

For Institution: University of Liverpool

Unit of Assessment: 13 Architecture

1. Unit context and structure, research and impact strategy

1.1 Context and Structure

Our research in the Liverpool School of Architecture (LSA) generates new insights, understanding and opportunities for the architectural, engineering, creative and cultural industries, and supports community needs, all of which provide pathways to impact. We have an established, inclusive research culture and have built on our strong performance in the last REF by refining our structure into six overlapping, interdisciplinary research groups:

Architectural and Urban History investigate historic and contemporary architecture, in relation to cities and urban situations. (Calder, Crompton, Iuliano, I. Jackson, N. Jackson (Lead), Kei, Kronenburg, Lawrence, Malathouni, Pepper, Ray, Swenarton, Schmiedeknecht, Zamarian)

Heritage carry out research on architectural and urban heritage and incorporate the Centre for the Study of Architecture and Cultural Heritage of India, Arabia and the Maghreb (ArCHIAM) which aims to provide an interdisciplinary research platform for historical and contemporary cultural developments across three interconnected global regions. (Alsalloum, Bandyopadhyay (Lead), Calder, N. Jackson, I. Jackson, Koeck, Kronenburg, Malathouni, Shepperson, Quattrone, Webb)

Urban Form and Social Space conduct research on the formation and transformation of urban forms in cities with an emphasis on social, political, design and planning implications. (Antonopoulou, F. Chen (Lead), Kei, Piazzoni, Xi)

Centre for Architecture and the Visual Arts (CAVA) carry out cross-disciplinary, practice-based research at the intersection of architecture and digital arts/media combining three interlocking knowledge domains: space, media and culture. (Antonopoulou, Iuliano, Koeck (Lead))

Acoustics Research Unit (ARU) conduct research into the measurement, prediction and subjective evaluation of sound and vibration in the built environment. (H-M. Chen, Gibbs, Hopkins (Lead), Lee, Seiffert)

Environment, Sustainability and Technology in Architecture (ESTA) investigate low carbon building performance, architectural resilience to future climate change, life cycle analysis of

sustainability strategies and advanced construction and digital technologies. (Agkathidis, H-M. Chen, Chow, Du, Finnegan, Lawrence, Mohammadpourkarbasi, Quattrone, Sharples (Lead), Urbano Gutiérrez).

These groupings have allowed us to expand research activity with targeted staff recruitment, and attract a high-calibre PGR cohort that engage with our areas of expertise. A degree of overlap in group membership has aided cross-fertilisation of ideas through the overarching LSA Research and Knowledge Exchange committee. We consolidated our groupings by increasing from 22.2 Category A FTE submitted in REF 2014 to 31.1 now*. By providing a rewarding and stimulating research environment, 74%* of Category A staff submitted in REF 2014 are submitted in REF 2021. Investment since REF 2014 has increased the number of Category A submitted staff by 57%*. This has supported our strategy to increase diversity, resulting in a 140%* increase in female staff, an 80%* increase in ECRs and a 122%* increase in international staff. One-third of our Category A submitted staff are female, up from one-fifth in REF 2014*. Since REF 2014, our PGR cohort has increased in size by 91%** and grant income has increased by 67%*** due to collaborations with industry, institutions and government (home and overseas) that have enriched our research environment and provided new sources of funding.

* Details in Section 2.1. ** Details in Section 2.4.1. *** Details in Section 3.1.

1.2 Achievement of strategic aims during the assessment period

To sustain our world leading research and impact we have invested in staff recruitment to diversify and strengthen the group structure, focussing on improving gender balance. Groupings have been honed to respond to imperatives and collaborative links outside the LSA and to promote our research strengths to PGR students. With a broad range of research, the vitality stems from the range of historical, technical, commercial, cultural and social impacts on the built environment, professional disciplines and associated industries, building users, communities of residents, consumers and city visitors. This has been supported by a more diverse and open dissemination strategy for outputs, along with research impact being embedded in the aims of the School through mentoring and individual research group meetings to support and identify pathways to impact.

