5 shows an example of 3DHOP being used by Insula V 1: The Swedish Pompeii Project (Insula V 1, 2018) to share interactive 3D visualisations with the public via the project's own website.

On the one hand, this service model places an onus on the author of supplying a website as well as large storage space for their 3D content. On the other hand, authors have complete control over their content and higher decision power about the website's interface and user interaction features, which makes 3DHOP an appealing option for museums, galleries and cultural institutions to share their content with the public.

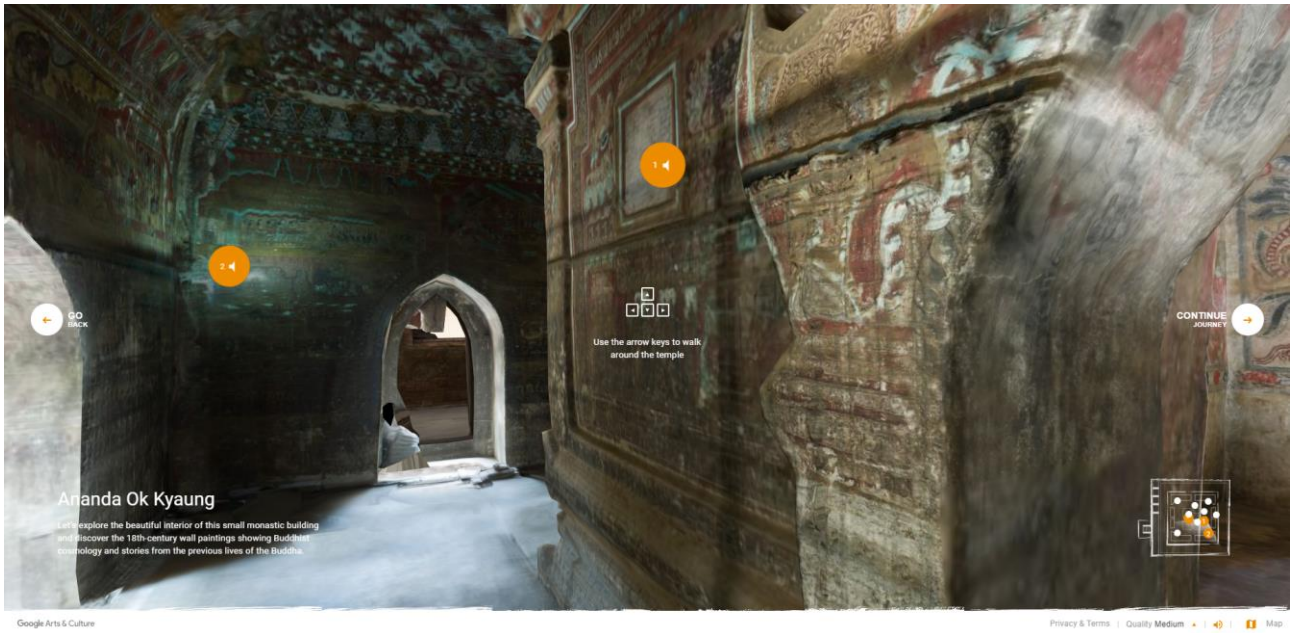

Figure 2: Example of virtual tour including 3D visualisation of heritage at GAC.

