Institution: University of Bradford

Unit of Assessment: C15 Archaeology

1. Unit context and structure, research and impact strategy

The Unit of Assessment C15 at Bradford is mapped onto the School of Archaeological and Forensic Sciences (SAFS), and sits within the Faculty of Life Sciences. Across the REF2021 period, our strategy, in partnership with University management, has been to provide an excellent research environment, blending archaeology, forensics and cutting-edge science to generate leading research with substantial public impact. Key developments include-

- **A new School of Archaeological and Forensic Science** (2017), and relocation of all staff to new research space at the centre of the university promoting an inclusive and vibrant research grouping.
- **A new heritage science facility, Visualising Heritage**, supported by a multi-million-pound IT investment, promoting. digital heritage as an overarching, "Grand Challenge" research theme.
- **New, flexible research structures** within SAFS to support collaborative, interdisciplinary partnerships externally and across the university with Engineering, Chemistry, Social Sciences, Health and Biosciences; along with increased access to university facilities including the Centre for Chemical and Biological Analysis (the Analytical Centre).
- **Enhanced research sustainability through increased research income, impact and publication opportunities** provided by collaborative research with HEIs, government agencies, commercial organisations and the voluntary sector.
- **Placement of impact at the forefront of research plans**, following the achievement of the REF14 impact submission, and exemplified through case studies celebrating impacts from our Visualising Heritage group and research within the Stonehenge landscape.

Radical change in our research structure has provided transformative opportunities compared to REF2014. Previous groups, defined as 'Social and Biological Identity' and 'Archaeological Sciences', have been replaced by interlocking research themes, characterised by flexible academic membership and a level of interdisciplinarity that exceeds the 'trans-disciplinary' approach to the human past defined in the REF14 submission. Themes are -

- Archaeological and heritage sciences
- Social and biological identities
- Landscape and settlement archaeology

Research and impact strategy is implemented by designated theme leads with responsibility for horizon scanning for funding, KT and impact opportunities. They facilitate, support and monitor research development and ensure inclusivity through mentorship of Early Career Researchers (ECR). The School Research Committee, chaired by the Director of Research, includes theme leads, Head of School, postgraduate and postdoctoral representatives. Strategy related to research priorities, staffing, investment and impact are developed here and adopted by the School. Implementation of our research strategy is supported by the University Research and Innovation Services (RaIS), who advise on best practice, research development, applications and post-award management. RaIS organise sandpits dedicated to specific funding opportunities and manages network events to enhance interdisciplinary engagement across the University. These events formed the base for successful applications including BReaTHe which incorporated academics from SAFS and Social Sciences (Croucher, Evans, Wilson). We recognise the value of embedding research across all of our activities (Croucher [Output 41]).

Research management is undertaken with a commitment to equality and diversity, with a proven value in respect of staff motivation and enhanced research activity.

The Unit's research strategy informs development of Faculty of Life Sciences' overarching research themes and University research strategy, promoting interdisciplinary excellence and enhancing opportunities for research and funding. The Unit provides leads for two of three faculty research lobes; Heath, Society, People and Place (Croucher), and Computational and Data-Driven Science (Gaffney V.), and Heritage has been adopted as a theme within the renewed University research agenda. The commitment of SAFS to impact is recognised by the University. Gaffney C. is Faculty and University Academic Impact Lead, assisting in the development of institutional impact strategy.

Theme 1. Archaeological and Heritage Sciences (Co-ordinator Wilson)

Archaeological science retains a leading role and has been developed through a strategic heritage science agenda, underpinned by the establishment of the new Visualising Heritage group. Visualising Heritage supports interdisciplinary, digital research across all three research themes. Key projects include AHRC-funded Fragmented Heritage and Curious Travellers projects (Wilson, Evans, Gaffney C. and V.). Research developing from these key programmes involves digital responses to natural and societal disasters, post conflict reconstruction and resolution e.g BReaTHe - Building Resilience, Well-being, and Cohesion in Displaced Societies Using Digital Heritage; Reducing Disaster Risk to Life and Livelihoods by Evaluating the Seismic Safety of Kathmandu's Historic Urban Infrastructure' (Croucher, Evans and Wilson). Climate heritage research includes contemporary heritage threats, e.g. Wetland Futures (Jennings) the Swandro project (Bond, Dockrill, Historic Environment Scotland) and prehistoric climate change impacts [outputs 7, 20], and palaeo-tsunami research within the ERC Advanced Grant project, Europe's Lost Frontiers (Gaffney V. [output 24]). An emerging area of digital research relates to heritage collections, heritage capacity-building and cultural enrichment. Projects include the GCRF Augmenting Jordanian Heritage, the joint Irish Research Council-AHRC Digital Humanities scheme Communicating Hidden Heritages (Wilson, Gaffney C.), and Encounters and Transformations in Iron Age Europe (Koon and Armit, now York, [output 39]). New 3D approaches to World Heritage Site research also feature as part of the SAFS/ National Trust, Fountains Abbey research consortium (Gaffney C.) and the Stonehenge Hidden Landscape project (Gaffney C. and V. [output 25]).

Digital heritage can provide significant information for archaeological analysis as demonstrated by study of the famous Star Carr headdresses (Evans [output 10]). The capacity of digital heritage research to generate social value, and enhance public participation, is demonstrated in both submitted impact case studies. These draw on collaborative work with regional government (Virtual Bradford/'Engines of Prosperity' - Industrial Heritage at Risk; Wilson, Gaffney C.), national curators (Crucible of Shetland's Broch Building, a Scottish Cultural Heritage Consortium funded CDP project), international partners (Stonehenge Hidden Landscape, the Ludwig Boltzmann Institute) and commercial partners including HS2 Ltd.

