A Review

WEB 3D Technologies in Digital Heritage

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1. Introduction

The digitalisation of Cultural Heritage i.e. Digital Heritage is a growing field that makes use of a wide variety of digital tools and techniques. Three main areas where digital technologies have become important in cultural heritage correspond to different stages in the process of digitalisation: documenting and collecting, processing and analysing, and archiving and presenting of the data. This paper discusses the data presentation, which is at the very end of this process; however, it has to take the requirements of the previous stages into account. Techniques such as laser scanning and photogrammetry have made it much easier to generate detailed 3D models. As a consequence, there is now a growing need to adequately present this type of data and make the heritage more visible and accessible to the broad audience.

This paper reviews state-of-the-art web 3D technologies used for digital presentation in the field of Digital Heritage; and presents a comparative analysis of the different tools. A broader overview of 3D graphics on the web, in general, is provided by Evans [1].

2. Web 3D Technologies

The World Wide Web has significantly evolved. From the tool for sharing a simple static text by HTML (Hypertext Markup Language), an introduction of „browsing", later including images, and followed by exploding development in mid-1990. XML (Extensible Markup Language), CSS (Cascading Style Sheets), JS (JavaScript), Adobe Flash, are just a few of the remarkable technologies incorporated into World Wide Web in following years. The interactive multimedia was heavily depending on Adobe Flash, allowing interactive audio, video and 2D animations, which were executed by an installed plugin. These applications were not suited for different platforms and they usually required long download time. At the same time, the need for more complex multimedia increased. As a first answer, the SVG (Scalable Vector Graphics) was introduced, allowing the complex 2D drawing to fit with HTML, eventually resulting HTML5 to be able to create dynamic web pages of complex interactive multimedia.

3D data is commonly used in many different scientific fields; however, even though web 3D technologies have been around for a long time there is still no de-facto standard, presumably due to the complexity of 3D data. Originally web 3D visualisation was entrusted to an external plugin, but this led to limited use and lack of standardisation. Nowadays, web 3D technologies are an eminent part of the multimedia web experience. Thanks to the recent development of both hardware and software, 3D content no longer involves complex and heavy plugins to operate fluently.

2.1 VRML and X3D

Starting in the mid-1990, VRML (virtual reality modelling language) [2] was a pioneer file format in the field of Web 3d technology. VRML was the first step to standardize the format for representing interactive 3D environments, specifically created for the World Wide Web. It was not a programming language, rather a descriptive language which uses text to describe the appearance and content of the scene. VRML was working on a similar principle like HTML however 3D content, from today's point of view its main limitation was that its specification didn't include advanced 3D data. The first version was released in 1994, and it was allowing users to move through the 3D environment and to use objects as links to the other web pages, however, it was not able to offer much more interaction than that. Next version was better in terms of interactivity with objects; however, it didn't last long until users asked for more, sound, upgraded interactivity, better control over objects... VRML had few more versions, each evolving from the previous one, however, the team behind VRML decided to stop and start from scratch and develop something new.

A decade later in 2004, VRML was replaced by X3D [3], an open-source standard for representing the 3D environment. X3D made it easy to create read and write tools, as well as great extensibility. By maintaining compatibility with VRML, it was supporting additional binary and XML formats. Among the usual options for displaying 3D and 2D static and animated graphics, it was possible to set sound and film as parts of a scene, then „sensors" and hyperlinks to other objects, whereby their interactions could be managed by scripts within the file itself. X3D was possible to allocate physical characteristics to objects. Apart from the application on the Internet, it was expected that X3D will become the standard for the exchange of 3D objects between 3D modelling and animation programs. In the end, X3D was also accepted, like its predecessor - VRML, as an ISO standard, not covered by patents and completely free to use. Nevertheless, the 3D visualisation of data was still passed on to external software, at least until 2011, when the Khronos Group released WebGL, a remarkable innovation.

2.2 WebGL

WebGL (Web Graphics Library) [4] is a cross-platform, royalty-free web standard for a low-level 3D graphics API (Application programming interface) as described by Khronos. It is designed for visualisation of interactive 2D and 3D content, implemented directly within the browser without the necessity of additional plugins. WebGL is built to use web technology standards, therefore a standard HTML page is working with WebGL and 3D content is drawn via JavaScript. The process of creating a 3D content is based on creating the HTML5 Canvas element, loading and defining the vertices and shaders, bind additional data (such as normal, colours and texture coordinates), control position and camera and draw the canvas.

