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Towards the Formal Teaching of CG Applications in Cultural Heritage for Computer Graphics and Animation Students

Eike Falk Anderson and Valery Adzhiev and Oleg Fryazinov

The National Centre for Computer Animation, Bournemouth University, UK

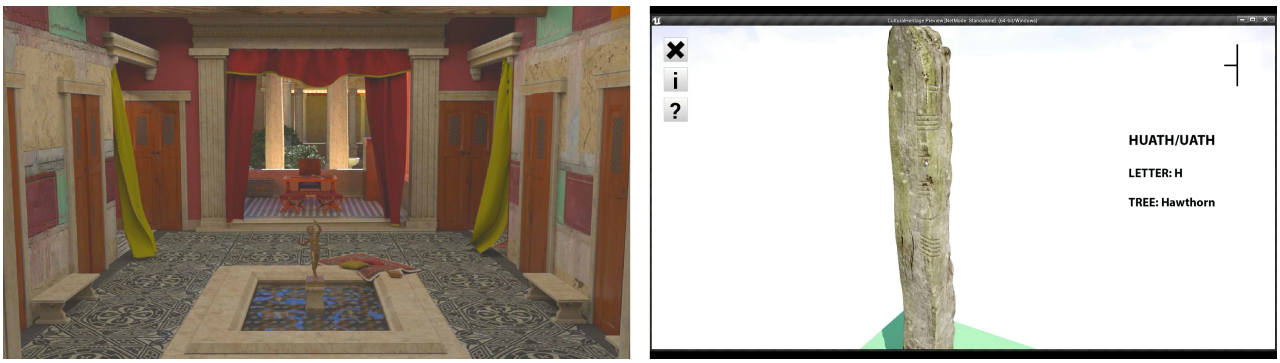

Figure 1: *Screenshots of student coursework created for our "CG and Animation for Cultural Heritage" course – Left: reconstruction of the House of the Faun in Pompeii by Ellen Conlan Ellis; Right: Rachel McLeod's Ogham Stones application introduces users to the Ogham writing system – a runic alphabet used on standing stones found around the Irish sea – by translating user-defined text into the Ogham system and 'carving' this into a virtual standing stone.*

Abstract

The rapid technological advances in computing and computer graphics of the past three decades have in turn fueled the proliferation of the use of these technologies for Cultural Heritage. Formal educational courses for the application of computer graphics to Cultural Heritage are few and far between, and the courses that do exist tend to be targeted at archaeology students, with hardly any courses catering to computing or computer graphics students. To address this gap in education provision, we introduce a final year undergraduate course on "CG and Animation for Cultural Heritage", which provides students on technical and art & design computer graphics and animation courses with a broad introduction to the creation of Cultural Heritage applications of CG and animation techniques more commonly found in digital entertainment and visual effects. In this paper we describe this course and its curriculum and discuss its outcomes.

1. Introduction

Over the past two to three decades, the use of computers, and especially the use of sophisticated computer graphics (CG) techniques, has become increasingly important for preserving, interpreting and presenting cultural heritage. The use of CG has been particularly useful for the digital preservation and reconstruction of cultural heritage sites and objects, with the inclusion of interactive CG providing the means for cultural heritage sites and artefacts to be examined and viewed not just on their own but also in the wider context, e.g. the environment, in which they exist.

CG and related techniques have proven especially useful for the preservation and dissemination of intangible heritage [And13], which primarily encompasses social actions and interactions, for which the use of interactive virtual environments, such as found in modern computer games, is ideal, as the relevant infrastructure for the creation of virtual heritage applications is identical to that of entertainment or serious computer games [AML*10].

With this increase in the use of CG, it is surprising that only few university-level courses cover the use of CG for cultural heritage, and even fewer are aimed at computing students, with the majority

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of these courses targeted at archaeology students. One of the few courses that do, is our new "CG and Animation for Cultural Heritage" (CGACH) course, which aims to provide computer graphics and animation students, who have both technical computing as well as art and design backgrounds, with a broad introduction to the use of CG and animation techniques in cultural heritage contexts and a sufficient understanding of relevant methods and techniques that would allow them to propose appropriate approaches for the design and implementation of cultural heritage applications. To our knowledge, there exists no other course with comparable content – in terms of breadth – or target audience.

In this paper we present our experience of developing and delivering the CGACH course. In section 2, we first examine the existing state of computing and computer graphics education in the field of cultural heritage. Then, in section 3, we discuss the educational context in which our course is set and the rationale for its development. This is accompanied by a description of the course structure and curriculum (3.1), as well as the assessment activities employed during the course, including examples of coursework produced by students (3.4). In section 4, this is then followed by a discussion of observations and course outcomes, including course evaluations based on student surveys, ending with our conclusions and an outlook on future course developments in section 5.

