Institution: Keele University

Unit of Assessment: UoA11 Computer Science and Informatics

Title of case study: Virtual 3D Artefact Reconstruction and Interaction

Period when the underpinning research was undertaken: 2014 - present

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Dr Sandra Woolley	Senior Lecturer	2016 - present

Period when the claimed impact occurred: August 2016 - present

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Keele's Virtual 3D Artefact Reconstruction and Interaction software and systems comprise novel interactive web-based 3D artefact interfaces, a low-cost portable 3D acquisition system with automated workflow, a joining algorithm for virtual artefact reconstruction (from previous research) and novel Augmented Reality (AR) museum apps for creating interactive 3D artefact exhibitions. The software and systems have impacts in Assyriology, archaeology, digital heritage, outreach and public engagement. They have been used to virtualise 3D photo-realistic museum artefacts, via online interactive interfaces and AR apps, that would not otherwise be accessible, and have been used to achieve the world's first long-distance virtual artefact reconstruction that joined together fragments of the famous Atrahasis epic, held 1000km apart in Geneva and in The British Museum.

2. Underpinning research (indicative maximum 500 words)

Within the scope of the impact case the research is underpinned by software and systems that support:

- 3D acquisition of photo-realistic artefact models
- web-based interactive visualisation software
- AR apps

The research is also underpinned by a 3D algorithm that automates fragment joining (developed pre-2016 at Birmingham University).

The original motivation for the research was to enable virtual access to, and virtual reconstruction of, the many thousands of cuneiform tablets and fragments that are distributed across international collections. Prior to joining Keele, Woolley led the original seed-funded digitisation research at Birmingham (published in the first paper on 3D-acquisition of cuneiform SPIE.2001.4298.103-10) and was co-investigator on two Assyriological and Archaeological Leverhulme Trust awards, evolving collaborative reconstruction. Following Woolley's arrival at Keele (2016), an international interdisciplinary collaboration (Computer Science: Woolley, Nottingham Ningbo NVIDIA Lab, China: Ch'ng; Electronic Engineering: Manchester Met: Collins; Assyriology: Institut für Archäologische Wissenschaften, Goethe-Universität Frankfurt, Germany: Gehlken) started work on the wider technologies that form this impact case and established The Virtual Cuneiform Tablet Reconstruction (VCTR) Project and accompanying website (virtualcuneiform.org).

Cuneiform script is one of the earliest systems of writing, used in Mesopotamia and beyond for over 3000 years, from c. 3000 BCE. Made from handheld clay 'tablets' (**3.1**) using a reed stylus to form wedge-shaped impressions, the tablets were *the* original portable information technology (**3.2**). Many thousands of tablets and fragments are held in museum archives and collections

worldwide. Few of these artefacts are on display and access is limited, even to Assyriological scholars. Where artefacts are on display, only one side of the writing is usually visible.

The epic of Atrahasis (a creation and flood story predating Judæo-Christian texts) is one of the most significant examples of Mesopotamian literature (**3.3, 3.4**). For over fifty years, one fragment of the third and final cuneiform tablet of the epic, held in Geneva, had been believed to join with another held in London. However, due to their 1000 km separation, the join had never been physically tested (**3.4**). In 2017, the team acquired 3D models of both fragments (using their photogrammetric acquisition system (**3.5**)) and verified and evidenced the match via the automated virtual join algorithm (**3.3, 3.4**).

The technologies developed through this research have achieved significant advances in virtual artefact reconstruction, 3D interactions and low-cost portable photogrammetric acquisition (with a synchronised turntable and camera/smartphone supported by an automated processing workflow) at sufficient resolution for virtual reconstruction, the alternative is costly or immobile, using laser or structured light scanners (**3.5**). In addition to joining the Atrahasis tablet fragments, the technology was also used to acquire almost 100 cuneiform tablet fragments from the study loan collection at The British Museum, and for the joining of two pairs. Exemplars of these fragment models are included on the VCTR website gallery via the interactive 3D viewer and in a join interaction (popularly accessed by schools).

Subsequent research has evolved the visualisation software and added Android and iPhone augmented-reality apps (**3.6**) that allow acquired virtual 3D models (and related information) to be viewed, arranged and manipulated. The team is developing an archive of 3D models (including non-cuneiform artefact fragments from local and national museums) as the basis for a range of educational and cultural outreach activities, and working with museums, citizens and scholars to create innovative and interactive designs.

