Peregrinations: Journal of Medieval Art and Architecture

Volume 6 | Issue 2 48-64

2017

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PEREGRINATIONS
JOURNAL OF MEDIEVAL ART AND ARCHITECTURE
VOLUME VI, NUMBER 2 (AUTUMN 2017)

A Fortunate Alignment of the Spheres: Overcoming the Problems of Integrating 3d into Daily Practice

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In 2007 during the comments section of a panel on 3d and buildings archaeology at the Theoretical Archaeology Group conference, Mark Gillings expressed a vision for 3d in research and teaching. "Let's pull it, paint it, candy stripe it!," he enthused. He was speaking about models of medieval church interiors and his imagination had been stirred by the potential rich rewards 3d modeling offered in its ability to freely manipulate time and space, color and texture. Perhaps, through 3d modeling, we could somehow get closer to understanding the emotional and embodied experience of medieval spaces. Perhaps.

3d technologies in art history have been arriving for over thirty years (the 1983 University of Bath reconstruction of Roman Bath may possibly have been the first).[1] Medieval sites have played a role from the start: in 1984 Anglo-Saxon Winchester Cathedral was the subject of one of the earliest applications of the technology to art historical investigation (**fig. 1**).[2] The promise of being able to explore sites in objects with a complete mastery of time and space has always been tantalizing but elusory. Technologies and standards meant to make creating and engaging with 3d content more stable and accessible such as VRML, the Cortona3d browser plugin, SecondLife,

[1] David Lavender, Andrew Wallis, Adrian Bowyer, and Peter Davenport, "Solid modelling of Roman Bath," *Science and Archaeology* 32 (1990): pp. 15-19.

[2] Paul Reilly, Stephen Todd, and Andy Walter, "Rediscovering and modernizing the digital Old Minster of Winchester," *Digital Applications in Archaeology and Cultural Heritage* 3:2 (2016): pp. 33-41.

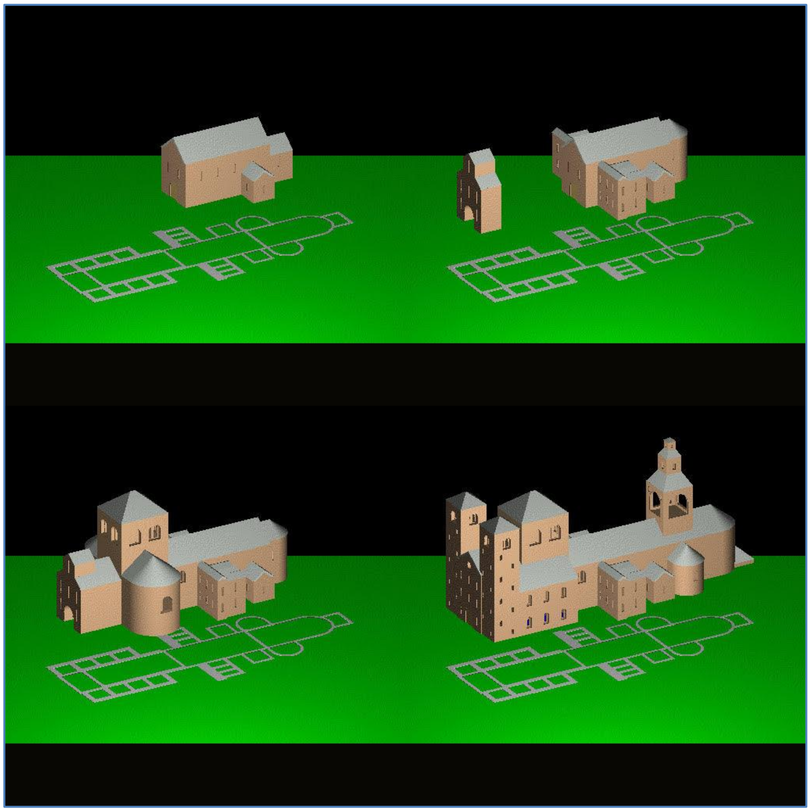

Figure 1 The evolution of Anglo-Saxon Winchester Cathedral, modelled, animated, and rendered using Winsom, IBM's cutting-edge modeling technology in 1984. Image: Paul Reilly, Stephen Todd, and Andy Walter, "Rediscovering and modernizing the digital Old Minster of Winchester," *Digital Applications in Archaeology and Cultural Heritage* 3:2 (2016): 35, fig. 1. Used with permission.