1.2.1 Strengthening and enhancing our research groupings

The **Heritage** grouping is aligned with the institutional research theme on the same topic and LSA has been fundamental in extending its capacity and recognition. Bandyopadhyay specialises in the architecture of the Middle East and South Asia, and re-joined in 2015, bringing the established ArCHIAM Centre with him. Starting as a PDRA in ArCHIAM, Quattrone carries out research on traditional Omani architecture and heritage management and was promoted to a lectureship in

2017. Alsalloum was recruited (2017) to complement the work in ArCHIAM with her research on world heritage policies and associated values, particularly heritage-led post conflict reconstruction and rehabilitation processes. To broaden the research capability to include architectural heritage of pre-Islamic periods back into pre-history, Shepperson was recruited as a lecturer (2020) after joining ArCHIAM as a PDRA in 2018. Her archaeological background expands the scope to include archaeologically recovered structures and sites where standing architecture is entangled with archaeological remains. Research on twentieth-century architectural heritage is led by Calder on brutalist architecture, Malathouni who specialises in twentieth century architectural heritage, and Kronenburg on interdisciplinary investigations of live popular music venues for the preservation and retention of historic buildings for cultural and economic reasons based around tourism.

At the **intersection of heritage and architectural history**, Webb was recruited (2014) with expertise in digital tools and techniques that enhance our understanding of architectural heritage. His leadership on heritage and digital technologies in the Centre for Digital Humanities and Social Sciences at Liverpool resulted in interdisciplinary collaborations with History and Sociology, Social Policy and Criminology. Webb has aided research in criminology using digital modelling to re-analyse Bentham's Panopticon prison (the original design was never built) and virtual reality to walk through the scheme. In the 'Tracing the Past' project, a 3D laser scanner has been used to investigate the design and construction of medieval vaults inside churches and cathedrals; the geometrical data are then shared with site architects to help them in structural modifications, such as installing disabled access lifts at Gloucester Cathedral. To promote heritage using digital approaches to storytelling, Koeck developed a mixed reality visitor experience (2018) for St Georges Hall (Liverpool), a Grade 1 listed building and UNESCO heritage site with ≈250,000 visitors p/a. Two systems were developed: a ground-breaking volumetrically filmed (hologram) experience using HoloLens headsets and a simpler, more affordable version using wall projections for the final installation. With Jadavpur University (India), I. Jackson and colleagues launched an augmented reality app for Kolkata using vintage photographs from the British Library (2015); a subsequent iteration has been tested through the AHRC-supported project in Chandannagar (India).

To extend the remit of the **Architectural and Urban History** grouping into research on the history of architectural education, Zamarian was recruited as a lecturer (2018) following his PhD in the LSA on the post-war period (1945–65) of the Architectural Association School of Architecture and a fixed-term teaching appointment. Zamarian's research on architectural competitions complements that of Schmiedeknecht. Calder's research on Brutalism, culminating in a widely-acclaimed monograph (2016), has enhanced public understanding of its architectural value, helped custodians of several Brutalist buildings to manage and celebrate them, and changed the

way in which architecture critics and journalists think and write about Brutalism. This links to Malathouni's research into Preston Bus Station which has changed the course of a fifteen-year heritage campaign, creating a landmark case in post-war concrete architectural heritage and providing heritage professionals nationally and internationally with a new exemplar about the retention of Brutalist buildings. To broaden historical perspectives, Kei was appointed as a lecturer (2020) for her work on New Brutalism, particularly in 1970s buildings in the UK and Hong Kong. Impact on the architectural profession is evident in Swenarton's research on high-density, low-rise, street-based housing developed by architects at the London Borough of Camden in the 1960s and 1970s (most famously Neave Brown's Alexandra Road) leading to the monograph 'Cook's Camden: The Making of Modern Housing' (2017). This research (funded by RIBA, BA, Leverhulme Trust and the Paul Mellon Centre for Studies of British Art) contributed to the re-evaluation of the work of Neave Brown, including the award to him of the 2018 RIBA Royal Gold Medal, with the research forming the basis for the citation.

