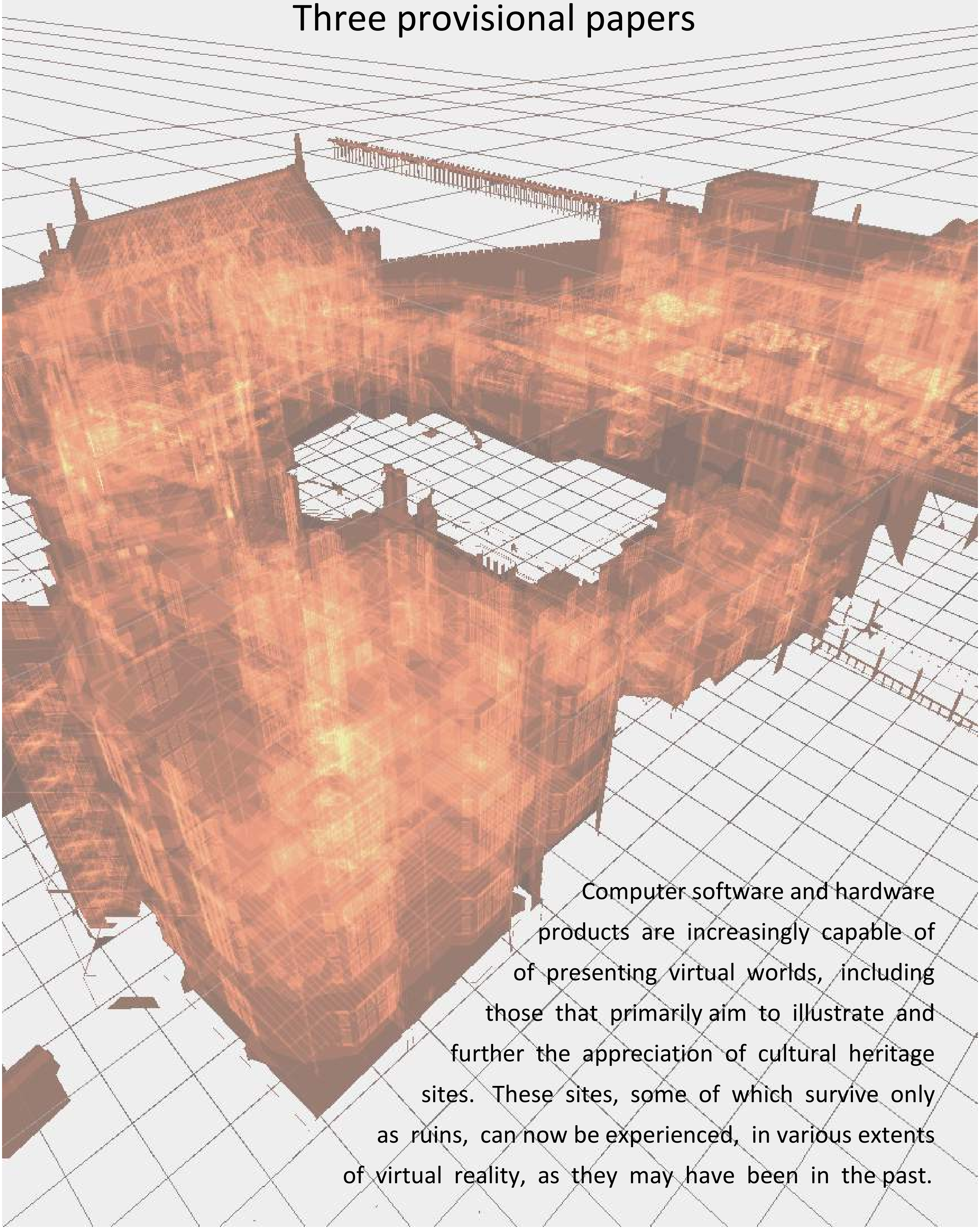
The Visualisation of a Virtual 3D Reconstruction of Kenilworth Castle

Three provisional papers



Computer software and hardware products are increasingly capable of of presenting virtual worlds, including those that primarily aim to illustrate and further the appreciation of cultural heritage sites. These sites, some of which survive only as ruins, can now be experienced, in various extents of virtual reality, as they may have been in the past.

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Creating and Evaluating a 3D Virtual Reconstruction of a Castle as an Educational Asset - A Search for Advice

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Abstract — Computer software and hardware products are increasingly capable of presenting virtual worlds, including those that primarily aim to illustrate and further the appreciation of cultural heritage sites. These sites, some of which survive only as ruins, can now be experienced, in various extents of virtual reality, as they may have been in the past. This review analyses 179 published studies and considers any findings which relate to best practice and the desirable and achievable features of a 3D virtual reconstruction of a castle (or similar structure) and which contribute most effectively to its further appreciation. This analysis was conducted within four predominant themes: 'Geometry Creation', 'Uncertainty Presentation', 'Standards and Desirable Features', and 'Educational Considerations'. It was found that the 3D CAD generated geometry imported into game engine software for presentation approach has not yet been superseded; that the basis and suggestions of the many uncertainty articles needs to be challenged; that further studies are required to provide specific examples of aspirational features, to solve the issue of 3D virtual model access, and to provide desirable frame-rate guides; and further research is required to provide more evidence supporting the effectiveness of learning about heritage sites via the range of 3D virtual reality experiences.

Keywords — Evaluation, 3D, Virtual, CAD, Reconstruction, Castle, Heritage, Education.

1. INTRODUCTION

Over a period of several years, a 3D CAD model of the Kenilworth Castle of 1575 has been created. The CAD geometry was initially extruded as planar faces from the floor plans of an official survey of the ruined site, and the long since missing parts reimagined as required. The CAD data has been imported into game engine software to significantly improve visual fidelity and user interaction, and thus potential accessibility.

This review analyses related available studies to discover any applicable methodologies, standards and expected or beneficial features which can be considered for application to this castle reconstruction (in its interactive 3D 'serious game' format) so that it can be accepted and respected as an educational asset. Considering that ultimately all such heritage virtual reconstructions are created to support learning of some form, the findings should be of widespread interest and benefit. Evaluation is an integral requirement, with Champion [123] concluding *"we need to cooperate in developing criteria in order to appraise both virtual heritage infrastructure and virtual heritage projects which leverage that infrastructure"*.

This was initially conceived as a systematic review, however the search for documents identified significant ambiguity in the interpretation of the keyword 'reconstruction'. This apparently long-standing issue [50, 62], relates to the creation and presentation of a virtual model compared with that of the original historical structure. For example, a 3D CAD reconstruction of a structure, as it was at some point in the distant past, can be considered as merely one of many possible interpretations. The uncertainty implicit in such a presentation has been the subject of debate and thus forms one of the main themes of this analysis. Alternatively, photogrammetric and laser scanning to point-cloud geometry methods are equally valid for reconstructions, although these reconstructions can only ever be generated from the current state of a structure, and are thus essentially a copy of what already exists. Finally, reconstruction can also refer to the reinstatement of a structure that has suffered recent damage, where, for example, reliable records such as photographs exist of its previous state. This review is predominantly interested in CAD related reconstruction outcomes, and since this therefore involved an early subjective interpretation of document titles and abstracts for likely relevant content, the transparent and reproducible search criteria of a systematic review were deemed inappropriate.

3D CAD software specialises in efficiently creating solid and/or surface geometry. Game engine software specialises in efficiently presenting geometry, providing visual effects, such as fire and smoke, and interactive exploration. The Kenilworth Castle project therefore assumed that the most effective methodology would be the combination of 3D CAD and game engine software. Further, it was assumed that surface rather than solid geometry was by far the most appropriate. Solid modelling facilitates more comprehensive and advanced functionality, but at the cost of complexity and much larger file sizes. Surface modelling can take advantage of the relative simplicity of castle geometry, although it does present issues of surface orientation, since 'back faces' are typically culled/ignored by game engines to optimise shading speed. Figure 1. illustrates these fundamental issues. Therefore a 'Geometry Creation' theme of this review will consider if these assumptions and perceived issues remain valid or are becoming outdated, if only within some scenarios.

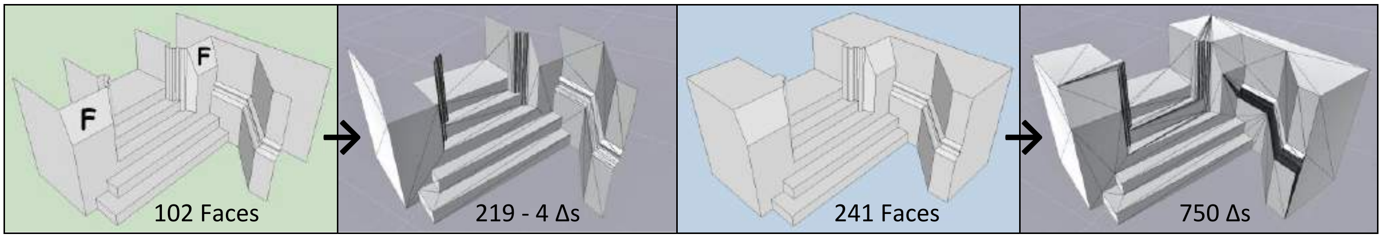

Figure 1: Comparison of CAD surface versus solid doorway geometry, and as processed as a mesh of triangular faces by game engine software. The two surface faces marked 'F' are incorrectly orientated and thus then not rendered. The more accurate solid geometry generates extra faces, all exactly trimmed together, and thus the game engine software would have to process over three times as many triangular faces.

A 'Standards and Desirable Features' theme and a specific 'Educational Considerations' theme will each consider how any individual or combined contribution of frame-rate, realism, engagement, storytelling and virtual reality features has been shown to be beneficial.

2. DOCUMENT SEARCH

The search for documents, dated within a period of the last 20-plus years, was initiated by simple sequences of the keywords. This period was chosen as sufficient to reveal any trends, while limiting the extent to which any observations might be considered obsolete due to the continual advancement of the technology involved.

Documents matching the keywords, and the many other similar documents also listed, were considered first by title. Those potentially relevant were then located in a database, for example; dl.acm.org, ieeexplore.ieee.org, researchgate.net, sciencedirect.com, tandfonline.com, or semanticscholar.org. Approximately 20 documents which were not completely available for review, and those without English texts, were ignored. Documents of similar subject matter proposed by the database websites were also considered. The abstract texts were reviewed and 97 documents not confirmed as potentially relevant were rejected.

Documents were rejected where the predominant subject content related to purely technological aspects, restoration, monitoring, museums, collaborative or remote learning, mobile or immersive reality (as opposed to a desktop display), or the recording of excavation over time. However, some such documents were not rejected if the resulting (particularly educational) findings might still be potentially considered as relevant. The document searches were conducted in April 2021. Figure 2. indicates no obvious trends, apart from a marginal increase in overall number.

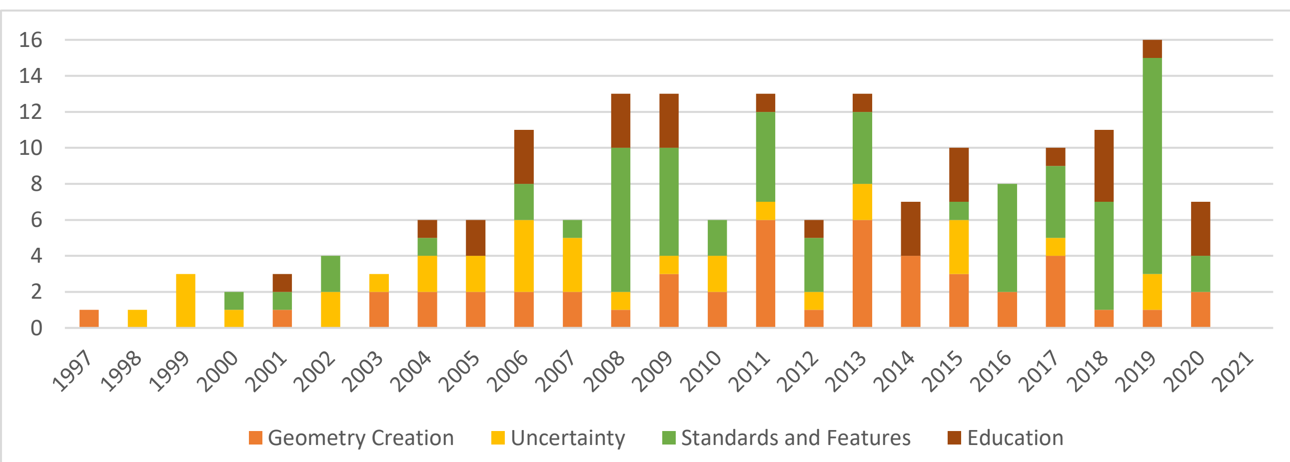

Figure 2: The results of the Document search, by publication year and predominant identified theme.

Figure 3. indicates the influence of some of the earlier articles, identified by date and predominant author, within the context of this review. The first three articles [56, 57, 60] address the subject of uncertainty. The *'London Charter for Visualisation of Cultural Heritage'* [99] had the highest number of references (22). However, only 30% of 158 later listed articles made reference to this or other similar standards related articles such as *'From CVR to CVRO: The past, present, and future of cultural virtual reality'* [84], *'Standards and Guidelines for Quality Digital Cultural Three-Dimensional Content Creation'* [95], *'The ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites'* [97], and the *'Principles of Seville'* [109]. This might reflect the practical applicability of the aspirational principles.

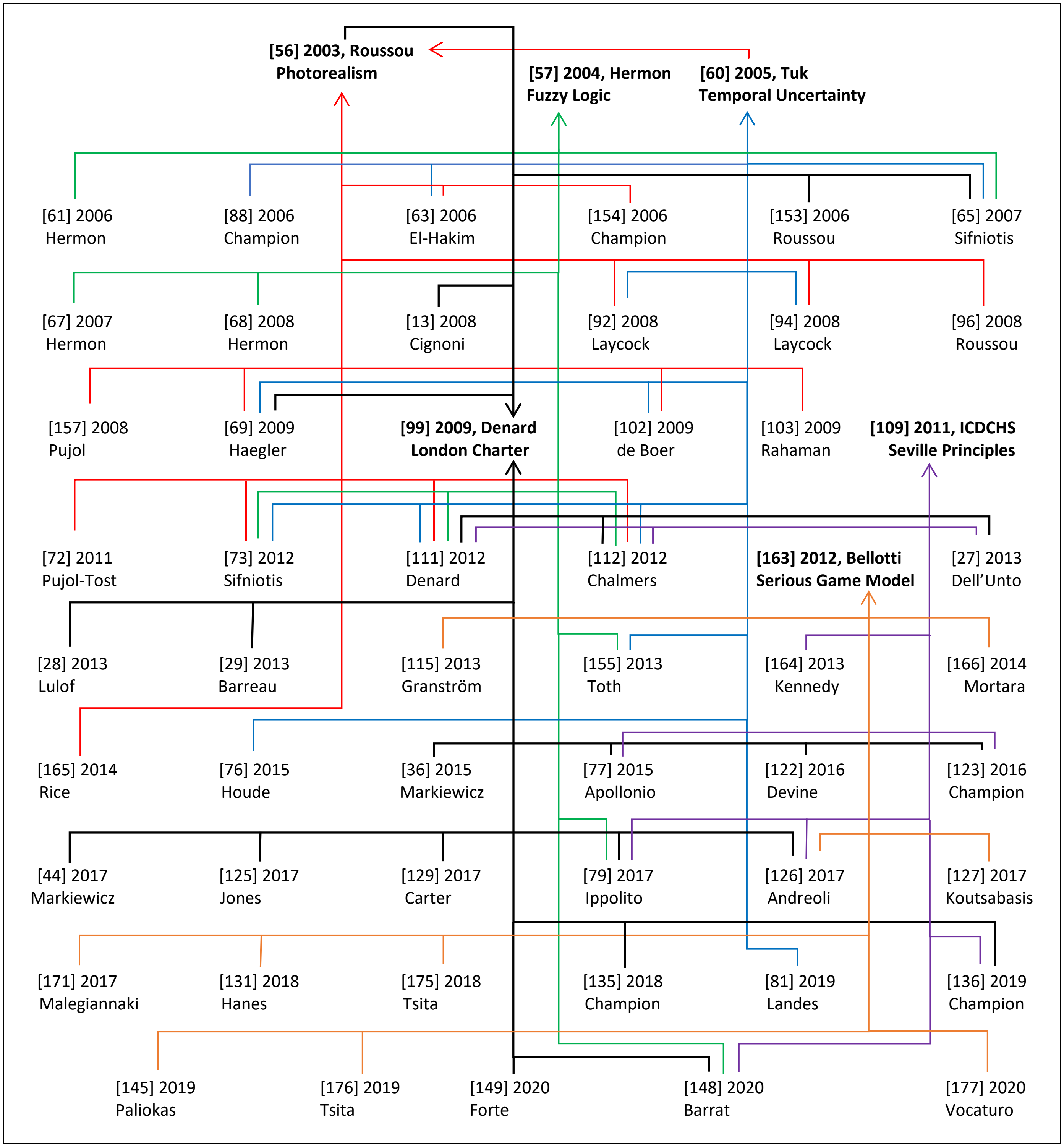

Figure 3: A references tree illustrating the 6 articles (in bold) with 10 or more references made by other listed articles. Note that the first references to the London Charter [99] were to an earlier version.

3. ANALYSIS

3.1 Geometry Creation Analysis

Despite the stated preference for CAD generated reconstruction-based articles, of the 76 which recorded a methodology, only 54% were reconstruction using CAD exclusively, a further 23% used CAD plus another method, and the remaining 23% used either photogrammetric and/or laser scanning to point-cloud geometry creation. Where multiple methods were employed (a 'multi-modal' approach as recommended by Andrés et al [22]), simple CAD geometry was often used to define location and scale, thereby merely providing a supporting framework for the main method. Less often, CAD was the main method, and photo- and scan-based output was used to augment the model with complex geometry, such as that of statues and gargoyles.

Geometric accuracy is subject to technology, the pragmatic judgements (Münster *et al* [119]) made during the modelling process, and the ultimate presentation intentions and implicit interactivity (frame-rate) considerations. The effect of geometric accuracy (and detail) on historical accuracy was not found to be specifically addressed. Although, Forte et al [149] noted that *"ultimately the models that we created from the laser scanning survey proved to have too high a polygon count to be effectively incorporated into the virtual learning environment, and so we choose instead to model our own buildings based on survey data"*. Studies [1, 6] recommending the use of solid modelling geometry creation methods failed to consider the size and complexity of a typical heritage site. Thus it is still the view that solid modelling might only be considered appropriate for small projects, such as museum artifacts, or limited environments, such as those with only a few internal spaces.

Champion [123, 135] ideally advises against proprietary geometry formats, (such as Unity3D, Unreal Engine, or Blender) since they cannot be guaranteed to be supported long-term, but this is impractical. There are no agreed standard formats that support all of the geometry, interaction and effects features of such fast developing game engines, or guarantee that any such format would itself be supported in perpetuity. Although currently this may be an intractable problem, he also identifies other pressing issues, such as access, dissemination and feedback mechanisms, and a supporting infrastructure, and suggests that virtual reconstructions could be provided in editable format to enable further development (with appropriate permission controls and recognition of ownership). These could indeed be addressed, but any solutions are not really integral to the virtual model/game.

The software used by any case study was noted, with the relative number of multiple uses depicted in Figure 4. Champion [135] noted that the *"the most popular interactive game engine for virtual heritage is Unity"*. 3D Studio Max is very evidently the software of choice for geometry creation. 27 other software products were used by only a single case study.