the .x3d open file format, the Unity web plugin, even the Collada open format have either disappeared or gained little traction. Technologies for capturing 3d data have developed rapidly over the past decade, making it increasingly cost and time-effective to produce 3d facsimiles of objects. But the integration of 3d data into research and teaching in art history continues to be slow or at least very unevenly distributed and poorly published. Progress has been so slow, in fact, that I once shaped a postgraduate module around "The Death of 3d." It is telling that in a review of the state of digital humanities and medieval studies published in October 2017, the authors devoted only four paragraphs of their 38-page article to what might be considered 3d content (and that includes acoustic modeling and VR as a platform).[3] There are reasons for this – reasons which are closely linked to the fundamental nature of "doing" art history – as well as to technical limitations, and the nature of 3d as a medium. However, we may now have reached the long-sought alignment of

[3] David J Birnbaum, Sheila Bonde, and Mike Kestemont, "The Digital Middle Ages: An Introduction," *Speculum* 92/S1 (2017): pp. S10-12.

technology, platforms, and scholarship which will usher in the era of 3d as a standard tool for research, teaching, and publication in medieval art history. Maybe.

Let's explore some of the reasons why 3d is different from other digital content and why it has been so slow on the uptake. First, 3d is fundamentally unlike conventional digital content such as images, video, or sound. Second, 3d content comes with a number of technical restrictions and limitations which are barriers to its creation and consumption. Finally, long-established theoretical, methodological, and pedagogical practice are not naturally open to the inclusion of digital 3d. In all of these areas, the fundamental strength of 3d models – their native spatiality and their flexibility – is also their biggest liability.

The nature of 3d content is unlike other forms of media used in research and teaching medieval art history. It *requires* manipulation and personal experience. A 3d object occupies space in its own right, albeit virtual space. 2d images representing the object can be produced, of course, but this is only representation, not the object itself. The analog equivalents of digital 3d content are sculpture and architecture – media which also suffer at the hands of established research methodologies which are almost exclusively limited to 2d representation. Digital 3d content, sculpture, and architecture all must be *experienced* in motion to be comprehended. This is difficult to do in conventional desk-based research, publication, and teaching. 3d digital objects also have the distinct disadvantage in that they cannot be directly experienced bodily, although perhaps advances in virtual reality (VR) are bridging that gap.

Digital 3d objects also have a wide range of inherent technical issues which complicate their creation and accessibility. 3d models are composed of geometry and materials. Geometry is the spatial definition of the object's surface in terms of 3d Cartesian coordinates (called vertices) connected into a web of triangular 3d polygons (called a mesh). Materials, then, define the object's appearance on screen in terms of color, ornament, micro-surface detail, interaction with virtual light sources, etc. 3d models are complex digital entities. In order to be used, there must be some way for them to pass from whatever software was employed to create them to other software intended to "consume" them.

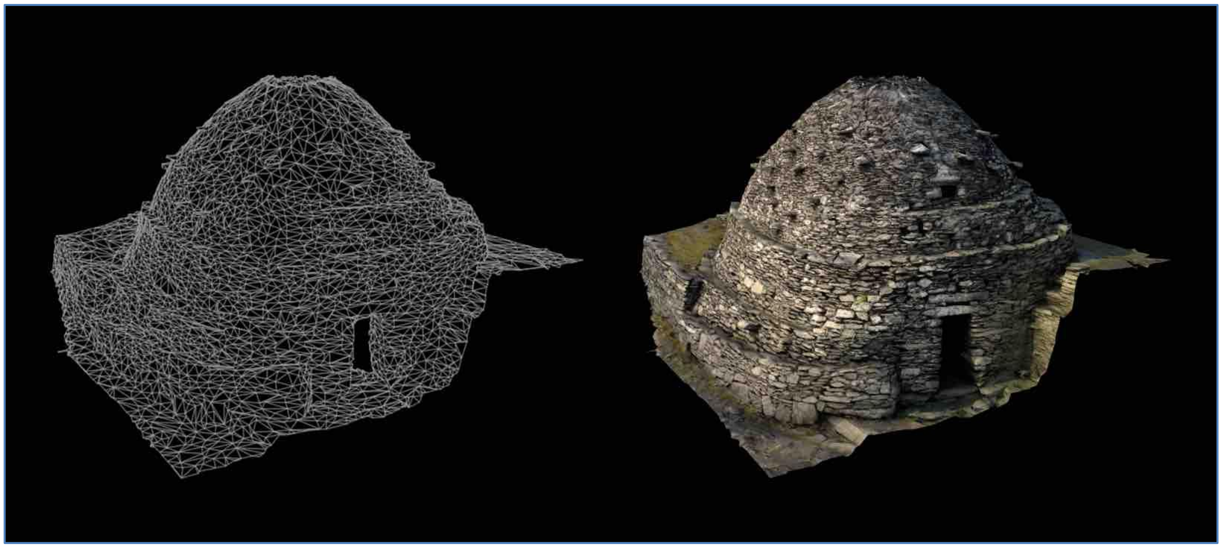

Figure 2 The Refectory at Skellig Michael, Co. Kerry, Ireland. (Left) Geometry (Right) Geometry with materials. Image: Author.

