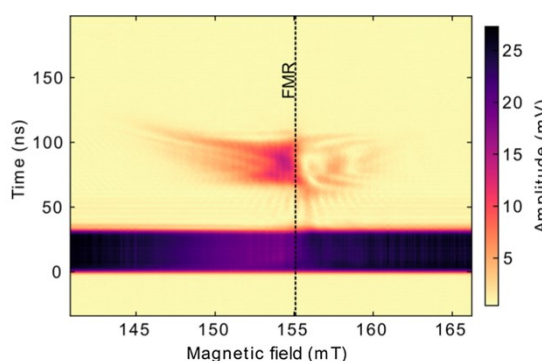


Institution: University of Oxford		
Unit of Assessment: 9 - Physics		
Title of case study: Preservation of Cultural Heritage through Application of Robust Scanning Technologies		
Period when the underpinning research was undertaken: January 2012 to July 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Dr Alexy Karenowska	Role(s) (e.g. job title): Researcher	Period(s) employed: October 2011 to present
Period when the claimed impact occurred: 1 January 2015 to 31 December 2020		
Is this case study continued from a case study submitted in 2014? N		
<p>1. Summary of the impact (indicative maximum 100 words)</p> <p>Since 2012, research in the area of microwave magnetism and signal processing conducted by Dr Karenowska has resulted in:</p> <ul style="list-style-type: none"> • The creation of digital and physical reconstructions of architectural-scale heritage objects visited by 7,000,000 members of the public in 6 countries across 3 continents. • Advances in cultural protection and enhanced awareness of the applicability of scientific approaches to the preservation of tangible and intangible cultural heritage through collaboration with UNESCO, the UN, the British Council, and the Governments of the UK, the USA, Italy, the UAE, Switzerland, and Luxembourg. • Enhanced heritage preservation and public interpretation of heritage through collaboration with municipalities and museums including the creation of a permanent exhibit at London's Victoria and Albert Museum (2018) and the renaming of a museum in Arona, Italy, to reflect local people's solidarity with those threatened by culturally motivated violence (2017). • Support to adults and children with visual impairments in the context of physical sciences education and cultural engagement including tactile exhibitions in New York City and Baltimore reaching several thousand members of the visually impaired community. • Educational resources at the interface between physics and cultural heritage reaching more than 5,000 children including 150 refugee children in the Syrian province of Idlib. 		
<p>2. Underpinning research (indicative maximum 500 words)</p> <p>Since 2012, Karenowska's academic research has been focussed at the interface between fundamental and applied microwave magnetism [Refs 1-4] and the application of electromagnetic and magnetic technology to cultural and historical projects [Refs 5-6].</p> <div style="display: flex; justify-content: space-between;"> <div style="width: 45%;">  </div> <div style="width: 50%;"> <p>Karenowska has developed a range of approaches to the investigation of microwave magnetic (spin-wave) systems. In a pure research context her work is particularly geared towards the experimental study of microwave magnetic structures at the level of individual quasiparticles (magnons and photons). As well as developing systems of practical utility, one of the overarching goals of this work is to visualise and understand the propagation of magnetic excitations and how they interact with their environment: most especially, how the presence of surfaces and surface imperfections [Refs 1-3], macroscopic geometries [Refs 1-4], and 2D and 3D structuring [Ref 4] influence their behaviour.</p> </div> </div> <p>Against this background, a common thread through Karenowska's experiments is the use of spin waves as a probe to explore the properties of the magnetic structures they inhabit. Her investigations employ local (1D) measurements made using microwave circuitry together with some relatively rudimentary but shrewdly applied knowledge about the geometries and boundary conditions of structures under investigation to generate high-quality, insight-rich datasets. An appreciation of the power of this methodology led to a broader interest in its possible applications.</p>		

Through contact with colleagues working in cultural protection, she was inspired to consider how the techniques could be harnessed to meet a very different scale of challenge: the creation of 3D digital objects in the heritage sector. The creation of digital renditions of significant objects has emerged as an important area of focus within the heritage community. A wealth of equipment is now available to enable 3D datasets to be collected for the purposes of model creation, among them, high-resolution stereo videography and laser-based scanning. Using these technologies, high-quality digital records can be produced with relative ease. However, in real-life situations applicable to *at-risk* heritage, these techniques are often impractical because many important objects are of an architectural scale (therefore not easy to scan using laser-based techniques), and/or are inside active conflict zones where resources including electricity and access to data networks are extremely limited, and/ or have already been badly damaged or even destroyed.