2. Computer Graphics and Computing Education for Cultural Heritage Purposes

The use of computers in cultural heritage contexts is not new and can be traced almost as far back as the emergence of digital computers itself. Fisher's recent historical survey of the domain of 'Archaeoinformatics', the use of computing and digital technologies in archaeological practice, not only charts the evolution of this field of knowledge, but also highlights that, already by the end of the 1960's, it was noted that archaeologists lacked computing knowledge to the point where this created barriers to their effective use of computing resources, prompting for a call of better computing education for archaeologists [Fis20].

Over the past three decades, a significant proportion of the use of computers in cultural heritage contexts have involved the use of CG and related techniques, which has partially been driven by the advances in CG over the same period. A side effect of these rapid advances in technology is a complication of the formal education in this field of knowledge, which constantly finds itself in the position of having to play catch-up with technological developments. For instance, during the refurbishment of Michelangelo's famous David, during which digital 3D scans of the statue were made for additional analysis, Callieri et al. found that "members of a modern cultural heritage restoration staff would benefit from a substantial IT and computer graphics education" [CCG*05]. Just as was the case in the 1960's, as well as more recently, the relevant literature confirms that the proliferation of computing and computer graphics technologies in the cultural heritage domain clearly indicates the need for professionals working in cultural heritage to have knowledge and skills in using these technologies.

One must, however, not forget, that overall, the use of CG in cultural heritage contexts – despite the rapid advances and spread of computing and computer graphics over the past decades – is still a fairly young field of both application and research. Many developments still have a tendency to be ad-hoc, bespoke or proprietary project solutions, which are not easily transferable to other projects, which, as Champion points out [Cha16], is partially due to a lack of commonly agreed standards and processes.

Whereas the literature provides numerous examples for the use of CG, especially interactive CG, for teaching cultural heritage in a wide variety of formal and informal settings, including in the shape of entertainment and serious cultural heritage games [AML*10, MCB*14], within the literature, there is a distinct lack of reports on educational courses that teach the use of tools, techniques or technologies for creating cultural heritage applications such as heritage visualisation or the reconstruction of digitised heritage objects.

The majority of existing higher education courses that teach the use of CG tools and techniques for cultural heritage purposes are focused on introducing relevant tools and techniques to archaeologists, such as the field archaeology course described by Derudas and Berggren [D21], which uses Project Based Learning (PBL), and which combines students' participation in a real archaeological excavation with their creation of several 3D models – various digital representations of the excavation trench during different stages of excavation and with finds in-situ – that are then used during subsequent analysis and reporting, so students are educated in the use of the technology while 'on the job'. Misiewicz et al. describe a course, teaching archeologists the use of Geographic Information Systems (GIS) [MMB*16], providing a balance of theoretical lectures supported by practical computer-based and field-based exercises and projects, using PBL-like elements that bear a resemblance to the Activity-Led Instruction cycle [APH*12].

The literature provides conflicting assessments of courses shared by archaeology and computing or engineering students, however. For example, Djindjian [Dji16] reports difficulties in establishing a course on Virtual Reality (VR) and Augmented Reality (AR), combined with digital photography and photogrammetry, targeted specifically at archaeologists and avoiding subject-specific complexities found in equivalent engineering or computing courses, as previous courses shared with engineering and computing students proved to be ill-suited for archaeology students. On the other hand, Cobb et al. [CSCF19] describe a project course attended by archaeology and software engineering students, suggesting that there are significant benefits when multi-disciplinary teams of engineering and archaeology students collaborate.

This notion of multi-disciplinary collaboration is reinforced by the "Seville Principles" [Ben13], which are London Charter [BND09] compliant implementation guidelines for 'virtual heritage' that explicitly emphasize the need for interdisciplinarity, meaning that the complexities of modern computing and computer graphics systems require the employment of subject experts from different fields of knowledge to effectively visualise archaeological heritage.