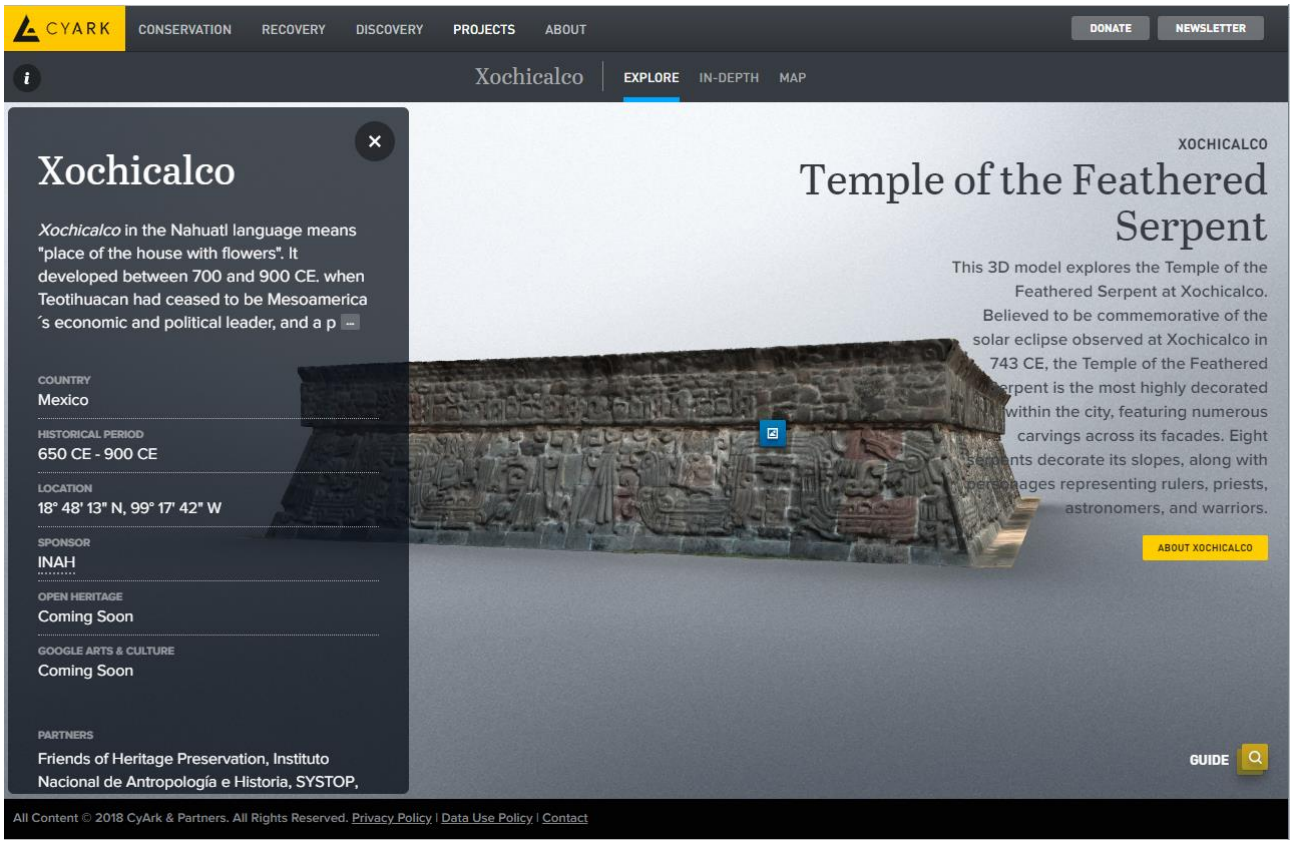

Figure 3: Example of an interactive 3D visualisation at CyArk featuring the temple of Xochicalco, Mexico.