For these reasons, and against the backdrop of increasing incidences of deliberate damage to heritage property, Karenowska recognised that the approaches used in her fundamental research [Refs 1-4] could be harnessed to serve the needs of at-risk heritage preservation. In 2015, Karenowska demonstrated for the first time that, in close analogy to the use of data from microwave circuits to obtain information about spin-wave propagation, photogrammetry — the process of creating digital models using ordinary photographs rather than expensive scanning equipment — could be used to create engineering-quality 3D models of architectural-scale heritage objects. Particularly, she recognised that, though groups of poor- or variable-quality images of architectural structures could not be used to create good-quality models using industry-standard automated techniques, useful information could be extracted from them using a procedure directly related to that used, for example, to match the geometrical magnetic mode structure of the magnetic sphere studied in Ref. 4 to the measured microwave signal, or the simulated magnon signal presented in Fig. 3(b) of Ref. 2 to the experimental signal of Fig. 3(a) (Fig. 1 above). In the first step of the modelling process, a set of constraints are extracted — basic geometrical information able to be obtained even from data that appears, by visual inspection, poor resolution and/or poor quality — including the position of the edges of objects, and the relative size of their constituent parts. This information then plays a role equivalent to that which constrains the refinement of models in the context of microwave measurements (chiefly, the known material properties and sample dimensions), supporting the tuning of the model using, for example, higher-resolution close-ups of localised surface features.

Karenowska recognised, further, that *physical* models derived from computer-based renderings produced in this way could have a range of applications. Notably, they could be used to produce quality tactile renditions of large-scale heritage objects otherwise inaccessible to those with sight impairments, or used in conjunction with large-scale 3D machining technologies to produce full- (or at least, large-) scale reproductions [Refs 5&6].

3. References to the research (5 peer-reviewed journal articles and 1 book)

[Ref. 1] *Oscillatory Energy Exchange between Waves Coupled by a Dynamic Artificial Crystal*, Karenowska, Gregg et al, Phys. Rev. Lett. 108, 015505 (2012). [10.1103/PhysRevLett.108.015505](https://doi.org/10.1103/PhysRevLett.108.015505). [Ref. 2] *Time-resolved measurements of surface spin-wave pulses at millikelvin temperatures*, van Loo, Morris, and Karenowska, Phys. Rev. Applied 10, 044070 (2018). [0.1103/PhysRevApplied.10.044070](https://doi.org/10.1103/PhysRevApplied.10.044070). [Ref. 3] *Measurement of a magnonic crystal at millikelvin temperatures*, Kosen, Morris, van Loo, and Karenowska, Appl. Phys. Lett. 112, 012402 (2018). [10.1063/1.5011767](https://doi.org/10.1063/1.5011767). [Ref. 4] *Strong coupling of magnons in a YIG sphere to photons in a planar superconducting resonator in the quantum limit*, Morris, van Loo, Kosen, and Karenowska, Nature Sci. Rep., 7 (1), 11511, (2017). [10.1038/s41598-017-11835-4](https://doi.org/10.1038/s41598-017-11835-4). [Ref. 5] *The Archaeology of Science in the Science of Archaeology*, A. D. Karenowska, Arion, Vol. 27, No. 3 (2020). [arion.27.3.0007](https://doi.org/10.1007/978-1-349-11835-4_3) [Ref. 6] *3D Digitisation*, Institute of Historic Building Conservation Yearbook, 2019, 44-46. <https://www.ihbc.org.uk/Yearbook/2019Yearbook/24/index>