Among the few courses that are specifically designed to educate computing students in the use of computing and CG for cultural heritage one can find the course by Dellepiane and Scopigno

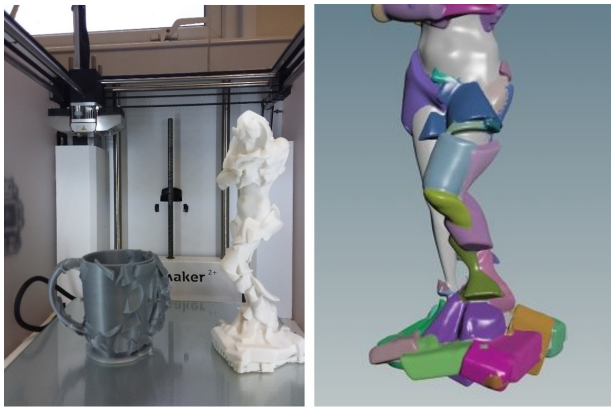

Figure 2: *"4D Cubism" project: artefacts produced by Quentin Corker-Marin*

Figure 3: *The "Town Cellars transformation" animation created by Isabella Deacon, Lucy Cole and Miguel Correia Jamal Pinto Goncalves as a visualisation for Poole Museum's (Poole, UK) "Our Museum" project, shows a transition of the medieval Wool Hall in the Grade I listed town cellars building from its current state as the Local History Centre to a planned restoration that more closely matches its original make-up.*

[DS12], which focuses on the use of low-cost (open source) off-the-shelf solutions for the 3D digitisation of cultural heritage models.

Finally, and different from the previously discussed courses, many of which focus on the acquisition of 3D models for use in computing applications for cultural heritage, Garstki et al. go full-circle, by employing 3D visualisations of virtual archaeological sites and finds that have previously been digitised to teach archaeological concepts [GLL19].

None of the courses we have found in the literature, however, appear to consider the teaching of cultural heritage concepts to art & design or creative computing students, which is surprising, as these students should have the skills and knowledge to produce digitised heritage objects or virtual heritage experiences of particularly high visual quality.

There seem to be some indications, that while it is beneficial for archaeologists or other cultural heritage professionals to have knowledge of computing and computer graphics technologies employed in their field, one should not expect them to develop a similar level of knowledge and experience in this field as would be provided by computing or engineering professionals. Similarly, it is beneficial for computing or engineering professionals contributing to cultural heritage related projects and working with archaeologists or other cultural heritage professionals to have some understanding, knowledge and experience in relevant cultural heritage domains. Our proposed course, which appears to be somewhat unique in terms of subject breadth as well as target audience, addresses the latter, providing a grounding in cultural heritage subjects for computer graphics and animation students.

3. CG and Animation for Cultural Heritage course

The National Centre for Computer Animation (NCCA) at Bournemouth University (UK) provides a set of cross- and inter-disciplinary undergraduate and postgraduate degree programmes designed around a philosophy of blending art and science, with an institutional motto of "science in the service of the arts" [CMA10].

The NCCA's degree programmes and the courses included in these, primarily prepare students for a career in the creative industries, with a focus on employment in computer animation, film visual effects and computer game development. Over the past few years, however, there have been several cultural heritage related projects that students of the NCCA's degree programmes have engaged in. For instance, in the context of a final year undergraduate research courses, in 2016, Michalik and Fryazinov developed low-cost tactile aids for the visually impaired to provide access to real spaces like shops and museums [MF16], during the 2016/2017 academic year, a project by Corker-Marin et al. [CMAP17] developed original techniques for creating time-variant cubist sculptures (Figure 2) and was awarded the second prize in the ACM Student Research Competition, in 2018, several students created a visualisation for a planned renovation/restoration (Figure 3)[1] of a listed building that is part of a local history museum [AJM*20], and during the 2018/2019 academic year, Mann and Fryazinov developed an Augmented Reality and Digital Fabrication approach for use in interactive museum displays [MF19], while a different student group collaborated with the university's maritime archaeologists to create a virtual heritage application (Figure 4), recreating a WW2 landing exercise during which several amphibious tanks sank, the wrecks of which can also be visited and investigated in the "Exercise Smash" virtual heritage experience [AS20].

To accommodate this growing interest by students in the cultural heritage domain, and to provide them with the knowledge that would allow them to pursue employment opportunities involving cultural heritage and CG, we designed a course specifically focusing on this subject area, the "CG and Animation for Cultural Heritage" course, which is offered as an optional course in the final semester (year 3, semester 2) of the NCCA's undergraduate degree programme framework.