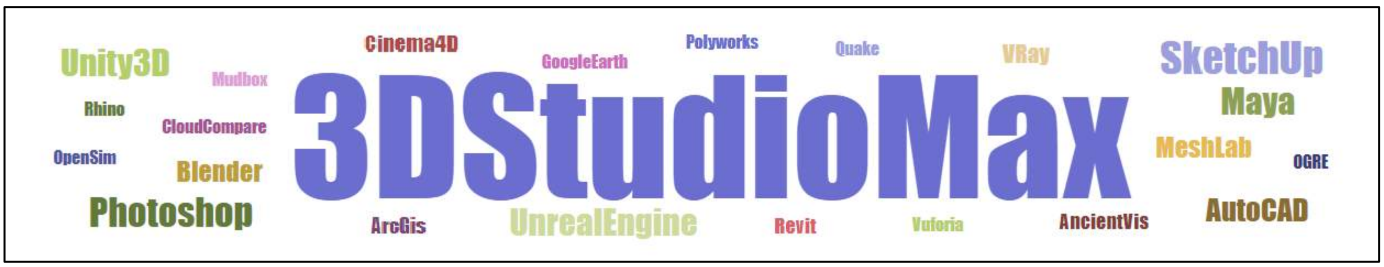

Figure 4: The relative popularity of 23 software products used by virtual reconstruction case studies.

3.2 Uncertainty Presentation Analysis

Authenticity and accuracy in the virtual presentation of heritage and archaeology, or *"the need to distinguish between real and hypothetical parts of a visualization",* Masuch *et al* [50], has proven to be a fertile field of study, with resulting suggestions as to how the presentation might be clarified. The use of non-photorealistic representations [49, 51, 52], proposals for opacity and false colour to indicate the level of uncertainty, and even multi-media links to the evidence, Kensek *et al* [54], are typically only illustrated for a simple 2D presentation.

It is often unclear how suggested effects can be implemented, particularly in an interactive 3D environment. For example, how a paper-grain rendering implying a hypothetical aspect instead of historical truth, Roussou *et al* [56], or similarly 'fuzzy logic' analysis, Hermon *et al* [57, 61], might be applied to a structure which partly still exists but has in parts been completed, speculatively to various degrees. Barratt [122] proposes *"a toggle allowing users to switch between a fully textured mode and one in which unclear elements are presented as wireframes"*, but such a simplistic binary approach would fail to clarify the levels of uncertainty.

Possibility theory has also been used to address the issue of *"possibly misleading the public",* Sifniotis *et al* [64, 65], although it is then based on a survey of only archaeologists to identify which archaeological features are deemed the most reliable. Even Bayesian probability has been co-opted to assign geometric transparency values, Sifniotis *et al* [70], but again, the practical implications of extending the concept to a substantial and detailed project are never considered.

Clark [71] dismisses any 'reconstruction' as a misnomer and fallacious, except when presenting multiple possible alternative 'visions' or simulations, or to aid research. The objection here is specifically to the use of the term 'reconstruction', since 'constructing a virtual model' is perfectly acceptable, but *"one cannot reconstruct* (that which) *existed at some point in the past"*, only how it *"may have looked"*. However, since this pedantic definition is undeniably true, the term cannot be factually misleading, but merely ambiguous as to nature, as described above. His objection is perhaps more fairly represented by the acceptance that *"in any given model, there will be ambiguity and uncertainty"* but that *"most virtual simulations do not employ any mechanism by which the level of accuracy is provided"*.

Considering *"How an archaeologist's belief in a reconstruction can be quantified"*, Sifniotis [73] is adamant that *"incompleteness should be reflected in digitised reconstructions of the past"*, and suggests multiple reconstruction models be created and shared so that the alternative hypotheses can be considered. She supports criticism of reconstructions that are of *"too-realistic appearance"*, but the study regarding perception appears to only consider reconstructions for archaeological research, and not also those for the dissemination of knowledge to the wider public. However, it can be agreed that, ideally, as much data as possible, including any level of uncertainty, should be made available in some form, regardless of purpose.

Kensek [59] lastly considers how other sensory inputs might form part of the reconstruction. A valid observation, but in this context one which then implies that sound, tactile feedback, taste and/or smell should also be subject to similar debate as to their accuracy and authenticity. A similar requirement for clarification of the certainty with which these were introduced would further increase the complexity of the issue.

There was, obviously, hopeful anticipation on finding the Landes *et al* 2019 article *"Uncertainty Visualization Approaches for 3D Models of Castles Restituted from Archeological Knowledge"*.[81] Unfortunately, and yet again, the implications of extending the 'by colour' approach to more substantial, complex and detailed projects are never considered. No evidence has been found to suggest that 'rendering by uncertainty' concepts are practical and scalable solutions beyond the most simple reconstructions and visualisations, despite the apparent appeal of generating psychedelic dazzle camouflage type imagery.

3.3 Standards and Desirable Features Analysis

The 2008 ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites [97] provides a framework for standards with a set of aspirational general principles, and was followed by the similar 2009 London Charter for Visualisation of Cultural Heritage.[99, 111] The latter is comprehensive but very general, needlessly exhorting that *"a computer-based visualisation method should normally be used only when it is the most appropriate available method for that purpose"*, and *"the creation and dissemination of computer-based visualisation should be planned in such a way as to ensure that maximum possible benefits are achieved"*. The 2011 Principles of Seville [109] extends the work of the London Charter, clarifying that the purpose of a computer-based visualisation should be one of research, conservation, or dissemination (which includes both educational and recreational projects). It should also *"always be possible to distinguish what is real, genuine or authentic from what is not"* via 'scientific transparency' (documentation), and a structure should not solely be presented in its *"time of splendour"*, since all historical phases are valuable. Ultimately, it declared, the final quality of a computer-based visualisation must be evaluated on the rigour of the reconstruction *"and not the spectacularity of the results"*.

In *'Realism vs Reality'* [53] Kantner clarifies that the level of known historical accuracy should largely be dependent on the purpose of the reconstruction, for example, research, education or entertainment, and recommends that the logic employed in the reconstruction should be recorded. For public consumption, de Boer *et al* [102] even suggest that non-photorealistic based presentations may simply be more efficient. Sanders [83] additionally stresses the importance of accessibility, and the worrying tendency to *'bury exciting and important* (virtual heritage) *data'* so that it is then never seen by the intended audience, for example by requiring specific and advanced hardware configurations. He also suggests user feedback mechanisms.

Frischer *et al* [84], in a comprehensive guide to Cultural Virtual Reality, cover all the main themes of this review. They note that a lack of communication and collaboration between the content creators and the content experts (archaeologists and historians) can result in a lack of official approval by the content experts. They also state that standards (for example for the presentation of accuracy and authenticity) can only be defined by agreement by all CVR developers, although their suggested extent of the sharing of texture libraries is unrealistic.

2008 and 2017 were good years for 4D visualisation articles [42, 43, 91, 92, 94], presenting the evolution of a structure over time, and even with the option to consider alternative possible interpretations. Some relied on bespoke software development, even though current game engine products already provide as standard the necessary features described, and could be customised to replicate the additional 4D function.

De Paolis *et al* [17] show that implementing voice and text interaction within a multi-player environment *"is one of the best ways for retrieving knowledge and experiences during the virtual game"*, and suggest continuous update and development to accommodate and present new knowledge.

Popular computer games have been evaluated for examples of desirable features and how they might be implemented in virtual heritage applications.[78, 115, 152, 165] Granström [115] suggests that character, culture, morality and plausible history might become more important than the accuracy and realism of the visualisation, but notes that the significant financial and expertise resources of commercial game developers, required to implement some desirable features, is not available in the field of virtual heritage. Rice [165] conducted a similar thesis study, with a survey indicating that 50% of the respondents would prefer an educational game to have a storyline, and 70% preferred realistic rendering to a stylised visualisation. No analysis within any (virtual heritage related) article was found addressing the key aspect of display render frame-rate.

3.4 Educational Considerations Analysis

Flynn [152] describes how virtual interactive tasks, based on the movement and activities of the time, can be introduced to encourage interpretation and further understanding. Additionally, different levels of user (for example, tourist, or historian) might be offered a different and tailored experience. Walsh *et al* [124] also suggest relating to users according to their expertise. Similarly, Roussou [96] confirms that *"the purpose for which a virtual heritage reconstruction is made is important"*, for example scholarly research or the education of non-experts (and that a single model might not adequately serve both). She also suggests that, for a successful edutainment experience, storytelling can trigger interest, empathy and imagination, and that ideally disbelief needs to be suspended (for which a merely credible environment is sufficient [110]). Vargas *et al* [178] take personalisation further, suggesting that a user's motivation would benefit from being able to contribute content. This would provide additional potential engagement, but at the expense of added design complexity. Further, no illustrative example is provided and what then happens to such content is not clarified.

Champion [154] argues that cultural engagement and context are often overlooked in favour of photo-realism. Avoiding a sterile environment and creating a sense of presence in a place of previous habitation is important for engagement and learning, but is difficult to evaluate. He also suggests that most engaging games incorporate challenge and reward, and that a tailored user experience could be provided by unobtrusive monitoring and automatic evaluation. Interactive virtual maps could be personalised by storing waypoints and the locations of interesting artefacts discovered, and thereby become a record of the journey of exploration and an aid to memory. Ultimately, he decides, *"the crucial issue is interaction and the learning that results from that interaction"*, and subsequently [108] considers whether the sense of 'place', a *'vague and ethereal concept'*, might possibly ever be gained without a visit to the real site. He also finds that inhabited or interactive environments are not necessarily considered more interesting or authentic, and notes that multiple-choice general knowledge questions do not guarantee cultural learning.

Di Blas *et al* [151] agree that virtual presence should be considered above photo-realism, otherwise *"the interest of the user wanes"* since *"the experience cannot be compared to the real-world experience"*. The sense of being there can in part be achieved by communicating with peers within a multi-player shared 3D environment. This interaction between users is important but it is recommended that they are within pre-planned activities. Devine [113] also recommends *"building places not spaces"*, and agrees that social interaction is important, but finds that realism and attention are also key presence factors.

Mosaker [150] explains that although *"an accurate reconstruction of the past... is what we want and expect from a historical reconstruction. If the past was not necessarily like the reconstruction, then what is the point?"*, and that *"detailed and realistic graphics are crucial for making a believable experience. The problem with photorealism is that people tend to think of such images as the truth about the past, and not just a version or what it could have been like."* Further, she cautions, experiencing impressive virtual reality technology can be the predominant recollection, rather than its historical content. Mortara *et al* [110] agree that *"an excess of realism could be counter-productive"*, but also conclude that *"believability is more important than realism"*.

Ch'ng *et al* [179] explained believability as a subjective perception of the combination of visual realism and the sense of presence. Their detailed study of a young (18-28) sample audience suggests that curiosity and exploratory behaviour can contribute to a sense of discovery which benefits learning, and also that this was not affected by any prior level of virtual reality experience.

Favro [62] suggests that an interactive 're-creation', with links to comprehensive metadata and various sensorial simulations, can be used by scholars *"to assess not only the symbiotic research relationship between different disciplines, but also the theorization of re-creations"*, or at least, *"digital re-creations hold the potential to open up the conversation"* by conveying the state of knowledge. She also points out that *"historical Virtual-Reality models are criticized for presenting a distorted idea of what ancient viewers actually saw"*, and yet critics do not consider that how what was seen and personally interpreted has changed considerably over the centuries. This same interpretation issue has been noted by others [66, 103, 107, 72], with the need to *'understand the viewer's cognitive processes'* to help quantify the *'visual accuracy'*.

Bellotti *et al* [163] introduce a virtual educational environment template (a visual authoring toolkit) in which a user explores, interacts and discovers. Customisable user tasks are classified as either observation (comprehension), reflection (reasoning) or arcade (interaction), according to the cognitive skills required, and several helpful examples of appropriate games and puzzles are presented and analysed.

4. CONCLUSIONS

4.1 Geometry Creation Conclusions

It was perhaps naive to look for a comparison of geometry creation and presentation software that might inform or validate selection for virtual heritage projects. The current rapid evolution, of game engine software and hardware in particular, will foreseeably tend to invalidate usefully detailed analysis and findings, such as Smith *et al* [147], which is an obvious disincentive. In any case, software selection is most likely influenced simply by what is readily available (together with the expertise to use it). Where a combination of products is used, for example CAD and game engine, then reliable data export/import, or preferably a direct native format import option, is then also a major consideration. Cost should not be an impediment, since versions of some professional solutions are essentially free (until a level of financial income results).

4.2 Uncertainty Presentation Conclusions

The issue of uncertainty is one of apparently confusing realism with authenticity and accuracy, of unintentionally misleading, particularly when disseminating knowledge. *"If the means of making ambiguity transparent is left unconsidered, then the money and time lavished on such reconstructions is not well spent and might be better directed toward programming a video game, which would at least have commercial potential",* Kensek et al [54]. This is a forthright view, but one that needs to be robustly challenged. The uncertainty theme is a popular but soft target, since it requires no related software product expertise or costly equipment. The benefits of reconstructions have been widely documented, typically including new insights gained during the process (Hermon *et al* [9]), and output which is increasingly expected by heritage site visitors and, moreover, which can be appreciated by a wide-ranging audience. By comparison, the referenced uncertainty themed articles are as hypothetical as the reconstructions to which they refer, since they fail to provide evidence that any serious scholar, archaeologist (or even member of the public) has ever actually been misled by a virtual reconstruction. And, without this premise first being proven, the immense time and effort required to categorise, and sub-divide accordingly, substantial amounts of 3D geometry, and then to effect multiple material and/or shader changes to effect the presentation, can never be justified. However, it is accepted that ideally the logic employed for the speculative elements of a virtual reconstruction can and should be recorded as ancillary documentation, as described by Barratt [122] and Carter [129], so that it might be used to inform further study and development.

4.3 Standards and Desirable Features Conclusions

It should be conceded that the discovery of revelationary new ideas and features that might transform, or at least notably improve, a virtual heritage project, was always suspected to be a distant prospect. The purpose of many of the articles was (very reasonably) to place on record an account of an investigation and/or reconstruction process, and to present the results, which did not necessarily need to be via an interactive virtual 3D environment. Thus, it must be emphasised, many referenced documents may have been considered and reviewed outside of their intended context. However, what has become apparent, above content, presentation, 'presence' and all other similar considerations, is the basic requirement for <u>access</u>. A virtual reconstruction should perhaps be considered a failure if is not ultimately made permanently available to other scholars for study and review, and widely experienced by a public audience. Sanders [83] and Champion *et al* [135, 136, 146] have already specifically highlighted this issue, referencing many other articles raising the same concerns and proposing similar official collaborative repositories as a sustainable long-term virtual resource preservation solution. Their study of 264 conference papers [136] revealed that only about 3% referenced 3D assets which were still accessible.

4.4 Educational Considerations Conclusions

Most heritage virtual reconstructions are ultimately created for public presentation, ideally to facilitate improved learning outcomes, for which an engaging and interactive experience is widely recognised as a desirable feature. However, the studies by Mortara et al [166] and Tsita et al [175] suggest that more research is required to provide formal evidence of effective heritage learning via 3D virtual reality experiences, and to establish the critical factors or features. The absence of a definitive and comprehensive understanding might be explained, again, by the rapidly changing products enabling so many more presentation options (Ott *et al* [162]), particularly for immersive reality experiences.

4.5 Concluding Findings

- Currently, for virtual reconstructions, presentation by game engine software of imported 3D CAD surface type geometry remains a good choice. Unity and particularly 3D Studio Max are the most commonly chosen software applications.
- The preoccupation with the clarification of uncertainty, within/integral to a 3D experience, is both misguided and impractical, and this should instead be confined to a separate published document.
- The published standards of aspirational principles are comprehensive, but there is an opportunity to provide detailed and specific evaluation criteria, and to consider the critical issue of access.
- Educational learning outcomes for a range of virtual experiences requires further study.

5. STATEMENTS

This work is independent, received no funding, and there is no conflict of interest.

6. REFERENCES

References have been grouped (sometimes requiring subjectivity) by the themes identified above, and then sorted by year and title. References to others within these lists, and similarly citations, and analysis data and summarising comment with respect to the review title, are appended. The data recorded for analysis includes: source(s) of 3D geometry (CAD, Photos, Scans), and the main software used by any case study.

6.1 Geometry Creation References

[1] 1997, The need for the solid modelling of structure in the archaeology of buildings. R. Daniels. *Internet Archaeology 2.* https://doi.org/10.11141/ia.2.1. Cited by [58], Data [CAD]
Contentious assertions indicate a significantly limited knowledge of 3D CAD software at the time.

[2] 2001, Virtual Reality applications in the field of architectural reconstructions. M. Mehta. *Seventh International Conference on Virtual Systems and Multimedia (VSMM '01)*. References [53], Data [CAD]
A summary of the content of its references (e.g. [53]), provides an overview of some creation and visualisation tools.

[3] 2003, Computer games and archaeological reconstruction: The low cost VR. M. Anderson. *Enter the Past*, *BAR International Series 1227.* Cited by [154], Data [CAD, AutoCAD, 3D Studio Max, Quake]
Evaluates (but is flawed by the consideration of only) one game engine for scientific archaeological Virtual Reality.

[4] 2003, On using state of the art computer games engines to visualize archaeological structures. M. Meister, M. Boss. *Enter the Past*, *BAR International Series 1227.* Data [Quake, Half-life]
Repurposes game products for archaeological visualisation, struggling with geometry creation within the game engines.

[5] 2004, Detailed 3D reconstruction of large-scale heritage sites with integrated techniques. S. El-Hakim, J. Beraldin, M. Picard, G. Godin. *IEEE Comput. Graph. Appl. 2004, 24, 21-29.* Cited by [8, 11, 14, 15, 47, 63, 115, 178], Data [CAD/Photos/Scans]
Identifies 8 requirements for reconstruction, describes automated processes, but only applicable to existing structures.

[6] 2004, Solid Modeling for Heritage Documentation. E. Mngumi, H. Ruther. *FIG Working Week, Athens, Greece.* Data [CAD, AutoCAD]
This superficial proposal fails to demonstrate any benefits to offset the resulting increase in data size and complexity.

[7] 2005, 3D Modeling for Non-Expert Users with the Castle Construction Kit v0. 5. B. Gerth, R. Berndt, S. Havemann, D. Fellner. *The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2005), p49-57.* Cited by [25, 31, 119], Data [CAD, Photoshop]
The flexibility of CAD tools exists for a reason – this kit generates only very simplistic output, which is of dubious benefit.

[8] 2005, Combining 3D Technologies for Cultural Heritage Interpretation and Entertainment. J. Beraldin, M. Picard, S. El-Hakim, G. Godin, E. Paquet, S. Peters, M. Rioux, V. Valzano, A. Bandiera. *SPIE: Electronic Imaging 2005, Videometrics IX.* References [5], Cited by [100], Data [Scans, Photoshop]
Augments range image scans with close-range photogrammetry + CAD to minimise uncertainty. Existing structures only.

[9] 2006, Virtual reconstruction of archaeological sites, some archaeological scientific considerations, Avdat Roman Military Camp as a Case-study. S. Hermon, P. Fabian. *BAR International Series 1075, p103-8.* Data [CAD, 3D Studio Max, Photoshop]
The model creation process raises new/useful insights and questions for research, and thus widens related discussion.

[10] 2006, Virtual Reconstruction of Heritage Sites: Opportunities and Challenges Created by 3D Technologies. J. Beraldin, M. Picard, S. El-Hakim, G. Godin, L. Borgeat, F. Blais, E. Paquet, M. Rioux, V. Valzano, A. Bandiera. *The International Workshop on Recording, Modeling and Visualization of Cultural Heritage, May 22-27, 2005, Ascona, Switzerland.* Data [CAD/Photos]
Details the modelling of current archaeological sites. Notes the potential, but provides no significant conclusions.

[11] 2007, Detailed 3D Modelling of Castles. S. El-Hakim, L. Gonzo, F. Voltolini, S. Girardi, A. Rizzi, F. Remondino, E. Whiting. *International journal of architectural computing issue, 02, volume 05, p199-220.* References [5], Cited by [14, 15, 33], Data [CAD/Photos/Scans, AutoCAD, PolyWorks, 3D Studio Max]
Prioritises speed, cost and fine geometric detail, but does not consider the adverse effects of geometric complexity.