Release of WebGL was the beginning of a new era in Web 3d technologies and emerging solutions developed into two alternative paths; The systems such as X3DOM and XML3D, extending X3D by following the declarative programming method, based on the scene-graph model; The systems using imperative programming method, such as WebGL associated libraries, that range from more programmer- friendly examples as SpiderGL and WebGLU, to scene-graph based interface, as Three.js and Scene.js.

Both declarative and imperative programming methods have their own advantages and disadvantages. It can be said that the declarative method had a bigger impact on the research community, while the imperative method is mainly used by the programming community.

2.2.1 X3DOM

X3DOM [5] is built to support 3D graphics in the browser, without the necessity of an additional plugin and it consists of both front-end (DOM) and back-end (X3D) structure. As X3D, X3DOM has a declarative approach and it is defined so that the X3D can be encoded directly into the webpage. It enables an X3D tag as XML namespace, so it can be used in HTML. Loading of the 3D models is defined by vertex geometry or by X3D scene, that can be imported as a separate file. Camera and navigation methods and patterns are supported via Viewpoint node and simple animation via CSS or X3D. Diffuse and specular shading as well as texture, reflection and light are supported, and for custom shaders, X3DOM allows the usage of custom codes supported via Composed-Shader node. For rendering X3DOM is using the fallback system, if the favoured renderer is not available, the next alternative option is used. At first, it will check if X3D code can be rendered natively, if not, it will try to work with WebGL, or as the last resort with Stage 3D (Flash) before it pop-up the error.

2.2.2 SpiderGL

Spider GL [6] was one of the first WebGL associated libraries. It is defined as a JavaScript library that uses WebGL for real-time rendering (providing standard structures for it, without the necessity of specific paradigms such as scene graph). It contains six libraries: MATH – mathematic routines; SPACE – geometric structures; GL – WebGL access, rendering; MESH – mesh import, edit and render; UI – user interface interactive handling; DOM – HTML and JavaScript utilities.

2.2.3 Three.js

Three.js [7] is a widespread WebGL associated JavaScript library and application programming interface. It is designed as a general-purpose graphic library that creates and presents 3D content directly in the browser without the usage of plugins. Three.js is an open source library which features a scene graph, level-of-detail style of loading and rendering with several different technologies such as Canvas, SVG, CSS3D and WebGL several light options, couple of predefined materials and shaders and the possibility to create custom ones and diverse navigation and camera modes.

3. Web 3D Tools

As web 3D content, thanks to web 3D technologies, is becoming easier to handle, it can be found widely spread and used by numerous fields of sciences and industries such as medicine, engineering, architecture, data visualisation, cultural heritage, education, digital creative, gaming, etc.

When it comes to applications of web 3d technologies, there is a wide range of frameworks i.e. tools, including both libraries and engines. It is difficult to divide these tools into simple categories as there are multiple aspects to be considered. For the purpose of this research, the following aspects such as licencing type, available tools and required skill-set, are selected as deal-breaking factors when it comes to the selection of the appropriate tool.

Frameworks licencing type can be: commercial, free or open-source. Commercial type of licence has usually different payment plans depending on whether the user is a company, school/university or whether it is for private use. In return for payment, a user is provided with a full version of the framework and complete support in terms of tutorials, templates, updates and technical support. Free type of the frameworks is as the name says - free for use, however, quite often this means restrictions in terms of features and support as well as limitation in exporting and publishing (not for commercial use). The open-source frameworks are allowing you full access to the source code of the framework, unlike commercial and free frameworks. This feature is granting the user the opportunity to use the framework to its fullest, to make adaptation or even to develop new features.

Second aspect i.e. available tools, is defined by frameworks original purpose. Some frameworks are developed as 3D platforms, game-engines or specialised tools. 3D platforms are created for publishing, sharing/trading of 3D content online. Simple systems, commonly only viewers, originally designed for the 3D artist. Game engines are very powerful, with complex editing features and as the name says, designed for the gaming industry. Specialised tools are focused on a specific need and demands of different user groups, frequently designed for the purpose of the particular project.

The required skill set is dividing frameworks into three groups: straightforward, complex and „best-of-both". Straightforward workflow is easy to follow, covering all the essentials for good-quality presentation, however, limited in terms of personalisation of the presentation itself. Complex workflow often indicates the need for coding skills, however, the user has unlimited creativity. „Best-of-both" group of frameworks are like insinuated, giving the option of following a predefined template or creating your own.