The aims of the CGACH course (worth 20 credits/10 ECTS cred-

[1] https://www.youtube.com/watch?v=E8L1U0HNhRo

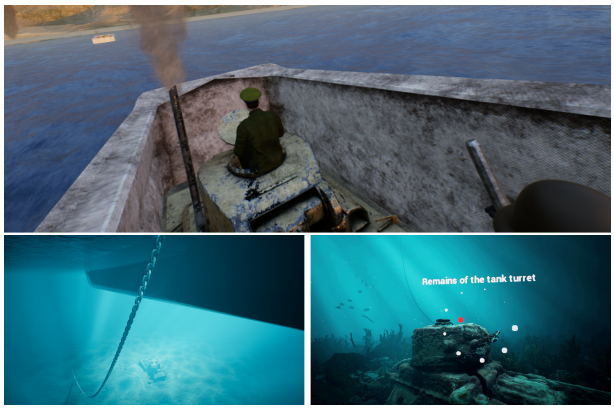

Figure 4: *"Exercise Smash" virtual heritage experience [AS20], created by Joseph Adams, Arran Bidwell, Dawid Kupisinski, Alexander Lechev, Manuella Nagiel and Radu Rosca, and supported by Tom Cousins of Bournemouth University's Maritime Archaeology team – Top: Valentine DD tank (disembarked from its landing craft) trying to reach the beach of Studland Bay; Bottom left: view from the diving boat with the tank at on the sea floor below; Bottom right: investigating the wreck on the sea floor.*

its) and its learning outcomes therefore are that after completing the course, students should not only have gained knowledge of and insights in methods and techniques used in the development of cultural heritage applications, but also be able to demonstrate their understanding of the field by proposing appropriate CG solutions for given cultural heritage projects and select appropriate image synthesis, animation and interactive techniques for their implementation.

The CGACH course, which first ran during the 2019/2020 academic year and which to date has run twice, provides students with a broad introduction to the subject matter, encompassing a wide range of topics from theoretical cultural heritage concepts and established definitions and conventions via relevant techniques and technologies, such as photogrammetry, VR, AR and digital fabrication to relevant application areas, such as computer art and virtual heritage experiences.

As all students of the NCCA's undergraduate degree programme framework will have had a solid grounding in the use of 3D modelling, animation and rendering from previous courses in the framework [RFA19], the CGACH course does not incorporate any teaching of such content creation programs. The main software packages that students tend to use for their practical coursework are Autodesk Maya[2] for 3D modelling, with some students employing ZBrush[3] for more complex sculpts, Adobe Photoshop[4] and Substance 3D[5] for texture creation and production renderers such as V-Ray[6] and Arnold[7] for final image/animation generation. For interactive heritage experiences, the students on the course tend to use Unreal Engine[8].

Theoretical aspects of the subject are delivered in expositional lectures, which are supported by domain-specific case studies that are used to demonstrate the covered material and related methods and techniques. Additionally, there are both staff-led and student-led seminar discussions that have the purpose to allow the students to develop fluency in the application of their gained knowledge. In preparation of their coursework submission, in the later stages of the course, students are given the opportunity to receive formative feedback on their work during lab-based workshops.

The course shares some content with "Digital Fabrication", another optional course in the NCCA's undergraduate framework that runs concurrently to the CGACH course. The two lectures shared between the two courses (lectures seven and eight – see below) present a wide range of case studies relevant to both subject areas, and therefore the shared lectures organically fit into the delivery of both courses. The shared content includes information on technologies that allow interconnections between the 'physical' world of real objects and the 'digital' world of computer representations and applications of digital fabrication for cultural heritage.

The overarching goal of the course design has been to provide students with an overview of the domain from a computer graphics point of view and employing a holistic approach to the presentation and discussion of technologies, methods, techniques, and application areas, demonstrating the interconnected nature of these, which is reflected in the course curriculum.

3.1. CGACH Course Curriculum

The bulk of the course are twelve lectures, spread out throughout the semester, with one two-hour lecture taking place per week, covering theoretical concepts as well as practical examples in the context of specific case studies, and where appropriate, pointing out suitable off-the-shelf as well as proprietary software solutions.

- The first of these lectures provides students with a brief history and overview of the subject, defining cultural heritage and covering concepts and aspects of cultural heritage visualisation, digital heritage and virtual heritage.
- The second lecture includes an introduction to the United Nations (UN) definition of heritage in cultural contexts, including Natural Heritage with cultural significance, and the UNESCO (United Nations Educational, Scientific and Cultural Organization) declarations and initiatives regarding tangible and intangible cultural heritage, focusing on the UN "Convention concerning the Protection of the World Cultural and Natural Heritage 1972" [UNE72] and the UN "Convention for the Safeguarding of the Intangible Cultural Heritage 2003" [UNE03]. The main focus of the lecture, however, is tangible cultural heritage, discussing possible manifestations of this as well as approaches to its visualisation, including an overview of related legal and ethical issues.