[12] 2007, Methods for 3D digitization of Cultural Heritage. G. Pavlidis, A. Koutsoudis, F. Arnaoutoglou, V. Tsioukas, C. Chamzas. Journal of Cultural Heritage 8 (2007) p93-98. Cited by [43, 100, 127, 168]
Describes variants of scanning and photography processes for creating a virtual 3D model, but inexplicably no CAD.

[13] 2008, Sampled 3D models for CH applications: A viable and enabling new medium or just a technological exercise. P. Cignoni, R. Scopigno. *Journal on Computing and Cultural Heritage 1, 1 (2008), 2.* References [99], Cited by [14, 102, 132], Data [Scans]
Considers the creation and processing of 3D scanned virtual models, concluding with remaining issues, but no advice.

[14] 2009, 3D Modeling of complex and Detailed Cultural Heritage Using Multi-Resolution Data. F. Remondino, S. Girardi, A. Rizzi, and L. Gonzo. *ACM J. Comput. Cult. Herit. 2, 1, Article 2 (July 2009), 20 pages.* References [5, 11, 13], Cited by [119], Data [Photos/Scans, Polyworks]
Compares and combines highly detailed scans and images, creating a model facilitating preservation and further study.

[15] 2009, 3D Virtual reconstruction and visualization of complex architectures, the 3D-ARCH project. F. Remondino, S. El-Hakim, S. Girardi, A. Rizzi, S. Benedetti, L. Gonzo. *3rd International Workshop, 3D-ARCH 2009, Trento, Italy.* References [5, 11], Cited by [31], Data [CAD/Photos/Scans, LandXplorer]
Demonstrates efficient, accurate, yet relatively low-cost workflow to seamlessly combine different modelling methods.

[16] 2009, A multi-resolution methodology for the 3D modeling of large and complex archeological areas. G. Guidi, F. Remondino, M. Russo, F. Menna, A. Rizzi, S. Ercoli. *Special Issue in International Journal of Architectural Computing (IJAC), p39-55.* Cited by [21], Data [Photos/Scans]
Essentially the same as [14] and [15], but with a different case study.

[17] 2010, Game-Based 3D Simulation of Life in the Middle Ages for the Edutainment in Cultural Heritage, the reconstruction of medieval Otranto. L. De Paolis, G. Aloisio, M. Celentano, L. Oliva, P. Vecchio. *International Journal on Advances in Intelligent Systems, vol 3 no 3 & 4.* Cited by [171], Data [CAD, AutoCAD, 3D Studio Max, Cinema 4D, Torque Constructor, Torque 3D]
A multi-disciplinary developed multi-sensory environment for collecting feedback and validating hypotheses.

[18] 2010, Modeling optimization for real-time virtual heritage visualization content, a research on e-Warisan SENIBINA. A. Rafi, A. Salleh, A. Paul, S. Noraisah, Y. Jun, R. Hanif, M. Mahadzir. *IEEE Information Technology 2010 International Symposium, vol. 1, June 15-17.* References [103], Cited by [170], Data [CAD, AutoCAD, 3D Studio Max, Quicktime VR]
Preserving culture and heritage via virtual 3D modelling and real-time visualisation aided by polygon count reduction.

[19] 2011, 3D Data Model for Purposes of Cultural Heritage Custody - Case study at the Castle Kozel. K. Bobek, K. Jedlička. *CIPA Sympozium, Prague, Czech Republic, September 12-16.* Data [CAD/Photos, Microstation, SketchUp, ArcGIS]
Proposes a data structure suitable for a castle multimedia database interoperable with the national systems.

[20] 2011, 3D models for cultural heritage: Beyond plain visualization. R. Scopigno, M. Callieri, P. Cignoni, M. Corsini, M. Dellepiane, F. Ponchio, G. Ranzuglia. *Computer Vol.44 No.7 p48-55.* Cited by [122], Data [CAD/Scans, MeshLab]
Web-based opportunities for research, artifact management and conservation by scholars, curators and restorers.

[21] 2011, Diachronic 3D Reconstruction for Lost Cultural Heritage. G. Guidi, M. Russo. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVIII-5/W16, 2011.* References [16, 84, 91], Cited by [43, 46, 140], Data [CAD/Scans, Rapidform, Polyworks, Rhino, V-Ray]
Virtual 3D models are a useful communication format, enabling discussion by experts and dissemination to tourists.

[22] 2011, Generation of virtual models of cultural heritage. A. Andrés, F. Pozuelo, J. Marimón, A. Gisbert. *Journal of Cultural Heritage 13 (2012) p103-106.* Cited by [170], Data [Photos/Scans]
Recommends the combination of different modelling techniques to achieve the best results.

[23] 2011, Reliving the Past: 3D models, Virtual Reality and game engines as supporting tools for Archaeology and the Reconstruction of Cultural Heritage: The case study of the Roman Villa of Freiria. H. Rua, P. Alvito. *Conference: Trends in Architecture and Construction, Chandigarh University, India.* Data [CAD, 3D Studio Max, Gambryo]
The potential of the real time visual quality of VR for archaeological research and "making history interactive".

[24] 2011, Using 3D Design software, BIM and game engines for architectural historical reconstruction. S. Boeykens. *14th International Conference on Computer Aided Architectural Design Futures (CAAD Futures 2011), p493-509.* Cited by [38], Data [CAD, ArchiCAD, 3D Studio Max, Cinema4D, SketchUp, Unity3D]
Proposes parametrics to control appropriate LOD. The authoritative general workflow/conclusions are now outdated.

[25] 2012, Medieval Castles and their Landscape. A Case Study towards Historic Reconstruction. O. Wagener, C. Seitz, S. Havemann. *Virtual Palaces, Part II, Lost Palaces and their Afterlife, p171-200.* References [7], Data [CAD/ Photos/Scans, MeshLab]
The importance of historical landscape (e.g. via LiDAR scans) in providing context for castles.

[26] 2013, 3D modeling technologies as tools for the reconstruction and visualization of historic items in humanities. A literature-based survey. S. Münster, T. Köhler, S. Hoppe. *41st Conference on Computer Applications and Quantitative Methods in Archaeology, Perth, 25-28 March 2013.* References [95], Cited by [119]
Authors, institution and nationality analysis illustrates the sharing/exchanging of ideas. Use of 3D tools is established.

[27] 2013, Digital reconstruction and visualization in Archaeology - Case-study drawn from the work of the Swedish Pompeii Project. N. Dell'Unto, A. Leander, D. Ferdani, M. Dellepiane, M. Callieri, S. Lindgren. *2013 Digital Heritage International Congress, Marseille, IEEE, p621-628.* References [99, 109], Cited by [77, 122, 137], Data [Scans, MeshLab]
Classifies reconstruction as either by: objectivity, testimony, deduction, comparisons, analogy or styles, or by hypothesis.

[28] 2013, The Art of Reconstruction - Documenting the process of 3D modelling: some preliminary results. P. Lulof, L. Opgenhaffen, M. Sepers. *International Conference on Digital Heritage, p333-336.* References [99], Data [CAD/Scans, Cinema 4D, MeshLab, 3D Studio Max, SketchUp, Photoshop]
Process highlighted inaccurate and incomplete previous textual and 2D descriptions and construction details.

[29] 2013, The West Digital Conservatory of Archaeological Heritage Project. J. Barreau, R. Gaugne, Y. Bernard, G. Le Cloirec, V. Gouranton. *DH, 2013, France. pp.1-8, 2013.* References [99], Cited by [33], Data [Photos, Photoscan, 3D Studio Max, CloudCompare]
A French archaeological data depository, for multiple disciplines and promoting the adoption of newly available 3D tools.

[30] 2013, Tutbury castle: Recovering a period site. L. Inman, P. Morris. *Digital Heritage International Congress, 28 Oct.-1 Nov. 2013, Marseille, France.* Data [CAD, Maya, Unreal Engine, Shadermap Pro]
Most observations are of the processing of historical sources for this reconstruction, and thus are specific to this castle.

[31] 2013, Workflows and the Role of Images for a Virtual 3D Reconstruction of No Longer Extant Historic Objects. S. Münster. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5/W1, 2013.* References [7, 15, 62, 68, 95], Cited by [77, 119]
Considers the strategies and logic (and images) used by the reconstruction process. No resulting conclusions or advice.

[32] 2014, 3D Modeling in Archaeology and Cultural Heritage - Theory and Best Practices. S. Campana. *BAR International Series 2598, p7-12.*
Virtual models should be integral to the communication and understanding process, and complement traditional records.

[33] 2014, Combination of 3D Scanning, Modeling and Analyzing Methods around the Castle of Coatfrec Reconstitution. J. Barreau, Y. Bernard, Q. Petit, L. Beuchet, E. Petit, V. Platen, R. Gaugne, J. Le Rumeur, V. Gouranton. *International Conference on Culturage Heritage, EuroMed, 2014, Nov 2014, Lemessos, Cyprus. pp.418-426.* References [11, 29], Data [Scans, Covadis, 3D Studio Max, MeshLab]
Inexplicably concentrates on volume estimation. No resulting conclusions or advice.

[34] 2014, Reconstruction and generation of virtual heritage sites. N. Rodrigues, L. Magalhães, J. Moura, A. Chalmers. *Digital Applications in Archaeology and Cultural Heritage 1 (2014) p92-102.* Data [3D Studio Max]
Procedural/rule-based modelling populating an urban site with automatically generated similar styled buildings.

[35] 2014, Restoring Fort Frontenac in 3D: Effective Usage of 3D Technology for Heritage Visualization. M. Yabe. *Thesis, Rochester Institute of Technology.* Data [CAD, Maya, Photoshop, CrazyBumps]
Extremely simplistic visual output and interaction. No resulting conclusions or advice.

[36] 2015, 3D Visualization as a Method of a Research Hypotheses Presentation - The case of the Medieval Palace in Milicz. M. Markiewicz, J. Kolenda. *Przegląd Archeologiczny, Vol. 63, 2015, p209-230.* References [99], Data [CAD, 3D Studio Max, V-Ray]
Uses colour to simplistically indicate uncertainty. Mainly a record of what was done. No resulting conclusions or advice.

[37] 2015, Challenging Heritage Visualisation: Beauty, Aura and Democratisation. S. Jeffrey. *Open Archaeology 2015; 1, p144-152.* Cited by [129, 130]
Argues that heritage visualisation should be more aesthetic/powerful, imply meaning/purpose, and have an aura.

[38] 2015, Development of High-Definition Virtual Reality for Historical Architectural and Urban Digital Reconstruction: A Case Study of Azuchi Castle and Old Castle Town in 1581. T. Fukuda, H. Ban, K. Yagi, J. Nishiie. *CAAD Futures 2015, CCIS 527, p75-89, 2015.* References [24], Data [CAD, 3D Studio Max, Photoshop]
Techniques (all standard in modern game engines) minimising view complexity at distance to improve frame-rate.

[39] 2016, Development of History Learning Support System - 3D Virtual Reconstruction and Visualization of Ancient Japanese Architectures. X. Zhou, X. Zhou, K. Kobashi, K. Sugihara. *The 11th International Conference on Computer Science & Education (ICCSE 2016) August 23-25, 2016, Nagoya University, Japan.* References [85], Cited by [173], Data [CAD, ArcGIS, 3D Studio Max, Google Earth, SketchUp]
Augmenting history education with virtual 3D model visualisation and 3D printed miniature heritage models.

[40] 2016, Virtual Archeology: Experiencing the Past Through Technology. A. Ali. *Indian Journal of Archaeology.* Data [CAD/Photos/Scans, 3D Studio Max, Geomagic Studio]
Mainly a record/description of 3 case studies. No resulting conclusions or advice.

[41] 2017, 3D model as a dynamic compilation of knowledge: Interim results on the city of Alet. Y. Bernard, J. Barreau, C. Bizien-Jaglin, L. Quesnel, L. Langouët, M. Daire. *Virtual Archaeology Review, 8(16), p51-60.* Data [CAD/Scans, 3D Studio Max, CloudCompare]
Illustrates potential of combining latest knowledge and technology to reconstruct a Roman city, but only image output.

[42] 2017, 4D Reconstruction and Visualisation of Krakow Fortress. E. Głowienka, K. Michałowska, B. Hejmanowska, S. Mikrut, P. Kramarczyk, A. Struś, P. Opaliński. *Baltic Geodetic Congress (Geomatics), Gdansk, Poland, 22–25 June 2017*. References [12, 43, 91], Data [CAD/Scans, 3D Studio Max]
Mainly a description of what was done. No clarification of what 4D output is produced. No resulting conclusions/advice.

[43] 2017, 4D Reconstruction and Visualization of Cultural Heritage: Analyzing our legacy through time. P. Rodríguez-Gonzálveza, A. Muñoz-Nieto, S. del Pozo, L. Sanchez-Aparicio, D. Gonzalez-Aguilera, L. Micoli, S. Barsanti, G. Guidi, J. Mills, K. Fieber, I. Haynes, B. Hejmanowska. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W3.* References [21, 91], Cited by [42, 81]
Mainly a description of processes. No description of the 4D output to be produced. No resulting conclusions or advice.

[44] 2017, The Medieval Bishop's Palace in Milicz. 3D Reconstruction as a Method of a Research Hypotheses Presentation. J. Kolenda, M. Markiewicz. *Studies in Digital Heritage, vol.1, No.2, p428-443.* References [99], Cited by [80]
A re-presentation of [36].

[45] 2018, Principles and characteristics of CAD geometric modelling of historical buildings. D. Carrizosa, P. Plaza, I. Zaforteza. *Building & Management, vol. 2(1), pp. 03-11*.
(Mostly in Spanish) Mainly a basic technology re-statement. No resulting conclusions or advice.

[46] 2019, Different Ways of 3D Reconstruction of Historical Cities for Gaming Purposes. A. Kargas, G. Loumos, D. Varoutas. *Heritage 2019, 2, p1799-1811.* References [21, 101], Data [CAD, Photoshop, 3D Studio Max, Unity3D, Blender]
Promotes collaboration of experts to create a cultural repository. No resulting conclusions or advice.

[47] 2020, Built heritage modelling and visualisation: the potential to engage with issues of heritage value and wider participation. R. Laing. *Developments in the Built Environment.* References [5]
Suggests development should be cyclical. No resulting conclusions or advice.

[48] 2020, From Archive Documentation to Online 3D Model Visualization of No Longer Existing Structures: The Turin 1911 Project. D. Einaudi, A. Spreafico, F. Chiabrando, C. Coletta. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLIII-B2-2020.* Data [CAD/Photos/Scans, SketchUp, V-Ray, Agisoft Metashape, AutoCAD, Google Earth Pro]
Very flexible and integrated software, and the geolocation/accessible storage of all data for all specialists, is required.

6.2 Uncertainty Presentation References

[49] 1998, Photorealistic Visualizations May Be Too Good. H. Eiteljorg. *CSA Newsletter, 11(2), p1-4.* Cited by [58, 65, 73, 146, 148, 154]
Suggests sequence of views, and even alternative interpretations, to clarify the hypothetical from the existing/known.

[50] 1999, Virtual Reconstruction of Medieval Architecture. M. Masuch, B. Freudenberg, B. Ludowici, S. Kreiker, T. Strothotte. *EUROGRAPHICS '99, Short Papers and Demos.* Data [CAD, 3D Studio Max, AncientVis]
Classifies virtual reconstruction certainty, lists advantages, and relates preferred level of realism to phase and audience.

[51] 1999, Visualizing Knowledge about Virtual Reconstructions of Ancient Architecture. T. Strothotte, M. Masuch, T. Isenberg. *CGI '99 (Canmore, June 8–11).* Cited by [52, 60, 65, 73], Data [CAD, 3D Studio Max, AncientVis]
Proposes new but limited forms of non-photorealistic presentation to help clarify the levels of certainty and accuracy.

[52] 1999, Visualizing Uncertainty in Virtual Reconstructions. T. Strothotte, M. Puhle, M. Masuch, B. Freudenberg, S. Kreiker, B. Ludowici. *Proceedings of Electronic Imaging & the Visual Arts, EVA Europe, Berlin.* References [51], Cited by [60], Data [CAD, AncientVis]
Recommends multiple visual and interaction techniques to help clarify how a virtual reconstruction has been determined.

[53] 2000, Realism vs reality: Creating virtual reconstructions of prehistoric architecture. J. Kantner. *Virtual Reality in Archaeology, p47-52, BAR International Series 843.* Cited by [2, 61, 68, 84, 141], Data [CAD]
The importance of realism and/or reality depends largely on the purpose of/intended audience for the reconstruction.

[54] 2002, Fantastic reconstructions or reconstructions of the fantastic? Tracking and presenting ambiguity, alternatives, and documentation in virtual worlds, K. Kensek, L. Dodd, N. Cipolla. *ACADIA 2002 Proceedings, Pomona, CA, October 2002.* Cited by [59, 71, 78, 148, 154], Data [CAD]
Proposes opacity and false colour to indicate the level of uncertainty, and multi-media links to the evidence.

[55] 2002, Virtual Reconstruction and the Interpretative Process: A Case study from Avebury. G. Earl, D. Wheatley. *Contemporary themes in archaeological computing, p5-15.* Cited by [73, 129]
How ambiguous archaeological features can be analysed and interpreted via a VR model (no longer available online).

[56] 2003, Photorealism and Non-Photorealism in Virtual Heritage Representation. M. Roussou, G. Drettakis. *VAST 2003: Virtual Reality, Archaeology and Cultural Heritage, p51-60.* Cited by [60, 63, 69, 72, 73, 94, 96, 102, 103, 111, 112,153, 154, 157, 165], Data [Photos]
Suggests combining photorealistic and non-photorealistic visualisations can create more believable virtual environments.

[57] 2004, A fuzzy logic approach to reliability in archaeology. F. Niccolucci, S. Hermon. *Proceedings of the 2004 Computer Applications in Archaeology Conference*. References [84], Cited by [61, 65, 67, 68, 73, 75, 79, 111, 112, 148]
Provides a numerical index to rate reconstruction model geometry between imagination and reality, but see [61].

[58] 2004, Virtual reconstructions in archaeology and some issues for consideration. S. Sylaiou, P. Patias. *Foundation of the Hellenic World, vol.4, p180-191.* References [1, 49, 82]
Reconstructions often lack identified purpose, e.g. to disseminate research for testing hypotheses or engage the public.

[59] 2005, Digital Reconstructions: Confidence and Ambiguity. K. Kensek. *Sigradi, Visualización en arquitectura y patrimonio.* References [54]
Lists all methods of indicating reconstruction uncertainty, which can then be used with regard to the intended audience.

[60] 2005, Visualizing Temporal Uncertainty in 3D Virtual Reconstructions. T. Zuk, S. Carpendale, W. Glanzman. *The 6th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2005).* References [51, 52, 56], Cited by [63, 65, 69, 73, 75, 76, 81, 88, 92, 94, 102, 111, 112]
Archaeological site record as animated timeline and other visual cues to display artefact dating ranges and uncertainty.

[61] 2006, Deconstructing the VR - Data Transparency, Quantified Uncertainty and Reliability of 3D Models. S. Hermon, J. Nikodem, C. Perlingieri. *The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006).* References [53, 57, 84]
Quantifies feature importance and reliability using 'fuzzy logic', but the results are only available in unrelated graphs.

[62] 2006, In the eyes of the beholder: Virtual Reality re-creations and academia. D. Favro. *Journal of Roman Archaeology, p321-334.* Cited by [31, 148], Data [CAD/Photos/Scans]
Focuses on cityscapes based on reasoned conjecture, with the modelling decisions documented by links to metadata.

[63] 2006, On the Digital Reconstruction and Interactive Presentation of Heritage Sites through Time. S. El-Hakim, G. MacDonald, J. Lapointe, L. Gonzo, M. Jemtrud. *The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006).* References [5, 56, 60], Cited by [92, 94, 101], Data [Photos]
Bespoke viewer combines documents, images, audio, video, but presentation format is not the required virtual reality.