Our broader archaeological science agenda is demonstrated through leading research in geophysical prospection (Gaffney C. and V. [output 25]), isotopic analysis (Curtis-Summers [output 28], Beaumont [output 6]) and pioneering use and refinement of archaeomagnetic data (Batt [outputs 8, 13, 15, 24]). Our role in the development of archaeological chronologies at key sites, is demonstrated at Old Scatness and Ness of Brodgar (Batt [output 8]), and includes research on multi-method Bayesian chronological approaches, work on palaeointensity, rehydroxylation dating of ceramics and palaeomagnetic applications in marine environments (Batt [output 24]). Another focus, linked through SAFS human remains collections and bioarchaeological expertise, concerns mechanisms of biological degradation and our ability to retrieve visible and trace molecular information on diet, disease and lifeways from archaeological and forensic remains (Janaway [output 34], Wilson [output 11], Tedder [output 38]), the survival

of materials (Janaway [output 34], Koon [output 23]), and exotic components in ritual or embalming practices (Thompson, Stern [outputs 2, 12]).

The outputs of heritage science projects with their rich potential for public participation and broad social impacts provide the core of one of our impact case studies 'Visualising Heritage. This draws on digital assets from across the Unit's themes and demonstrates our commitment to interdisciplinarity and the facilitating role of digital technologies.

Theme 2. Social and biological identities (Coordinator Croucher)

Our research maintains a focus on the human body and its centrality in social relations spanning the Neolithic to 21st century, and scales ranging from the individual to the societal. It addresses issues including social inequality, conflict and violence, diet, health, migration and death. It draws on osteological and isotopic analysis and theoretical studies of personhood from across Europe and the Near East. Following REF2014, this theme now includes cultural archaeology, biological anthropology, forensics and healthcare in the study of past societies and the contemporary context of such knowledge.

Central to this development has been the AHRC Continuing Bonds and related projects (Croucher [output 40]). These inter-disciplinary studies position archaeological perspectives on death and dying within contemporary end-of-life experience, and link our researchers with educators and charitable organisations in health-related projects including the GCRF Mainstream Global Mental Health Network in Leeds. Other projects linking past health and death with contemporary issues include the 'Bradford Tooth Fairy' project, using human dentine as a biomarker for stress (Beaumont [output 3]), and dietary studies linking health and wellbeing in the Highland National Health Service with monasticism and lay communities in Early Christian Scotland (Curtis-Summers [output 28]).

Recent infrastructure investment has allowed us to redefine future research directions and support investigations into life-histories, rather than snapshots at death. Incremental high-resolution isotope analyses generate insights into diet and physiology including impacts on weaning and child health (Beaumont [output 6]), social identity in Mesopotamia (Croucher [output 1]), and the effects of famine and mobility (Beaumont [outputs 3, 5]). Our research considers life and health, from birth to sometimes violent death, as at the siege of Stirling Castle (Buckberry), and across forensic studies (Janaway [output 34]). Age of death estimates and skeletal markers pathology continue to be used to investigate individual osteo-biographies and supra-regional patterns of heath (Buckberry [output 17]). These investigations are supported by ground-breaking research testing the efficacy of high-resolution intra-dentine carbon and nitrogen isotope profiles (Beaumont [output 3]) and oxygen isotopes in collagen. Past cultural selection of animal and human bone for projectile points have been identified through ZooMS and genetic studies (Tedder [output 22]), whilst our expertise in microscopic integrity, isotopic characteristics and DNA survival in hair enhances studies including Denmark's iconic Egtved Girl/Strydstrup Woman (Wilson [output 21]).

Our existing strength in bioarchaeology also supports important new lines of enquiry concerning the nature and development of past social and biological identities. These include reviews of the genomic evidence for the Beaker phenomenon and migration chronologies (Armit [output 4]), Iron Age identities [output 39] and legacy projects on human remains in key sites such as the Sculptor's Cave (Evans [output 32] and Koon), and studies of the Viking diaspora (Buckberry [output 16]).

Contemporary digital heritage applications within the theme build upon earlier, ground-breaking projects, such as Digitised Diseases, and include the Wellcome Trust, Calvin Wells digitisation project, and projects supporting individual and communal wellbeing including BReaTHe (Buckberry, Wilson, Evans, Croucher).

Theme 3. Landscape and settlement archaeology (Co-ordinator Gaffney V.)

Our record of research excellence in landscape and settlement studies continues to attract funding in new research areas, including marine palaeolandscapes e.g. the ERC Advanced Grant, Europe's Lost Frontiers (Gaffney V. [outputs 19, 24, 30]). Alongside new projects, we maintain long-term research excellence in Scotland through Dockrill and Bond's work [outputs 35, 37] at Old Scatness, Swandro, the Gateway to the Atlantic, Brodgar (Batt), Jarlshof and Mousa in the Visualising the Crucible of Shetland's Iron Age project (Wilson) and Sculptors Cave, Moray (Wilson, Evans). New research on Lewis (Gaffney C. and V. [output 29]) and Shetland (Jennings) also occurred during the REF period. Elsewhere, we built upon established strengths in settlement studies (Gibson [output 26]), imaging and remote sensing at the World Heritage Site at Fountains Abbey, and Mediterranean landscape research at Olynthos and Megara Hyblaea, Greece (Gaffney C.). Gaffney C. and V. continue to lead within the European collaborative Stonehenge Hidden Landscapes project, providing mapping across the world heritage landscape, information on unexplored areas of the landscape and novel insights into well studied sites, including Durrington Walls henge [output 25]. During major change across the Stonehenge landscape, the data has informed structural plans and supported management of the landscape by national curators. This project forms the core of one of our impact case studies.

Since REF2014 significant new landscape research themes have emerged relating to wetland and inundated landscapes. Jennings' research on wetlands [output 27], and the lake-dwelling of Viverone, initiated with Menotti (retired), generated an international research network Wetland Futures in Contested Environments, informing conservation and legislation policy. The ERC Advanced Grant, Europe's Lost Frontiers is a global exemplar for research into climate impacts, settlement and colonisation of marine palaeolandscapes [output 24], and includes research with European partners to locate early settlement within deep areas of the southern North Sea [output 30].