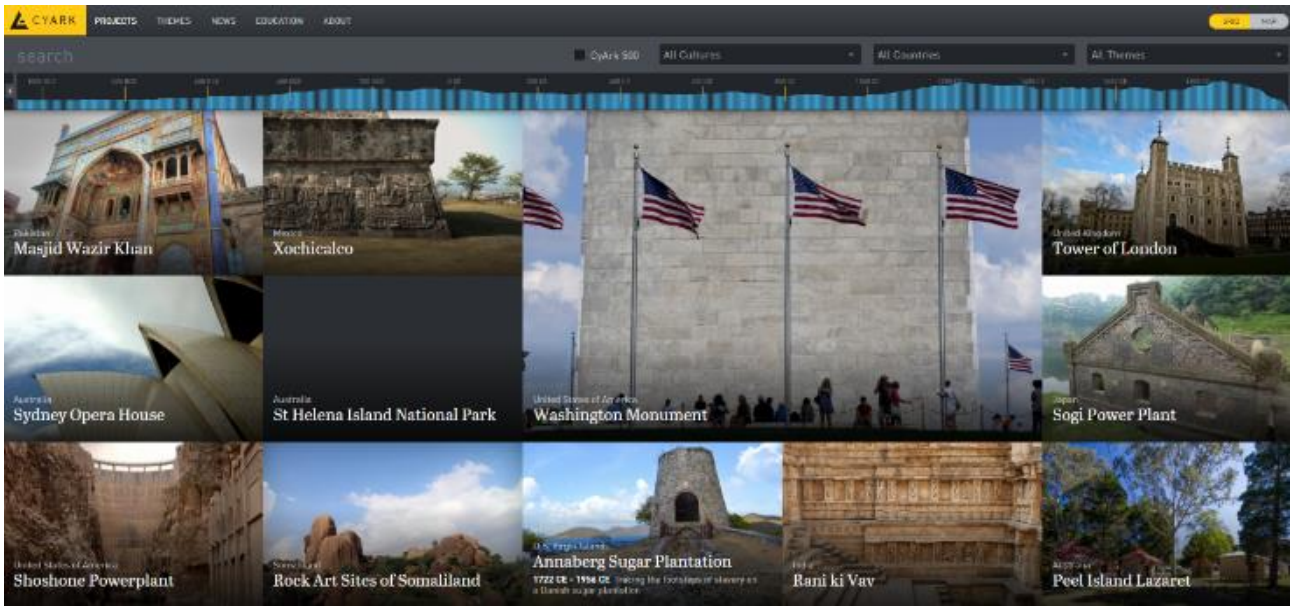

Figure 4: Navigational screen for CyArk featuring several options to sort and choose content.

3DHOP offers specialized tools to visualise 3D scans of heritage, such as support of high-resolution content up to 100 million triangles combined with multi-resolution display to accommodate slow internet connections. It also offers interactive tape measure and isometric cuts (Scopigno et al., 2017). While it does not include textual fields, 3DHOP offers hotspots that can be associated with extra-textual or visual content on the hosting website, as shown in the example on Figure 6 where clicking on the hotspots (marked in red) calls for supporting content (left) in the hosting website.

The platform has no native support for user participation other than the interactive visualisation tools, leaving it to the hosting website to provide user interaction features such as user accounts for a customized experience, creating personal collections, comments, etc.

3DHOP was developed in the framework of V-MUST.NET –Virtual Museum Transnational Network, a four-year European project that ran from 2011 to 2015 to support the development of virtual museums (3DHOP, 2018). While 3DHOP's adoption is not yet widespread, the platform continues to be supported by the research

Figure 5: 3DHOP used by Insula V 1 to share high-resolution 3D scans of their project.

Figure 6: Example of the use of hotspots in 3DHOP.

team at ISTI-CNR with an increasing number of museums and cultural institutions adopting it to host their content online.

4.4. Sketchfab

Online platform aimed at the interactive visualisation of 3D content in general, Sketchfab offers a category dedicated to Cultural Heritage & History, seen in Figure 7, hosting examples uploaded by cultural institutions as well as amateurs. Any static 3D visualisation is compatible with Sketchfab, with a limit of up to around one million triangles (Scopigno et al., 2017). Short length bone-based animations are supported, meaning that while it can display a schematic animation of how a watermill worked, for example, it cannot support extensive virtual tours nor the use of mini-maps or “travelling” between locations.

The visualisations are hosted by the platform without costs to authors, who have the option to choose between displaying the content only, offering the content for free download via Creative Commons, or offering the content commercially via the Store portal. Authors can customize the visualisations by adding paradata annotations, seen in Figure 8, which when clicked display a small textual field (Scopigno et al., 2017). They can also add custom lights, sound, background images, representative static image and textual description; free accounts have limited functions and upload size whereas paid accounts enjoy more options and generous upload limits.