The new grouping on **Urban Form and Social Space** builds on the research of F. Chen with three new lecturer appointments. Xi and Piazzoni (2019) strengthen the study of contemporary architecture and urbanism, with Antonopoulou (2018) examining the role and agency of digital mediation and representation in the perception of urban space which also complements research in **CAVA**. The group's expertise covers urban morphology, spatial representation, urban regeneration, critical heritage, everyday urbanism, and transit-oriented urban developments; their research aligning with the interdisciplinary Faculty research theme, 'Sustainable and Resilient Cities'.

Five lecturer appointments have been made to expand the research covered within **Environment, Sustainability and Technology in Architecture (ESTA)**. Finnegan (2016) for his work on whole life sustainability and the financial aspects of sustainable design, Mohammadpourkarbasi (2018) for thermal simulation modelling, post-occupancy evaluation and life-cycle assessment for energy-efficient, cost-effective sustainable buildings, and H-M. Chen (2020) for circular economy and sustainability (her work on finite element modelling of heavyweight buildings also feeds into ARU research on structural dynamics). Du's appointment (2019) strengthened ESTA's capability on daylighting, with Lawrence (2020) providing an interface between environmental performance and history. To increase collaborative links with architects, artists and industry, Urbano Gutiérrez founded the Environmental Ceramics for Architecture Laboratory (ECALab) to develop new forms and production processes (2011).

The research capability of the **Acoustics Research Unit (ARU)** was extended through the recruitment of Lee as a lecturer (2014) whose expertise is in subjective and psychophysiological evaluation in building acoustics as well as urban soundscapes. Lee collaborates with

psychologists on noise in hospitals and the Institute of Ageing and Chronic Disease at Liverpool. Research on the measurement and prediction of sound transmission in buildings has driven new developments in International and European standards on building acoustics. Fulfilling a key initiative flagged in REF 2014, Gibbs and Hopkins developed new measurement methods to predict machinery noise in timber-frame multi-occupancy buildings. Impacts on society, creativity and education derive from their research on using safe levels of vibration to facilitate musical performance for deaf children and adults which stems from the group's expertise on vibration in buildings. For people who are d/Deaf, there are barriers to music education and participation in music-making. Hopkins and collaborators transformed the way that music is taught at a school for the d/Deaf where it has given children an understanding of pitch, enabled group musical performances, significantly improved engagement in music lessons and helped protect the teacher's hearing by reducing sound levels in the classroom.

1.2.2 Role of non-academic sectors

We have achieved our strategic aim from REF 2014 to increase the role of non-academic sectors in steering our research directions, activities and impact.

National and foreign governments help shape our research directions as evidenced by ARU researchers being invited to carry out funded research for the UK government to improve the assessment of speech security and for the Korean government on the prediction and evaluation of impact sound insulation in buildings due to heavy impacts. The latter topic had a high profile with Korean politicians and media due to many neighbour disputes in apartment buildings. The outcome was a prediction model to allow the Korean construction industry to estimate impact sound insulation; this was implemented in open access software. ArCHIAM's research activity influences, and is influenced by the government of Oman, in particular, the Ministry of Tourism and the Ministry of Heritage and Culture. Non-governmental international organisations, such as the Qatar National Library, National Museum (Oman), The Aga Khan Trust for Culture (Geneva) and The Barakat Trust (UK) have also supported ArCHIAM's work, making possible cross-cultural comparisons of Islamic vernacular heritage.

In the **cultural and creative sectors**, CAVA's activities have moved into digital architectural heritage and immersive experiences. CAVA has successfully built on existing collaborations with local partners (e.g. FACT, National Museums Liverpool, Tate Liverpool) to significantly and strategically expand their reach into cultural industries. The opening of RIBA North allowed CAVA to apply its digital expertise on practice-based, live R&D projects with creative industry SMEs in Liverpool and London (e.g. Draw & Code, Dimension) as well as global partners (e.g. Microsoft, JCDecaux). Using internal pump priming, CAVA partnered with Liverpool City Council to build a prototype around the concept of 'digital placemaking' using Microsoft HoloLens and this led to a

series of local collaborations including with the Mayor's Office and Culture Liverpool. Expanding into China, Koeck has partnered with Aardman Animations and Shanghai Theatre Academy to introduce a mixed reality cinema experience in Shanghai. This aims to give sustained economic, cultural and intellectual benefits for the UK and China through the AHRC UK-China Creative Industry Network Grant by transforming the delivery of Aardman's high-end animation work from a linear and pre-rendered TV/cinema or screen-based product into a non-linear, real-time, responsive, spatially immersive experience.