[2] https://www.autodesk.com/products/maya/overview
[3] https://pixologic.com/features/about-zbrush.php
[4] https://www.adobe.com/products/photoshop.html
[5] https://www.substance3d.com/
[6] https://www.chaosgroup.com/vray/maya
[7] https://www.arnoldrenderer.com
[8] https://www.unrealengine.com

- The third lecture focuses on the Intangible Cultural Heritage, covering different types of intangible cultural heritage that are suitable for treatment using the means of CG and Animation, as well as the possibilities of recording, preserving and presenting these by employing interactive cultural heritage infrastructure and visualisation techniques [And13].
- The fourth lecture introduces and discusses the 2009 "London Charter for the Computer-Based Visualisation of Cultural Heritage" [BND09] and the related "Seville Principles" [Ben13], mentioned above, expanding on previously introduced topics of cultural heritage visualisation. In this context, related issues such as 'interpretation' and 'reconstruction uncertainty', as well as the frequent need to consolidate information from different sources are raised and different – alternative as well as complementary – approaches and techniques for the digitization of cultural heritage, such as 3D scanning using photogrammetry, are considered, including their potential benefits and drawbacks.
- In the fifth lecture, the notion of CG techniques and applications as a service for cultural heritage recording, preservation and presentation, e.g. for archaeology and (art-)historical research, is introduced, including a detailed discussion of CG aspects of 'archaeoinformatics' [Fis20], such as linkages to GIS and Building Information Modeling (BIM).
- The theme of the sixth lecture is the use of Interactive Virtual Environments for cultural heritage, e.g. in the shape of educational cultural heritage serious games [AML*10, MCB*14], including discussions of relevant related techniques such as VR or AR and their application to cultural heritage. This is aided by the analysis of concrete examples of the use of Mixed Reality and live performance for Virtual Heritage, such as the Egyptian Oracle [GJ15]. This is accompanied by a discussion human factors that are relevant to the development of Virtual Heritage experiences, including the evaluation of Virtual heritage experiences through user studies.
- As mentioned above, two lectures (lectures seven and eight) are shared with the "Digital Fabrication" course and dedicated to the use of digital fabrication in the context of cultural heritage. The theme of these two lectures is a connection between the computer-generated world and the physical world. The first lecture revisits 3D scanning with a focus on high-quality laser scanning, introduces principles of digital fabrication with a main focus on 3D printing and presents several scenarios of multi-step connections between the real and the digital (virtual) world. The second lecture presents applications of digital fabrication for cultural heritage, such as replicas for use in museums, including the use of such replicas to replace missing parts in restored artefacts, 3D printed materials for use by anthropologists, and even the creation of personalised memorabilia.
- The ninth lecture covers the application of CG techniques in the context of museums, charting the history and evolution of museums and considering both physical (real-world) and virtual museums, e.g. on-line museums associated with real-world ones, discussing different approaches to the public presentation and digital curation of cultural heritage, illustrated with relevant case studies and exemplars.
- The Computer Art in a cultural heritage context theme is covered in two lectures (lectures ten and eleven). In the first of these two lectures, some novel trends in Computer Art production and exhibiting are discussed with an emphasis on the specifics of this emerging kind of art. Following on from this, both established and experimental computer art techniques are surveyed and representative works by modern artists working in different genres and styles are discussed. In the second lecture, several case-studies of computer art with an emphasis on the technology employed for producing these are presented in detail. In particular, such well-known productions as "The Next Rembrandt"[9] and "Touching Prado"[10] are presented with consideration of the AI-based methods and 3D printing technologies used in their creation. Special attention is devoted to projects of a research nature, such as M.C. Escher's "Seemingly Impossible Objects" [Elb11] and Andy Lomas's "Morphogenetic Creations" [Lom18]. Finally, the research projects "Augmented Sculpture " [ACP03] and "4D Cubism" [CMPA18]. produced by NCCA staff members with student participation, are presented in detail.
- The final lecture consists of a summary of the course, presenting students with a synthesis of the themes covered throughout the lecture series, and emphasizing the previously taught materials, as well as highlighting appropriate off-the-shelf software solutions [AJM*20] for the different cultural heritage application areas. To conclude the lecture series, this is finally followed by a discussion of foreseeable developments in and future opportunities for CG and Animation in Cultural Heritage.

3.2. Course Assessment

The assessment of the course comprises two independent parts, both of which students have to complete. These are, firstly, a case study presentation, which is worth 30% of the course grade, and secondly, the creation of a project portfolio, worth 70% of the course grade.