The "portability" or "transferability" of any digital content from software to software is a matter of standards – both in practice and in file formats. A standard for 3d content creation does exist. The London Charter was established in 2006 as a kind of standard defining good practice in 3d for cultural heritage visualization. It is actively maintained, having its second edition in 2012.[4] Its principles are clearly defined and extensive. Yet this is one of the issues preventing the London Charter from widespread adoption in practice. Its principles are based on a conception of visualization which is too narrow to admit the wide range of applications of 3d content in cultural heritage. The London Charter approaches heritage visualization as if it were GIS with its largely data-driven, analytical toolset which generates its own metadata. While this *is* the case with 3d datasets produced by scanning and photogrammetric methods, it is *not* the nature of 3d

[4] Hugh Denard, "A New Introduction to the London Charter," in A Bentkowska-Kafel, D Baker, and H Denard (eds), *Paradata and Transparency in Virtual Heritage* (Farnham, UK: Ashgate, 2012), pp. 57-71.

content using more artist-focused toolsets to create what is fundamentally an act of imagination. Until a lighter-weight, flexible version of the Charter emerges, it will remain something of an unattainable ideal. Its precepts are too burdensome to address in the already time-consuming process of creating visualizations of the past. Personally, I know of only one recent attempt at fully and openly engaging with the London Charter while creating a heritage visualization.[5] Most other practitioners I know continue to view the London Charter as a good idea, but a practical impossibility.

Standards in file types are even more fundamentally important to the long-term curation and accessibility of 3d content in the humanities. But, like the London Charter, standards have not been widely accepted in practice. Unlike images, video, and sound, there are no file format standards for 3d. Attempts at creating standards have been made. Polygon File Format (.ply) and Stereo Lithography (.stl) are some of the oldest formats and also some of the most successful, having been widely adopted by 3d scanning hardware and software developers. Their simplicity of structure and human-readable nature are their chief attractions, as well as the large body of legacy 3d data which now exists in these formats. They do not support any form of material definition, being restricted to geometry only. Nonetheless, these two formats do serve as a kind of standard for 3d printing technology. VRML (.wrl) and its successor .x3d are other notable attempts at creating a standard format. They are open formats which include material definitions and can be written in binary or human-readable code. Still, despite these advantages they have not been widely adopted, perhaps because they were simply ahead of their time; .wrl was published in 1994, and .x3d in 2001. In contrast, in geospatial data, standard formats have been widely adopted, helping ensure the long-term accessibility and preservation of data.

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[5] William M Carter, *Virtual Archaeology, Virtual Longhouses and "Envisioning the Unseen" Within the Archaeological Record* (unpublished PhD thesis, The University of Western Ontario, 2017), http://ir.lib.uwo.ca/etd/4902 (accessed 27 October 2017).

The non-geospatial 3d content producing community, however, has proven remarkably resistant to standards of any kind. 3d content production is dominated by the entertainment industry and the commercial software developers who serve it. The pace of change in the industry is breathtaking – far faster with which any standards can keep pace. Commercial software development is market-bound to propriety formats which lock users of specific software packages into dependence on those very costly packages. Commercial developers have very little motivation to engage in standards-making and use. This may be changing, however. The Khronos Group, a consortium representing the leading commercial developers in the industry, creates and manages a set of standard data formats which have become increasingly integrated into commercial software over the past ten years as the commercial benefits of interoperability are becoming more and more apparent.[6] Still, industry remains resistant to standards.