Our work in built environments, heritage townscapes and historic parkland includes digital capture in Kathmandu (Wilson), Fountains Abbey and in historic sports grounds (Gaffney C.). These form the base for ambitious projects including collaboration with Bradford Council, to develop Virtual Bradford, a digital twin of the City, including World Heritage Site Saltaire. Funded through EU-Smart Cities and Open Data Reuse (SCORE), heritage research will support cultural tourism and regional regeneration.

Our commitment to open access (OA) research is implemented by mandatory peer review of applications to ensure OA compliance, an annual OA research day, social media workshops and a university research development fund supporting projects with OA components and OA publication of non-RCUK funded outputs. Our commitment to open research goes beyond these and is built upon open access and legacy digital projects including The Detection of Archaeological Residues using Remote Sensing Techniques (Gaffney C.). Our open data strategy promotes data sharing and public participation through citizen science research using crowd-sourced and web-scraped data, e.g. AHRC Digital Transformations Programme Fragmented Heritage/ Fossil Finder/ Curious Travellers projects (Wilson, Evans, Gaffney C. and V.).

We are committed to the highest ethical standards in relation to individual staff, the research community, funders of research and society. All staff follow the University's ethical and research integrity frameworks. RaIS advise on compliance and provide staff with induction and ongoing advice on best practice. Research involving human participants, tissues or personal information databases requires approval by the University Research Ethics Panels. These include Croucher and Wilson as members and follow guidance on historic remains provided by Buckberry. Our commitment to upholding and developing research standards and professional frameworks is recognised by accreditation through the Chartered Institute for Archaeologists and Chartered Society for Forensic Sciences

Our future research development will build upon transformative investment made during REF2021. Strategic investment during the REF period (see section 2), combined with a flexible research structure, has supported development going beyond the aspirations presented in REF2014, promoting interdisciplinarity, innovative research, publications and impact spanning Europe, Western Asia, Africa and the Americas. Over the next REF period the strategy will ensure a sustainable, funding stream based on these investments and linked to increased collaborative activity across the university, academia, government agencies, commercial organisations and the third sector.

2. People

Personal development is central to our research strategy and is outlined at University level through the "Bradford Academic" contract between institution and researchers. We follow best practice to provide equality of opportunity for academic staff to flourish and succeed in a supportive research environment. We support staff through processes tailored to discipline and personal requirements. Individual research development centres on the Personal Development Review (PDR) process, the Personal Research and Innovation Plan (PRIP) and the Workload Module (WLM). Research staff are provided with 15% research time in the WLM. This may be increased to support research and impact development. The PRIP and PDR allow staff to reflect on research goals and identify required support from School and Faculty. Additionally, the Research Director interviews staff on an annual basis to review research performance, explore development opportunities and agree future progression and targets. Although there is no formal sabbatical process, staff are supported to seek external funding for sabbaticals, e.g. Heron's GBP51,962 Humboldt fellowship (2014-15). Double peer review supports researchers during development of funding applications and ensures quality and transparency across the research process. The SAFS research structure has created a close-kit research community, engaging staff and postgraduate researchers. Our research process provides clarity of purpose, and effective line-management between formal meetings, whilst optimising research opportunities for staff and research students.

Staff engagement in strategic development assists the School to respond rapidly to staff change and pursue research opportunities. Within the REF period several senior staff retired (Menotti, Gibson), or moved to pursue career opportunities (Heron, Director of Scientific Research, British Museum and Armit, University of York). These changes provided an opportunity to re-shape our research profile in line with emerging research strategy and facilities investment, and to engage a dynamic blend of senior academics and ECR staff to shape research within an innovative, interdisciplinary environment.

Our staffing policy strengthens and enhances our research by recruiting expertise in strategic areas earmarked for development, and by building a strong and sustainable research culture. This is demonstrated during this REF period through the University sponsored "50th Anniversary Chair" scheme. This supported a substantial investment in research leaders. Gaffney V. was recruited as Chair in Landscape Archaeology, and Menotti as Chair in European Prehistory. Curtis-Summers' employment as lecturer, following appointment as maternity cover, strengthened the human osteology and stable isotopes group. The School's commitment to create career pathways for staff on fixed-term contracts is illustrated through promotion of Jennings (PDRA wetland archaeology) and Evans (PDRA Digitised Diseases/VAHT/Fragmented Heritage/Curious Travellers/Fossil Finder) to lecturer. Sparrow, now employed as Senior Scientist, arrived on a CIfA workplace learning bursary and progressed through employment on temporary contracts to a permanent position.

Diversity and inclusivity are central to SAFS development. Bradford was Times University of the Year for Social Inclusion in 2020, and SAFS is committed to the University's equality, diversity and inclusion strategy. All staff complete mandatory Diversity in the Workplace and Unconscious Bias e-learning modules and take ongoing equality and diversity training. Croucher is Director of Equality and Diversity at Faculty level and has demonstrated enhanced good practice through a successful School Athena Swan application. Diversity issues remain

prominent through a standing item on the monthly SAFS staff committee agenda. The School actively seeks to enhance diversity in recruitment and selection. University regulations require an 'Equality Impact Assessment' as part of the recruitment process and recruitment panel members receive training for this purpose. Our recruitment panels contain at least 25% female representation. Data indicate a balanced gender ratio between applicants and shortlisted candidates, and females have a higher employment success rate. We have an increasingly balanced gender ratio: 43% of the staff submitted to the REF2021 are female. During 2020, Batt became the first female Head of School, and two members of staff (Croucher and Buckberry) undertook the Aurora leadership development initiative for women. In addition to the on-site nursery (see Institutional statement), SAFS support returning parents to attend international conferences, including funding for academics travelling with young children (e.g. Koon, SAA; Croucher TAG USA). The positioning of inclusivity, gender and diversity as research topics is a strength at SAFS, and is exemplified by diversity themed conferences including TAG, research events during WOW (Women of the World) festivals (Croucher), Soapbox Science and Women in Science events (Beaumont), and Koon's presentations on female scientists in stable isotope related fields (Konstanz, Germany).