Industrial research drivers on the production of high-performance, environmentally-friendly ceramics in modern architecture from the Spanish Association of Ceramic Tile Manufacturers (ASCER) have steered research by Urbano Gutiérrez towards using flat and modular tiles to create complex surfaces and recycling tiles with minor defects. Morgan Industries have directed industrial research in the ARU by funding the development of new measurement systems to assess the acoustic performance of ceramic fibre blankets up to high temperatures (800°C) because standard test rigs used in architectural acoustics could not be used. This opened up new design applications for sound absorbing materials in power generation processes such as heat recovery steam generators. Primasonics Ltd carried out a KTP with the ARU on the acoustic cleaning of ship holds which was a new business opportunity. Interdisciplinary research between the ARU and the medical engineering group at Liverpool has demonstrated the efficacy of acoustic cleaning for porous metal implants used in the human body.

1.2.3 Dissemination and open access

Our research is disseminated in traditional academic formats with 42 books, 50 book chapters and over 200 journal articles published during this REF period. To reach audiences outside academia we increased the number of publicly accessible exhibitions, artefacts, designs and internet publications to make up 12% of our outputs. While open access journals are less common in some of our research areas, 15% of our journal articles were published as gold or green open access. Open access publishing has been supported by the Library's Research Support Team who advises on publisher and funder policies and manages the University fund to help staff publish gold open access where external funding is not available. To ensure credit and recognition for our researchers' outputs, all staff have an ORCID identifier.

Presentations at national and international conferences are facilitated by School of the Arts funding for registration, travel and subsistence. During this REF period our staff and their PGR students delivered over 370 national and international conference presentations. Internally, staff share their latest research with colleagues and students at the Staff Research Symposium. All research outputs are registered on the intranet to help researchers capture, collate and showcase

their research and impact activity as well as to comply with REF open access requirements and the University policy that all journal articles and conference proceedings should be available from the Institutional Repository. The Liverpool Data Catalogue allows our researchers to create a record of their research data in a secure online environment, recognising that data are a key asset that continue to yield benefits after the conclusion of a project. One example is ARU research on speech security for the UK government which resulted in an open access, creative commons, database of anechoic speech recordings (currently the University's 9th most downloaded dataset).

1.3 Future strategy, aims and goals

Our ambition for the future is to build on the successes, opportunities and capacity developed during the current REF cycle. The major strength of LSA has always been the broad portfolio of research expertise with significant geographical reach, combining solo researchers and research clusters spanning humanities, science and engineering, a characteristic we aim to maintain. Our aim is to provide world-leading research to understand, analyse and improve the built environment, and make impact by engaging with the community and the architectural, engineering and cultural professions.

We will continue to work across the humanities, sciences and engineering using cross-disciplinary academic appointments and interdisciplinary funding opportunities. Specialist groupings in the humanities – Heritage, Urban Form and Social Space, CAVA, but also emergent areas such as health and well-being – all sit at the intersection of disciplinary boundaries and provide the basis for future senior research leadership appointments. Our capacity in digital humanities will be used to underpin and enhance our outputs, demonstrate our outreach commitment through exhibitions, films and digital media productions and use digital fabrication to address environmental sustainability.

Even before the arrival of COVID-19, we were planning to grow our research on health and well-being and its effects on the design and sustainability of the built environment. Over the coming years, the pandemic will be a driver of new research directions and funding. In this respect, our research groups are well-placed to set the agenda, and deliver high-quality research through our technical expertise, historical perspectives and analysis of the state-of-the-art. Research areas are expected to include the future of housing design and refurbishment, portable architecture, and the interplay between ventilation, energy usage, lighting and sound insulation for home working and in the offices, hospitals and schools of the future.