[64] 2006, Visualising uncertainty in archaeological reconstructions: a possibilistic approach. M. Sifniotis, B. Jackson, M. White, K. Mania, P. Watten. *ACM- SIGGRAPH 2006, Sketches and Applications, Boston, MA, USA.* Cited by [65, 73, 112]
Ultimately relies on colour/hue/intensity changes for clarification, but fails to consider resulting geometry complexity.

[65] 2007, Influencing Factors on the Visualisation of Archaeological Uncertainty. M. Sifniotis, P. Watten, K. Mania, M. White. *The 8th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2007).* References [49, 51, 57, 60, 64, 84, 99]
A survey of archaeologists using possibility theory to process the uncertainty associated with differing interpretations.

[66] 2007, The 'truthlikeness' of virtual reality reconstructions of architectural heritage: concepts and metadata. C. Ogleby. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVI, Part 5/W47. Cited by [100]
How material/texture maps, environment, lighting, post-production effects and metadata can affect interpretation.

[67] 2007, Three Dimensional Visualization and Virtual Reality in the Research and Interpretation of Archaeological Data. S. Hermon. *Unspecified, p143-150.* References [57, 84]
The full potential of VR as a research tool is yet to be applied to improving the archaeological reasoning process.

[68] 2008, Reasoning in 3D: A Critical appraisal of 3D modelling and VR in archaeology. S. Hermon. *Beyond Illustration: 2D and 3D Digital Technologies as Tools for Discovery in Archaeology, p 36-45.* References [53, 57, 84], Cited by [31, 119]
Essentially a reformatted version of [67].

[69] 2009, Procedural Modeling for Digital Cultural Heritage. S. Haegler, P. Muller, L. Van Gool. *EURASIP Journal on Image and Video Processing Volume 2009, 11 pages.* References [56, 60, 84, 86, 99], Cited by [73, 148, 166]
Suggests multiple semi-automatically generated model versions instead of transparency/colour to indicate uncertainty.

[70] 2010, 3D visualization of archaeological uncertainty. M. Sifniotis, B. Jackson, K. Mania, N. Vlassis, P. Watten, M. White. *ACM Symposium on Applied Perception (2010).* Cited by [112]
Assigns geometric transparency values based on Possibility Theory and Bayesian probability.

[71] 2010, The Fallacy of Reconstruction. J. Clark. *BAR International Series 2177.* References [54, 155]
Rejects 'reconstruction' as a description of a virtual model, claiming that then "it purports to be what it cannot be".

[72] 2011, Realism in Virtual Reality applications for Cultural Heritage. L. Pujol-Tost*. The International Journal of Virtual Reality, 2011, 10(3).* References [56, 150, 161], Cited by [117, 141]
"VR does not simulate the world as we see it, but as we represent it", and now exceeds static photographical dimension.

[73] 2012, Representing archaeological uncertainty in cultural informatics. M. Sifniotis. *Thesis, University of Sussex.* References [49, 51, 55, 56, 57, 60, 64, 69]
A study of the interpretation and presentation of uncertainty in reconstructions by archaeologists.

[74] 2013, 3D modeling and data enrichment in digital reconstruction of architectural heritage. F. Apollonio, M. Gaiani, Z. Sun. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-5/W2, 2013, p430-441.* References [90], Cited by [77], Data [CAD, Revit]
Proposes either 2D images or attached BIM type metadata to clarify uncertainty.

[75] 2013, Imagining the past of an Italian garden - A historical-virtual reconstruction of Villa lo Zerbino. A. Toth, D. Spallazzo, M. Ceconello. *Conference: Digital Heritage International Congress.* References [57, 60], Data [CAD, 3D Studio Max, Photoshop]
Illustrates simple virtual model reconstructions, and a very basic representation of uncertainty using colour.

[76] 2015, An Evaluation of Three Methods for Visualizing Uncertainty in Architecture and Archaeology. S. Houde, S. Bonde, D. Laidlaw. *IEEE Scientific Visualization Conference (SciVis) 2015, 25-30 October, Chicago, Il, USA.* References [60], Data [CAD, SketchUp]
Simplistic study (features considered without detail) of uncertainty visualisation by colour, transparency or texture.

[77] 2015, Classification schemes and model validation of 3D digital reconstruction process. F. Apollonio. *International Conference on Cultural Heritage and New Technologies, Vienna, 2015.* References [27, 31, 74, 99, 109]
Proposes Virtual Reconstruction Information Management Modelling, but no effort versus benefits study is provided.

[78] 2015, Theoretical Issues for Game based Virtual Heritage. E. Champion. *EiED 2014, CCIS 486, p125-136, 2015.* References [54, 108]
Presents a Critical Gaming Checklist of game design theory for reviewing intent, themes, content and assessment.

[79] 2017, The Importance of Being Honest: Issues of Transparency in Digital Visualization of Architectural Heritage. A. Ippolito. *Handbook of Research on Emerging Technologies for Architectural and Archaeological Heritage.* References [57, 99, 109, 111]
Brief/superficial suggestion for multiple-windowed representations of transparency. No consideration of practicalities.

[80] 2019, Processing Textual and Visual Certainty Information about Digital Architectural Models. M. Glaser, S. Schwan. *Computers in Human Behavior 96 (2019) p141-148.* References [44]
Unsurprisingly concludes that the uncertainty presentation format and content affect how well it is understood.

[81] 2019, Uncertainty Visualization Approaches for 3D Models of Castles Restituted from Archeological Knowledge. T. Landes, M. Heissler, M. Koehl, T. Benazzi, T. Nivola. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-2/W9, 2019.* References [43, 60, 122], Data [CAD/Scans, SketchUp, Lumion]
Considers Level of Uncertainty/Level of Detail combination, but only shown applied to very simplistic reconstructions.

6.3 Standards and Desirable Features References

[82] 2000, Computer Simulation of Stonehenge. E. Pasztor, C. Roslund, Á. Juhász, M. Dombi. *Virtual Reality in Archaeology, p111-113, BAR International Series 843.* Cited by [58], Data [CAD, ArchiCAD, 3D Studio Max]
Animates sun paths to investigate light and shadow at the summer solstice to further understand the stones' function.

[83] 2001, Persuade or Perish: Moving Virtual Heritage beyond Pretty Pictures of the Past. D. Sanders. *Seventh International Conference on Virtual Systems and Multimedia (VSMM '01).* Cited by [115]
Intended audience consideration and accessibility is key. Virtual Reality can index comprehensive databased information.

[84] 2002, From CVR to CVRO: The past, present, and future of cultural virtual reality. B. Frischer, F. Niccolucci, N. Ryan, J. Barceló. *Virtual Archaeolog Proc. VAST Arezzo, Oxford, BAR International Series 1075.* References [53], Cited by [21, 57, 61, 65, 67, 68, 69, 111, 129]
Seeks to establish a Cultural Virtual Reality Organisation which would develop and oversee CVR standards.

[85] 2002, Reviving the Past: Cultural Heritage Meets Virtual Reality. A. Gaitatzes, D. Christopoulos, M. Roussou. *Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage, ACM, p103-110.* Cited by [39, 132], Data [CAD]
"Both the hardware and the software employed have to become as human friendly as possible".

[86] 2004, Total Recall: A Plea for Realism in Models of the Past. L. Van Gool, M. Waelkens, P. Mueller, T. Vereenooghe, M. Vergauwen. *Proceedings of the XXth ISPR Congress p332-343.* References [97], Cited by [69, 148], Data [Photos, Paraform, Maya, Photoshop, Alias]
Illustrates how the most detailed possible reconstructions are important for increasing involvement and understanding.

[87] 2006, Learning about Cultural Heritage by Playing Geogames. P. Kiefer, S. Matyas, C. Schlieder. *Proceedings of ICEC 2006, p217-228.*
An implementation on mobile devices can support location-based games which can encourage exploration and learning.

[88] 2006, Playing with a Career in Ruins: Game Design and Virtual Heritage. E. Champion. *VIè Seminari Arqueologia i Ensenyament Barcelona, 26-28 d'octubre, 2006*. References [60, 154], Cited by [115]
Challenge to create "an entertaining and appropriately educational environment with playfully significant interaction".

[89] 2007, Photorealistic Real-Time Visualization of Cultural Heritage: A Case Study of Friedrichsburg Castle in Germany. R. Kuchar, T. Schairer, W. Straßer. *Eurographics 2007.* Data [CAD, RadioLab, Commander]
How to combine photorealistic and fast HDR lighting and rendering with intuitive interactive navigation, but all bespoke.

[90] 2008, Architectural Information Modelling for Virtual Heritage Application. P. Pauwels, R. Verstraeten, R. De Meyer, J. Van Campenhout. *Proceedings of the 14th International Conference on Virtual Systems and Multimedia, Cyprus, p18-23.* Cited by [74], Data [CAD, Revit]
Proposes extending IFC and BIM for archaeological 3D documentation, but no effort versus benefits study is provided.

[91] 2008, Digital reconstruction and 4D presentation through time. S. El-Hakim, J. Lapointe, E. Whiting. *ACM SIGGRAPH, 2008.* Cited by [21, 42, 43], Data [Photos]
Brief proposal for the use of a bespoke 4D viewer, without considering existing/available offerings.

[92] 2008, Exploring Cultural Heritage Sites through Space and Time. R. Laycock, D. Drinkwater, A. Day. *ACM J. Comput. Cult. Herit. 1, 2, Article 11 (October 2008), 15 pages.* References [56, 60, 63], Cited by [102, 132], Data [CAD, 3D Studio Max]
Bespoke semi-automatic generation of surrounding urban structures, but uninformative about the landmark structure(s).

[93] 2008, Personalizing virtual and augmented reality for cultural heritage indoor and outdoor experiences. F. Liarokapis, S. Sylaiou, D. Mountain. *VAST08: The 9th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage (2008), p55-62.* Cited by [101]
Satisfying visitor needs with a choice of multi-media presentations for kiosk exhibitions, and mobile located guides.

[94] 2008, Real-time visualisation of multiple time dependent reconstruction hypotheses for a cultural heritage site. S. Laycock, R. Laycock, D. Drinkwater, A. Day. *The 9th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2008).* References [56, 60, 63], Cited by [112], Data [CAD/Scans]
Bespoke consideration of varied hypotheses based on modular time, location and version stamped components.

[95] 2008, Standards and Guidelines for Quality Digital Cultural Three-Dimensional Content Creation. M. Ioannides, A. Addison, A. Georgopoulos, L. Kalisperis. *Digital Heritage - Proceedings of the 14th International Conference on Virtual Systems and Multimedia, p229-233.* References [99], Cited by [26, 31, 119]
Summarises EPOCH and MINERVA projects, agreeing guidelines, recommendations and standards. No conclusions.

[96] 2008, The components of engagement in Virtual Heritage Environments. M. Roussou*. In Proceedings of New Heritage: Beyond Verisimilitude - Conference on Cultural Heritage and New Media, Hong Kong, p265-283.* References [56], Data [Photos]
What attracts visitors to virtual heritage is the convergence of convincing visualisation with interactive experience.

[97] 2008, The ICOMOS Charter for the Interpretation and Presentation of Cultural Heritage Sites. International Council on Monuments and Sites. Cited by [86, 107, 148]
Defines a list of principles to which all aspects of access, communication, authenticity and understanding should aspire.

[98] 2009, Level of Realism for Serious Games. A. Chalmers, K. Debattista. *2009 Conference in Games and Virtual Worlds for Serious Applications.* Cited by [101, 122]
How focused multi-sensory input augments visualisation for the perception of real-world level of realism. See also [112].

[99] 2009, London Charter for Visualisation of Cultural Heritage. H. Denard*.* Cited by [13, 27, 28, 29, 36, 44, 56, 65, 69, 77, 79, 111, 112, 122, 123, 125, 126, 129, 135, 136, 148, 149]
A similar set of aspirational principles to [84, 97]. Comprehensive and general, but lacking detail and examples.

[100] 2009, Metadata-based heritage sites modeling with e-learning functionality. A. Styliadis, I. Akbaylar, D. Papadopoulou, N. Hasanagas, S. Roussa, L. Sexidis. *Journal of Cultural Heritage 10 (2009), p296-312.* References [8, 12, 66], Data [Photos]
Confusingly complex proposal for a 3D model-based metadata standard, requiring a database server.

[101] 2009, Serious Games for Cultural Heritage. E. Anderson, L. McLoughlin, F. Liarokapis, C. Peters, P. Petridis, S. de Freitas. *The 10th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2009)*.
References [63, 93, 98], Cited by [46, 126], Data [Quest 3D, Unreal Engine, OGRE]
Describes game-related technologies contributing to increasing levels of fidelity, usability and interactivity.

[102] 2009, Towards a 3D Visualization Interface for Cultural Landscapes and Heritage Information. A. de Boer, H. Voorbij, L. Breure. *Computer Applications to Archaeology 2009 Williamsburg, Virginia, USA. March 22-26, 2009.* References [13, 56, 60, 92]
Non-photorealistic representations of landscape/heritage can provide an appropriate interface for the general public.

[103] 2009, Virtual heritage: Reality and criticism. B. Tan, H. Rahaman. *13th International Conference of CAAD Futures 09, Montreal, Canada, June 17-19, p143-156.* References [56, 150, 154, 157], Cited by [107, 117, 150]
Argues that understanding an end-user's interpretation of content is as important as creation process and realism.

[104] 2010, A taxonomy of visualization strategies for Cultural Heritage applications. A. Foni, G. Papagiannakis, N. Magnenat-Thalmann. *ACM J. Comput. Cult. Herit. 3, 1, Article 1 (June 2010), 21 pages.* Cited by [112]
Suggests a quantitative classification of the contributors to requirements and modelling and visualisation method effort.

[105] 2010, Authentic Interactive Reenactment of Cultural Heritage with 3D Virtual Worlds and Artificial Intelligence. A. Bogdanovych, J. Rodriguez-Aguilar, S. Simoff, A. Cohen. *Applied Artificial Intelligence 24, 6, p617-647.* Cited by [141]
Bespoke virtual agents with AI to preserve/simulate culture and convey knowledge. Requires network access to others.

[106] 2011, Adopting Game Technology for Heritage Information Modelling. C. Sinclair, B. Loranger, D. Livingstone. *DOI:10.13140/RG.2.2.30471.75685.* Data [Photos/Scans, Unreal Engine]
Suggests bespoke game-engine functionality required, since heritage site management BIM toolsets are limited.

[107] 2011, Interpreting Digital Heritage: A Conceptual Model with End-Users' Perspective. H. Rahaman, B. Tan. *International journal of architectural computing issue 01, volume 09.* References [97 , 103], Cited by [141, 170
Presents a similar end-user centric theme, and diagrams, as a previous article [103].

[108] 2011, Playing with the Past. E. Champion. *Book, 234 pages, Springer-Verlag London.* Cited by [78, 120, 129, 165, 169]
Describes virtual travel, environments, places, presence, interaction, augmented reality, and cultural heritage evaluation.

[109] 2011, Principles of Seville. International Forum of Virtual Archaeology. *The XXIVth International Committee for Documentation of Cultural Heritage Symposium (2011).* Cited by [27, 77, 79, 111, 112, 123, 126, 136, 148, 164]
Extends the aspirational guidelines of The London Charter [99], particularly for archaeological heritage.

[110] 2011, Serious Games for Cultural Heritage: the GaLA Activities. M. Mortara, F. Bellotti, R. Berta, C. Catalano, G. Fiucci, M. Houry-Panchetti, P. Petridis. *The 12th International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2011)*. Cited by [165]
SG players must interact to gain knowledge and progress, and believability more important than excess realism.

[111] 2012, A New Introduction to The London Charter. H. Denard. *Paradata and Transparency in Virtual Heritage, p57-71.* References [56, 57, 60, 79, 84, 99, 109, 126, 128, 129], Cited by [125, 148]
A review of v2.1 [99], emphasizing the importance of access to bridge research and public understanding boundaries.

[112] 2012, Cultural Heritage Predictive Rendering. J. Happa, T. Bashford-Rogers, A. Wilkie, A. Artusi, K. Debattista, A. Chalmers. *Computer Graphics Forum 31 (2012), p1823-1836.* References [56, 57, 60, 64, 70, 94, 99, 104, 109]
Promotes the most plausible and ultra-realistic lighting and rendering of the past. A contended priority.

[113] 2012, Making Place: Designing and Building an Engaging, Interactive and Pedagogical Historical World. K. Devine. 16th *International Conference on Information Visualisation*. References [154, 156, 157], Data [CAD, Maya, 3DVIA Virtools]
Has user specified date, time, and speed of time options determine the position of the sun, sounds and weather.

[114] 2013, Disciplinary Issues: Challenging the Research and Practice of Computer Applications in Archaeology. J. Huggett. *40th Conference on Computer Applications and Quantitative Methods in Archaeology, Southampton, 26-29 March 2012.* Cited by [129]
No tangible current issues to be considered, solved or avoided are presented.

[115] 2013, Elements in games for virtual heritage applications. H. Granström. *Thesis, University of Skövde.* References [5, 83, 88, 157, 162, 163]
Determines desirable features list, then analyses video game examples for inspiration for virtual heritage development.

[116] 2013, Modeling in Archaeology: Computer Graphic and Other Digital Pasts. G. Earl. *Perspectives on Science. Vol. 21 No. 2 p226-244.* Cited by [122]
Restates the benefits of 3D virtual modelling for archaeology, e.g. collaboration, interpretation, and hypothesising.

[117] 2013, User Requirements for Virtual Reality in Architectural Heritage Learning. J. Bakar, P. Jahnkassim, M. Mahmu. *International Journal of Interactive Digital Media, Vol. 1(1).* References [72, 103, 150, 153, 154, 157, 159]
Study of factors contributing to a successful virtual educational installation, but lacking tangible conclusions.

[118] 2015, Roleplaying and Rituals for Cultural Heritage-Orientated Games. E. Champion. *DIGRA 2015 "Diversity of play: Games–Cultures–Identities".* Cited by [141]
Virtual worlds should recreate the past by simulating meaningful roles and rituals, and act as curators of tradition.

[119] 2016, A classification model for digital reconstruction in context of humanities research. S. Münster, W. Hegel, C. Kröber. *3D Research Challenges in Cultural Heritage II: How to Manage Data and Knowledge Related to Interpretative Digital 3D Reconstructions of Cultural Heritage, p3-31.* References [7, 14, 26, 31, 68, 95], Cited by [137], Data [CAD, SketchUp, Cinema4D, ArcGIS]
Proposes basic schema of Technology: tools, geometry type; Project: effort, dates; History: location, date, type; Context.

[120] 2016, But that's not accurate: the differing perceptions of accuracy in cultural heritage videogames between creators, consumers and critics. T. Copplestone. *Rethinking History, 21:3, p415-438.* References [108], Cited by [131]
Creators minimise risk. Criticism is based on preceding media forms. Only consumers appreciate/challenge this situation.

[121] 2016, Experiencing the Digital World: The Cultural Value of Digital Engagement with Heritage. L. King, J. Stark, P. Cooke. *Heritage & Society, 9:1, p76-101.* References [157], Cited by [125]
Close gap between heritage professionals and audiences via more cooperation to realise the potential of digital heritage.

[122] 2016, Interpreting and presenting archaeological sites using 3D Reconstruction. R. Barratt. *Thesis, University of Cambridge.* References [27, 98, 99, 116], Cited by [81], Data [CAD, SketchUp, Unity3D, V-Ray]
Considers issues of recording the reconstruction process and clarifying uncertainty using paradata.

[123] 2016, The Missing Scholarship Behind Virtual Heritage Infrastructures. E. Champion. *The 14th Eurographics Workshop on Graphics and Cultural Heritage, Genova, Italy, p57-65.* References [99, 109, 157], Cited by [146]
Proposes dynamic real-time configuration of the virtual experience. Agreed evaluation criteria required for VH assets.