3.2.1. CG in Cultural Heritage Case Study

The 30% 'case study' element of the coursework takes the form of an assessed presentation, discussing an existing application of CG to the cultural heritage domain that students have to prepare, providing an overview of the chosen application, including a brief contextual discussion of the relevant cultural and historical background, an analysis of the use of CG techniques demonstrating insights in the methods and techniques employed in the development of this cultural heritage application, and an evaluation of the cultural heritage application.

The case study should try to identify the CG techniques employed for the implementation of the cultural heritage application and critically reflect on the appropriateness of the chosen techniques or possible alternatives that could have yielded a better result, which should be supported and informed by knowledge gained during the students' previous studies.

[9] Blurring the lines between art, technology and emotion: https://news.microsoft.com/europe/features/next-rembrandt

[10] A hands on approach to accessibility: https://advisor.museumsandheritage.com/features/touching-the-prado-a-hands-on-approach-to-accessibility

Figure 5: *'Stonehenge Past and Present', created by Isabella Deacon, interactively visualises the famous neolithic monument, allowing users to not only experience the modern ruins of the ancient henge in its current state (left), but also in the form of a best-guess reconstruction of the completed monument as it may have looked when the site was in active use (right). An additional intermediate version displays translucent outlines stones that are missing from the modern ruins (centre), highlighting the reconstruction and areas of reconstruction uncertainty [And21].*

3.2.2. Coursework Portfolio

The Cultural Heritage (CH) Project is an individual assignment that requires students to demonstrate their understanding of the field by proposing appropriate CG solutions for a cultural heritage project of their choice and then to implement this through the creation of a portfolio, consisting of a 3D Cultural Heritage object (e.g. a 3D model, reconstructing a historic building or an archaeological artefact), accompanied with supporting background research and designs to provide a rationale for decisions (e.g. the selection of suitable image synthesis, animation and interactive techniques) made during the artefact production.

Students have to select an appropriate cultural heritage object – they are encouraged to discuss their choice with members of the teaching team – and decide on an approach to its 3D visualisation. They then are required to implement this using relevant CG, animation and Virtual Heritage methods and techniques, demonstrating their knowledge of the field and the ability to make appropriate implementation decisions for their chosen cultural heritage artefact. The type of cultural heritage object that students can select for this is fairly broad, ranging from the reconstruction of artefacts and buildings to complex virtual heritage experiences, several of the latter having been previously presented [And21].

3.2.3. Assessment Criteria

3.2.3.1. For the case study, two thirds of the 30% mark are reserved for the content of the case study presentation in terms of relevance and quality of the background research and contextual information. This specifically takes into account the quality and clarity of explanations of the analysis of CG techniques and the evaluation of the application of these CG techniques in the evaluated system. The remaining third of the case study mark is equally distributed between firstly, the structure of the case study presentation and the quality of the supporting presentation materials (i.e. the presentation slides and the clarity of the used images and text), and secondly the presentation pace, timings and subsequent question handling and participation in the group discussion.

3.2.3.2. For the portfolio, making up 70% of the course mark, half of the grade is based on the quality of the artefact. This includes the effective choice of appropriate image synthesis, animation and interactive techniques, but also encompasses attention to detail and understanding of the relevant context, e.g. in cases of reconstruction uncertainty, which should be demonstrated in the project documentation. The remaining half of the grade is determined by the quality of the project documentation, including the description of relevant background research and the citation of relevant and appropriate references.

3.3. Running CGACH Course

As stated above, the course is organised as a series of twelve lectures, supported by irregular seminars to deepen understanding and facilitate discussion of the taught cultural heritage visualisation principles and approaches both for preservation as well as public presentation of cultural heritage. For this, four seminars are interspersed throughout the course, used not only to provide students with example case studies, but also to allow for students to discuss their coursework, such as their selection of case-studies and portfolio projects. In week 8 and week 11 of the course, there are also lab-based workshops that allow students to receive formative feedback on their portfolios and to provide an opportunity for students to update the cohort on the progress of their portfolio projects.

A set of timetabled, student-led seminars during the final three weeks of the course have been set aside for the presentation of the case studies, in which each of the presentations is followed by questions and answers before being opened up to a ten to fifteen minute group discussion of the case study. As the teaching restrictions created by the pandemic required all lectures and seminars to be held remotely through videoconferencing software, and because not all students had access to stable internet connections, they were given the choice to either present their case studies as a live ten-minute talk or alternatively as a prepared video-presentation of equivalent length.

3.4. Portfolio Project Examples

Overall, the coursework created by the students was of an excellent quality, providing the teaching team with a pleasant surprise, reflected in the following set of portfolio artefacts that can be seen as exemplars for the work accomplished by students taking this course.