We provide a flexible working environment that supports all staff to achieve a successful and fulfilling academic career. There are no zero-hour contract staff; teaching and research staff in the School are on permanent contracts, and researchers on fixed-term contracts are employed on specific projects. Five technicians support research and are fully integrated within the School, supporting research across geophysics, dating, forensics, isotopes, digital capture, microscopy and palaeopathology. Staff safety is a priority. Compliance with all health and safety requirements is a standing agenda item for the staff committee, overseen by our Health and Safety officer.

SAFS provides positive messages concerning flexible career trajectories for all employees, and supports part-time working, flexible working and career breaks, including absence related to illness and support for disability. Staff, including new parents, are supported through the PDR process and mentor system, where support needs are identified. Detail on support is available in the SAFS staff handbook and the University website. The University HR web-portal, has a searchable database of policies, processes and forms, including information on maternity/adoption pay, pensions, annual leave and returning to work.

Staff are replaced during maternity, illness or long-term leave career breaks, and moves between full-time and part-time are supported. During periods of absence, regular contact is maintained between line managers/mentors and staff or postgraduate students, via the employee's preferred method (telephone, email, or in person during "keeping in touch days" for those on maternity leave). Regular meetings ensure risk assessments and related requirements are considered throughout pregnancy and ill-health. Staff are made aware of cover arrangements and HR offer one-to-one meetings to discuss maternity and adoption leave options. Returning staff are supported via mentoring. In 2020, a SAFS staff survey reported a supportive environment in relation to career breaks (100% in the REF period) and Covid support (95%).

New staff have reduced teaching and administrative duties, prepare a research development plan and are assigned a senior colleague as a mentor; potentially from another School. Staff receive training and support for developing funding applications from the RaIS team, who also assist grant-holders post-award. We facilitate all staff to use central training on research related topics, including writing grant applications and preparation of research costings. Support for preparing publications is also offered, including writing retreats. Specific training requested by our staff has included the use of social media for academics.

Post-doctoral researchers (PDRA) are fully integrated within the School and undertake the induction process and online training common to all staff. Individual PDRAs are usually managed by the academic responsible for a research team. Individual training is organised by the research leader or identified as part of the PDR process. School funding for attendance at

major national and international conferences is available for PDRAs, as are funds to support research development. PDRAs are encouraged to use the university careers service.

We have a dynamic postgraduate (PGR) community with students holding awards from research councils, the Heritage Consortium, North East Consortium for Arts and Humanities, Collaborative Doctoral Awards, ERC and national government awards. We provide funding for PGR studentships by open competition, and doctoral partnerships have been held with a range of institutions and collaborators (Historic Environment Scotland, Museum of London, National Trust, Sutton Hoo Society, Yorkshire Dales National Park Authority, Dales Landscape Research Trust, Norwich Castle Museum, Orkney Museum and the National Roads Authority of Ireland). The increasingly interdisciplinary nature of our research has also facilitated joint PhD development, e.g. linking Europe's Lost Frontiers and School of Chemistry and Biosciences through geochemical study of marine cores.

PGRs at Bradford are supported through the institutional 'PGR framework' requiring monthly audits and annual needs analysis. PGR-led conferences, workshops, seminars on shared skills, methods or transdisciplinary topics are also available. Our students have a support committee, with a principal supervisor, associate supervisor and mentor. The development of staff as PhD supervisors is mentored, with progression to principal supervisor status following initial involvement as associate supervisors. Regular contact with postgraduate students includes monthly meetings and annual progress monitoring. The University Graduate School provides a programme of research and transferable skills training (including employability skills). Like staff, PGR students are provided with free printing, and can apply for GBP1,000 research expenses to cover research costs and conference attendance. Further financial support for postgraduates is available through the Heritage Consortium, the North East Consortium for Arts and Humanities and through QR funding to postgraduates associated with GCRF International Development Fund projects. Within the university, PGR connect provides a peer support scheme and forum for postgraduates from across the university, and all faculty and PGR groups.

We have a highly engaged research community representing a wide range of experience, interests and specialisms. Representation at research committee meetings supports the integration of ECR, PDRAs, and PhD students. PDRAs and PGR students benefit from the clustering of research and teaching activities within dedicated space provided through the recent move into the main University building. Social and academic interaction is encouraged to enhance cross-fertilisation of research ideas and methods. The SAFS lecture series comprises 12 lectures per year and provides exposure to a broad range of research and an opportunity to network with leaders in a wide variety of fields. PGRs and PDRAs also have access to the joint common room to meet staff in an informal setting. Our highly connected structure integrates researchers at every career level.

Postgraduates and PDRAs participate in management of academic events and organise seminars, workshops and conferences. These have included the Iron Age Research Student Symposium (2017), and Modern Conflict Research Symposium (2018). The University's Statement of Principles Relating to the IPR of Student Research ensures inclusion of students as authors wherever their research contributes to a paper. PGR students also benefit from free access to CPD modules on Palaeopathology and Dental Anthropology and specialist analytical courses provided through the jointly administered Analytical Centre.

The University has recognised our work through awards for excellence in research publication (which include funds for further research), impact development, media training and public engagement. Beaumont, Gaffney C. and V., and Croucher have received publication awards for research e.g. Calanais [output 29], dietary signatures from dentine, and archaeological impacts on contemporary death [output 40]. The impactful work of academics is also celebrated through profile features on the university website (Gaffney V., Wilson and Evans), and all our successes are promoted through our dedicated mobile app, staff and Faculty Board meetings, Faculty and University research newsletters and social media. Our researchers have also been recognised through the Vice Chancellor's Prize for Excellence and Faculty Award for Excellence. Groups

receiving these include Curious Travellers/Visualising Heritage, Osteology and Digitised Diseases, the Forensic Team and the local TAG organising committee. The University assists in developing impact and social value from research through competitive funding for specific projects. SAFS staff have successfully sought central research development fund money to support impactful research including the Continuing Bonds toolkit for bereavement counsellors (Croucher), subsidiary surveys at Durrington Walls (Gaffney C. and V. [output 25]) and to fund travel to Jordan to initiate the successful BReaTHe application (Croucher, Evans).