3. References to the research (indicative maximum of six references)

3.1 A Collaborative Artefact Reconstruction Environment, S.I. Woolley, E. Ch'ng, L. Hernandez-Munoz, E. Gehlken, T. Collins, D. Nash, A. Lewis and L. Hanes, Proceedings of the British HCI Conference. BCS. Sunderland, UK, 2017. https://doi.org/fgqj

3.2 A Virtual 3D Cuneiform Tablet Reconstruction Interaction, T. Collins, S.I. Woolley, E. Ch'ng, L. Hernandez-Munoz, E. Gehlken, D. Nash, A. Lewis and L. Hanes, Proceedings of the British HCI Conference. BCS. Sunderland, UK, 2017. https://doi.org/fgqk

3.3 Computational Aspects of Model Acquisition and Join Geometry for the Virtual Reconstruction of the Atrahasis Cuneiform Tablet, T. Collins, E. Ch'ng, E. Gehlken, S.I.Woolley, A. Lewis and L.H. Munoz, IEEE Virtual Systems & Multimedia (VSMM) International Conference, Dublin, 2017. https://doi.org/fdz7

3.4 Searching the Past in the Future - Joining Cuneiform Tablet Fragments in Virtual Collections, E. Gehlken, T. Collins, S.I. Woolley, L. Hanes, A. Lewis, L.H. Munoz and E. Ch'ng, 63rd Rencontre Assyriologique Internationale, 2017.

3.5 Automated Low-Cost Photogrammetric Acquisition of 3D Models from Small Form-Factor Artefacts. T. Collins, S.I.Woolley, E. Gehlken and E.Ch'ng, 2019. *Electronics*, *8*(12), p.1441. https://doi.org/fdw2

3.6 Virtual Museum 'Takeouts' and DIY Exhibitions –Augmented Reality Apps for Scholarship, Citizen Science and Public Engagement, S.I. Woolley, J. Mitchell, T. Collins, R. Rhodes, T. Rukasha, E. Gehlken, E. Ch'ng and A. Cooke, Int Conference on Digital Heritage (EuroMed 2020), Nov 2020, Cyprus.

4. Details of the impact (indicative maximum 750 words)

The research has engaged new audiences, delivered new virtual artefact interactions and reconstructions, provided scholars with a means of quantifying and verifying joins, and has 'unlocked cuneiform' by supporting virtual 3D access to artefacts that are not normally accessible without specialised hardware or software.

Impact in virtual artefact interaction and reconstruction

VCTR interactive outputs can support museums to design and curate virtual, physical, augmented and blended reality exhibitions (**3.6**) that democratise collections, enable access to artefacts, and provide presence for repatriated and loaned objects. The joining algorithm, incorporated in VCTR, uses a novel algorithm that handles the incompleteness of broken 3D surfaces, which was critical in joining degraded cuneiform tablets.

Evolving from the interactive 3D viewers the team developed Android and iPhone AR apps to allow virtual museum artefacts to be collected and arranged. This work was inspired by conversations with the Lead Curator of Antiquities at National Museums Liverpool (World Museum), who sought a virtual replacement for the Shabti of Padineith whilst it was on loan to the Florence Nightingale Museum. The AR app enables users to interact with artefacts and to view them either as fragments or as reconstructions (**3.6**).

Impact in Assyriology and archaeology

The research team used the VCTR toolset on artefacts held at The British Museum; Musée d'Art et d'Histoire, Geneva; and National Museums Liverpool. The most significant impact to date is the first remote artefact reconstruction, joining fragments of the famous Atrahasis epic held in Geneva and The British Museum (**5.2, 5.7**). Acquisitions were made using the 3D photogrammetric acquisition systems developed as part of the VCTR toolset (**3.5**), one of which was adapted for the large British Museum tablet (**5.7**). Other tablet reconstructions are reported in key Assyriological outlets: the Nouvelles Assyriologiques Brèves et Utilitaires (NABU 2014 (4), 119-120) and Rencontre Assyriologique Internationale conferences ("From Uruk to Ur: Automated Matching of Virtual Tablet Fragments" 2016 and 2017: **3.4**). In addition, joins have been made for flint fragments provided by Bradford University and investigations are on-going into the joining of archaeological cast fragments from statues lost in antiquity provided by the Katholische Universität Eichstätt-Ingolstadt in Bavaria (**5.8**).