- An example of a virtual heritage application (Figure 5) that was

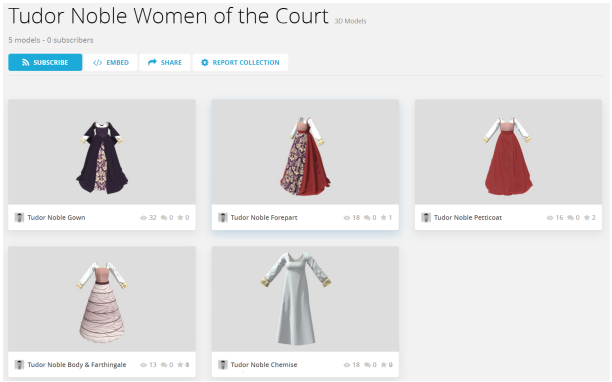

Figure 6: *Annotated reconstruction of the multiple layers of a Tudow noblewoman's court dress by Kayleigh Wadlow, accessible on Sketchfab*[12]

originally planned to be a VR application, but due to the pandemic was not fully implemented for this, is a the "Stonehenge Past and Present" reconstruction of Stonehenge, which was created during the first iteration of the course and employs Unreal Engine. The application not only demonstrates effective use of available archaeological reports, but also shows insights in approaches to highlight reconstruction uncertainty [And21].

- One of the more impressive coursework submissions of the 2020/2021 academic year was an animated fly-through of the reconstruction of a section of the "House of the Faun" in Pompeii (Figure 1, left image), which was based on published excavation records and – although less extensive – of a quality similar to professional reconstructions [DFD*16]. The only element of the reconstruction not created by the student was a freely available 3D scan of the sculpture that is the centrepiece of the scene[13], with the remaining scene elements created using Maya, Photoshop and Substance Painter.
- A completely different type of cultural heritage artefact was the interactive "Ogham Stones application" (Figure 1, right image), also created during the 2020/2021 academic year, which provides a playful learning experience implemented in Unreal Engine, teaching the concepts of the Ogham runic script[14] to users by enabling them to create their own Ogham Stone inscriptions.
- Another coursework submissions of the 2020/2021 academic year investigated Tudor fashion as an example for combining tangible and intangible heritage through the design and modelling of of a hypothetical Tudor noblewoman's court dress, based on dress patterns and cloth colours that were typical for the period and match those found in historical collections and museums (Figure 6). The model implementation, in addition to the common off-the-shelf solutions Maya and Substance Painter, also employed the cloth-simulation software Marvelous Designer[15], and presented the resulting models, annotated with historical background information, on the Sketchfab online platform.
- Finally, one student contacted a museum in Colombia and received photographs of a number of damaged ceramic pots originating from the Pre-Colombian Calima Culture's Yotoco period, missing pieces and having lost parts of their pigmentation. Three of these were reconstructed and repigmented during the first instance of the course in the 2019/2020 academic year (one of these is shown in Figure 7), employing Maya, ZBrush and Substance Painter.

Figure 7: *Pre-Colombian Calima Culture (Yotoco period) ceramic pots reconstruction (and repigmentation) by Manuella Nagiel*

4. Evaluation and Discussion

At the time of writing, the CGACH course has run in two iterations, the first with a cohort of 13 students during the 2019/2020 academic year and the second with a cohort of 14 students in the 2020/2021 academic year. Of these 27 students, 16 students (9 students of the 1st and 7 students of the 2nd cohort) responded to student surveys evaluating the course, answering questions modelled on those found in the UK's National Student Survey (NSS[16]).

Over both cohorts, all of the students who took part in the survey agreed to some degree that the course provided them with opportunities to explore ideas or concepts in depth (81% definitely, 19% mostly), that staff were good at explaining things (87% definitely, 12% mostly) and made the subject interesting (81% definitely, 19% mostly), and that assessment requirements, as well as marking criteria, had been clear in advance (81% definitely, 19% mostly). None of the respondents provided any negative evaluation and additional qualitative feedback was similarly very positive. The majority of qualitative comments were highly complimentary, e.g. stating that the course "is among the best [...] I had" or "I'm enjoying this [course], it's different then my other previous [courses] and it's very interesting". Separately from the course evaluation surveys, anecdotally, several students have also highlighted their satisfaction with the course, stating that they enjoyed it very much.