As mentioned, all these aspects are playing an important role when it comes to choosing a suitable framework. Each web 3D tool is a combination of different, discussed above, factors that distinguish it amongst the other web 3D tools. The following section will focus on the review of the state-of-the-art representatives of web 3D tools used in the field of Digital Heritage.

3.1 Marmoset

Marmoset [8] is a commercial creative suite featuring renderer and online viewer. The user creates the scene in Marmoset Toolbag and exports it into Web 3D presentation optimized for hosting and embedding. Marmoset Toolbag features materials, lights, cameras, all essential tools for setting a scene and creating an animation. Marmoset Viewer is WebGL based, real-time renderer that supports different display mode for a topology, texture, normals etc. Thanks to WebGL technology, the Marmoset Viewer runs without any plugins on a variety of browsers and devices. There is no restriction in terms of geometry, however complex scenes and high-poly models are known to crash on weaker devices.

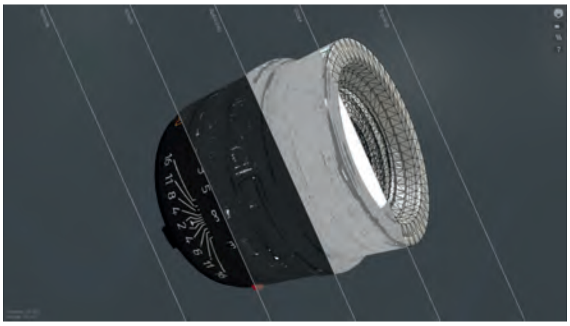


Figure 1 - Screenshot of the presentation made with the Marmoset Viewer

3.2 Cl3ver

Cl3ver [9] is also a commercial, browser-based Web 3D tool designed to create, present and share complex interactive 3D content. It supports model import, lights, materials and interactive animation. User can design interactivity using a predefined template or by writing own scripts in JavaScript. Data is stored on the cloud which is convenient for sharing, team collaborations and client presentations, wherever and on any device; however it is raising the questions of data privacy and property.

3.3 SketchFab

Sketchfab [10] is a well-known platform in the field of Digital Heritage, used for publishing, sharing and discovering 3D, VR and AR content on the Web. It provides a simple viewer based on WebGL and WebVR technologies that allow displaying 3D models on the Web, to be viewed on any mobile browser, desktop browser or Virtual Reality headset. Widely used, it supports the import of a variety of 3D file formats. There is a pro licence with advanced features and the framework is free for personal use. On the downside, sketchfab has a limit on a geometrical complexity, the interactivity of the model is limited and models are stored on the cloud, what's ones more, raising issues of data privacy and property.

Figure 2 - Screenshot of the presentation made with the Sketchfab

3.4 Blend4web

On a related topic, Blend4web [11] is a framework developed for creating and presenting interactive 3D graphics on the web. Scene creation relies on Blender while rendering is done via WebGL. It has both commercial and free, open source licence with GitHub hosted source code. Blend4web has a number of characteristics typically found in game engines such as physics, audio, animation, dynamic loading, subsurface scattering, image-based lighting, etc.

3.5 Unity

Unity [12], a multi-platform game engine is one of the most standard platforms for developing both 2D and 3D video games and simulations for computers, consoles, and mobile devices. It has a pro licence and it is free for personal use. Unity is extremely powerful, and it is providing high-quality rendering, sound, physics, interaction and fast development of simple visualisation. However, complex scenes and interaction are requiring complex, and not so fast workflow, same as the integration of the visualisation into a webpage. Also, typical for game engines, Unity is not working well with high poly geometry.