Nevertheless, *de facto* standards have emerged, established through custom and coincidence. The Wavefront .obj format is a long stalwart of the industry, having been developed in the mid 1990's by Alias Wavefront as a proprietary format. It is a human-readable format defining geometry and materials when paired with a companion .mtl file. The early market dominance of Alias Wavefront combined with the relative ease with which an .obj importer/exporter can be written ensured its widespread adoption. Although Alias Wavefront has long-since ceased trading, their format continues to enjoy widespread use, being a fundamental import/exchange interchange format in almost all 3d software. Another proprietary format, fbx, owned by 3d graphics giant Autodesk, has risen to prominence as an interchange format over the past decade too. Unlike .obj it includes animation and character rigging as well as geometry and materials. There is no officially-published standard definition of the format, which

[6] The Khronos Group Inc, https://www.khronos.org, (accessed 27 October 2017).

remains exclusive property of Autodesk. Yet it is human-readable and clearly structured, allowing the open source Blender Foundation to publish an unofficial standard, leading to its widespread adoption.[7] Collada (.dae), .fbx's truly open-source twin has also seen widespread adoption, but is somewhat less-well supported, primarily amongst Autodesk's own software applications which happen to be the majority of the 3d software in use today. The point of this discussion of 3d file formats is to explain how precarious many 3d models are, their ties to industry and commercial interests, and how prone content is to being rendered inaccessible by market forces and the whims of industry.

Creating 3d content is also not as direct a process as point-and-shoot photography, although, for some applications, this is rapidly changing. 3d content creation and use has historically been throttled by the capabilities of computer hardware. Displaying and manipulating 3d content at almost any level of complexity was, until the second decade of this century, computationally intensive. In the 1980s and early 1990s only expensive, dedicated 3d graphics workstations were capable of loading, displaying, and manipulating 3d data composed of more than a few hundred polygons. Now, of course, most mobile devices are capable of displaying 3d meshes of hundreds of thousands of polygons and laptop and desktop computers can handle millions. Still 3d data capture techniques continue to out-pace display technology. Laser scanning and photogrammetry routinely produce meshes composed of tens of millions or even billions of polygons. The digital facsimiles scanning techniques produce can be at a level of fidelity beyond what the human eye can meaningfully detect. But the "heavy weight" of these meshes is still too computationally intense to be of practical use. There are numerous tricks to reduce the complexity of scan data while retaining visual fidelity, but all of these require a base level of training and ample time for

[7] Blender Foundation, "FBX binary file format specification," *Blender Developers Blog* (2013), https://code.blender.org/2013/08/fbx-binary-file-format-specification (accessed 27 October 2017).

experimentation, as well as the hardware, software, funding, and time to build competence. These are luxuries not all of those interested in creating 3d content can afford.

Scanned 3d data is also limited to objects that still exist. If an object or space no longer exists, or has been significantly altered from its original state, the task increases in complexity significantly. When the goal is representing an object which does not exist, or which existed in a different state at some time the past, scanning technologies are of limited utility. The skills of specialists and artists become essential. The process of creating 3d objects from scratch involves numerous stages, which, depending on the project specification, may require numerous specialists, inflating the costs of producing the content. As an illustration, consider that IMDB lists 91 animators, visual effects specialists, and art directors involved in the creation of Disney's 1937 cell-animated *Snow White*.[8] Everything on screen was drawn and painted by hand: all the backgrounds, all the characters, every frame. By contrast, the IMDB entry for the 2013 computer-animated Disney hit *Frozen* lists 180 individuals involved in the animation department alone. Across art direction, visual effects, and animation, at least 358 artists are credited.[9] 3d content creation – especially from scratch – is always several orders of magnitude more time and labor-intensive than conventional forms of representation.

Finally, consider that research, publication, and teaching have been developed on an exclusively 2d, primarily paper-based delivery platform for centuries. Physical interaction with content is limited. I would argue that intellectual interaction is implicitly restrained as well. Sculpture becomes drawings or photographs. Artifacts are meticulously measured and rendered in pen and ink. Architecture is reduced to plans, sections, and elevations. Lighting is static. Time is frozen. By contrast, 3d content must

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[8] IMDB, "Snow White and the Seven Dwarfs (1937)," http://www.imdb.com/title/tt0029583/fullcredits (accessed 27 October 2017).

[9] IMDB, "Frozen (2013)," http://www.imdb.com/title/tt2294629/fullcredits (accessed 27 October 2017).

be actively engaged with and manipulated to be understood. It can be recolored, stretched, twisted, reduced and enlarged at will. But this requires both display hardware capable of computing these transformations, and an interface stable and intuitive enough to allow such manipulation without getting in the way. Fortunately, the hardware issue is now largely solved, although problems remain for in-person teaching, using digital 3d objects. The more difficult problem of interface remains: there exists no standard way of manipulating an object, and, even more difficult, no universal software governing how any particular object can be manipulated. The requirements of 3d content in research, publication, and teaching are often tied to the unique requirements of each investigation, publication, or the goals of the class session. For this, custom software applications remain the most common. For example, there is no standardized software for museum exhibitions. Every touchscreen or other digital interface is a unique piece of software written for that display device and exhibition. Software development is time-consuming, therefore expensive, posing yet another obstacle for the integration of 3d content in research, publication, and teaching.