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

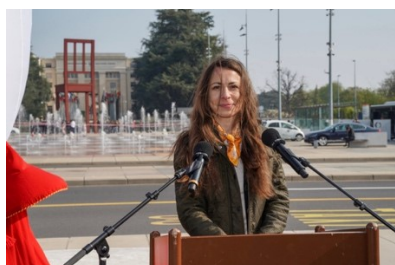
Building a collaboration including the then head of the Directorate General of Antiquities and Museums in Syria, Karenowska led a project within the heritage protection consortium called The Institute for Digital Archaeology to produce a reconstruction of a third century triumphal arch demolished by the group calling itself Islamic State in Palmyra, Syria. Data were gathered by crowdsourcing images between December 2015 and January 2016. A digital model was created and, using this dataset, a 1:3 scale facsimile was milled from solid marble. Soon after being

established, project attracted significant attention among those working in the heritage sector and was featured on the front pages of The Times newspaper and of Newsweek magazine.



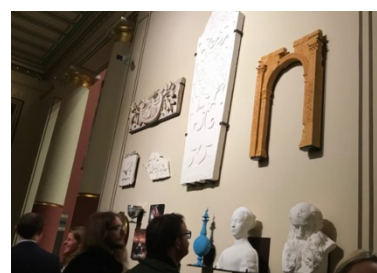
Trafalgar Square, April 2016

The replica arch was first revealed to the public on London's Trafalgar Square in April 2016. It was unveiled by then Mayor of London Boris Johnson who described the structure as a "*triumph of technology and determination*" [E1]. The arch was seen by many thousands of people during the exhibition and attracted coverage from almost every major news network in the world. The unifying power of the installation and its status as an act of solidarity with the people of Syria was widely discussed in the media and among project participants from the region; visitors were reported to be "*overcome by the achievement*" [E1], and the Director General of Antiquities and Museums in Syria said that it was a "*double happiness*" to see the arch unveiled after the recent liberation of Palmyra. He described the arch as "*a message and gift to the Syrian people*" [E1].



Dr Karenowska at Place des Nations, Geneva.

Between Sept. 2016 and March 2020, the arch travelled, at the invitation of a range of science and heritage-related government and non-government organisations to five countries: the USA (City Hall Park NYC, and the National Mall, Washington DC), the UAE [E2], Italy (Florence and Arona) [E3, E4], Switzerland (UN HQ at Geneva, and Bern) [E2], and Luxembourg. These public installations attracted 1,000,000s of visitors [E3] and



A miniature version of the replica arch forms part of the permanent collection at The Victoria and Albert Museum.

reached many more through media coverage. In addition, several major invited satellite exhibitions presenting the underpinning science and discussing the importance of physical science's role in preserving cultural heritage took place at the Venice Biennale (A World of Fragile Parts, 2016); the Italian consulate, New York (2017); the United Nations HQ, New York, with the Italian Permanent Mission to the UN (2017) and the UK Permanent Mission to the UN (2018). A permanent exhibition showcasing the project was installed in the V&A in 2018 [E5].

Overall, the impact of the work spans several sectors:

- As a powerful influence on **professional practice** in the areas of:

Cultural protection: particularly at the interface between science, cultural protection and cultural diplomacy. The project has stimulated policy discussions by such bodies as the United Nations (especially within the UN permanent missions of the United Kingdom and Italy), UNESCO, the US House Foreign Affairs Committee, the G7 nations, and the government of the United Arab Emirates concerning measures to protect at-risk cultural property and the communities to whom it belongs, particularly in connection with the role of reconstructions of different kinds — from on-site physical reconstructions to virtual reconstructions — to the protection of the tangible and intangible cultural heritage [E2-E6]. Sir Simon Jenkins, former Chairman of the National Trust and former Editor of The Times commented that "*Th[e project] has redefined the boundaries of what can and should be restored*" adding, "*[m]ost remarkable of all the project specifically changed minds at UNESCO in a desperately important direction*" [E7]. British diplomat and former British High Commissioner to New Zealand Hon. George Fergusson said of Dr Karenowska "*Her involvement [in] protecting cultural items which face risks of destruction, whether from political turmoil or excessive exposure to tourism, has been particularly significant. She has shown enormous commitment to raising public awareness of these risks and has*