[124] 2016, User Categories for Digital Cultural Heritage. D. Walsh, P. Clough, J. Foster. *Proceedings of 1st International Workshop on Accessing Cultural Heritage at Scale (ACHS'16), June 22, 2016, Newark, NJ, USA.* References [170]
Suggests categorising users by expertise (knowledge, experience and motivation) to improve design of DCH services.

[125] 2017, 3D Heritage visualisation and the negotiation of authenticity: the ACCORD project. S. Jones, S. Jeffrey, M. Maxwell, A. Hale, C. Jones. *International Journal of Heritage Studies.* References [99, 111, 121], Cited by [130], Data [Photos/Scans]
See comment for [121]. Suggests 'ownership' and 'attachment' will impart 'authenticity'.

[126] 2017, A Framework to Design, Develop, and Evaluate Immersive Games in Cultural Heritage. R. Andreoli, A. Corolla, A. Faggiano, D. Malandrino, D. Pirozzi, M. Ranaldi, G. Santangelo, V. Scarano. *ACM J. Comput. Cult. Herit. 11, 1, Article 4 (December 2017), 22 pages.* References [99, 101, 109, 111, 156, 162], Cited by [145, 175], Data [CAD, 3D Studio Max]
Attempts to formalise creation process based on many assumptions, confuses game perception with criteria validation.

[127] 2017, Empirical Evaluations of Interactive Systems in Cultural Heritage: A Review. P. Koutsabasis. *International Journal on Computational Methods in Heritage Science, 1(1).* References [12, 163, 164], Cited by [141]
Summarises features and aspects recorded by others – does not evaluate, for example by relative importance ranking.

[128] 2017, Reliving Past Architecture: Virtual heritage and the reproduction of history through creative modes of heritage visualisation. M. Abdelmonem. *International Conference on Trends in Architecture and Construction, 2017.* References [111, 150, 155]
Mainly a restatement of the history of the emergence and evolution of VH basics. No resulting conclusions or advice.

[129] 2017, Virtual Archaeology, Virtual Longhouses and "Envisioning the Unseen" within the Archaeological Record. W. Carter. *Thesis, University of Western Ontario.* References [37, 55, 84, 99, 108, 111, 114], Data [Unity3D, Unreal Engine, Maya, Mudbox]
Explores meaning-making/wayfaring. Paradata clarifies interpretation. Interactive immersion preferred to photorealism.

[130] 2018, 3-D Virtual Replicas and Simulations of the Past – "Real" or "Fake" Representations? F. Galeazzi. *Current Anthropology Volume 59, Number 3, June 2018.* References [37, 125]
Digital record can track decisions during the reconstruction process, thereby providing interpretation transparency.

[131] 2018, A model of heritage content to support the design and analysis of video games for history education. L. Hanes, R. Stone. *J. Comput. Educ.* References [120, 163, 166]
Proposes activity theory evaluation criteria for entertainment and educational games. Ignores 3D format presentation.

[132] 2018, A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. M. Bekele, R. Pierdicca, E. Frontoni, E. Malinverni. *J. Comput. Cult. Herit. V, N, Article 1 (2017), 35 pages.* References [13, 85, 92, 153, 168], Cited by [134, 139, 143, 178]
Considers appropriate technology e.g. CAVE/HMD mixed reality for indoor exploration/reconstruction/education.

[133] 2018, Assessing the user response to differences in functionality when visualising 3D models of cultural heritage sites using the Technology Readiness Index. M. Smith, N. Walford, C. Jimenez-Bescos. *Digital Applications in Archaeology and Cultural Heritage 10 (2018).* Cited by [147], Data [CAD, Maya, Unreal Engine]
Study of only 25 similar participants, thus minimising the significance of any (e.g. interactivity) related conclusions.

[134] 2018, Recreating Sheffield's Medieval Castle *in situ* using Outdoor Augmented Reality. M. Leach, S. Maddock, D. Hadley, C. Butterworth, J. Moreland, G. Dean, R. Mackinder, K. Pach, N. Bax, M. Mckone, D. Fleetwood. *Virtual Reality and Augmented Reality, EuroVR 2018, 22-23 Oct, London.* References [132], Data [CAD, SketchUp, Unity3D]
Rendering realism by directional lighting matching the sun, and depth-based masking to avoid obscuring real buildings.

[135] 2018, The Role of 3D Models in Virtual Heritage Infrastructures. E. Champion. *Chapter 2, Cultural Heritage Infrastructures in Digital Humanities.* References [99, 109, 157], Cited by [146]
Proposes scholarly ecosystem for virtual heritage providing collaborative access to model and documentation assets.

[136] 2019, 3D Digital Heritage Models as Sustainable Scholarly Resources. E. Champion, H. Rahaman. References [99, 157]
A study supporting and restating [135]. 3D models underpinning scholarly articles should be recognised and preserved.

[137] 2019, A white-box framework to oversee archaeological virtual reconstructions in space and time: Methods and tools. E. Demetrescu, B. Fanini. *Journal of Archaeological Science, Reports 14 (2017), p500-514.* References [27, 119]
Documenting/presenting reconstruction process and providing digital asset context. Assumes simple modular building.

[138] 2019, Augmented Reality Tour Guide for Cultural Heritage. S. Koo, J. Kim, C. Kim, J. Kim, H. Cha. *ACM Journal on Computing and Cultural Heritage, Vol. 12, No. 4, Article 24.*
Specific to mobile/hand-held devices at predefined Points of Interest with e.g. QR code targets. No relevant conclusions.

[139] 2019, Can Augmented Reality enhance to a greater visitor satisfaction of historical landmarks? C. Wakefield, A. Simons, D. John. *Eurographics Workshop on Graphics and Cultural Heritage (2019).* References [132], Data [CAD, Unity3D, Vuforia]
Very similar study to [138], finding that typically only some older visitors were prepared to pay for the experience.

[140] 2019, Diachronic Reconstruction and Visualization of Lost Cultural Heritage Sites. P. Rodríguez-González, Á. Campo, Á. Muñoz-Nieto, L. Sánchez-Aparicio, D. González-Aguilera. *ISPRS Int. J. Geo-Inf. 2019, 8, 61.* References [21], Data [CAD/Scans]
4D modelling as a means to manage/preserve archaeological site data. Bespoke viewer. No relevant conclusions

[141] 2019, Did We Just Travel to the Past? Building and Evaluating with Cultural Presence Different Modes of VR-Mediated Experiences in Virtual Archaeology, L. Pujol-Tost. *J. Comput. Cult. Herit. 12, 1, Article 2 (February 2019), 20 pages.* References [53, 72, 105, 107, 118, 127, 161, 167, 170], Cited by [143], Data [3D Studio Max, Substance, Photoshop, Unity3D]
Photorealism not expected, sense of place provided by buildings but also by interaction within populated environment.

[142] 2019, Interactive Timeline Visualization with Games Engines and Conceptual Frameworks for Disseminating Historic Architecture and Archeology. K. Mitchell, M. Murphy. *Unspecified publication.* Data [CAD/Scans, Unity3D, Unreal Engine, Twinmotion, CADmapper, Revit, Vuforia]
Mainly a description of what was done. No resulting conclusions or advice.

[143] 2019, Methods and Practices for Assessing the User Experience of Interactive Systems for Cultural Heritage. V. Nikolakopoulou, P. Koutsabasis. *Applying Innovative Technologies in Heritage Science, Chapter 9.* References [132, 141, 164, 167, 171, 173]
Reviews 89 articles and then merely suggests "supplementary investigations".

[144] 2019, No Story without a Backstory - The role and importance of the backstory in an augmented reality application for cultural heritage. F. Vanoverschelde. *NHT '19, September 17, 2019, Hof, Germany.*
A study proposal to consider if a backstory could help the immersive experience. No conclusions or advice.

[145] 2019, Serious Games Classification for Digital Heritage. I. Paliokas. *International Journal of Computational Methods in Heritage Science, Volume 3, Issue 2, July-December 2019.* References [126, 163]
Schema: Users (type, number), Contents, Theme (history), Experience, Technology (devices), Intention (learning).

[146] 2019, The Scholarly Rewards and Tragic Irony of 3D Models in Virtual Heritage Discourse. H. Rahaman, E. Champion. *Intelligent & Informed, Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia 2019, Volume 2, p695-704.* References [49, 123, 135]
Study supporting/restating [136], raising awareness for the preservation/dissemination of 3D digital heritage assets.

[147] 2019, Using 3D modelling and game engine technologies for interactive exploration of cultural heritage: An evaluation of four game engines in relation to roman archaeological heritage. M. Smith, N. Walford, C. Jimenez-Bescos. *Digital Applications in Archaeology and Cultural Heritage, 14.* References [133, 161, 166], Data [CAD, Maya]
Concludes cost/licensing override technical factors, PC (not specialist game device) installation best for widest audience.

[148] 2020, Defining a Methodology for 3D Approximations in Archaeology: The Issue with Alternative Models. R. Barrat. *23rd International Conference on Cultural Heritage and New Technologies 2018.* References [49, 54, 57, 62, 69, 86, 97, 99, 109, 111]
Proposes Metadata/Paradata documentation of data and process, to facilitate (inexplicably) a duplicate reconstruction.

[149] 2020, The Fort Ross Virtual Warehouse Project: A Serious Game for Research and Education. M. Forte, N. Lercari, L. Onsurez, J. Issavi, E. Prather. *ACM Journal on Computing and Cultural Heritage, Vol. 13, No. 1, Article 7, 21 pages.* References [99], Data [CAD/Photos/Scans, Maya, 3D Studio Max, Mudbox, Photoshop, Unity3D]
Virtual agents, storytelling, and textual, verbal and visual communication provides a more effective learning experience.

6.4 Educational Considerations References

[150] 2001, Visualising historical knowledge using virtual reality technology. L. Mosaker. Digital Creativity 2001, Vol. 12, No. 1, p15-25. Cited by [72, 103, 117, 128, 154, 165], Data [CAD]
Historical VR is copy of lost original past, the experience depends on expectations, building is sterile without inhabitants.

[151] 2005, 3D Worlds and Cultural Heritage: Realism vs. Virtual Presence. N. Di Blas, E. Gobbo, P. Paolini. *Museums and the Web 2005.* Cited by [157]
Prioritises multi-user shared access using avatars over realism to provide virtual presence and an emotional experience.

[152] 2005, Games for Cultural Heritage. B. Flynn. *IADIS International Conference e-Society 2005.*
Considers how game play type interaction can contribute to a more informing engagement with cultural heritage.

[153] 2006, A Versatile Large-Scale Multimodal VR System for Cultural Heritage Visualization. C. Christou, C. Angus, C. Loscos, A. Dettori, M. Roussou. *Proceedings of the ACM symposium on Virtual reality software and technology, ACM, p133-140.* References [56], Cited by [117, 132], Data [Photos]
Performing tasks using haptic interfaces to enhance the sense of presence and thus appreciation and learning.

[154] 2006, Evaluating Cultural Learning in Virtual Environments. E. Champion. *Thesis, University of Melbourne.* References [3, 49, 54, 56, 150], Cited by [88, 103, 113, 117, 169, 170], Data [Adobe Atmosphere, 3D Studio Max]
Creating a sense of presence in a place of previous habitation is as key for engagement and learning as is photo-realism.

[155] 2006, Why Do Virtual Heritage? D. Sanders, *Digital Discovery: Exploring New Frontiers in Human Heritage, CAA 2006, Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 34th Conference,* p427-36. Cited by [71, 128], Data [CAD]
Interactive 3D environments provide new insights/understanding impossible with traditional analytical/visual tools.

[156] 2008, Ancient Architecture in Virtual Reality: Does Visual Immersion Really Aid Learning? J. Jacobson. *Thesis, School of Information Sciences, University of Pittsburgh.* Cited by [113, 126, 164]
Concludes that students recall more of an educational game via a visually immersive display than via a standard screen.

[157] 2008, Educational tool or expensive toy? Evaluating VR evaluation and its relevance for virtual heritage. M. Economou, L. Pujol. *New heritage: New Media and Cultural Heritage, p242-60.* References [56, 151], Cited by [103, 113, 115, 117, 121, 123, 135, 136, 161]
Social aspect of experience is important, learning studies currently inconclusive, more research/new methods required.

[158] 2008, History educators and the challenge of immersive pasts: a critical review of virtual reality 'tools' and history pedagogy. J. Allison. *Learning, Media and Technology, Vol. 33, No. 4, December 2008, p343-352.*
That 'virtual reality tools deserve the attention of history educators' is the only resulting insight.

[159] 2009, Design and Development of a Virtual Reality Application for Edutainment in Cultural Heritage. L. De Paolis, G. Aloisio, M. Celentano, L. Oliva, P. Vecchio. *15th International Conference on Virtual Systems and Multimedia.* Cited by [117], Data [CAD, Torque Constructor, Torque 3D]
A case study based on an incomplete project and therefore inconclusive.

[160] 2009, Developing a Measurement Scale for the Evaluation of AR-Based Educational Systems. A. Balog, C. Pribeanu. *Studies in Informatics and Control, Vol. 18, No. 2, June 2009.*
Analyses aspects of motivational, usability and educational features according to technology acceptance theories.

[161] 2009, Worth a Thousand Words? The Usefulness of Immersive Virtual Reality for Learning in Cultural Heritage Settings. L. Tost, M. Economou. *International Journal of Architectural Computing, January 2009.* References [157], Cited by [72, 141, 147, 169]
Considerable analysis confirms VR facilitates a different kind of learning, but is not necessarily better for younger users.

[162] 2011, Towards a new era for Cultural Heritage Education - Discussing the role of ICT. M. Ott, F. Pozzi. *Computers in Human Behavior 27 (2011) p1365-1371.* Cited by [115, 126, 173]
Interactive Computer Technology facilitates new scenarios for Cultural Heritage Education, but requires expert oversight.

[163] 2012, A serious game model for cultural heritage. F. Bellotti, R. Berta, A. De Gloria, V. Fiore, A. D'Ursi. *ACM Journal of Computing and Cultural heritage.* Cited by [115, 126, 127, 131, 145, 166, 171, 175, 176, 177], Data [Torque 3D]
Presents a Sandbox Serious Game design framework for task-based knowledge acquisition, retention and verification.

[164] 2013, Exploring Canons and Cathedrals with Open Virtual Worlds - The Recreation of St Andrews Cathedral, St Andrews day, 1318. S. Kennedy, R. Fawcetty, A. Miller, L. Dow, R. Sweetman, A. Field, A. Campbell, I. Oliver, J. McCaffery, C. Allison. *Digital Heritage International Congress, Vol. 2, p273-280.* References [109, 156], Cited by [127, 143], Data [CAD, OpenSim, Blender]
Describes holistic appreciation, links to internet-based metadata, and dissemination with educational agenda examples.

[165] 2014, Exploring the Pedagogical Possibilities of applying Gaming Theory and Technologies for Historic Architectural Visualisation. H. Rice. *Thesis, University of York.* References [56, 99, 108, 110, 150], Data [CAD, Blender]
Reconstruction of St. Mary's Abbey, York. Information retention via participation. Tests educational goals/outcomes.

[166] 2014, Learning cultural heritage by serious games. M. Mortara, C. Catalano, F. Bellotti, G. Fiucci, M. Houry-Panchetti, P. Petridis. *Journal of Cultural Heritage 15 (2014) p318-325.* References [69, 163], Cited by [131, 147, 171, 173, 175, 176]
Advocates more research into formal evidence of effective learning from SG, and postgraduate courses on SG creation.

[167] 2014, Virtual Worlds vs Books and Videos in History Education. K. Ijaz, A. Bogdanovych, T. Trescak. *Interactive Learning Environments 25, 7 (2014), p904-929.* Cited by [141, 143], Data [Second Life]
Study (of 60) suggests the virtual environment (with virtual agents) provides a 20% better learning environment.

[168] 2015, A flexible platform for the creation of 3D semi-immersive environments to teach Cultural Heritage. A. Bustillo, M. Alaguero, I. Miguel, J. Saiz, L. Iglesias. *Digital Applications in Archaeology and Cultural Heritage 2 (2015) p248-259.* References [12], Cited by [132, 173, 178], Data [Maya, Blender, WorldViz, Ogre]
Study illustrates the concept, but required complicated and expensive facilities, such as data-gloves and a render farm.

[169] 2015, Effects of interactive digital media on architectural heritage learning. J. Abubakar, P. Jahnkassim, M. Mahmud. *Jurnal Teknologi (Sciences & Engineering) 78:2-2 (2016) p41-48.* References [108, 154, 161]
Study indicated that (museum) virtual reality has lower learning retention rate than passive video or low-interactive web.

[170] 2015, Factors Facilitating Cultural Learning in Virtual Architectural Heritage Environments: End User Perspective. N. Ibrahim, N. Ali and N. Yatim. *ACM Journal on Computing and Cultural Heritage, Vol. 8, No. 2, Article 8.* References [18, 22, 107, 154], Cited by [124, 141]
Presents trivial conclusions, for example, "the inclusion of cultural information… is important… for cultural learning".

[171] 2017, Analyzing the educational design, use and effect of spatial games for cultural heritage: a Literature Review. I. Malegiannaki, T. Daradoumis. *Computers & Education, 108 (May 2017).* References [17, 163, 166], Cited by [143, 173, 175, 176, 177]
Advocates complex storytelling and "a tighter connection with teaching in formal educational settings".

[172] 2018, A Comparison of the Capacities of VR and 360-Degree Video for Coordinating Memory in the Experience of Cultural Heritage. S. Cai, E. Ch'ng, Y. Li. *3rd Digital Heritage International Congress, and 24th International Conference on Virtual Systems & Multimedia.* Cited by [179], Data [Photos, Blender, Unity3D]
Although 360 video can have a sense of reality advantage, virtual reality prolongs/reinforces memory of the experience.

[173] 2018, Evaluating Learnability in a 3D Heritage Tour. R. Zamora-Musa, J. Vélez, H. Paez-Logreira. *Presence, Vol. 26, No. 4, Fall 2017, 366–377.* References [39, 162, 166, 168, 171], Cited by [143], Data [OpenSim]
SUMI ISO9241-11 study of 52 users unsurprisingly reveals correlation between learning and usability of the experience.

[174] 2018, Exploring Cultural Heritage Using Virtual Reality. L. Debailleux, G. Hismans, N. Duroisin. *Digital Cultural Heritage, p289-303.* Cited by [178], Data [CAD, Rhino, Unity3D]
Immersive HMD tour tested by children concluding that site layout and tourist information were not well recalled.

[175] 2018, How serious games in cultural heritage are being evaluated. C. Tsita, M. Satratzemi. *11th Pan-Hellenic and International Conference, ICT in Education, Thessaloniki.* References [126, 163, 166, 171], Cited by [176]
Finds body of work by others is limited/largely non-experimental, with no pre-/post-comparison, and of small samples.

[176] 2019, A Serious Game Design and Evaluation Approach to Enhance Cultural Heritage Understanding. C. Tsita, M. Satratzemi. *Games and Learning Alliance p438-446.* References [163, 166, 171, 175]
Learning effectiveness evaluation (defined goals/measured results) should be embedded, and experience personalised.

[177] 2020, Educational Games for Cultural Heritage. E. Vocaturo, E. Zumpano, L. Caroprese, S. Pagliuso, D. Lappano. *1st International Workshop on Visual Pattern Extraction and Recognition for Cultural Heritage Understanding, and 15th Italian Research Conference on Digital Libraries.* References [163, 171]
Promotes 'personalized interactive experiences' (choose character/mentor), suggests digital souvenirs for social media.

[178] 2020, Survey: Using Augmented Reality to Improve Learning Motivation in Cultural Heritage Studies, J. Vargas, R. Fabregat, A. Carrillo-Ramos. T. Jové. *Appl. Sci. 2020, 10, 897.* References [5, 39, 132, 168, 174]
Few experiences consider user's motivation, which, it is claimed, would benefit from a content co-creation option.