It is easy to see why I once structured a class around the death of 3d. And yet, I am hopeful. While modeling things which do not exist may always be the domain of specialist artists, modeling things which do exists and, more importantly, displaying and manipulating 3d content has become much less problematic. A conjunction of data capture, cross-platform display technologies, and distribution is occurring which may finally make incorporating 3d as easy as choosing slides.

When it comes to capturing objects that exist, photogrammetry has been a democratizing revolution in recent years. Photogrammetry is measurement from photographs. It is a technique that has been used by engineers and archaeologists for creating 3d measured line drawings of real-world objects since the early twentieth century. Until 2010, however, photogrammetry has been something out of reach of non-enthusiasts because it required expensive photographic equipment, workstation

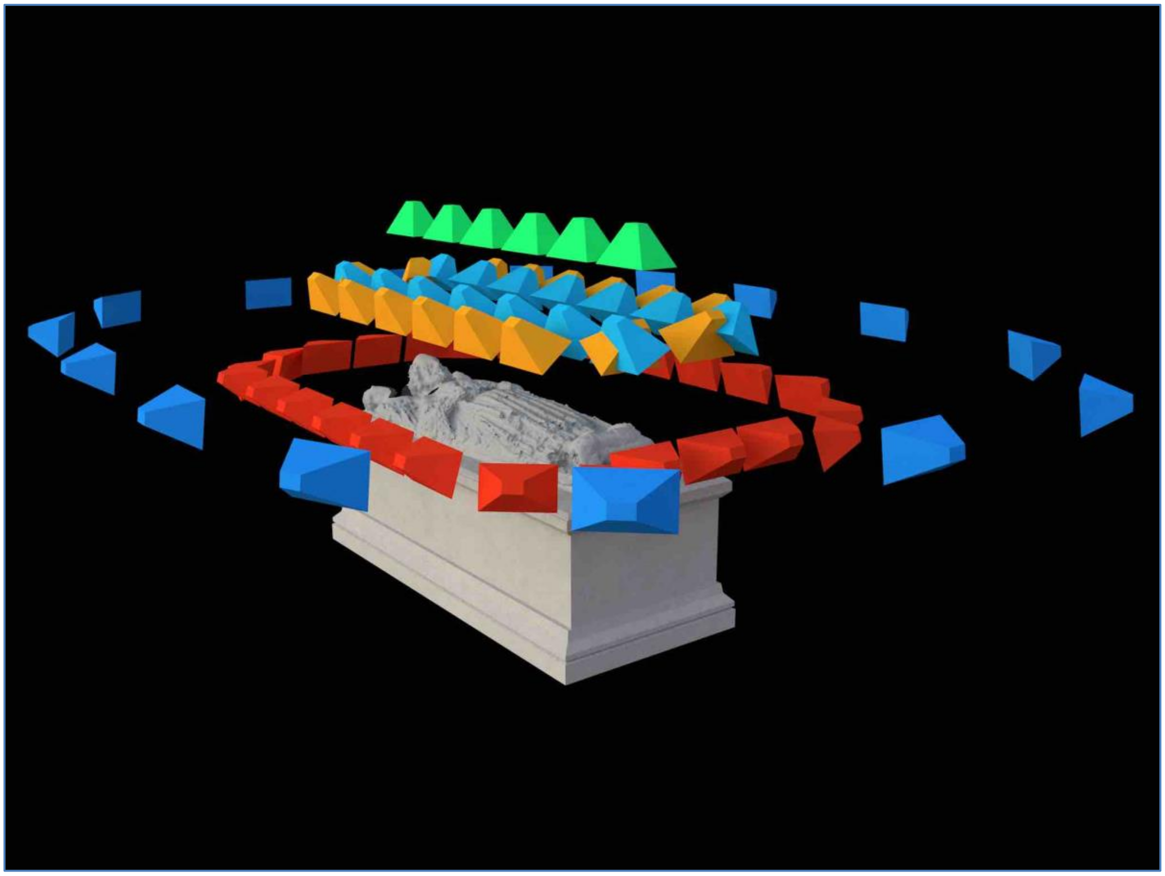

Figure 3 Camera positions for photogrammetric survey of the tomb of King John, Worcester Cathedral. Image: Author.