Virtualisation and reconstruction of cuneiform tablets has the potential to provide scholars with new, accessible insights into the social, political, religious, scientific and historical aspects of Mesopotamian culture (**5.6**-**5.9**). The VCTR project has been mentioned on the Ancient World Online (AWOL) blog and tweeted by curators at The British Museum and Penn State as well as Harvard and Leiden researchers (**5.6**).

The VCTR 3D viewer has been successfully integrated into the Cuneiform Digital Library Initiative (CDLI: https://cdli.ucla.edu/), a joint project with UCLA, University of Oxford, and the Max Planck Institute for the History of Science, Berlin (**5.10**). The CDLI curates and publishes a searchable international digital repository of cuneiform artefacts, including hand-drawn sketches, photographs, reflectance transformation imaging views, transcriptions and translations. The VCTR 3D viewer provides an interactive interface designed for artefact manipulation and 3D script reading and has been successfully implemented with VCTR-derived 3D models into the current CDLI framework (**5.10**). Additionally, the latest version of the VCTR 3D viewer will be fully integrated into the new CDLI framework that is currently in development (**5.10**).

Engaging new audiences

Cuneiform and virtual reconstruction have been introduced to new audiences locally and globally (**5.1**). The work has been published in the media through a 2018 Conversation article (**5.2**) (7,500 reads, including the UK, US, Australia and France) and republished in the European Union News (01/03/2018), reported in a German national newspaper (**5.3**), and presented in a German radio

documentary (**5.4**). The team has taken the VCTR 3D digital artefacts and exhibits to outreach events including Potteries Museum "Night of Science" (28.09.18) (1600 visitors), and a Pint of Science talk ("Virtual archaeology and ancient beer)" (21.05.19) (**5.5**).

Also, audiences have engaged with the research through the VCTR project website. The software used to link fragments (**3.3**) is demonstrated on the website (**5.1**), allowing users to virtually join fragments and to experience the difficulties faced in attempting to identify joining surfaces (**5.1**). Between 2016 and 2020, the website had an average of 2000 visitors per week (90.9% are first-time visitors to the VCTR), from the UK, Spain, Germany, France and USA (**5.2**).

Reviews of website analytics showed US schools accessing the website (**5.1**). This prompted development of educational resources and the creation of a Schools Workshop (**5.5**). The first workshop ran for 147 year 8 pupils at a Staffordshire school (06.02.19). Children explored joining cuneiform fragments and other 3D museum artefacts. Students suggested improvements that were incorporated into the evolved VCTR tools and 3D viewer (**5.6**). Following the workshop, students reported an improved understanding of 3D models and an increased interest in computer science (50% for girls and 32% for boys).

Several public engagement and research events were cancelled due to the COVID-19 outbreak. These included a contribution to an exhibition at National Museums Liverpool; a school engagement event and two interactions at the July 2020 BCS Human-Computer Interaction Conference Interaction Gallery. However, overall, ambitions were achieved, for example, via contribution at the European Digital Heritage Conference (November 2020) (**3.6**) and via the development of AR apps and web pages.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1. Virtual Cuneiform Tablet Reconstruction (VCTR) Project web pages: http://virtualcuneiform.org/ and Google analytics

5.2. Conversation article "Virtual Archaeology: How we Achieved the First Long-distance Reconstruction of a Cultural Artefact", S.I. Woolley et al., The Conversation, UK, 28 Feb 2018 and Google analytics

5.3. National German newspaper article, Ein Puzzle aus Alten Zeiten ("A puzzle from ancient times"), Frankfurter Allgemeine Sonntagszeitung, 30 Sep 2018 (*in German*)

5.4. National German radio documentary feature "So Setzen Archäologen Verstreute Texte Wieder Zusammen" ("How archaeologists put scattered texts back together"), SWR Wissen, June 2018 (*in German*)

5.5. Public engagements, School and museum visits and Pint of Science

5.6. Social media compilation

5.7. British Museum testimonial - Dr Jonathan Taylor, Department of the Middle East, The British Museum

5.8. Archaeological testimonial - Dr Michael Müller-Karpe, Leibniz Research Institute for Archaeology, Römisch-Germanisches Zentralmuseum

5.9. Assyriological testimonial - Prof. Dr. Dirk Wicke, Institut für Archäologische Wissenschaften Goethe-Universität

5.10. CDLI testimonial - Émilie Pagé-Perron, Wolfson College, University of Oxford