applied advanced scientific techniques to constructing exact replicas which have caught public imagination and helped engage governments and intergovernmental bodies” [E7]. Speaking at the opening of an exhibition Karenowska designed and installed in New York at the invitation of the United Nations, His Excellency Mr. Miroslav Lajčák President of the United Nations General Assembly said *“Tonight’s exhibition steals the limelight. That is not only because of what it looks like, but also for what it represents”* [E5]. This exhibition featured not only materials relating to the reconstructed arch but also a second large-scale reconstruction of a Palmyrene statue of the goddess Allat, destroyed during the sacking of the Palmyra museum, [E5]. Karenowska’s work, moreover, resulted in the British Council’s first heritage protection initiative in Syria during the conflict. The “Protecting Syrian Heritage” project was conceived to support local people in Syria in technologically-enabled heritage documentation efforts [E6].

Representation of cultural objects in public spaces:

including in collaboration with the Government of Italy, and the Victoria & Albert Museum [E5]. Speaking in Washington DC during the inauguration of the 2018 installation of the replica arch on the National Mall, Hon. Edward Royce, Chair of the United States House Foreign Affairs Committee commented *“Projects like this recreation of the Arch of Palmyra are a critical way to celebrate these iconic pieces and keep them very much alive and present in our collective consciousness... Dr Karenowska, thank you for what you've done in making certain that this chapter of Syrian history is not forgotten”* [E2].



In Washington DC with Representatives Engel and Royce.

Architecture and urban design: The structure has stimulated extensive debate and discussion around the modern-day status of monuments and memorial objects and the role of science and technology in defining that relationship in the context of post-conflict reconstruction [E1-5].

- **As a symbolic new object of art and memorial.** The structure has helped define a new genre of public sculpture — the monumental heritage reconstruction. In 2016, the New York Times judged the arch “the most talked about public art installation of the year” [E8].
- **The creation of public awareness of cultural protection imperatives** and a vehicle for communities, governments and public policy groups to explore and express their support for heritage initiatives [E1-10]. In 2017, the structure was at the focus of the City of Florence’s cultural program in connection with the G7 Culture Summit where it received 2,000,000 visitors [E3]. Mayor of Florence, Dario Nardella described the arch as *“a symbol with which we all from Florence want to send a message of peace and resistance against terrorism and violence”* [E3]. Opening a similar installation in connection with the United Nations General Assembly in New York City, Deputy Mayor of New York City, Hon. Alicia Glen described the arch as *“a symbol of freedom”* and *“that we will not stand for acts of terrorism”* [E2].
- **Education and accessibility.** Karenowska has delivered highly successful educational activities and workshops directly related to the science underpinning the project. These have reached 5,000 children in the UK, USA, and Europe. In connection with these activities, Karenowska was described by Boston University Professor Herbert Golder (a prominent public scholar and well-known advocate for engagement between the sciences and humanities), as *“simply one of the most skilful and engaging presenters of scientific materials I have ever seen, stimulating debate, opening up fresh ways of thinking about the past (as well as about science, and the present), and informing opinion on matters as important as our shared cultural heritage”* [E7]. One young workshop attendee wrote in their thank-you note *“you have showed all pupils that... if we set our aspirations high and work towards them, we can fulfil our dreams”* [E9]. In parallel, a program for refugee children in the Syrian province of Idlib organised by Karenowska and delivered by local professional educators has reached almost 200 children. One project leader commented *“They [the children] learn about cultural heritage and its importance to communities, as well as technical aspects like excavation.... These workshops are so important for the children, not only do they learn, but they have a chance to have some fun.... Our collaborative documentation projects [with Dr Karenowska] support the team and the whole [Heritage protection] centre”* [E9]. Through collaborations with the Royal National Institute of Blind People (UK) and the

National Federation of the Blind (USA) the work has also been presented at tactile exhibitions at the intersection between science and cultural heritage and the challenges of learning about these topics faced by those with visual impairments in New York and Baltimore. These exhibitions have stimulated significant dialogue concerning equality of access to heritage and related enabling technologies. In a powerful response to the installation of the arch in New York City, and the accompanying tactile exhibition, the Technology Coordinator at the New York Public Library's Andrew Heiskell Braille & Talking Book Library wrote *"The shelter of the arch reminds me that I belong inside the larger story; I'm a little part of it now as I discover the language of architecture at a scale I can reckon with, and learn to know my own perceptions as authentic without calling out for a sighted person to confirm them"* [E6].