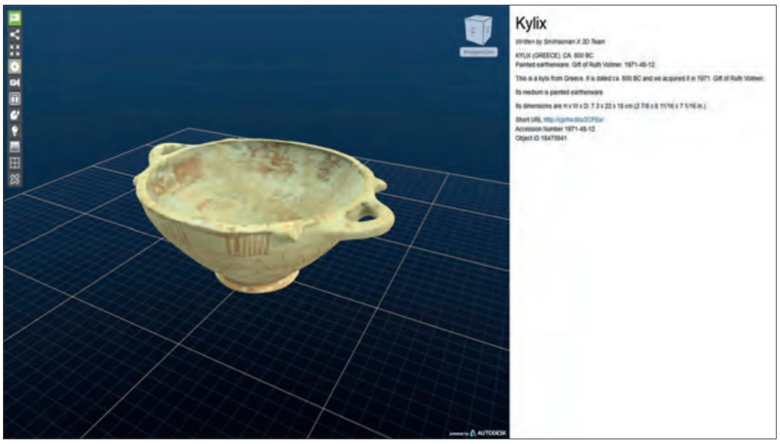
3.6 Unreal Engine 4

Another well-known game engine is Unreal Engine 4 [13]. It is designed as a suite for game development, as well as the creation of simulations and visualisations. Unreal Engine 4 has integrated tools for scene design, physics, interaction, rendering etc. Like Unity, it has a complex workflow for complex scenes, interaction and integration of the visualisation into a webpage, and it's not compatible with high poly geometry.

3.7 Smithsonian X 3D

Another scientific example would be Smithsonian X 3D [15]. A WebGL solution developed for the online presentation of the Smithsonian museum 3D scans. In the collaboration with Autodesk, Smithsonian Foundation technologists created a framework that

Figure 3 - Screenshot of the presentation made with the 3DHOP



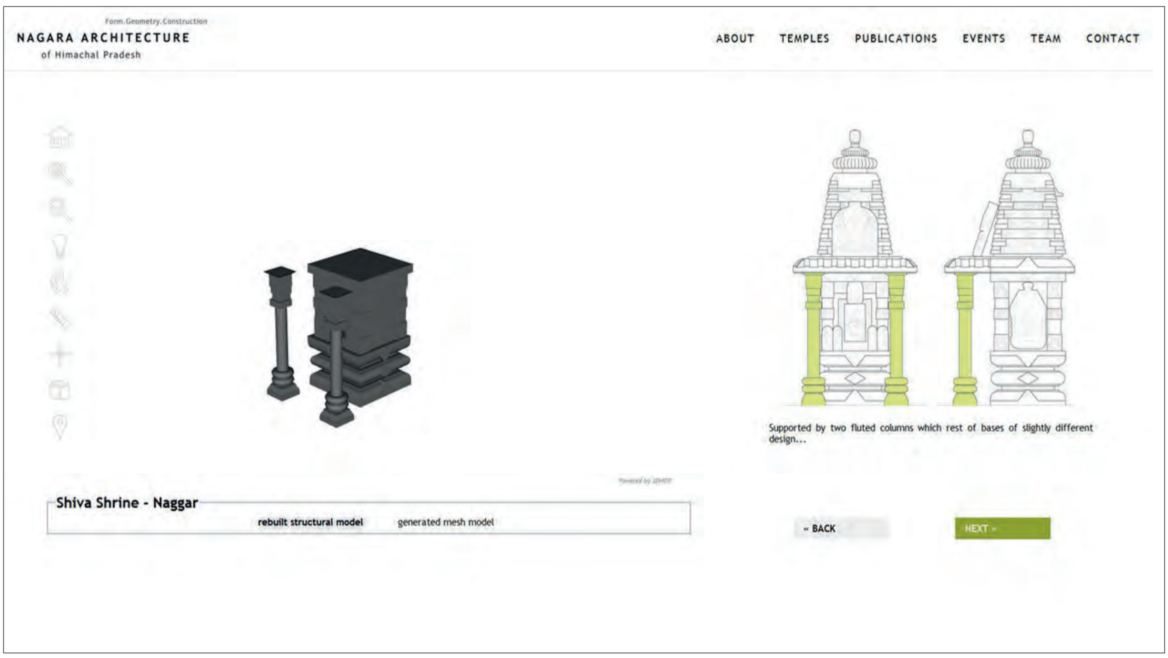


Figure 4 - Screenshot of the presentation made with the Smithsonian X 3D

features common 3D tools, diverse layer view, lighting, explanation panel and interaction with the model. Unfortunately, even thou well developed with all the desired features; it is a closed solution, accessible to the public only as a web presentation of 3D scans.

3.8 3DHOP

On a more scientific note, 3DHOP (3D Heritage Online Presenter) [14] is a framework for the creation of advanced Web-based visual presentations of high-resolution 3D content, created by a team of researchers. More precisely, a tool that deals with the visualisation of a high-resolution single object (especially with dense models coming from 3D scanning) or, more in general, a simple static scene composed of complex models. It is based on WebGL and SpiderGL technology, completely open source with GitHub hosted Source code, and it allows the creation of interactive visualization of 3D models directly inside a standard web page, just by adding some HTML and JavaScript components in the HTML code. The 3D scene and user interaction can be easily configured.