The 3D visualisations can be shared via Sketchfab’s own website or embedded in other websites, forum threads and custom platforms. Content can only be visualised individually, but two visualisation

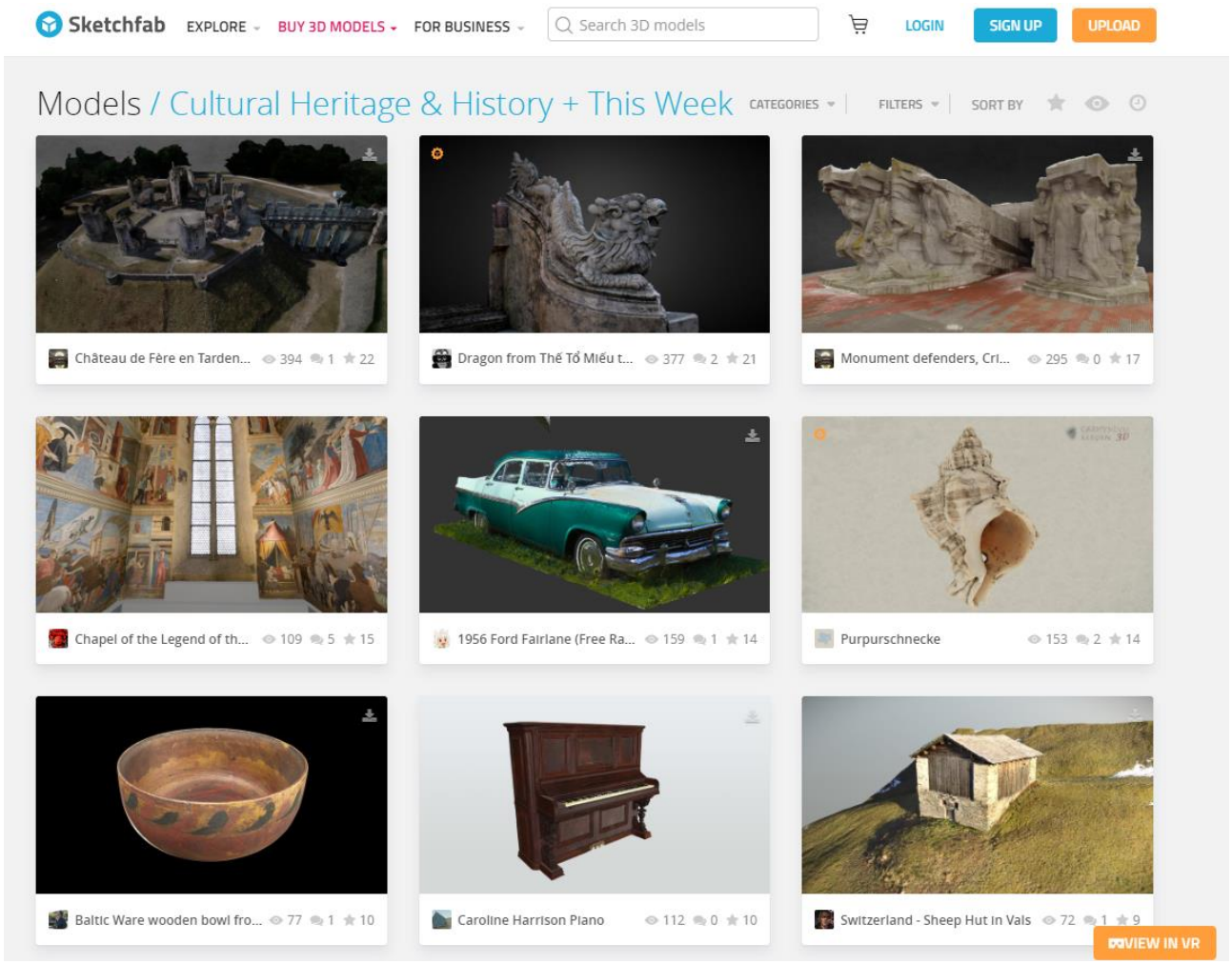

Figure 7: Sketchfab, category Cultural Heritage & History.