computers, and very specialist input devices (involving wheels and pedals).[10] It also did not produce meshes, but was rather used for defining 3d coordinates in space represented by stereo pairs of photographs and the user crossing their eyes *just so*. In the first decade of the twenty-first century, however, research into reconstructing mesh surfaces automatically based on photos from uncalibrated cameras (also known as "structure from motion" (SfM)) made rapid progress and its applications were demonstrated on a range of historic sites, including some medieval ones – Notre Dame

[10] For an interesting series of images of early photogrammetric equipment see Washington State Department of Transportation (WSDOT), "Photogrammetry & Remote Sensing," http://www.wsdot.wa.gov/mapsdata/Photogrammetry/About.htm (accessed 27 October 2017).

Cathedral in Paris being the most famous.[11] In 2010 Agisoft released PhotoScan: simple-to-use, robust surface reconstruction software at a price of less than $200 ($80 for teachers and students) and single-handedly revolutionized archaeological field recording.[12] Other software solutions followed, including the slightly more expensive Autodesk solution ReCap Photo (formerly known as ReMake and, before that, 123dCatch).[13] Inexpensive and, in some cases, free photogrammetry software capable of obtaining results from even poor-quality photo sets while running on mid-grade computers is an absolute gift.[14] While achieving *really* good results takes care, specialist equipment, and experience, basic and usable results can be achieved with a handful of photographs from a phone camera and a few minutes with the software. Anyone can capture a 3d copy of just about any object – and many, many people have (see Sketchfab, below).

While Agisoft, Autodesk, Microsoft and others were busy developing their photogrammetry solutions the html5 and webgl standards were also being developed. These standards form the foundation for the present generation of the plugin-free web where access to content of all types no longer relies on proprietary plugins which are at the mercy of commercial entities and market forces. For example, prior to 2014 viewing video online was dependent on browser plugins from Adobe (Flash), Apple

[11] SfM photogrammetry made its big debut with this 2006 SIGGRAPH paper: Noah Snavely, Steven M Seitz, Richard Szeliski, "Photo tourism: exploring photo collections in 3D," *ACM Transactions on Graphics* 25:3 (July 2006): pp. 835-846. http://phototour.cs.washington.edu/Photo_Tourism.pdf (accessed 27 October 2017). This was followed-up in 2007 with a TED Talk which was widely circulated amongst archaeologists: TED, "Blaise Aguera y Arcas: Jaw-dropping Photosynth demo," YouTube video, 9:27, June 2007, https://www.youtube.com/watch?v=M-8k8GEGZPM (accessed 27 October, 2017).

[12] Agisoft, *Photoscan*, http://www.agisoft.com (accessed 27 October, 2017).

[13] AutoDesk, *ReCap*, https://www.autodesk.com/products/recap/overview (accessed 27 October, 2017).

[14] A good, recent review of photogrammetry software, including a number of free solutions is: Peter L Falkingham, "Trying all the free Photogrammetry!" https://pfalkingham.wordpress.com/2016/09/14/trying-all-the-free-photogrammetry/ (accessed 27 October, 2017).

(Quicktime), or Microsoft (Silverlight), which were used by an uneven distribution of content hosts and were subject to numerous patches and incompatibilities. Now, browsers which support html5 (which is most of them in versions less than three years old) can playback video natively, without relying on plugins. Video is now truly cross-platform. WebGL is the standardized version of html5 video, has been adopted by most browsers in the past year and, importantly, by most 3d content creation software as well. WebGL is not a 3d file format like .obj or .fbx, but, with the help of a wide range of software libraries which provided additional features and functionality, can read these *de facto* standard interchange formats and display them across browsers and platforms. All of this means that the web now has an open, stable, and almost universally supported framework for the display and manipulation of 3d content.

Hardware has also continued to develop in encouraging ways. No longer is computation and display tied to desktop or laptop machines. It is now common for people to rely exclusively on mobile devices – phones or tablets – for content consumption. Most mobile processors can now easily handle the display of hundreds of thousands of polygons of 3d content in real time. But 3d content display is also taking increasingly confident steps toward true immersion with the official debut of virtual reality (VR) headsets. Encouragingly, this new, still very actively developing technology is not the domain of one or two manufacturers, but rather runs a wide range of solutions. Practically free, but also very basic, is Google Cardboard which leverages technology already present in most mobile phones.[15] The user is confined to single-position standing or seated experience with interaction controlled by head movements and a physical button. Far more advanced (and expensive) is the HTC Vive which offers room-scale VR where the user is visually and aurally immersed in virtual worlds which they can physically move through (albeit within a limited range), interacting with

[15] Google, *Cardboard*, https://vr.google.com/cardboard/ (accessed 27 October 2017).

virtual objects using handheld controllers.[16] By the time this article reaches publication, VR hardware capabilities and manufactures will have made further significant advances.