3. Income, infrastructure and facilities

REF2021 has been a transformative period for our Unit. The restructuring of the School, the realignment of our research themes, facilities investment, and new and improved spaces for research, have significantly enhanced opportunities to engage with external academics, commercial and governmental partners, and facilitated impact beyond the University. In 2017 University restructuring provided the opportunity to aggregate School activities into new or refurbished teaching and research spaces at the heart of the campus. These changes allowed staff to engage in the design of world-leading research environments including specialist laboratories, dedicated workspaces and social areas to engage with, and promote, research in new ways. At the heart of these changes is access to computing and visualising technologies hosted by our 'Visualising Heritage' facility.

The opportunities provided by relocation have allowed us to group research teams synergistically, within clusters of project workrooms and archive facilities, and to accommodate project PDRAs, PGR students and associated technical and research staff. These include dedicated spaces for ENTRANS (Armit, Gaffney C. and Koon), Continuing Bonds (Croucher), the Biological Anthropology Research Centre (BARC, Buckberry, Curtis-Summers), Visualising Heritage (Gaffney C. and V., Wilson, Evans), Fragmented Heritage (Wilson and Evans), the North Atlantic Research Laboratory (Bond and Dockrill), Europe's Lost Frontiers (Gaffney V.) and the Adriatic Islands Project (Gaffney V.).

SAFS is a leading partner in the campus-wide Analytical Centre. The Centre provides access to a comprehensive suite of resources for chemistry and bioscience analysis which includes dedicated technical staff, service contracts and instrumentation including scanning and transmission electron microscopy (SEM/TEM), gas chromatography/liquid chromatography-mass spectrometry (GC-MS, LC-MS/MS), X-ray diffraction and vibrational spectroscopy. Staff are involved in the centre as instrument managers or members of the advisory panel (Koon, Stern and Wilson).

This arrangement has provided us with excellent stable light isotope laboratories, as well as specialised laboratories for histological and molecular sample preparation and analysis. From this, we have achieved a leading position for bulk, multi-isotopic analysis of archaeological materials, including bone, teeth, hair, shell and pottery residues, through the analysis of stable isotopes of hydrogen, carbon, nitrogen, oxygen and sulphur. The facility, including three, University-funded isotope ratio mass spectrometers, is set within a new, improved research space. The facility supports research collaborations managed by Beaumont, Koon, and Curtis-Summers, and innovative research outputs include incremental analysis of dentine and enamel (Beaumont, Bond [outputs 3, 5, 14]), sequential analysis of hair (Wilson [output 21]), and 'food crusts' preserved on the earliest pottery in northern Europe and East Asia. External funding from diverse sources provides a sustainable research income supporting key facilities including Raman and GC-MS analysis of mummy samples for Liverpool, Leeds, Manchester Museums and Harvard. Raman analysis supported artist attribution for the De Brecy Trust, analysis of frescoes and wall painting for Southwell Archaeology and Southwell Minster. Raman and GC-MS forensic analysis confirmed sources of organic remains for Police Scotland, while SEM, Raman and FT-IR analysis of historic mortars enabled historic building refurbishment by Womersleys Ltd. Our research using isotope data and services provided through the Analytical Centre has been published in leading journals including Nature, Science, PLoSONE, American

Journal of Physical Anthropology, Journal of Archaeological Science, and Proceedings of the Prehistoric Society.

Forensic Sciences, now fully integrated within SAFS, has also benefitted substantially from major investment in facilities. We have a brand-new forensic examination suite with a wide range of additional, realistic crime scene simulation spaces. The dedicated forensic taphonomy laboratory, with associated entomology facilities, supports whole animal taphonomic research for incorporation into staff and PGR projects. Forensic Sciences are also supported by the refurbished, off-campus, Crime Scene Facility and Taphonomic Field Station set on moorland west of Bradford.

The Biological Anthropology Research Centre (BARC) is an established, world-leading research cluster at SAFS [outputs 16, 17]. BARC pathology suites, and our Forensic facilities, provides an exceptional research resource and is designed to encourage interdisciplinary activity across Schools.

The dramatic enhancement of digital research capacity is illustrated through the level of investment the university has made to support analysis and visualisation of the large data sets that are now characteristic of almost every aspect of our research. Mobilising funding to create the capacity to capture, manipulate and display data has been facilitated through a GBP400,000 investment from a competitive University business award and Research England World Class Laboratories grant, support from the World Technology Universities Network and GCRF-QR, plus synergistic spends through UKRI-funded research. We now possess two, adjacent, visualisation suites for stereo imaging and videoconferencing. Facilities include a 2x2m stereo cube with tracking for interactive data visualisation and a 2x2m ROVR system (donated by the Mechdyne visualisation group). Analysis of data is supported by a dedicated High Performance Computing cluster with 280 Cores, 1.3TB of memory and 1.5 petabytes of dedicated storage. These facilities are managed by us in partnership with University IT services.

SAFS also possesses exceptional capacity for digital data capture through Visualising Heritage. This investment includes 5 aerial imaging drones, high-end photographic capabilities from Gigapan to macro work (including z-stacking), 3 FARO laser scanners, the first UK Geoslam Zeb Horizon mobile mapping system, 4 structured light scanners, an Insta 360 Pro 2 VR camera, RTI and photogrammetry for 3D recording of objects, computed radiography, and 3D microscopy (confocal and FVM). The research opportunities provided by such investment, and the pervasive requirement for visualisation within SAFS, has driven development of a new, interdisciplinary grouping, Visualising Heritage (Croucher, Evans, Gaffney C. and V., Wilson) with a remit to support research across the three designated research themes. With a dedicated Senior Scientist (Sparrow), the group supports software development, visualisation and agent-based modelling within research projects including BReaTHe, Fountains Abbey, Curious Travellers, and Fragmented Heritage and agent-based modelling within Europe's Lost Frontiers.