[179] 2020, The Effects of VR Environments on the Acceptance, Experience, and Expectations of Cultural Heritage Learning. E. Ch'ng, Y. Li, S. Cai, F. Leow. *ACM Journal on Computing and Cultural Heritage, Vol. 13, No. 1, Article 7, 21 pages.* References [172]
Study of 61 aged 18-28. Prior VR experience unimportant. Curiosity and exploratory behaviour benefits learning.

A Qualitative Evaluation for Heritage Site 3D Virtual Reconstruction Features

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Abstract — Computer software and hardware products are increasingly capable of presenting virtual worlds, including those that primarily aim to illustrate and further the appreciation of cultural heritage sites. These sites, some of which survive only as ruins, can now be experienced, in various extents of virtual reality, as they may have been in the past. The content and level of engagement offered by these virtual experiences varies considerably, and there is currently no indicative means of measure for comparison or analysis. Therefore, with an aim to simplify and qualify, a percentage scale rating based on a range of desirable features is proposed, and illustrated by application to a current castle 3D virtual reconstruction. An accommodation of the subjectivity inherent in this process is also considered.

Keywords — Evaluation, Assessment, Subjectivity, Heritage, 3D, Virtual, Reconstruction, Castle.

1. INTRODUCTION

It has been shown, by Ch'ng *et al* [50], that subject curiosity, and a willingness to explore via a virtual reconstruction, provides the opportunity to inform. The extent to which such an experience might successfully engage, and disseminate historical appreciation to an interested public audience, depends on the nature of the content and interactivity. However, currently there is no simple method to consider the contributing features. Domain standards have been established in the form of a series of aspirational principles, but the documentation [13, 16, 21] is very general in nature, applying also to primarily research or conservation projects, and does not attempt to identify desirable features, or provide any indication of their possible relative importance for an educational objective.

However, several articles have previously specifically considered these and other similar requirements, and Balog and Pribeanu [14] proposed the very same objective - to develop a measurement scale for evaluation purposes. They defined 19 items organised into the 5 'constructs' of ergonomics, perceived ease of use, usefulness and enjoyment, and intention to use. Ultimately, though, this analysis was according to technology acceptance theories, and was not feature based. Foni *et al* [18] presented complex diagrams and analysis based on themes of precision, interactivity, 'automatism', virtuality, preferences and 'affinity volumes'. They produced a conceptual framework of modelling and visualisation strategies, but not the clear and usable analysis of content features required. The thesis by Granström [25] identified 17 desirable elements for virtual heritage applications, grouped into main themes of interactivity, meaning, characters and accuracy/realism, but the emphasis was on the extent to which they then appear in selected popular modern entertainment video games.

Bakar *et al* [26] considered the requirements for learning architectural heritage from the perspective of experts. They identified content, experience, setting, support and interface attributes for virtual reality development guidelines, but did not then suggest any relative importance. Münster et al [31] proposed a *"classification model for digital reconstruction"* which described a project in some detail, with the criteria employed providing a useful insight. However, within its stated context of humanities research, it did not aim to describe (or classify) the reconstructed content. Champion [33] recognised the need for *"developing criteria in order to appraise"* and for implementing a review mechanism, i.e. the need to *"improve the evaluation and feedback of virtual heritage projects"*. He considered the fundamental supporting issues, such as lack of infrastructure, but did not suggest specific appraisal criteria.

Andreoli *et al* [35] introduced a framework for serious games in cultural heritage, which included evaluation in terms of effectiveness, efficiency and satisfaction, according to demographic and video gaming experience. However, the administered questionnaire generated results based on either general perception, such as playability or enjoyment, or task completion, rather than specific content or feature contributions. Koutsabasis [37], Tsita and Satratzemi [40], and Koutsabasis and Nikolakopoulou [45] have presented reviews of previous evaluations of interactive systems in cultural heritage. The most popular criteria were user experience, usability, learning, and engagement, and these were most commonly evaluated by questionnaire, interview, or by observation. The emphasis of these analyses was on the rigour of the evaluation approaches employed. There was no analysis of the significance of content or features of cultural heritage models, but a prerequisite would have been the common existence of such data in the original evaluations.

Thus it has long been recognised that there is a need for evaluation criteria for cultural heritage projects, but that a readily useable method of identifying and measuring desirable content and features is apparently unavailable. The proposed form of evaluation will consider desirable features under the headings of Content, Engagement, Education, and Delivery.

2. IDENTIFYING DESIRABLE FEATURES

2.1 Content

Content, most significantly the geometry representing the heritage site building structures, is of fundamental importance, and typically the primary purpose and focus of the reconstruction project. To help distinguish between, for example, photogrammetric generation based on drone site video footage, and a full CAD based site reconstruction as it might have been in the past, external and internal content will be considered separately. Wagener et al [24] demonstrated the particular importance of terrain in providing context for castles, and this consideration of historical landscape is just as key in understanding why other types of structure came to be built where they were, for example, perhaps also to similarly dominate the surroundings, or to take advantage of specific vistas. Accessible internal spaces help to provide the experience of occupation, and ideally these would have appropriate fixtures and fittings to help indicate function. Currently, a reconstruction project describing article may not clarify how much of a heritage site structure has been modelled, or, apart from assumptions based on cited software, whether a 3D reconstruction is then presented and experienced via sequences of images, video clips, or interactive exploration. Both external structure and internal spaces can be evaluated according to the extent to which they are complete, detailed and historically accurate where possible.

Eiteljorg [1], Kantner [2], Van Gool *et al* [5], Chalmers and Debattista [15], and Pujol-Tost [22] have all discussed the appropriate levels and importance of realism. Although Mortara *et al* [23] suggested that believability is more important than excess realism, Mosaker [4] clarified that *"detailed and realistic graphics are crucial for making a believable experience"*. A combined level of realism and sense of believability can be assessed as a proportion of that attainable. To support the sense of realism, appropriate audio can be added, and the display rate should ideally exceed 30 frames per second, or at least not be considered a distraction.

El-Hakim [10] and Laycock *et al* [11] advocated presenting the evolution of a structure over time, and the Principles of Seville [21] stated that a structure should not solely be presented in its *"time of splendour"*, since all historical phases are valuable. In reality, the vast historical knowledge required for a viable and meaningful 4D presentation encompassing several centuries of change and development would rarely if ever be available. However, it should at least always be possible to display a 'then and now' version to enable comparison of the historical reconstruction with the current state.

To avoid the impression of a dead or sterile environment, naturally moving features, such as any flags or fire flames and smoke should be animated, and bodies of water should reflect surroundings. Champion [8] considered a place of previous habitation sterile if it has no sense of presence, which is important for engagement and learning, and Mosaker [4] contended that a building is sterile without inhabitants. Generating appropriately attired and moving inhabitants requires advanced expertise, but the resulting more compelling experience and increased sense of presence could be seen as equally important as basic feature animation.

2.2 Engagement

Considering *'The Components of Engagement in Virtual Heritage Environments'*, Roussou [12] concluded that convincing visualisation needs to converge with the interactive experience, Flynn [7] noted how game play type interaction can contribute to a more informing engagement with cultural heritage, and Mortara *et al* [23] found that serious games players must interact to gain knowledge. Champion [8] suggested that engaging games incorporate challenge and reward, ultimately deciding that *"the crucial issue is interaction and the learning that results from that interaction"*. These requirements for interactive features can be addressed by considering the general user interface and the provision of specific activities. Flynn [7] described how virtual interactive tasks, based on the activities of the time, can be introduced to encourage interpretation and further understanding.

The user interface, it almost goes without saying, should be as simple and intuitive as possible to encourage use. Navigation and gameplay by mouse, keyboard, and/or gamepad device, should therefore conform to any established standards and typical expectations. The highly positive impact of augmented reality devices has been noted, for example by Baus *et al* [44] and Flavián *et al* [51] regarding the provision of appropriately corresponding odours. However, the support for currently very specialised and less affordable devices should only be considered if they are completely optional, otherwise any benefit would be offset by a negative rating when considering their likely availability. While it is accepted that storytelling has been widely shown to be a beneficial feature, for example by Roussou [12], Malegiannaki and Daradoumis [36] and Vanoverschelde [46], and *'guided navigation'* is recommended by El-Hakim *et al* [17] so as to provide a more controlled experience, instead the non-prescriptive nature of the complete freedom to explore (possibly with the assistance of a map) will be considered, having been noted by Champion [8], Ibrahim *et al* [28] and Pujol-Tost [43]. Support for information in multiple languages would be a bonus.

A customisable or personal experience has often been suggested, for example by Flynn [7], Roussou [12], Walsh *et al* [34] and Vocaturo *et al* [49], whereby different levels of user expertise, such as tourist or historian, might be offered a different and more appropriate experience. Alternatively, or perhaps additionally, if age (young or old) and sex is determined (or chosen), then a more relatable experience becomes possible, contrasting likely life experiences of the time depending on status (master or servant) and then enabling comparison with other demographics.

2.3 Education

These interactive 3D virtual reconstruction related proposals are not intended to imply that only this medium or experience is always the most appropriate for the best learning outcomes, and similarly it is conceded that they are not comparable with more wide-ranging analyses of the educational experience, such as the framework for evaluation proposed by de Freitas and Martin [9]. However, the development of these proposals may still be justified by the overriding intention to provide a simple, feature based, and readily usable process.

Typically, as the primary structures of a designated heritage site, the buildings, and any internal spaces and content, already intrinsically provide a significant educational experience. This can be augmented by any operational installations, such as an animated drawbridge, portcullis or mill of a castle. More detailed educational information such as history and context can be provided by text (or audio) description. A guided tour option, for example, goes some way to satisfying the observation by L. Mosaker [4] that *"A well-designed virtual environment will lead the visitor through the highlights"*. Additionally, any interactive activities would be expected to have an informative purpose.

Champion [29] considered in detail the concept of culture, explaining how virtual worlds should recreate the past by simulating meaningful roles and rituals, and how they can act as curators of tradition. Although appropriate cultural artifacts may be recreated and displayed using geometry, it is much harder to represent the traditions, customs, skills and etiquette of the time. Incorporating such contemporary behaviour, activity and experience, such as combat, praying, eating, dancing and entertainment, into the virtual world will be beyond the capabilities of the vast majority of reconstructions. However, it remains important to specifically recognise cultural content as part of the educational experience.

Over and above the experience of being able to interactively explore a reconstructed historical site, any original aspects of the reconstruction or presentation providing new historical insights or understanding should be recognised as adding to the unique appeal and contribution of the reconstruction. Lastly, De Paolis *et al* [19] have shown that a multi-player environment, with voice and text interaction, *"is one of the best ways for retrieving knowledge and experiences during the virtual game"*. Di Blas *et al* [6] agreed, but recommended that these activities are pre-planned. Therefore, despite the likely requirement for more complex installation and support, facilitating the option for a teacher led educational virtual tour remains appealing.

2.4 Delivery

The critical importance of access, the availability of the content and experience for both academic evaluation and public consumption, has been stressed by Sanders [3] and repeatedly by Champion *et al* [41, 42, 47]. Access can be severely limited by the requirement for specific, advanced and expensive hardware configurations, notably any immersive CAVE type display systems, which also have significant installation space and supervisory requirements. Smith *et al* [48] recommended the use of standard personal computer equipment in preference to specialist gaming devices, thereby limiting complexity and expense and improving the likelihood of reaching a wide audience.

According to Barratt [32], Carter [38] and Galeazzi [39] the reconstruction process should be recorded as 'paradata' to inform further study and development. Champion [30] agreed on the need for maintenance and future development support, and that therefore the delivered format must be sustainable in the long term. Thus the software employed should be in common use and ideally freely available.

3. A SIMPLE FORM OF EVALUATION

The features identified above as desirable have each been assigned a percentage score estimating their relative maximum potential contribution to the promotion and appreciation of the reconstructed cultural heritage site. These score values will always be subjective, but the extent can be mitigated if required by wider consultation.

Heritage Site 3D Virtual Reconstruction Features Evaluation

Description:

1.0 Content (45)

1.1 External Structure and Terrain/Context (15)
The extent to which they are complete, detailed and historically accurate where possible.

1.2 Internal Spaces and Fixtures/Fittings (12)
The extent to which they are complete, detailed and historically accurate where possible.

1.3 Realism/Believability (7)
Texturing/lighting/shading realism and believability as a proportion of that attainable.

1.4 4D/Historical Context (5)
Depiction at different time periods helping to appreciate the evolution of the site structures/landscape.

1.5 Animated Features/Inhabitants (4)
E.g. Fluttering flags, rising smoke, water reflections (2). Appropriately attired/moving inhabitants (2).

2.0 Engagement (15)

2.1 User Interface and Freedom to Explore (8)
Intuitive/supporting standard input devices, with unrestricted/helpful viewing options.

2.2 Interactive Activities (5)
Encouraging exploration, and/or contributing to learning/appreciation of the period.

2.3 Customisable Experience (2)
For expert/non-expert, and/or from different perspectives such as age/status.

3.0 Education (20)

3.1 Educational Information/Tour Texts (9)
Availability of supporting historical information, and guided tour option.

3.2 Cultural Content (6)
Contribution of the structures and fittings/fixtures, and depiction of contemporary traditions/skills, etc.

3.3 Original Content/Insights (3)
New historical insights or understanding.

3.4 Teacher led Multi-player Tour Option (2)
Availability (assuming reasonable support requirements).

4.0 Delivery (20)

4.1 Access (15)
Hardware availability, level of opportunity for public (and others) to experience and benefit.

4.2 Sustainability/Documentation/Development (5)
Software availability, published methodologies and/or ‘paradata’, maintenance/development options.

Heritage Site 3D Virtual Reconstruction Features Rating 100

4. APPLICATION EXAMPLE

Judging the extent to which desirable features exist within the reconstruction will also always be subjective, but, again, the subjectivity can be mitigated if required by aggregating multiple perspectives.

Heritage Site 3D Virtual Reconstruction Features Evaluation

Description: Kenilworth Castle, Warwickshire, UK, as it may have been circa 1575 when it was owned by Robert Dudley, earl of Leicestershire, and the stage for the lavish entertainment of Queen Elizabeth I. Slighted after 1645, the current ruins are a scheduled monument managed by English Heritage.

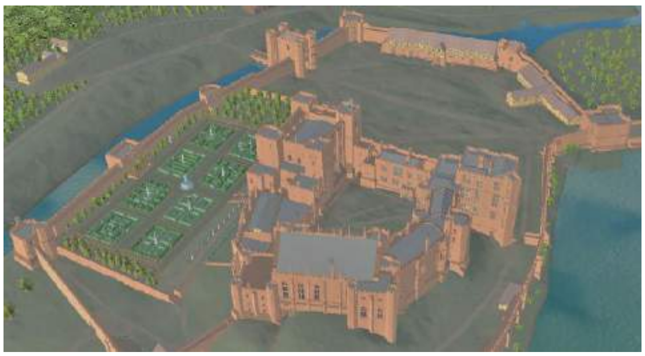

Figure 1: Inner and outer courts viewed from the West.

Figure 2: Great Hall dais with compass/floorplan displayed.

1.0 Content (45)

1.1 External Structure and Terrain/Context (15)
(See Fig. 1) All of the castle structures have been generated, from a detailed English Heritage 1:200 survey plan. 6 km^2 of surrounding terrain is based on LIDAR data and calculated water. levels. The East wing facades and most roofing arrangements are by necessity conjecture. **14**

1.2 Internal Spaces and Fixtures/Fittings (12)
(See example, Fig. 2) All internal spaces have been generated, using onsite measurement confirmation where possible. However, despite a detailed inventory, the location of fixtures and fittings, and wall finishes or coverings, are unknown. Thus very few chambers have appropriate and informative content. **7**

1.3 Realism/Believability (7)
The complete recreation of the structures, in some detail, and the use of sound effects and some realistic 3rd party assets, has created a believable experience. Baked (precomputed ray-traced) lighting with ambient occlusion has improved realism, but also caused issues for darker spaces (such as cellars) and the implementation of day or night time lighting (to support the fireworks display). **5**

1.4 4D/Historical Context (5)
In Guided Tour mode, while within a small central area, the visualisation of the buildings of the inner court can be toggled between the reconstructed geometry and a virtual representation of the ruined remains of the present day. **3**

1.5 Animated Features/Inhabitants (4)
In addition to rising smoke, flickering flames, fluttering flags, reflections in water, and all doors opening and closing, a number of specialised installations are also animated, such as a drawbridge, portcullis (x3), a working water mill, and a medieval tower clock mechanism. The resources to incorporate inhabitants are currently unavailable. **2**

Heritage Site 3D Virtual Reconstruction Features Evaluation

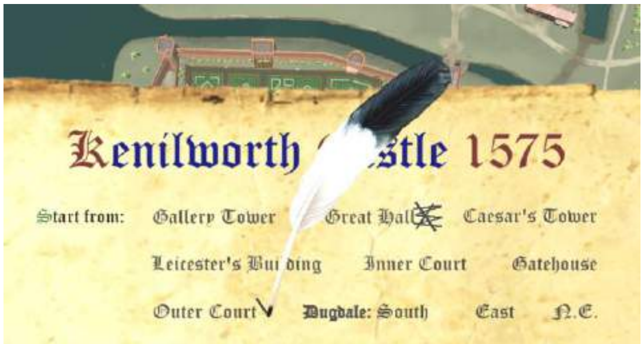

Figure 3: Main menu: making a mark to change location.

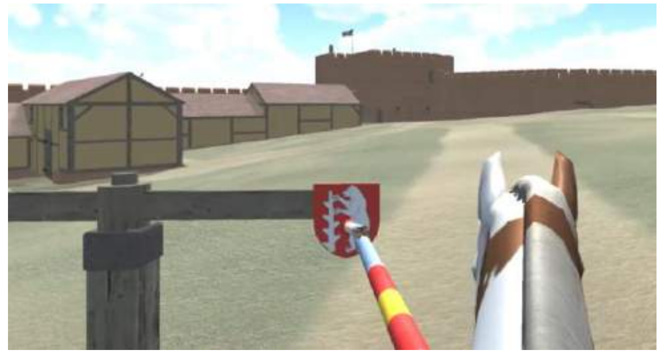

Figure 4: Breaking a lance *'running at the quintain'*.

2.0 Engagement (15)

2.1 User Interface and Freedom to Explore (8)

Support for keyboard and mouse, and/or a gamepad device, facilitates unrestricted navigation throughout the model. The *'quill and parchment'* effect menus (see Fig. 3) provide options to efficiently transport around the large site, to obtain *'bird's eye views'* via flight modes, and to explore at night using a hand-held candle. Within the inner court buildings, a compass with an inset annotated floorplan can be displayed (see example, Fig. 2). All user options are documented within the game and available at any time via the main menu. **7**

2.2 Interactive Activities (5)

Activities include archery and musket target practise, and a popular form of entertainment, based on, but much less serious than, jousting (see Fig. 4). A flying activity requires learning the names of the towers, and a search activity is based on the location of notable features. **4**

2.3 Customisable Experience (2)

There is no meaningful option to consider either knowledge level, or age, sex or status. **0**

3.0 Education (20)

3.1 Educational Information/Tour Texts (9)

Supporting information and explanation is available via the optional guided tour texts (see Fig. 5). Deviation to any extent from the suggested sequence of 30 information points is optional. A multiple choice quiz option revisits many points of interest and contemporary references, such as *'pomander', 'napery', 'Leicester's men', 'virginals', 'damsels', 'pantlers'* and *'scullions'*. **7**

3.2 Cultural Content (6)

In addition to the site structures, interactive activities, and tour and quiz texts, installations include a blacksmith's forge, an annotated suit of armour, the annotated working parts of a water mill, and the curation of a significant art collection (for example see Fig. 6). However, there are no inhabitants, in Elizabethan dress, illustrating the activities, customs and skills of the period. **3**

3.3 Original Content/Insights (3)

In addition to the unique reconstruction of the site structures, including a more definitive location for some outer court buildings and locating additional well references, there is the most complete presentation of Robert Dudley's seminal portrait collection, in context and revealed by curtains according to the fashion, and a working reconstruction of the medieval tower-clock mechanism in Caesar's Tower suggesting the unique nature of the installation for the first time. **3**

3.4 Teacher led Multi-player Tour Option (2)

The resources to support multiple concurrent players in the same game are currently unavailable. **0**

Heritage Site 3D Virtual Reconstruction Features Evaluation

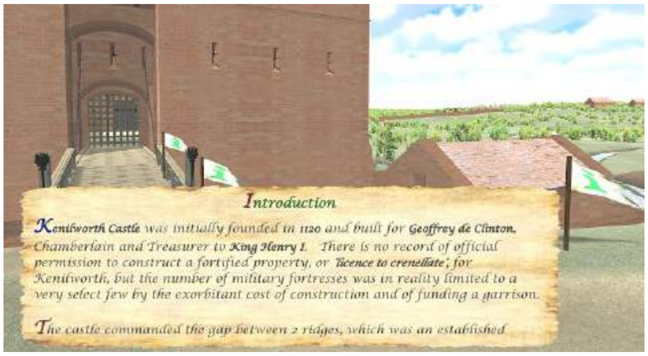

Figure 5: Guided tour scrollable texts, and information points.