Figure 4 VR still has … issues. Photo: Andri Koolme, https://flic.kr/p/EEKzSW (accessed 3 December 2017), used under Creative Commons Attribution 2.0 Generic (CC BY 2.0).

VR remains inherently problematic. Users frequently report motion sickness, making traversal of virtual space difficult. The experience depends on the user wearing a headset, and in the case of high-end VR such as Oculus Rift and the Vive, the headset must be tethered by cables to a high-end computer. Also, the world the user experiences is entirely virtual – placing a heavy burden on the 3d content producer. Finally, adoption of the technology, while widespread, is still far from common. Many of these problems are under intensive development and many of them will be overcome in the

[16] HTC, *Vive*, https://www.vive.com/ (accessed 27 October 2017).

next couple of years, assuming steady growth in the sector. Still, these are not trivial barriers, and they will continue to hamper widespread adoption of the hardware in medieval art historical research and teaching.

Perhaps more interesting for art history purposes is the rise of augmented reality (AR). AR overlays digital content on a live video stream of the real world from a device's camera. For art history/archaeology, the most obvious application is the AR-enabled device as a kind of "magic lens" where the user can move through real space (such as a historic site or a museum) watching the video feed from their device with 3d content displayed "in the real world" and explorable in real time.[17] AR provides many of the benefits of VR, but also relieves many of the burdens. It relies on lightweight devices most people already have with them, it is not confined to limited areas of sensor coverage, and content creators can focus their effort on specific objects rather than complete environments. AR also presents a lower bar to entry for developers because the core software packages are now universally and freely available. Apple and Android have recently released their own AR software development kits and the 2017 iteration of popular mobile devices have been designed around making AR more stable and compelling. Because of this commitment to AR, the sector is set to grow substantially over the coming two or three years. A growing ubiquity of AR-enabled devices combined with 3d content creation tools readily able to export content for these devices will provide fertile ground for moderately tech-savvy researchers and teachers to find new ways to incorporate 3d content into their daily work.

Software, hardware, and cross-platform frameworks have converged to provide a stable foundation for enthusiastic but not necessarily computer-science-minded creators to build upon. What the future of 3d and medieval art history/archaeology research,

[17] For a cursory introduction see: Jennifer Billock, "Five Augmented Reality Experiences that Bring Museum Exhibits to Life," Smithsonian.com (June 29, 2017), https://www.smithsonianmag.com/travel/expanding-exhibits-augmented-reality-180963810/ (accessed 27 October 2017).