Within the REF2021 period, we have acquired new laboratories dedicated to lithic microwear analysis, soils/biological processing and environmental archaeology. Our Geophysics and Archaeomagnetic Dating Laboratory has been relocated within new, improved facilities and incorporates the only dedicated archaeomagnetic dating laboratory in the UK (Batt [outputs 8, 13, 24]). The existing suite of archaeomagnetic instruments has been supplemented by refreshed equipment enabling temperature dependent magnetic susceptibility measurements to allow identification of magnetic minerals. Our geophysics resource has been enhanced to provide excellent laboratory and field capabilities. Ground Penetrating Radar capacity was enhanced through a long-term loan of MALA equipment and a new earth resistance machine was recently provided through a commercial donation. The School maintains its established reputation in terrestrial geophysics through large scale surveys at major sites including Stonehenge (Gaffney C. and V. [output 25]) but has moved beyond terrestrial geophysics and now operates within the marine environment. Europe's Lost Frontiers (Gaffney V.) has established an internationally important, marine palaeolandscape group and the specialist seismic interpretation team provided by the project has added significantly to our analytical

capacity [outputs 24, 30]. Separately, the acquisition of a towfish sonar has facilitated Jennings' research in riverine, lacustrine and wetland environments. Europe's Lost Frontiers also provides capacity for large-scale 3D visualisation and agent-based modelling. Supported by SAFS massively enhanced computing capacity, geophysical research undertakes novel data fusion outputs integrating surface and sub-surface data, generating impactful models of heritage assets with richer interpretation value e.g. Fountains Abbey (Gaffney C.).

We have excellent research support provided by 5 technicians, a Senior Scientist and a specialist subject librarian, many of whom have published their own research. The University provides staff and PGR students with access to an excellent range of electronic and paper resources and significant archaeological collections. These include the Raistrick archive on the prehistory of the Yorkshire Dales and the Jacquetta Hawkes archive. The Wellcome Trust Bones, Bodies and Diseases project supported digital development of the Calvin Wells resource which holds the largest teaching collection of human skeletal remains in any archaeology department in the UK (4500+ individuals). These are now curated within new, environmentally controlled storage facilities, and co-located with three new osteology laboratories and a new radiography laboratory with traditional and digital radiography equipment. The co-location of the Integrated Life Sciences Resource Centre with shared digital autopsy and palaeopathology archive. IT support is provided centrally within the University and in conjunction with our imaging and visualisation specialists.

SAFS had a research income totalling GBP6,098,000 during the REF2021 period, from sources including UK and European research bodies, charities, government agencies and commercial companies. Recent funding applications have benefited from our interdisciplinary structure and projects such as Continuing Bonds operate across health and social sciences and generate funding from traditional research councils and emerging grand challenge sources including GCRF (e.g. BReaTHe). The development of computer capacity and digital heritage as a key, facilitating research theme, within the unit and across the University, has tapped into new research and commercial streams to fund studies requiring big data processing and visualisation. These include Europe's Lost Frontiers (2015-2021, GBP1,762,864.08), the HERA ENTRANS Project (2013-2016 (GBP779,534), the AHRC Fragmented Heritage project (GBP1,900,000), with supplementary funding for the Curious Travellers project (GBP229,332).

Commercial activity remains an important source of sustainable income, but also provides research data, routes to impact and development of KT networks. Within the REF period, contract income has been linked to archaeomagnetic dating (Batt), collagen and isotopic analysis (Beaumont, Curtis-Summers, Koon), organic residues (Stern) and digital services (Wilson). This activity supports academic institutions (Croatian Academy of Sciences and Arts, Zentrum für Baltische und Skandinavische Archäologie (Germany), The Danish National Research Foundation), museums (National Museum of Chile, Tyne & Wear Archives & Museums, Museum Lolland-Faster (Denmark), the Royal Ontario Museum, (Canada)), universities (Dublin, Warsaw, South Denmark, Otago, South Carolina, La Trobe, Oxford, Durham), and archaeological contractors (Wessex Archaeology, Oxford Archaeology, MOLA, Thames Valley Archaeological Services).

Research partnerships with commercial groups have been supported by our new, digital capacity and has provided significant in-kind research support from external partners. This includes Petroleum Geo-Services (PGS) and Royal Haskoning who have provided no cost, research access to marine seismic data, with a value of hundreds of millions of dollars in acquisition costs, for use in Europe's Lost Frontiers. Commercial geophysics groups, including MALA, provide access to remote sensing equipment for our research and train research students.

Our researchers utilise a range of national and international services to undertake research. Within Europe's Lost Frontiers, large survey ships for coring and remote sensing survey have been provided through national services for work in the North Sea. These include the Marine Institute in Ireland for research in the Irish Sea, the Dutch Geological Survey (TNO),

and the Flanders Marine Institute (VLIZ). Core sediments from SAFS research projects have been processed in facilities in Ireland, Belgium and the Netherlands and are shared with researchers from other institutions working on separately funded research projects, e.g. the University of York. These arrangements provide an exemplar of research collaboration, effective use of finite research materials and cost-effective analysis in facilities across multiple countries.

4. Collaboration and contribution to the research base, economy and society

We undertake research with economic and social impact through engagement with wider research communities, policy makers and society as a whole. To achieve this, we foster research relationships beyond HE, with commercial groups, non-governmental and non-profit-making organizations including charities, voluntary and community groups and third sector groups.

The staff have excellent support for collaborative research and networking through training, available to both staff, PDRAs and postgraduate students, and competitive research development funding, study visits and strategic network grants. Examples of activity include funding for attendance at closed events including the National Science Foundation/Smithsonian meeting on American Palaeolandscapes (Gaffney V.), group staff attendance for networking at major conferences including the annual SAA Conference and TAG, US TAG, CIfA, American Association for Physical Anthropology, Palaeopathology Association, and collaborative study at Durrington Walls with Warwick, St Andrews and University of Wales, St Davids (Gaffney C. and V.).