During the final stages of the course, while students were concentrating on their coursework projects, one of the challenges we encountered was – at least with some students – the necessity of

[13] https://sketchfab.com/3d-models/dancing-faun-2f5dde86328049139e8b62408713d92b
[14] https://en.wikipedia.org/wiki/Ogham
[15] https://www.marvelousdesigner.com
[16] https://www.thestudentsurvey.com

repeatedly having to convey the need for historical rigour to students, who by the nature of their degree programmes are used to the creative freedom afforded to computer graphics for entertainment. Here it was important to repeatedly emphasize the need to highlight areas where there was reconstruction uncertainty, and to clearly justify related design decisions through appropriate evidence, such as similar but more complete artefacts from the archaeological record. The difficulties in communicating this to the students might have been an unwanted side-effect of the distance education model that both cohorts experienced – the 2019/2020 cohort for the second half of their course and the 2020/2021 for the whole duration of their course – during the government mandated lock-downs due to the Covid-19 pandemic.

Nevertheless, in both cohorts, the course outcomes, in terms of the coursework completed by the students, were very good, resulting in a 100% pass rate. Although the assessment criteria were rigorously applied, we found that the cohorts' average grade was at the low end of the top third of the marks spectrum, which in the UK HE system means a grade percentage in the high 60's and low 70's. Whether this could be seen as an indication for the marking criteria to be too lenient, which we do not believe, or whether this is related to the type of student selecting this optional course, remains to be seen, and will require further investigation. Our estimation, as well as anecdotal feedback from archaeologists who we have shown the students' coursework results, suggest that the work produced by the majority of the students who took the course was of a very high quality, easily comparable to cultural heritage visualisations that are created professionally by subject experts.

The shared nature of the cultural heritage course with the "Digital Fabrication" course allows projects connecting both topics to be created in either of the courses. For example, in 2021 one student of the "Digital Fabrication" course developed a CH-related project, creating a low-cost customisable and tactile map of a national park.

However, a wider range of topics for both courses was significantly impacted by restrictions imposed by the UK government because of the Covid-19 pandemic, which a few students also mentioned in the qualitative comments of the course evaluation surveys. As a result of the restrictions, access to relevant hardware was significantly limited during the second semesters of both the 2019/2020 and the 2020/2021 academic years during which the CGACH course was running. This included photographic equipment, high-precision (laser) scanning hardware and 3D printing hardware for projects that aimed to seek connections between the real and the physical world. Similarly, restricted access to VR hardware prevented CH projects from using that technology.

As mentioned above, due to the pandemic requiring on-line teaching, adjustments were made to the assessments, particularly through the option to create a video presentation for the case studies instead of a live on-line presentation. Given many students' reluctance to present their work in front of a live audience (even online), it is not surprising that all of the students chose to create videos of their case study presentations, which actually worked very well. The resulting videos were generally of a very good quality and will undoubtedly be useful as additional case studies in future iterations of the course, so we intend to make the video presentation a permanent fixture in the assessment of the student's coursework.

Despite its relevance to cultural heritage being less obvious, we have found that the Computer Art theme, which is continuously being refined, has resonated well with students. There are two main perspectives to Computer Art in the context of cultural heritage:

1. Computer Art as an instrument to preserve existing traditional artworks, to mimic or simulate them and thus reproducing them using a new computer-related medium, as well as to re-imagine them (e.g., through animating initially static sculptures or paintings or modifying the sculpture's material, e.g. by making it transparent).
2. Computer Art as an art in its own right. It is interpreted as a novel form of arts producing artefacts using completely new computer-related media, materials, techniques, and forming original artistic forms, styles and movements different from the traditional fine arts.

Only recently, such artefacts are being considered as belonging to current cultural heritage: they are exhibited in galleries, museums, and public places, and some of these artworks are becoming a part of permanent public and private collections.

5. Conclusions and Future Work

To address the gap in formal education provision for the application of computer graphics to Cultural Heritage, we have introduced and described a successful final year undergraduate course on "CG and Animation for Cultural Heritage", which provides students on technical and art & design computer graphics and animation courses with a broad introduction to the creation of Cultural Heritage applications of CG and animation techniques more commonly found in digital entertainment and visual effects, which we believe to be the first course of this type in terms of breadth of content and target audience.

The main focus of the course is on virtual heritage and methods that can be employed to aid public presentation of cultural heritage, and while the course as it stands – with two complete iterations – seems to work well, one area that so-far has been underdeveloped is a closer examination of available tools, for example the use of cheap computing hardware, such as Arduino[17] boards or Raspberry PI[18] computers to power and control interactive museum exhibits, which we plan to rectify by giving greater emphasis to this the next iteration of the course.

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[17] https://www.arduino.cc
[18] https://www.raspberrypi.org

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