Our future research directions are reinforced by links to institutional research themes including Heritage, Digital, Infectious Diseases and Advanced Materials. The climate emergency provides the impetus to intensify our activity on zero carbon developments (including carbon positive and

zero carbon cities), whole life impact of modern methods of construction and the recycling of construction materials, linking to the new cross University Climate Futures theme. This will be complemented by an increased focus on influencing policy at local, national and international levels. Recent collaborations with heritage, museum and cultural sectors will allow us to expand our research in a post-pandemic era using digital techniques and tools including virtual, augmented and mixed realities (VAM realities), laser scanning, remote sensing and large-scale digital repositories. Worldwide, the form and usage of the urban environment is likely to change and we are in a strong position to lead this research into urban morphology, regeneration and future forms of transit-oriented urban developments.

Much of our research impact stems from its cross-disciplinary nature, ranging from digital storytelling of cultural heritage to the role of mechanical vibration in facilitating musical performance for the d/Deaf. During this REF period all our research groups have significantly increased their interaction with museums and the cultural sector. Our intention is to build on existing pathways to impact that have combined humanities- and environment-based research with emergent digital opportunities offered through laser scanning, VAM realities, digital archiving and artificial intelligence. We will consolidate this form of impact in the coming years with support from University pump priming funds, UKRI, Industrial Strategy Challenge Fund, Overseas Development Assistance (ODA) and the Global Challenges Research Fund. This will allow us to cultivate cross-disciplinary research across the humanities and social sciences (archaeology, cultures, history, music), and science and engineering (building physics, climate, computing and environmental science).

To ensure diversity and sustain research excellence and leadership, we will recruit staff at lecturer level and replace retiring senior staff. Recent recruitments have introduced wider disciplinary and cross-disciplinary interests alongside greater geographical coverage. This enhances our ability to address global challenges faced by the UK, developing countries and diasporic communities. Current staff expertise is mapped against the key global challenges that we aim to address in the future so that we can strategically focus on recruiting personnel that offer global leadership through cross-disciplinary approaches. This will allow us to continue attracting a wider range of national and international funding sources by fostering new collaborations between research groups and industry.

To sustain vitality in the PGR cohort and research groups our aim is for each FTE to have a minimum of two PGR students at any time, increase the number of post-doctoral researchers through external grants, and increase usage of open access research outlets using internal funding.

To support our ambitions, the University is investing in a £23M extension of the current premises to be completed in 2023. This new building will house LSA teaching and research staff and enhance the research environment for PGR students and PDRAs by locating research labs at the heart of the building. We will gain a significant enhancement of the research infrastructure and accommodation along with extended physical workshops and digital laboratories. Each research grouping will benefit from dedicated workspaces to support their activities and PGRs. The new extension will provide greater visibility for our research output, with opportunities for outward-facing galleries that facilitate public engagement and impact.

2. People

2.1 Staff profile

Our strategy for growth and diversity has led to an increase in our return from 22.2 Category A FTE submitted in REF 2014 (with 26.2 Category A FTE eligible) to 31.1 Category A FTE submitted in REF 2021.

LSA has seven Professors, four Professorial Fellows, four Readers, five Senior Lecturers, and 15 Lecturers with a responsibility for research. Our rewarding research environment has led to the retention of 74% Category A staff from REF 2014 (Agkathidis, Calder, F. Chen, Crompton, Gibbs, Hopkins, I. Jackson, Iuliano, Pepper, Schmiedeknecht, Sharples, Swenarton, N. Jackson, Koeck, Kronenburg, Malathouni, Urbano Gutiérrez). To maintain vitality and to increase the range of expertise we recruited more Lecturers to expand from six in REF 2014 to 15 now. This has increased the number of Category A submitted ECRs to nine (seven female) from five (three female) in REF 2014 (80% increase). Architecture has benefited from seven new Teaching and Research (T&R) posts and three replacement T&R posts. The majority of staff are full-time with seven staff on part-time contracts.