Our collaborative research includes many UK HEIs, independent research institutions and research consortia. UK universities undertaking collaborative research with SAFS include St Andrews, Bath, Birmingham, Durham, Edinburgh, Exeter, Glasgow, UCL, UCLan, Warwick, Oxford, Royal Holloway and York. Major independent research institutions working with us include the National Museum of Scotland, the British Museum and the Natural History Museum. UK collaborative research is also supported through The Heritage Consortium, an AHRC Centre for Doctoral Training (2014-2019) and the North East Consortium for Arts and Humanities. Together these groupings create deeper linkages between researchers across seven HEIs in the north of England. These consortia incorporate eight regional, national and international heritage organisations and networks, as well as with a wider cluster of 70 partner organisations. The Heritage Consortium is supported by GBP1,850,000 of postgraduate funding from the AHRC and GBP1,110,000 provided by the partners, and has funded five jointly supervised SAFS PhD students. Support for research in key areas in Scotland, including Jarlshof, Moussa and Old Scatness, is provided through the Scottish Cultural Heritage Consortium and enhanced PGR opportunities are provided through industrial placements, e.g. through digital collaborations with Historic Environment Scotland's Conservation Directorate at the Engine Shed, Stirling.

International and transnational research is supported through large collaborative projects. Europe's Lost Frontiers incorporates Cork; Copenhagen; Ningbo (China), Ghent, The Dutch Geological Survey, the Flanders Marine Institute, and the Sligo Institute of Technology through study of marine palaeolandscapes. The Estonian Research Council funded an embedded researcher to support knowledge transfer from this important research group to the Baltic area. The Stonehenge Hidden Landscapes Project is undertaken with the international Ludwig Boltzmann Institute and ArchPro. Collaborative remote sensing projects at Megara Hyblaea and Olynthos involved CNRS, Université de Provence, University of Michigan, SUNY at Buffalo (Illinois) and the Greek Archaeological Service (Gaffney C.). Fragmented Heritage and FossilFinder projects collaborate with the Universities of Tulsa, UC Berkeley, Tarragona (Spain), Dar es Salaam and the Turkana Basin Institute (Tanzania). BReaTHe and Augmenting Jordanian Heritage work with the Jordan Museum and Department of Antiquities (Wilson, Evans, Croucher), and Koon with the Cyprus Institute and University of Turin. Prestigious research collaborations include a biomolecular study of medieval metabolic syndrome undertaken alongside McMasters (Buckberry). The IRC-AHRC Network Communicating Hidden Heritages works with NUI Galway, UC Cork and Aberdeen (Wilson, Gaffney C.). AHRC-funded research

with the Universities of Schleswig and Kiel included a Humboldt Foundation Fellowship for work in Germany (Heron). Beaumont collaborates with University of South Carolina through the NSF/AHRC Diet, Migration and Health project and the Wenner Gren Spitalfields project. The Adriatic Islands Project is undertaken with the Universities of Split and Lakehead in Canada (Gaffney V.). The ENTRANS collaboration continued during the period in association with the Universities of Zagreb and Ljubljana. Dockrill and Bond's Gateway to the Atlantic: UNESCO BRIDGES projects, have partners in Iceland, Greenland, USA and Sweden. Viverone and Wet Futures includes the Universities of Cork, Wageningen, Turin, Padova, Cambridge, Goethe Frankfurt am Main, Terramare and Archaeologische Dienstleistungen (Jennings), whilst the chronological models and archaeomagnetic dating project includes the University of Reykjavik and the German Research Centre for Geosciences (Batt). A British Academy International Fellowship awarded through Bradford to Dr Chiara Villa resulted in an ongoing collaboration with the University of Copenhagen.

Our staff provide leadership within the discipline through significant committee roles or offices in learned societies including President of the Prehistoric Society and Council Member of the Royal Archaeological Institute (Gibson), Trustee of the Society of Antiquaries, Corresponding member Archaeology Data Service, A303 Scientific Advisory Panel (Gaffney V.), Chair of the International Society for Archaeological Prospection (Gaffney C.), Chair and Trustee, Swandro-Orkney Coastal Archaeology Trust (Dockrill and Bond), Chair of the British Association of Near East Archaeology steering committee (Croucher), Theoretical Archaeology Group Trustee (Croucher), President of the British Association for Biological Anthropology and Osteoarchaeology (Buckberry). SAFS staff are founder members of UK Research Infrastructure for Heritage Science and signatories to the memorandum on European Research Infrastructure for Heritage Science (Wilson, Gaffney C.). The exemplary position of UK Higher Education is demonstrated by Gaffney V.'s appointment as expert assessor of research performance in HE and national research institutes for the Croatian Agency for Science and Higher Education

Our staff undertake grant assessment for national and international agencies including NERC, BBSRC, AHRC, ERC, Welcome Trust, NRF (South Africa), NSF (USA), Historic Environment Scotland, the Polish Academy of Science, Deutsche Forschungsgemeinschaft, Canada Foundation for Innovation, Israeli Research Council, European Research Council, Belgium Research Council. Jennings's exemplary contribution to academic reviewing was recognised by the AHRC Peer Review College.

Staff undertake editorial duties for journals including the Journal of Archaeological Prospection (Gaffney C.), Archaeometry (Batt), Journal of Wetland Archaeology (Jennings), Journal of World Prehistory (Wilson), Science & Justice (Janaway). Staff regularly review manuscripts for a wide range of international journals including PNAS, PLOSone, Archaeological Prospection, Nature Scientific Reports, American Journal of Physical Anthropology, Antiquity, Archaeometry.