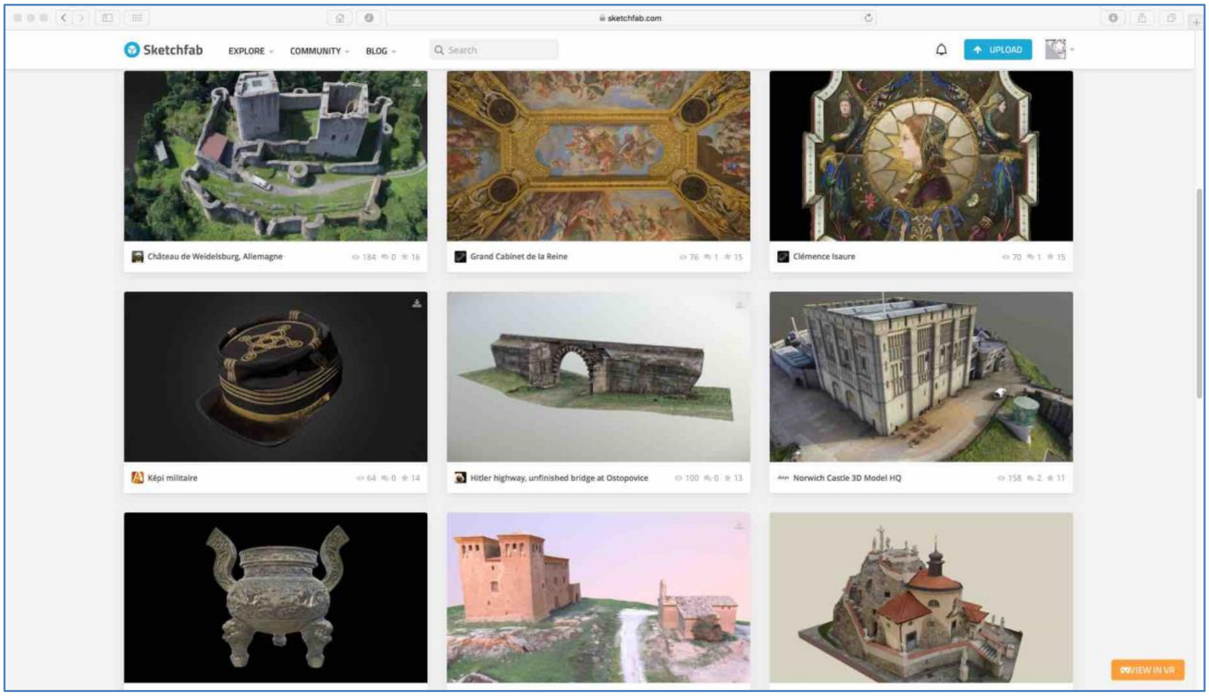

Figure 5 Sketchfab, the equivalent of a worldwide slide collection for art history – but in 3d. Image: Author.

publication, and teaching looks like is still very much an open question. Perhaps it looks a bit like Sketchfab, a 3d content sharing site which has rapidly become the YouTube of 3d.[18] It is built on html5 and webgl, capable of importing and displaying 3d models complete with textures, sound, and animation on any platform, from mobile devices to VR headsets. Users may register an account, upload their own 3d content or view others' work, embed that content into other websites or social media – all for free. Sketchfab is just about the most pain-free way of sharing, displaying, and interacting with 3d content I have ever encountered. It also hosts well over 1,000,000 models with a large category dedicated to cultural heritage. The British Museum is leading the way in making their collections accessible in 3d with over 230 models on Sketchfab as of this

[18] Sketchfab, https://sketchfab.com (accessed 27 October 2017).

writing, including models of medieval objects such as the Lewis Chessmen.[19] The British Museum is also tackling the digital rights issues now posed by the rise of photogrammetry and sharing platforms like Sketchfab by making a number of their models freely downloadable under a Creative Commons Attribution-NonCommercial-ShareAlike license. It is my sincerest hope that other curators of medieval objects – and buildings – follow their lead. Widespread virtual access to such collections will only help drive public interest and investment in the physical objects and sites themselves. The most intractable problem with Sketchfab, of course, is that it is a for-profit startup, subject to all of the issues and potential short lifespan such projects entail. Creating and maintaining the infrastructure which allows for ubiquitous sharing of such complex content is expensive on many levels and the long-term stability of Sketchfab is not guaranteed. Perhaps the future of 3d content sharing will be based on a less-centralized clearinghouse model and will begin to look like the rest of the web: a collection of content uploaded, hosted, and maintained by millions of individuals around the world.

Medieval art history "in 3d" has been a long time coming. It still hasn't arrived. However, software, hardware, and research and teaching practice may now have aligned to make that arrival possible. Substantial barriers to creation, interaction, and distribution of 3d content exist, but their impact has been reduced considerably. The future of 3d and art history is still unclear. It is impossible to say that it will tend one way or another. Yet, for the first time, the right building blocks are in place to allow that future to be built. It will be built by enthusiasts, teachers, and researchers project-by-project, borrowing from and building upon each other. The inclusion of 3d content into daily practice will not be something remarkable in itself, but will simply contribute to

[19] The British Museum, Sketchfab, https://sketchfab.com/britishmuseum, (accessed 8 November 2017). For the Lewis Chessmen see: The British Museum, "Lewis Chessmen," Sketchfab, https://sketchfab.com/britishmuseum/collections/lewis-chessmen (accessed 8 November 2017).

truly remarkable insights. This is as it should be. Perhaps I will never have to teach "the death of 3d" again.

Figure 6 The Royal Chapel of St. Stephen, Palace of Westminster, *c*. 1360. A 3d research-based reconstruction produced through the collaboration of dozens of scholars across numerous disciplines. Perhaps there is a colorful future for 3d content in medieval art history. Image: Author and the University of York. Used with permission.

Published by Digital Kenyon: Research, Scholarship, and Creative Exchange, 2017