Figure 8: Example of the annotations featured in Sketchfab.

screens can be shown side by side in custom websites. The platform supports VR devices as well as offering mobile apps for Android and iOS. Users can search for content based on categories, keywords, most recent, most popular, or features (download enabled, animations, VR). The platform

favours a participatory approach and users can interact through comments, marking favourites, following authors, creating personal collections, sharing content in other platforms, downloading content (when enabled by the author), expanding upon, adding to and reappropriating content. All users are invited to be authors, and creating a Sketchfab account immediately provides both user and authorship privileges. The platform also offers discussion forums for users and authors, promotes content challenges, keeps a blog and offers newsletters. Sketchfab does not control published content but offers a reactive moderation model where users can report inappropriate or offensive content.

4.5. Game Engines

Unlike the previous platforms where authors upload content within a pre-established set of tools and interface layout, game engines offer a high level of customization: the format is limited only by the creativity of the authors, their artistic and programming skills as well as available resources (development deadline, budget and team size). Game engines allow interactive visualisation of vast 3D spaces through virtual tours, exploring both the inside and outside of buildings (Caro & Hansen, 2015), making it an ideal tool for visualizing large heritage sites. It is possible to zoom in details and interesting areas, and authors can also add supporting visual, textual and audio resources, background characters, narrators, vegetation, animals, etc. Users have a high degree of control of how to interact with the 3D visualisation, offering an immersive and personalized exploration of virtual heritage sites as well as recreations of historical periods (Esclapés et al., 2013; Lužnik & Klein, 2015).

While there are hundreds of game engines, two are the most popular for the 3D visualisation of heritage: Unreal (Epic Games, 2018) and Unity (Unity Technologies, 2018). Both can be used without initial costs and offer support for 3D content, VR and AR. Unity is particularly popular with researchers as it offers a large selection of pre-available content that can be acquired at low cost and is compatible with PC, Web, Android and iOS (Lužnik & Klein, 2015).

Game engines provide several features that can facilitate the 3D visualisation of heritage: examining interesting areas; visualisation in normal and "investigative" mode with extra layers of information; taking on the role of customized character or of a character relevant to the historical period; sharing experiences with other users through multi-player, live streaming and screenshots; missions with objectives that guide the user through a systematic exploration of the 3D visualisation; guidance from a narrator; use of mini-maps and being able to instantly travel between locations that are geographically or historically separate; as well as puzzles, quizzes, mini-games and other pedagogical activities.

The greater the complexity of the game, the greater resources needed for its development in terms of time, size and specialization of the team, as well as total costs. It is worth pointing that popular commercial games set in historical periods –Assassin´s Creed, Red Dead Redemption, The Order 1886, Far Cry Primal, etc.- are developed by teams with hundreds of specialized professionals and development costs easily surpass 40 million dollars (Schreier, 2017). However, small teams with limited resources are also capable of developing extremely interesting and immersive experiences, and the average size of a team developing serious games is around five.

Despite game engines being too expensive as a universal solution for 3D visualisation of heritage, their high degree of flexibility makes them an attractive solution for large projects with a comfortable budget. Another advantage is that games are outputted via an executable file instead of relying on websites, offering higher long-term sustainability and lower maintenance costs: it is just as easy to play a game published yesterday as one published ten years ago (especially for PCs), whereas online platforms must be constantly updated and are rarely still active after ten years.

5. Comparative Analysis

This paper aims to evaluate how online platforms commonly used today to share 3D visualisations of heritage facilitate or hinder the scientific rigour of these visualisations. To this end, 32 ICOMOS and UNESCO documents were reviewed in Section 3 and key recommendations were summarized in Section 3.5. It is based on these recommendations that the online platforms are analysed and compared; Table 2 compares the supported features between the platforms, followed by a discussion on how these features are used to meet or not the recommendations of Section 3.5.