SAFS provides expert guidance with impact beyond Higher Education e.g. degradation of archaeological materials in Churchyards for Historic England (Koon), revision of BABAO standards on human remains and subject specialist guidance on human remains (Buckberry), national heritage capacity building for Jordanian Museums and Department of Antiquities, the UNHCR (Croucher, Evans, Wilson), the Historic England Standard Operating Procedure for Organic Residue Analysis and Archaeology: Guidance for Good Practice (Stern), Research Agenda for Scotland's Island Research Frameworks for Archaeology (Dockrill), revision of standards for archaeomagnetic dating (Batt), and the first Pan European Guidance on Ground Based Remote Sensing. Work by Gaffney C. for the Irish National Roads Authority was accepted in full into the new Transport Infrastructure Ireland standards for remote sensing in Irish road schemes after its formation in 2015. Janaway drafted the forensic archaeology component standard for the Chartered Society of Forensic Sciences and advises on best practice in archaeological forensics through the UK Forensic Archaeology Expert Panel (CIfA), the European Network of Forensic Science Institutes (ENFSI) and individual police forces. Staff provide CPD courses for the profession, e.g. the Archaeomagnetic Dating laboratory course

trains field archaeologists to take archaeomagnetic dating samples, enhancing their skills and ensuring valuable dating materials are retained. This has been attended by MOLA, Wardell-Armstrong, Headland Archaeology, Wessex Archaeology and seven other companies. Wilson provides digital CPD though Historic Environment Scotland and the Shetland Amenity Trust. CPD delivery on using archaeology for grief counselling has also been provided to the British Psychological Society, Division of Counselling (Croucher).

We hosted and organised national and international symposia and workshops during the REF2021 period. High-profile examples include the Royal Society-funded Theo Murphy International Scientific meeting on Marine Palaeolandscapes; the 12th International Conference on Archaeological Prospection; Wetland Archaeology 30th Anniversary conference; North Sea Lowlands to the Celtic Shelf Edge (Utrecht); the Croatian Archaeological Society Annual Conference (Hvar); Old Scatness Broch 20th Anniversary Conference; the Wellcome Trust Bones, Bodies and Disease meeting; the Anatomical Society Conference (Skin & Bones); Theoretical Archaeology Group, CAA-UK; and the SAFS, British Council/Newton Picarte Fund workshop, with Chile's Servicio Medical Legal, on restorative forensics in the context of human rights violations under Pinochet.

We generated economic and social value through collaboration with diverse communities, government agencies, commercial organisations, and the voluntary sector as KT partners. For example, NGO Mercy Corp uses digital heritage research by us to engage with displaced communities in Jordan and to promote refugee causes through UK government stands at the Royal Highland Show and at the Peace Festival, London (Wilson, Evans and Croucher). Research by Continuing Bonds supports UK health services and trains health workers to consider death in different and more positive ways through linked studies of archaeology and end of life care (Child Bereavement UK, CRUSE Bereavement, the NHS and Bradford Bereavement Support). Outreach events include virtual and live," death cafes", exhibitions at the Bradford Science Festival and in Bradford and Leicester Cathedrals, events for Managed Clinical Networks services and Association of Palliative Day Services, and a 'Festival of the Dead' with school children as part of the Dying to Talk project. We also engaged with the economy through commercial groups; we supported technical development or product testing (Geoscan Research, Mala), regional regeneration (Bradford City Council), major infrastructure development (HS2) heritage management (Historic England, Historic Environment Scotland, the National Trust) and marine exploration (PGS and engineering groups including Royal Haskoning)

Engagement with wider communities is key to our research and is demonstrated in both impact studies, specifically the high level of media interest in our research. Significant outreach also includes the Stonehenge Hidden Landscapes participation in the Royal Society Summer Science Exhibition, and the National Science Museum 'Lates' (Gaffney C. and V.). Fragmented Heritage and Europe's Lost Frontiers participated in the Edinburgh Science Festival and British Academy Festival of Science respectively. SAFS staff promote research through Science Cafes within Bradford (Jennings, Croucher, Evans and Gaffney V.). Fragmented Heritage, Curious Travellers and Fossil Finders engage global communities through Citizen Science web portals. Wilson and Croucher organised and chaired a Bradford South Asian Heritage and Black History Month online event.

Art collaborations emphasise the maturity of our interdisciplinary work and include participation by Europe's Lost Frontiers in the Waveney and Blyth Arts/Touching the Tide partnership "Discover Doggerland" Arts festival, and the "New Doggerland" exhibition (Thames-Side Studio). Follow on funding for Fragmented Heritage supported performance art at Coldstones Quarry (Hanson Aggregates), and textile artist Karina Thompson's Arts Council reflective on Digitised Diseases "From Cemetery to Clinic". A creative writing anthology inspired by archaeology and contemporary grief was produced as a project outcome of the Continuing Bonds Creative Dissemination project (Croucher). Gaffney C.'s (HEIF-funded) research into historic football grounds featured in 'Breaking Ground: Art, Archaeology and Mythology', and was shortlisted for

the prestigious William Hill Sports Book of the Year and showcased at the National Football Museum.

Our research is recognised through awards and prizes which demonstrate that the extent and quality of research by SAFS is recognised widely. Jennings and Menotti's publications on lake dwellings received the Ben Cullen Prize from Antiquity [output 27]. Gaffney (C. and V.)'s work at Durrington Walls was the British Archaeology 2017 research project of the year [output 25]. Gaffney V. received an MBE for contributions to landscape archaeology. Jennings is a British Academy Rising Star for engagement activity; Wilson's research on the Skrydstrup Woman won the 'World's Archaeological Research Award' in Shanghai [output 21]. Dockrill and Bond's work at Swandro attracted royal patronage for the Swandro-Orkney Coastal Archaeology Trust.

The quality of research by SAFS students also attracts accolades. Fitzpatrick received the Lloyd Binns Prize awarded by the Glasgow Naturalist. Tellier's PhD on prehistoric funerary practises in Wales was nominated for the 2020 CBA Book of the Year and AHRC Heritage Consortium students Rebecca Cessford and Laura Castells Navarro won the Cockburn prize for the best student presentation at the international Paleopathology Meeting. Castells Navarro also gained one of only ten places on the BSA Media Fellowship Scheme and a Cumberland Lodge Fellowship. Li Sou and the Historic Environment Scotland Collaborative Doctoral Partnership team were 'Highly commended' in the National Association of Learning Technologists Research Awards (Shetland Brochs).