4. Comparative Analysis

Mentioned frameworks are selected from a growing number of web 3D tools. The selection was made, based on advantages and disadvantages, regarding the discussed requirements, aspects and factors, and some of the additional properties, such as implementation into the web page, supported geometry types etc.

The frameworks were tested with identical scene configuration on multiple operating systems (Microsoft Windows, Mac OS, Android and iOS) as well as on different web browsers (Firefox, Chrome, Internet Explorer, Opera and Safari) and on both, desktop and mobile devices.

The following table shows ten important properties of ten different frameworks; the technology they are based on, licencing type, given toolbox, data storage type, scripting, modelling, animation, physics and WebVR possibilities and supporting file formats.

5. Conclusion

As already argued, the field of Digital Heritage has its own specific requirements that naturally dictate the needs and demands from a certain framework. There is a broad array of more or less similar solutions, but only a few are fulfilling the whole set of given requirements. Most of the frameworks are advertised, in theory, to work in any field, however, in practice, there is a difference. The bigger part of the offered solutions is primarily intended for the artist community and gaming industry and just a small part is actually developed for scientific use.

Not to be misunderstood, the commercial frameworks are developed because there are a clear need and market for them. Nonetheless, there are issues with soft-

Name	*Technology*	*License*	*Toolbox*	*Storage*	*Scripting*	*Modeling*	*Animation*	*Physics*	*WebVR*	*Import*
3DHOP	WebGL	Open-source	Specialized tool	Server	JavaScript	No	Yes	No	No	ply, nxs
Babylon.js	WebGL	Open-source	3D Platform	Server	JavaScript	No	Yes	Yes	Yes	obj, fbx, stl, gltf, babylon
Blend4web	WebGl	Commercial + Open-source	3D Platform	Server	JavaScript	Yes	Yes	Yes	Yes	obj, fbx, 3ds, ply, stl...
Cl3ver	WebGL	Commercial	3D Platform	Cloud	JavaScript	No	Yes	No	No	rvt, 3ds, 3dm, fbx, stl, obj...
Marmoset	WebGL	Commercial	3D Platform	Server	Python	No	Yes	No	No	Mview / fbx, obj
Playcanvas	WebGL	Commercial + Open-source	3D Platform	Cloud	JavaScript	No	Yes	Yes	No	fbx, obj
Sketchfab	WebGL	Commercial + Free	3D Platform	Cloud	JavaScript	No	Yes	No	Yes	3ds, obj, blend, fbx, ply, stl...
Smithsonian X 3D	WebGL	Closed	Specialized tool	n/a	n/a	No	Yes	n/a	No	n/a
Unity	WebGL	Commercial + Free	Game-engine	Server	UnityScript, C#	Yes (asset)	Yes	Yes	Yes (asset)	fbx, obj
Unreal Engine 4	WebGL	Free	Game-engine	Server	UnrealScript, C++	Yes	Yes	Yes	No	fbx, obj

Table 1 - Comparison of the Web 3D tools

ware dependence, presentation restriction and data storage; therefore they are just not the right choice in the case of digitalisation of Cultural Heritage.
The online 3D platforms are still the great place to publish, share and trade digital 3D content. However, the storage of data (in the most cases) on the cloud, limited interactivity and lack of personalisation of the presentation are raising issues with data privacy and property and this type of frameworks in general.
The game engines and related solutions are very powerful frameworks with large user bases, and one would argue there is no such presentation they can't handle. Nevertheless, even with the probably limitless model interactivity and complete presentation personalisation, the fact that they can't handle the common type of data used in Digital Heritage, which is high poly 3D scan model, is making them inadequate for this field.

In the end, there is the smallest group of specialized frameworks that ware actually developed as an answer to the shortcomings of the above-mentioned frameworks. These frameworks adequately addressed all the needs and demands of the field of Digital Heritage; they are developed by a scientist working in the field and constantly updated when the new requirements are established.
After the evaluation of selected frameworks reviewed in the presented paper, the clear conclusion is that currently, 3DHOP stands out as a logical decision, when it comes to the selection of the appropriate framework for the interactive web 3D presentation. The open source code allows the full control over interactivity, design and personalisation of presentation, high poly 3D geometry is being rendered without an issue and the data is under the user's jurisdiction.

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