Table 2: Comparison of supported features between the five online platforms.

	GAC	*CyArk*	*3DHOP*	*Sketchfab*	*Game Engines*
Type of contents	Text, images, videos, 360 photos and videos, sound	Text, images, 360 photos, 3D	3D	3D, sounds, text, limited animations	3D, images, videos, 360 photos and videos, text, sounds, animation
Level of customization	Low	High	Medium	Low	High
Interactive tools	Low	Low	Medium	Medium	High
Paradata support	Non-existent	Non-existent	Low	Medium	High
Curatory tools	High	Non-existent	Non-existent	Low	Non-existent
Scientific rigour of the content	High	High	Variable	Variable	Variable
User participation	Low	Non-existent	Non-existent	High	Variable

- **Multi-disciplinary teams:** none of the platforms dictates team composition; however Sketchfab is aimed at individual users whereas GAC and CyArk are exclusive to authors associated with cultural institutions, which in itself elevates the scientific rigour of their content. Game engines, due to their technical complexity, benefit from multidisciplinary teams although not necessarily reflecting the traditional skills of multidisciplinary teams working with heritage projects. None of the platforms require supervision by qualified professional or collaboration between international teams when dealing with transnational heritage.
- **Objective-driven methodology and tools:** GAC requires contents to be pre-rendered, limiting the interactivity with 3D visualisations, whereas the other platforms rely on real-time rendering for higher interactivity, which on the other hand limits the resolution of the 3D visualisation (with the exception of 3DHOP). While GAC recommends the use of Google's proprietary hardware to capture 360 content, the remaining platforms do not recommend specific tools.

  CAG and CyArk fully host and present their content on their own platform, with the support of text, images and 360 photos. 3DHOP relies on a hosting website for supportive features, and Sketchfab offers a basic set of supportive features, but also allows sharing the visualisations via external hosting websites where more supportive features might be available. Whereas these four offer features that can be added to or modified at any time after implementation, game engines on the other hand output an executable package, meaning that any supportive features and content must be decided and implemented beforehand. For example, in order to change supporting textual information in a visualisation presented via a game engine, the whole game needs to be repackaged and re-exported.

  With the exception of game engines, the remaining platforms do not document methodological development. Both Unreal and Unity offer detailed support and methodological recommendations as regards the development of the visualisation, and both game engines and Sketchfab offer discussion forums where authors can exchange ideas and get support. Nonetheless, such documentation is generic and not case-specific; none of the platforms offers space to document project-specific objectives, methodology, used tools, or the motivation for choosing them.
- **Careful documentation:** While most platforms offer text fields alongside the 3D visualisation, none make explicit requests for documentation. GAC and CyArk generally offer textual description about the heritage itself, but not about the methodology and rarely about sources; 3DHOP offers no native support for documentation; Sketchfab offers text fields and paradata annotations that can be used at the discretion of the author; game engines offer a range of documentation resources that can also be used at the discretion of the author.

  In general, although it is possible to add supporting documentation, it is left at the discretion of the author. Rarely is information about the project or team that developed the 3D visualisation available in any of the platforms, nor links to related publications.
- **Type of reconstruction and level of certainty:** Even though GAC, CyArk and 3DHOP are developed specifically for the digital visualisation of heritage, they lack native tools to clarify what type of visualisation it is or its level of certainty, and none of the platforms recommends or requires transparency about the type of visualisation, its source or level of certainty. None of the platforms offers features to support the use of a visual scale of historical evidence, as exemplified in Figure 1, although it can be overlaid to the 3D visualisation in game engines with the use of an investigative mode.
- **Authenticity:** Framing authenticity as described in Section 3.5, GAC offers the least amount of authenticity as regards presentation of content due to its low level of customization where, regardless of the subject, the presentation follows a similar minimalistic webpage design. This limits the freedom authors have to customize their presentation, but allows GAC to offer a high level of curatory tools, where related content by different authors can be presented seamlessly. This lack of authenticity does not reflect the quality of the content itself, which is high, but reduces its contextualization and fails to reflect its values and use. Game engines and CyArk offer a wider range of features for the authenticity of both content and presentation, whereas Sketchfab and 3DHOP offer fewer resources for authenticity and limited customization.
- **Alternative hypotheses:** The only platform that offers technical support for the display of alternative hypotheses is game engines and, to a more limited extent, GAC.
- **Multiple historical periods:** GAC and CyArk offer interactive timelines and game engines can support the visualisation of several historical periods as well as transition between different historical periods, while Sketchfab and 3DHOP do not offer technical support for this feature.
- **Respectful use of the heritage and community engagement:** On the one hand, GAC, CyArk and 3DHOP offer a high level of control over their content and its reappropriation, but it is at the cost of disabling community participation; they adopt a mass media model where users are passive consumers of contents.