A vehicle for community action and positive political and economic progress. In 2017, the arch was installed in Arona, Italy, at the invitation of the Municipality in connection with the renaming of the local archaeological museum after the murdered Syrian archaeologist Prof. Khaled Al Asaad — a gesture inspired by the project [E4]. The project is credited with boosting local tourism by at least 50,000 and promoting a tolerant outlook in an area of Italy where the anti-immigration policies of the extreme political right have traction [E4]. Speaking at the event, Prof. Al Asaad's son said, when asked about the impact of the project on him and the Syrian community more generally, *"We are very honoured here in Italy also in France and everywhere because we feel like all the people all around we meet them or we didn't meet them yet they support us, they give us more power to face this tragedy"* [E10]. Speaking in connection with the inauguration of the installation in Arona, the town's Mayor, Alberto Gusmeroli said: *"For months we have worked for this important moment, not only for us in Arona, but for the whole region. We are here to celebrate how civilization, thousands of years of human culture, is stronger than barbarism"* [E4]. Gusmeroli also travelled to the United Nations HQ in New York in connection with the project. He said of this visit *"Making ourselves known to the UN, where in decades of diplomatic activity we try to change the world for the better and to bring peace, was indescribable. Arona is now even better known and, together with Lake Maggiore, it shone"* [E4]. Regional actors have also embraced the project as a peaceful vehicle for the expression of shared aspirations for the protection and respect of the region's cultural heritage and cultural identity. HE Mohammed Al Gergawi, Minister of Cabinet Affairs in Dubai UAE wrote *"This [project] means that we can literally roll back the clock and restore what the nihilists have damaged. It is a message to them: everything they are working to erase can be preserved. Their destruction is as futile as their ideology"* [E2].

5. Sources to corroborate the impact

[E1] Front pages, The Times, Newsweek, 2015. BBC News; "Palmyra's ancient Triumphal Arch resurrected in London's Trafalgar Square" & Reuters, CGTN (including [Video 1](#)), and CNN (inc. [Video 2](#)) coverage, 2016. [E2] Daily News & the Guardian, Sept. 2016; [Video 3](#) showing Washington DC ceremony; communication from HE Mohammed Al Gergawi; front page, The Gulf Today, 2017; Le Temps, 2019; [Video 4](#) of invited speech at UNESCO Conference, Geneva, 2019; official description of the installation with city of Bern and Swiss Commission for UNESCO; communication from Govt of Luxembourg. [E3] MUSE Network statistics, and coverage in La Nazione, Florence, 2017. [E4] Coverage of Arona installation (2017): Sempione News, Aronanelweb.it, La Stampa, free Novara, prima Novara. [E5] The Architect's Newspaper article, 2016; Guardian documentary [Video 5](#), V&A webpages and [Video 6](#) which accompanies exhibit; event announcement from Italian Consul General in NYC; official statement from the President of the General Assembly of the UN. [E6] Webpage: British Council project announcement; event images and online announcement, the National Federation of the Blind, and the New York Public Library collaboration; written response of NYPL's Technology Coordinator. [E7] Letters from Sir Simon Jenkins, Hon. George Fergusson, and Prof. Herbert Golder. [E8] "2016 as seen by 3 artists", New York Times. [E9] Note from UK student; comments from Syrian workshop leader ([Audio 1](#) and English transcription); photographs showing participants. [E10] Testimonials from Syrian project participants inc. [Video 7](#) showing recorded comments of the son of the murdered archaeologist Khaled Al Asaad (in connection with the arch installation in Arona, Italy) and an email from a Syrian project team member.