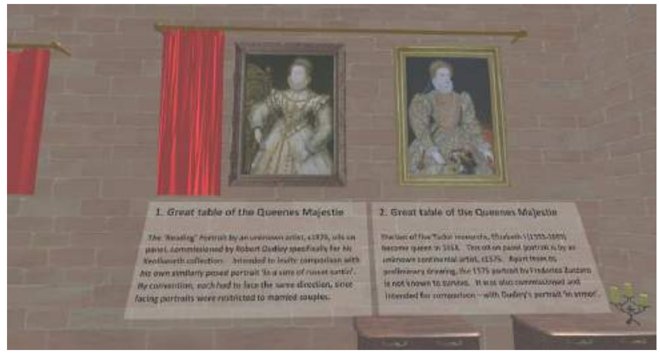

Figure 6: Captioned royal portraits in the Great Chamber.

4.0 Delivery (20)

4.1 Access (15)
A standard (Windows 10) personal computer, optionally with a gamepad controller, is the only equipment required, and very limited (if any) instruction or supervision should be necessary. Support for a bespoke 32-character activation key enables distribution without uncontrolled proliferation. However, this potential for widespread academic and public access has yet to be realised. **2**

4.2 Sustainability/Documentation/Development (5)
The CAD geometry (for example all of the site structures) has been created in Trimble SketchUp, version 14.1 (but note that this should not be taken as a recommendation). The interactive user experience has been created in the Unity 3D gaming engine, version 2019.4. Both of these software products have freely available versions. The reconstruction process, notably the references and assumptions, have been documented [52], but not reviewed. **4**

Heritage Site 3D Virtual Reconstruction Features Rating **61**

5. SUBJECTIVITY

Champion [30] cautioned that *"Evaluating cultural learning is very difficult"* and that *"Evaluating serious games featuring the latest technology raises several issues"*. The main issue being, of course, subjectivity. This proposal does compound subjectivity across three stages; the selection of desirable features, their relative importance rating, and to what extent they exist within the 3D virtual reconstruction project being considered.

Ideally, these choices would be supported by extensive statistical evaluations of questionnaires and other records of the virtual experience. Unfortunately, the holistic studies required, and the resulting authoritative tables of statistical deviations and analysis, are unavailable and may well remain so. There is currently not always a consensus when considering the relative evaluation and educational benefit of features. For example, the appropriate levels of realism have often been scrutinised (see above), and Champion [20] documented the difficulties in the statistical evaluation of presence in virtual environments and similarly in the assessment of *"cultural learning via knowledge and recall questions"*. Further, Mortara *et al* [27] and Tsita *et al* [40] have identified that more research is required to provide formal evidence of effective heritage learning via 3D virtual reality experiences and to establish the critical factors or features.

Although there are some advantages of not relying on statistical analysis for support, such as avoiding debate regarding the size and composition of samples and the degree of correlation between test and reality, the subjective, even speculative, basis of this proposal remains. Ultimately, it may be possible to combine several expert opinions, "*cognitive walkthroughs undertaken by domain experts (visualization experts, archaeologists, or cultural historians)*" as suggested by Champion [20] as a means of evaluating virtual heritage, to establish the feature set and relative rating values, although he also concedes that *"it can be difficult to obtain such a range of expertise"*. In practise, finding any interested expert at all has been an issue.

However, an alternative perspective remains, since the proposed scoring process (and resulting rating) is intended to be constructive and informative (via the accompanying notes and explanations) rather than any formal competitive exercise. Additionally, the features considered desirable and their relative ratings are clearly presented and can be modified, and so, notwithstanding the inherent subjectivity, it is therefore suggested that this form of evaluation is still able to provide a simple, flexible, transparent and informative measure.

6. CONCLUSIONS

- A range of desirable features can be derived and used to assess the completeness (in comparison to an ideal) of a heritage site virtual reconstruction project and its likely ability to successfully disseminate historical and cultural content.
- The evaluation process provides both a degree of documentation and clear indications of which absent features might contribute to a more compelling experience.
- When applied to a specific long-term project example, a rating of 61% provided a satisfactory benchmark, but the obvious and critical contribution which could be made by realising widespread access was evident. It is also perhaps unsurprising that advanced resources and expertise, in content creation and game generation, would be required to implement a more complete range of desirable features necessary to achieve a much higher evaluation value.
- Further research into effective heritage learning outcomes achieved by 3D virtual reality experiences, formally establishing the critical factors or features, could be used to adjust the evaluation criteria, provide new evidence and insights, and go some way to address the current inherent subjectivity.

Heritage Site VRFR (Virtual Reconstruction Features Rating) anyone?!

7. STATEMENTS

This work is independent, received no funding, and there is no conflict of interest.

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The Virtual 3D Reconstruction of a Medieval Castle – How far can basic research and logic take you?

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Abstract — Computer software and hardware products are increasingly capable of presenting virtual worlds, including those that primarily aim to illustrate and further the appreciation of cultural heritage sites. These sites, some of which survive only as ruins, can now be experienced, in various extents of virtual reality, as they may have been in the past. The 3D virtual reconstruction process necessarily involves degrees of presumption and conjecture where parts of structures are missing and the historical records incomplete. This article considers the extent to which publicly available information and a logical approach can support the creation of a virtual 3D reconstruction of a medieval castle. Accordingly, many of the recreated features are examined, concurrently going some way to address the widely promoted requirement to provide documentation of reconstruction sources and decisions made during such modelling projects. It was found that substantial results could be obtained, but, perhaps unsurprisingly, there are limitations.

Keywords — Logic, Heritage, 3D, Virtual, Reconstruction, Castle.

1. INTRODUCTION

In 2019, Pujol-Tost [39] listed the team which created virtual reconstructions of a Neolithic site in Turkey as: *"a professional 3D artist (environment and settlement); 3 training modellers/animators (objects and characters); two professional multimedia designers (soundscape); a professional sound engineer (sound mixing); 2 professors, 4 Ph.D. candidates in Human-Computer Interaction, and 5 students in audio-visual communication (voices and narration); and a professional VR programmer (3D sound, interaction, lighting, stereo visualisation, user interface)."* Such exceptional levels of resourcing are enviable, but do not preclude projects with significantly less resources. This can be the case when attempting to establish viable and likely forms for the missing structures and features of cultural heritage sites.

The internet provides access to an almost infinite collection of subject related images and texts. Images might include engravings or paintings of the period, the earliest photographs and postcards, and modern artistic historical reconstructions. Texts can include contemporary accounts and surveys, and articles by historians and archaeologists, with many older historical publications now in the public domain and freely available digitally. The websites of special interest groups and local history societies can provide additional insight and references, and libraries hold books referring to local heritage sites and even archaeological reports. The search for and study of such publicly available reference material, and visits to the heritage site in question, can be considered basic research.

"A cloud of suspicion continues to hover over all historical re-creations" suggests Favro [31], which is largely due to *"the need to distinguish between real and hypothetical parts of a visualization"*, according to Masuch *et al* [30] and many others. The provision of metadata within the project is often promoted, for example by Münster [35], Galeazzi [38], and Champion [36], to address these issues of provenance and authenticity. However, since details of how in-project metadata might be uniformly implemented in practice have yet to be determined and agreed, the medium of print has been a more popular choice. For example, Hermon and Fabian [32] have described the reconstruction of a Roman military camp, Inman and Morris [33] Tutbury castle, Kolenda and Markiewicz [37] a medieval bishop's palace, and Rice [34] provided a comprehensive account for St. Mary's Abbey, York. Thus a written document is an established and proven format for documenting the reasoning behind a virtual reconstruction.

The examination of several features of a current virtual 3D reconstruction of Kenilworth Castle will form the basis of this article. The Kenilworth Castle project began as an exercise to model and visualise the extent and level of the surrounding mere when the castle was a lake fortress – this was before it became evident that LIDAR based GIS software could easily have performed this task as a basic function. The aims of the project were continually extended until all of the castle structures, features and contextual terrain were modelled in some detail, and then presented as a fully interactive 3D virtual educational experience using Unity game engine software.

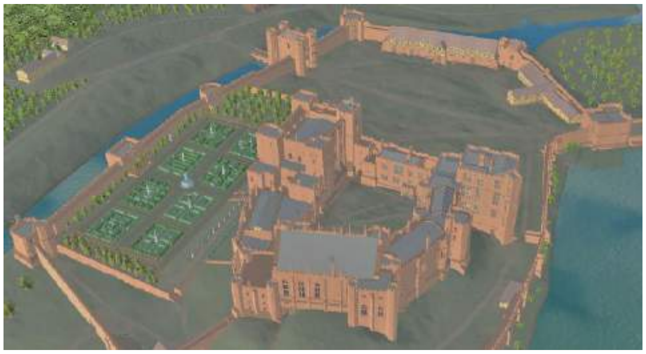

Figure 1: 3D virtual reconstruction circa 1575, inner and outer courts viewed from the West.

Figure 2: Present day, same viewpoint and perspective.

2. HISTORICAL BACKROUND

Kenilworth Castle was initially founded in 1120 and built for Geoffrey de Clinton, Chamberlain and Treasurer to King Henry I. The castle commanded the gap between two ridges, which was an established crossing point over marshes, and it became the greatest lake fortress in England. In the early 13th century, King John constructed the curtain wall and wall towers, thereby enclosing a site of several acres. The castle defences were famously tested in 1266, when supporters of Simon de Montfort held out against King Henry III for 6 months. 60 years later, King Edward II was brought here and deposed in favour of his son Edward III, remaining a prisoner for several months. In the late 14th century, John of Gaunt, a son of Edward III, rebuilt the Great Hall, the kitchens and the southern range of state apartments, thereby starting the transition of Kenilworth Castle from fortress to entertainment palace. In the 1570's, Robert Dudley (earl of Leicester) added Leicester's Building, redesigned the garden, rebuilt the north Gatehouse, and improved the Gallery and Mortimer's Towers. These later works were specifically to impress Queen Elizabeth I, and provided a stage for lavish entertainment during her royal progress of 1575. The development of the castle up until this time could be considered the most complete before the subsequent decline, and this date was therefore chosen for the reconstruction.

The castle was significantly slighted after the end of the Civil War in 1645 and the mere was drained. Valuable lead roofing to the inner court and other structures was removed, heralding further inevitable deterioration. The castle ruins site is now a scheduled monument managed by English Heritage as a popular public attraction. Contrasting 'then and now' images are provided by figures 1 and 2, and some notable differences will be considered by this article.

3. HISTORICAL RESEARCH

The most valued resources are obviously those created at or around the date chosen for the reconstruction, of which there are precious few. In 1563 the 'Chirk Survey' [1] recorded the dimensions of the castle chambers and other spaces, but, without the added clarification of floorplans, not all can be definitively located. 'Langham's Letter' [2], the verbose account of attendance at the royal festivities in 1575, does provide some incidental details. The central and castle portion of a site map of 1628 by Thomas Harding was unfortunately damaged by fire. The 'Antiquities of Warwickshire' by Sir William Dugdale [3], published in 1656, provides a detailed history largely based on official records. Crucially, plan and elevational engravings of the castle before it was slighted are also included, although they are not entirely consistent. The expenditure by Robert Dudley was recorded in annual accounts [4], although many of these accounts have since been lost. Following his death in 1588, a detailed inventory of the castle fittings was made [5], but here again critically useful location details are missing. On the assumption that rapid change, particularly in land allocation, was not a common feature of the period, lastly the 1692 map by James Fish provides a relatively detailed illustration of the surrounding landscape, buildings and water courses.

Over 550 images of the castle have been collected, and, despite several attempts at an exhaustive search, yet more continue to be found. These images post-date the slighting of the castle, and the early etchings and paintings tend to reproduce very similar elevational views, presumably because these had established commercial appeal. Where a more unique or informative viewpoint has been presented, the unknown degree of 'artistic license' becomes a necessary consideration. For example, the infamous Newnham Paddox painting, a copy of a drawing of a no longer existing 1620 fresco, while recognisable as of Kenilworth Castle, is unreliable due to pervasive and obvious errors of scale and proportion. On the contrary, details in a drawing by James Ward (1769-1859), of the farmyard setting of the stables, are corroborated by an 1867 painting by Henry Moore.

With the advent of photography in the early 19th century, artistic subjectivity becomes less of an issue. For example, in 1872, E. H. Knowles [10] published his authoritative castle guide containing early photographs. Together with those of photography pioneers, such as William Henry Fox Talbot, Francis Bedford and Francis Frith, the state of the castle in the Victorian era is well documented by images. The extent of remedial work during this period, particularly to the loggia (adjacent to the keep), also become evident with reference to an 1850's view by Frederick Scott Archer, and, more importantly, what is not as original as it might now appear to be.

Detailed architectural drawings for the main castle structures were produced by Sidney Toy F.R.S.A. in 1931, coincidentally exactly 100 years after a similar endeavour by A. C. Pugin [8]. Impressive reconstruction artworks are also available, for example those made by Ivan Lapper to illustrate English Heritage guidebooks, although there are significant feature discrepancies compared with the virtual 3D model, and these will be addressed (see 4.5 below). A copy of a 1983 English Heritage detailed topographical survey [14] of the castle site was purchased to provide accurate floor plans of the existent structures.

Over 60 publications, dedicated in whole or in part to Kenilworth Castle, and over 30 additional archaeological reports, were found available for reference. Many of the early castle guides were predominantly a retelling of the history, largely based on that published by Dugdale, although some intriguing, unsubstantiated (but not necessarily false) additional observations regarding building features were also made. A significant contribution has been made by local historian Richard Morris, not only as the author of the current English Heritage Kenilworth Castle Guide [28], but also in providing related investigation and informed explanation [19, 22]. The comprehensive work of John Goodhall [23] was consulted for general analysis on the form and function of English Castles, and that of Eugène Viollet-le-Duc [9] for an insight into portcullis and drawbridge mechanisms.

4. CONSIDERATION OF RECONSTRUCTED FEATURES

4.1 The recreation of the missing East range

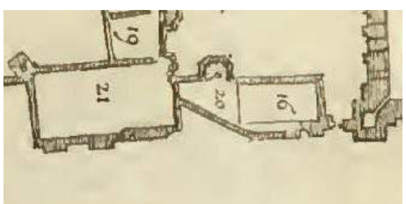

Figure 3: Dugdale ground plan


Figure 4: Dugdale East elevation


Figure 5: Reconstructed East elevation

The East range of the inner court, also known as Henry VIII's Lodgings or Leicester's Apartments, once linked Leicester's Building (marked *21* on the plan) and Caesar's Tower (the keep) on the right/to the North, but can now only be seen as remnants of the foundations, as shown in Figure 2. Issues of reconstruction arise from the serious distortions and inconsistences in the illustrations provided by Dugdale [3]. In Figure 3, the width of the portcullis entrance to the inner court has been reduced to no more than several inches, and the gatehouse is entirely missing in Figure 4. The main concern, in Figure 3, is the return of the façade into Leicester's Building, following the line of the original curtain wall. Morris [19], writing in 2006, conceded that the evidence, which also includes *"toothed masonry scars* (high up) *on the north face of Leicester's Building"*, *"is not without contradictions"* and presents *"a major difficulty of interpretation"*, and he listed queries outstanding. He presented a possible arrangement of the 6 East range chambers described in the 1563 survey [1], but again cautioned that *"it cannot be certain which floor these chambers were on, nor indeed that all the rooms were on the same floor"*, as his plan suggested. He also wrote that a recommendation to rebuild those parts of timber with stone from the demolished abbey was likely never actioned, and that instead these remained timber framed but plastered and painted to resemble the adjoining stonework. Fortunately, even if this was the case, the virtual 3D visualisation would be largely unaffected.

In the absence of detailed or more reliable evidence, the reconstruction (shown in Figure 5) prioritised the presentation of the 'English Perpendicular Style' to the East, incorporating in the inner court the elaborately carved classical entrance porch and staircase (both later moved to Leicester's Gatehouse, where they remain today), and facilitating progress to and from both Leicester's Building and Caesar's Tower. Both of these buildings still have the external door openings, the elevations of which define the necessary height of a connecting structure. Contrary to the plan by Morris, the 48 by 10 foot 'long chamber' (the connecting corridor) has been located instead along the West side, facing the inner court, so that the high-status chambers receive direct sunlight, and have impressive views over the base (outer) court and beyond.

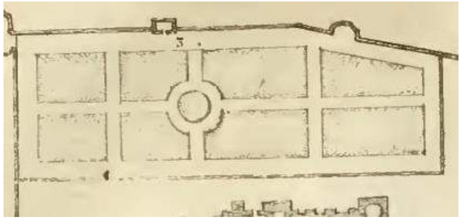

Figure 6: Dugdale's garden layout

4.2 The degree of symmetry in the garden layout

Figure 6. is of the garden plan provided by Dugdale [3], clearly showing 8 non-symmetrical segments extending beyond the line of Caesar's Tower and necessarily tapered as a result. This layout was approximated by the restoration by English Heritage in 1975, using 6 segments, as recorded by Dix, Parry and Finn [29]. However, Langham [2] described *"four even quarters"*, and greater emphasis could be attributed to the strict fashion of the period for garden symmetry, and less credence to the Dugdale plan.

Following further archeological excavation and a re-evaluation [18, 29], a new restoration by English Heritage in 2009, using 8 symmetrically sized segments, resulted in the current layout which avoids any tapering of the North-east segment, as shown in Figure 2 and the virtual reconstruction in Figure 1. The pioneering garden features, such as the terracing, water installation, obelisks, statues of human form, and the aviary, were specifically identified by Langham. The *"two fine arbours, one at each end"* were already quite common at the time, and the virtual recreation is based on an image of those of the 1565 gardens at Montargis in France.

4.3 The arrangement of the absent base court buildings

The 1563 survey [1] provided dimensions for a *"bruehowse"*, *"a water myll"* and *"a bakhowse and a bowltinge howse"* in the base court. Although it is possible these may have been largely dismantled by 1575, this is not certain, and their inclusion in the virtual reconstruction was considered more informative than their omission. It has not been possible to identify a definite path for the conduit of water, required to power the mill, from geophysical survey of the area by Stratascan [17]. According to an 1814 plan presented by Britton [7], it is shown originating from the mere, near to Mortimer's Tower, before exiting under the Water Tower. Morris [19] illustrated possible arrangements for these buildings against the East curtain wall, but his diagrams were not to scale, ignored the prohibitive risk of explosion for a mill including a fireplace, and did not appear to consider a path for the water conduit. These extra considerations enabled a more viable solution to be presented, exactly matching the available length of curtain wall. The watermill protrudes from between the other buildings, see Figure 1, top-right. The mill-wheel is unusually within the building, but such an arrangement can still be seen today, locally, at the Saxon Mill in Warwick.