  Sketchfab and game engines offer several native features for community participation, but on the other hand have lower control over how users interact with or reappropriate content. It is possible with both platforms to impose artificial limits, but it is impossible to have complete control over how users choose to interact with the 3D visualisations, especially with game engines. Game design methodologies also encourage the engagement of a representative section of the community during the development process (as partners in the decision-making process), regarding contents and interactive mechanisms (Adams, 2010), an approach that is unusual in traditional heritage studies.

6. Conclusion and recommendations

This paper analised how five online platforms commonly used today to share 3D visualisations of heritage facilitate or hinder their scientific rigour according to prevailing scientific guidelines. The study suggests that

these platforms face challenges not unlike those of traditional heritage managers, especially as regards community participation: the platforms that offer higher community participation are also those that have lower control over how their content is used and lower scientific rigour. On the one hand, GAC and CyArk carefully manage their content but do not allow the community to interact with or generate meaning around the published contents; on the other hand, Sketchfab allows any user to become an author without screening for quality or authenticity, which while lowering the scientific rigour and even at times disseminating content of dubious quality, does, however, encourage community participation, experimentation and allows communities and individuals to engage with their own heritage, generate meaning around it, and share their heritage with others.

There is a noticeable lack of support for authors working with 3D visualisation of heritage, without encouragement of discussion about research methodology and only limited discussion about development methodology; dissemination of methodological documentation in the analysed online platforms is in general either minimal or non-existent, with the exception of discussion forums hosted by Sketchfab and game engines Unity and Unreal, where authors can ask for peer support.

Only GAC and CyArk have control or impose guidelines over the presence of qualified historians or similar in the research team. In general, it is up to authors to ensure adequate historical and scientific support. This attitude is reflected in the lack of contextualization and documentation: even though most platforms offer text fields that could be used to support the 3D visualisation, their use is neither mandatory nor encouraged. As a rule, the platforms fail to disclose information about the project the visualisations are related to, their scope, teams, or related publications, with only CyArk and GAC faring better, but with a varying level of documentation between examples. This goes directly against the strong emphasis for contextualization and documentation observed on the ICOMOS and UNESCO documents summarized in Section 3.

In 2016, a survey was conducted with 203 users about the contextualization of 3D visualisations of heritage in Sketchfab, where the majority of users valued the use of annotations in helping to understand and contextualize the 3D visualisations. At the same time, users found that the limitation of only being able to see one visualisation at a time and not being able to travel between related visualisations hindered understanding of their historical context (Lloyd, 2016). This indicates that users would prefer if 3D visualisations of heritage had a higher level of contextualization and support documentation, reflecting the consulted scientific guidelines.

Meanwhile, recommendations such as the representation of alternative hypotheses and multiple historical periods are dependent on technological features that are not supported by most of the platforms analysed and would require higher financial and development commitment than most teams have available –after all, to display multiple historical periods as 3D visualisations, it is necessary to first create multiple 3D visualisations.

Nonetheless, taking advantage of the resources currently offered by most platforms either natively or in conjunction with their hosting websites, the author suggests that it is possible to significantly increase their scientific rigour with the adoption of a basic information package to support 3D visualisations of heritage. The information package is based on textual and image content that can be displayed alongside the 3D visualisation, within the layout of each platform. As the objective is to increase scientific rigour without discouraging community participation, the fields should not be mandatory, but by presenting users with visualisations that have supporting information and those that do not, users can distinguish between visualisations created by enthusiasts from those created as a result of a research project.

The proposed information package should include:

- **Descriptive name:** Provide the name of the depicted heritage. Where one is not assigned, use a description suitable to the general public.
- **Type of 3D visualisation:** In the format of a drop-down menu, allowing authors to choose between: a) Photogrammetry and/or laser scanning without added reconstruction; b) 3D reconstruction based on historical evidence; c) Mix of photogrammetry/laser scanning and reconstruction based on historical evidence; d) 3D reconstruction based on hypothesis; e) Mix of photogrammetry/laser scanning and reconstruction based on hypothesis; f) Other.
- **Level of certainty of the reconstruction**: For options b to f, use a scale of historical evidence to indicate the level of certainty of the reconstruction. Depending on the features offered by each platform, it can be displayed as added images, diagrams, or an interactive overlay on the actual 3D visualisation.
- **Description:** Short description to contextualize the depicted heritage.
- **Original location:** Location where the depicted heritage was originally found.
- **Current location:** Applicable to objects that have been moved from their original location, such as museum collections.
- **Date:** Best approximate date of the depicted heritage.
- **Author:** Where an author is known, such as a painting or sculpture.
- **Team responsible for the visualisation:** List team members involved in the project that generated the visualisation and their qualifications where appropriate.
- **Team supervisor:** List the team supervisor where applicable and their qualification.
- **Funding:** List funding sources where applicable.
- **Part of project(s):** List and link to related project(s) where applicable.
- **Project description:** Short description of the project itself, including goals, duration and scope.
- **Related publications:** List and link to related publications where applicable.
- **Related visualisations:** Link to other 3D visualisations hosted online that are related to the current one.

- **Sources:** List consulted sources.
- **Visualisation methodology and tools**: Short description of the tools used to create the visualisation and how they were integrated.

These fields should be incorporated into the search options so users can, for example, search only for visualisations that are supervised by a historian, or that are part of a specific project. Apart from the information package, the author also recommended that platforms allow accredited authors (limited) customization to increase authenticity, such as changing the background, adding sound and narration, adjusting the colour scheme, adding supportive images and video, etc. Limiting this feature to accredited authors minimizes the risk of it being overused by well-intentioned amateurs.

As seen earlier, community participation is valuable and can be encouraged with user accounts that include personalization features and public space for discussions such as comments and forums. This should be implemented carefully with tools and protocols for moderation to minimize spammers and trolls.

Although this proposed information package is designed around features that are already available to most of the analysed platforms –such as textual fields, supportive images, links, user accounts, and basic customization– the author foresees that the platforms will nevertheless be reluctant to incorporate items that affect their design and corporate image. Therefore, a close collaboration between institutions and the platforms that host their content is necessary to promote positive change.

Educating authors is important and authors need to be made aware of the tools available on their favourite platforms and how to use them. This review indicates that authors tend to underuse supporting textual fields that might be used to enhance and support their 3D visualization, even when authors are accredited cultural and research institutions.

While it is important that some platforms remain primarily scientific, such as CAG, CyArk and the dedicated museum and cultural institution websites created using 3DHOP, it is also important to support popular platforms such as Sketchfab where the general public has the opportunity to become authors and share content. The support and participation of cultural institutions in popular platforms allows them to reach wider audiences that might not otherwise normally engage with cultural institutions. At the same time, the development of online platforms dedicated to heritage, such as GAC and 3DHOP must be encouraged. An example is project Gravitate (Gravitate, 2017), which is currently in development as a European partnership and proposes a set of tools for the online documentation, reconstruction and distribution of 3D visualisations of heritage.

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