4.4 Did water from the mere flow through the ditch around the Brays?

Considering the Brays earthworks ditch in 2009, local historian David Brock [21] concluded, based on English Heritage surveys from 1983, that *"the bottom of the ditch will not have been raised by much"* and that therefore a *"watercourse within the ditch is only a borderline possibility"*. Despite the tendency over time for earthwork peaks to be eroded and troughs to fill, this view was accepted by Richard Morris [28] and presented in his official castle guide of 2010, (see Figure 9), despite the contrary illustration in the 2006 edition of the same guide. Previous informed published views, for example from prior guide author Michael Thompson [15], and the Birmingham and Warwickshire Archaeological Society [16], had also concluded that *"the Brays ditch was filled with water"*. The official scheduled monument listing [13] states *"The external ditch around the Brays … was originally water filled. It was fed from the mere"*. Further evidence is provided by the Fish map of 1692, which unambiguously shows water around the Brays feeding into an identified mill pond, the necessary source of power for the water mill (now merely stone ruins at the main site entrance). The originating water supply at this later date, by which time the mere had been drained, is a separate issue, shown by the map to be far to the West at the limit of water engineering feasibility.

4.5 Discrepancies with the artistic reconstructions made for English Heritage

It is assumed that the artistic reconstructions by Ivan Lapper, commissioned by English heritage for its official castle guides, benefited from the input of significant historical expertise, and therefore provide a valuable source of reference. Deviations from the understandings presented by these impressive images therefore need to be considered.

Figure 10 includes a representation of the re-erection of the two-storey *'Pleasance'*, either side of the cross-wall to the West, to scale according to dimensions supplied by the 1563 survey [1], and taking advantage of the curtain wall which is (still) uniquely high at this location and contains remains of fireplaces set high in the wall. In Figure 7, bottom-left, the portion of higher curtain wall is not shown, and a free-standing building is shown instead North of the cross-wall. This understanding appears to have been corrected by the later image of Figure 8, but the buildings are then shown in stone.

Considering the 'Strong Tower' (North of the Great Hall) in Figure 7, apart from exaggeratedly high corner turrets, the roof is shown pitched and tiled, and in Figure 8 it is shown flat and leaded. This roof is not a timber construction as elsewhere, but uniquely stone vaulted, and it has therefore been assumed to have been stone paved, as shown in Figures 1 and 10.

The height of the East range, as shown in Figure 7, is insufficient to access the only doorway into Caesar's Tower to the North. This opening is over 16 feet (5 meters) above the level of the doorway opening into the top floor of the range from Leicester's Building to the South. This same issue is even more evident in the different interpretation shown by Figure 8. Here the doorway into Caesar's Tower appears to be shown as inaccessible and incorrectly in place of the second face of the tower clock. Morris [28] did commend a *"Victorian lithograph by John Branded, depicting the 1575 entry of Elizabeth and Leicester into the castle"* as showing a credible East elevation, (which does more resemble that shown in Figure 5), but simultaneously believed that the second floor *"seems never to have been constructed"* [22], due to tenuously attributing the contextless request in Dudley's will *"to build out the Gallery which I once intended"* [6] to refer to an additional East range level, instead, for example, to the first floor of Caesar's Tower which *"should probably be seen as the equivalent of a long gallery"* [22].

In Figure 7, the turrets of Caesar's Tower (the keep) are all shown with completely square profiles, although the outer walls step in at each floor level (and the floor area increases), and thus such an internal turret profile would be unsupported. This issue is avoided in Figure 8 by leaving the turret profile open, but also unroofed. No images were found where turret walls do not extend above those adjacent, and therefore the arrangement shown in Figure 7 was used, but with corrections made to the internal edges of the turret profiles, as shown in Figure 10.

Neither of the images, shown in part by Figures 7 and 8, show the garden arbours (see 4.2 above) known to have been present at the time. Also, according to Langham [2], the garden quarters were separated by *"fair alleys, green by grass"* edged with sand, as implied by Figure 1. In Figures 7, 8 and 2, the English Heritage artistic reconstructions, and their real-world reconstruction (albeit by necessity), instead depict gravel paths.

The 1563 survey [1] describes *"a fayer pare of stayers of hard stone … having xx stepps to the porche of the halle"*. These steps are shown as a single flight in Figure 8, and correctly as a double flight in Figure 10. The turret, at the North-East corner of the Great Hall, providing access at the main entrance to the roof, and as shown in Figure 10, is missing in Figure 8. Figure 9 depicts a speculatively steep pitch for the lead roofing of Caesar's Tower. Markings on the still remaining East wall stonework suggest that the pitch was much less, as shown in Figure 10.


Figure 7: View from West


Figure 8: The inner court


Figure 9: Brays and Tiltyard

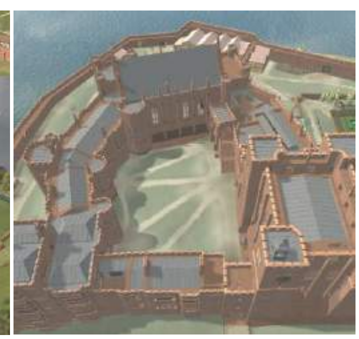
Figure 10: Virtual Reconstruction

Figure 9 implies an absence of water in the main ditch around the Brays earthworks, but this contention has already been addressed (see 4.4 above). Stone ramparts are shown along the ridges, although it was conceded that *"the fortifications of the Brays … are entirely hypothetical"*. Supporting evidence has still yet to be found; only stone ruins of the outer entrance and the mill remain. The Brays are named from the French for 'military outwork surrounded by palisades'. Palisades are by definition constructed using timber stakes, and by 1575 these would have long since perished after any period of military purpose. Therefore neither stone ramparts nor palisades have been included in the virtual reconstruction.

Figure 9 illustrates a water mill adjoining the Gallery Tower gatehouse. However, the Gallery Tower and Tiltyard walls still exist, and show that there never has been direct access here into the castle. A water mill in this location would therefore effectively be isolated on an island, all but inaccessible for the conveyance of raw and finished product. A photograph from 1965 records substantial excavation in this area, but if current stone walling remains authentic, then even access to the water for power would be impossible. There are also low-level stone remains in the bank opposite, and therefore the virtual reconstruction locates the water mill here instead, adjacent to identified water control features, enabling easy access, and without compromising the defences of the Gallery Tower.

4.6 The tower clock installation in the South-East turret of Caesar's Tower

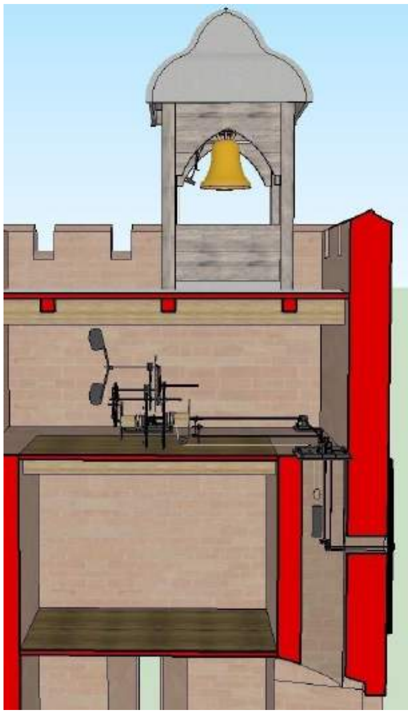

Figure 11: Tower clock (without frame)

Langham [2] confirmed the existence of this clock in 1575, describing *"two dials … set aloft upon two sides of Caesar's Tower … to show the hours to the town and country"*, and a *"clock-bell, that is good and shrill".* The reconstruction of the tower clock mechanism is based on the 14th century Salisbury Cathedral clock and the almost identical 1564 Winterthur clock mechanism in Switzerland. Therefore it has a verge and foliot escapement to control the rate of advance of the clock gears at regular intervals, or 'ticks'. Such a mechanism could have achieved at best an accuracy of only 15 minutes per day – since the more accurate pendulum clocks did not emerge for another 80 years [26], along with the addition of another hand so that both hours and minutes could be displayed.

The reconstruction identified a very unusual, almost certainly unique, installation of the clock in the chamber above the chamber which is level with, but has no access to, the clock faces. Why the more logical lower chamber was not used is unknown. As a result, the clock hour hands have to be driven by a more complicated arrangement via two shafts within the outer walls. These shafts, detailed by historian Sidney Toy in 1931 and still evident today, accommodate the falling weights which would have needed to be wound up every day.

Knowles [10] reproduced a valuation survey, conducted in the reign of James I, which valued the *"clocke bell which waieth 500^{lb}"* at £30. The known density of brass and the sectional profile of a bell were then used to accurately determine the dimensions for the recreation of the bell.

4.7 The accommodation of 50 horses in the stables

Figure 12: The Stables, looking North

The 1563 survey [1] describes *"a new stabull … wherin there are XXX romes for greate horses besydes romes for XX geldings".* These have been assumed to be medium sized horses of about 16 hands, kept mainly for riding out and hunting. The only evidence of the likely arrangement of the stalls is provided by an early photograph, published by local historian Graham Gould [25], showing relatively small partitions approximately 8 feet apart. Despite the stables being one of the most impressive of its day, the accommodation of so many horses would have required two per stall along both sides, as shown in Figure 12.

The Birmingham and Warwickshire Archaeological Society [16] stated that the stables had *"horses in stalls facing the curtain wall"*. However, horses are social animals, and can be unnerved by activity behind them. Additionally, the drains (identified by Gethin and Rann [20]) are thought to run both sides the length of the building, and wall facing horses would have either their front or rear legs in these drains. Therefore, the horses are shown as if tethered facing inwards, although the details of this arrangement are unknown.

4.8 Access to potable water supplies

The official castle guide [28] describes only the well accessible at two levels within Caesar's Tower, despite the critical nature of features providing a reliable supply of water to the castle. The excavations reported by Gethin and Rann [20] identified a well or cistern just outside of the stables. However, they suggest this feature to be from a later period, when the base court was in use as a farmyard. Although the source for the significant quantities of water required to maintain the large stables is therefore uncertain, the virtual reconstruction speculatively includes the well/cistern to raise this issue, (with its provenance explained in associated virtual tour guide notes).

Describing Lunn's Tower, George Clarke [11] recorded in 1875 that *"close in the rear of this tower is a well, lined with ashlar, 4ft. diameter"*, and Ribton-Turner [12], writing later in 1893, agreed. Although there is currently no visual sign of this well, it remains modelled for the virtual reconstruction (until archaeological excavation indicates otherwise). In 1872 Edward Knowles [10] observed that *"close to the Pleasance wall. The well has been filled up"*. No exact location or evidence of this well has since been found, but it has also been modelled for the virtual reconstruction on the same basis.

4.9 The staircases and the latrine chute in Leicester's Building

Figure 13: End wall scarring

Figure 14: Private staircase

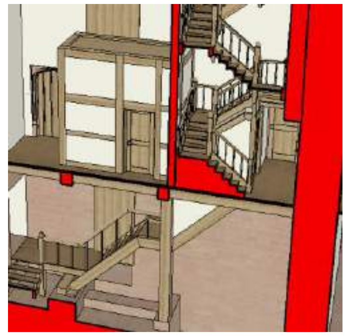

Figure 15: Main staircase

Figure 16: 48x17'' vertical recess

An archaeological approach, into the reconstruction of the missing staircase in the South-West corner of Caesar's Tower, has been provided by Thomas Cromwell [24]. Considerable emphasis was placed on closely matching the current pockets (beam slots) in the walls, despite noting how these might not be completely reliable due to erosion and repair work. As a result, the sequence of the number of steps in each flight varied, for example, from top to bottom, 2-4-3-3-3-4-3-3-3-4-4-3-2-7. For ladies wearing the wide skirts of the period, their footing on these steps would have been obscured, and for servants carrying bulky objects, even use of the handrail would not have been possible. Therefore, for practical and aesthetic reasons, in the virtual reconstruction all the flights of this staircase were of 4 steps, requiring only very minimal deviation from the pockets. This greater emphasis on a consistent number of steps also informed the reconstruction of both staircases in Leicester's Building.

Robert Dudley made a late addition to the accommodation for his Queen; an extension to provide a private staircase, serving every floor excepting the basement but including the roof. Figure 13 is an image of the end wall, with scarring implying that this staircase would have been clockwise. However, the landings would have been too narrow, the inclination insufficient, and if this was indeed staircase related, then similar scarring would be expected to be repeated at multiple levels. Modelling for the reconstruction, as shown in Figure 14, found instead that only an anti-clockwise staircase would readily accommodate the existing floor levels.

The main staircase is shown in Figure 15, providing access to the basement (bottom-left) and to the floors above (top-right), and has been reconstructed against the inner wall. The partition separates the staircase from the latrines (top-left) and provides further support. Richard Morris [22] described *"timber-framed latrines on the ground and principal floors"*, but their existence is conditional on his identification of a 48 by 17-inch vertical recess as a latrine chute, see Figure 16. The recess might be considered to have an excessive section for this purpose, and no water source for flushing has been suggested. Further, the carriage, of wardrobe items for example, to and from the three large basement storage chambers, would have to pass the base of this chute, built-in garderobes were becoming unfashionable, and at least 36 'close stools' or commodes were recorded at the castle. Therefore a dumbwaiter installation was considered as a possible alternative, and to provide safer and more efficient movement of storage items. However, no supporting reference, even within a contemporary building, could be found. Moreover, according to Morris [28], the chute drains to a culvert beneath the basement floor. The culvert is presumed to exit towards the mere (although, similarly, no archaeological or other supporting evidence has been found). Thus the virtual reconstruction incorporates fixed latrines.

4.10 Features of the Water Tower

Figure 17: Internal features

The Water Tower is believed to have been added to the curtain wall in the early 14th century, but the origin of its name is unknown. A water culvert does pass under, which services its latrines, and it does have four existing 'scuppers', (drain spouts to clear water from the roof) even though just one would suffice.

Figure 17 illustrates one of two first floor passage openings, oddly occupying a corner position, and an irregular vertical channel cut into a ground floor wall, which has been recreated but its purpose cannot be clarified or presented.

The most intriguing mystery remains over the claim by John Britton [7] that *"from this tower the buildings in the upper ward of the castle were supplied with water, by means of an engine"*, but, without further explanation there can be no recreation.

4.11 Curating Robert Dudley's seminal art collection

Figure 18: *"Fyve of the Plannetts, painted in frames"*, and *"a picture of Ceser enamiled in brasse"*

The 1588 inventory [5] describes the items of art at the Castle at this date, which mainly consisted of portraits by the finest artists of rich and powerful contemporaries. The authoritative work by Elizabeth Goldring [27] describes how Robert Dudley used the European wide resources at his disposal to compile this collection for Kenilworth (and for his other residences), and provides a more definitive identification of many of the portrait subjects. Since multiple portraits of the same subject were not common, except in the case of royalty, many of the portraits presented by the virtual reconstruction have a good probability of being those owned by Dudley.

The collection also included a large number of maps, and some other works, for example, *"Fyve of the Plannetts, painted in frames"*. Since the first telescopes were not available until the following century, any meaningful images would have been impossible, and therefore this description was taken instead to refer to their association with Roman gods. Coincidentally, a sequence of 5 such images was eventually found, as shown in Figure 18; apparently illustrations in the fifteenth century Lombard manuscript 'De Sphaera'. Similarly, an image of *"a picture of Ceser enamiled in brasse"* was found only after several search attempts. Only a tomb sketch could be found to represent *"the picture of Sir William Pickering, in clothe, whole proportion"*, and no virtual interpretation was possible of *"a tabell of an historie of men, women, and children, molden in wax"*.

4.12 Where logic would have failed recreating existing features

Figure 19: Gatehouse dormer

A predominant reliance on logic for historical interpretation and understanding has its limitations. Logic cannot explain the apparent absence of lead flashing on the lower string courses of both Leicester's Building and Gatehouse, and the apparent termination of the drainpipes far above. Logic could not determine the function of *"another fayre chamber called the nursery"*, in the vicinity of the kitchens in the 1563 survey [1], and therefore could not inform the virtual reconstruction.

However, limitations become even more evident when considering the hypothetical reconstruction of features which still exist. For example, the reconstruction of a passageway which exits at the corner of a chamber, as shown in Figure 17, would not have been contemplated had this arrangement not been still evident today, or been recorded in reliable plans or other images. Similarly, Figure 19 illustrates a yet more unlikely construction, as part of the residential extension to the East side of Leicester's gatehouse in the 1650's. A main purpose of a dormer window would be to admit extra light into a loft space, and yet, contrary to all logic, here it has been unnecessarily located close behind the wall of a corner turret.

5. CONCLUSIONS

- Basic research and logic have been used successfully to inform the first detailed and comprehensive 3D reconstruction of Kenilworth Castle and its environment. All of the missing timber and stone staircases, elevations, features and spaces, have been recreated, based on the existing ruins and readily available historic images and accounts, to generate a viable and compelling virtual record of the cultural heritage site structures.
- Several discrepancies with established written and artistic works, regarding the East range elevation for example, have been noted and explained; new understandings have been discovered and presented, such as the tower clock installation; and new queries have been raised, for example the tethering of horses and the source of water for the stables.

- Although the virtual 3D reconstruction of the site buildings was completed, without both a broader and detailed historical knowledge (and technical expertise) it was not possible to add fittings and fixtures which would have provided educational insight into the likely purpose of the many resulting spaces. Simple, speculative contents were added to the Great Hall and the main kitchen, but even 35 high-status beds, for example, described by the 1588 inventory [5], could not be placed with any certainty to indicate sleeping quarters.
- Basic research and logic could obviously never completely compensate for a lack of in-depth knowledge, for example of Elizabethan history, culture and architecture. Despite this, there now exists an historic resource with the potential to inform a wide audience, support further study, and to increase interest and understanding.

6. STATEMENTS

This work is independent, received no funding, and there is no conflict of interest.

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Appendix (Comments)

1. Why are these articles only to be found on an obscure personal website?

Inclusion by one of the standard online databases very reasonably requires previous publication by a recognised journal and/or author academic accreditation, and adherence to very strict formatting rules. These articles cannot qualify on either count, and also have a much more informative references section format than that permissible.

2. Does this mean that these articles have not been reviewed?

Unfortunately, yes – even though the obvious benefit of expert review and constructive criticism is recognised. Leading experts in heritage management and visualisation were approached and asked if they might provide a brief perspective/comment on the observations and conclusions of these articles. Despite an initial positive response, no feedback had been received some several weeks later. Additional academics (referenced by these articles) were also approached, but no communication was acknowledged.

This is particularly disappointing considering the many academic papers promoting the need to improve the evaluation, review and feedback of virtual heritage projects; a sentiment that evidently does not appear to be flourishing in the real world! An explanation might be ‘pressing work schedules’, or that the articles are simply unworthy of comment, or (as suspected) ‘not-invented-here syndrome’. Hopefully, in the near future, the field of virtual heritage visualisation will become more inclusive.

3. Of course, academics are under no obligation at all to acknowledge or comment on specific works by others, so might other issues have contributed to this lamentable observation?

Well, (leaving aside an aborted attempt to accept an offer for advanced study); it might reasonably be assumed that the primary purpose of academic papers is to clearly communicate new information and insight. However, often the priority appeared to be to present an aura of intellectual authority and superiority, via what might be termed ‘academic English’, to impress peers and invigilators. The following examples of this pretentious vocabulary, particularly impenetrable for the many for whom English is a second language, were noted from the studied references…

Amphiboly,	Anastylosis,	Anthropogenic,	Cardinality,	Diachronic,
Didactic,	Diegesis,	Endogenous,	Emic,	Epistemological,
Etic,	Folksonomy,	Goniometric,	Hermeneutics,	Lacunae,
Ludic,	Maieutic,	Miasma,	Neologisms,	Nomothetic,
Ontology,	Palimpsest,	Palynology,	Paradigmatic,	Pedagogical,
Phenomenology,	Plenoptic,	Praxis,	Taxonomy,	Typology,
Veridical,	Verisimilitude.			

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- 1575 Langham and Gascoigne
- 1656 Antiquities of Warwickshire Dugdale
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