Gender balance has significantly improved during this REF period with an increase from five female Category A submitted staff in REF 2014 to 12 now (140% increase); this corresponds to an improvement in the female:male Category A submitted FTE ratio from 1:3.4 to 1:1.7. Through our planned staff expansion we now have a staff gender split that is more representative of our PGR cohort which, on average, has been 1:2.0 (female:male) over this REF period. This achievement has been aided by training for all staff with modules on Diversity and Equality and Unconscious Bias since 2014 alongside the University recruitment policies that ensure fairness with gender-balanced appointment panels. We continue this process to ensure a diverse and representative group of staff and maintain our active role in the School's Athena SWAN self-assessment group.

With 25% of current Category A submitted staff identifying as BAME, the expansion of LSA has allowed us to increase diversity across grades from Lecturer to Professor. We have a rich mix of international staff with 56% of Category A submitted staff from countries including China, Germany, Greece, India, Iran, Italy, South Korea, Spain, Switzerland and Syria; an increase of 122% since REF 2014. This has extended the geographical reach of the School, added new research perspectives, diversified the audiences engaging with our research beyond academia and resulted in overseas grant capture and collaborations.

2.2 Staffing strategy

Recruitment strategies have been guided by the development of key thematic areas of research and impact (acoustics; architectural and urban history; architecture and the visual arts; environment and sustainability; heritage), with positive action to improve the gender balance and support research-led curriculum development. This has been supported by a drive to expand the number of lecturers whilst maintaining a similar number of senior staff, allowing us to introduce vitality alongside stability.

As an external appointment, Bandyopadhyay's appointment to the Sir James Stirling Chair (2015) strengthened heritage research leadership, especially in the Middle Eastern and Indian Subcontinental regions. Lecturer appointments in building science and technology areas have expanded the capability of ESTA and the ARU (Lee, 2014 - promoted to Senior Lecturer in 2019; Finnegan, 2016; Mohammadpourkarbasi, 2018; Du, 2019; Lawrence, 2020; H-M. Chen, 2020). Lecturer appointments in the humanities topics have strengthened the Heritage group (Alsalloum, 2017; Quattrone, 2017; Shepperson, 2020), Architectural and Urban History (Zamarian, 2018; Kei, 2020) and established a new grouping, Urban Form and Social Space (Antonopoulou, 2018; Xi, 2019; Piazzoni, 2019). Eight of the thirteen Lecturer appointments are female which should lead to improved gender balance across senior staff grades in the future.

There were promotions for 19% of Category A submitted staff during this REF period, these were: Personal Chair for I. Jackson (2017) in recognition of his research investigating architecture and planning in 'tropical' climates; Readerships for Crompton (2015), Urbano-Gutierrez (2019), Iuliano (2019), Schmiedeknecht (2019); and Senior Lecturer roles for F. Chen (2015) and Lee (2019).

Four Professorial Fellows have been employed on fractional contracts allowing three of these (Pepper, Swenarton and Gibbs) to act as mentors to other staff and offer advice on impact, publications and grant applications.

Five postdoctoral researchers (three female) have been employed during the REF period that have extended our research capability: two in ArCHIAM, one in the ARU, one in Architectural and Urban History, and one in Heritage. These were funded by Ministry of Heritage and Culture (Oman), UK government, Leverhulme Early Career Fellowship and AHRC respectively.

2.3 Staff development

2.3.1 Time commitment to research and impact

All staff on teaching and research contracts are guaranteed at least one day every week to dedicate to research and/or impact, and typically have two days. They can also apply for research and impact leave after completion of at least five semesters of teaching and administration. Staff applying for leave give clear aims and deliverables, such as outputs, impact and grant applications. In this REF period, 12 members of staff were awarded research leave from six to 12 months or allocated lightened teaching and administrative loads for completion of research projects or developing new research initiatives. This is a notable increase from only five in REF 2014.

2.3.2 Internal funding support for research activity

The School of the Arts provides competitive funds (≈£130k annually) for pilot studies, conference attendance and pump-priming for international collaborative research initiatives; since 2014, the majority of LSA staff have been recipients of this funding.

Since 2017, LSA has benefited from its own David Foster Wicks endowment fund (≈£330k total). To-date there have been 12 successful projects which have enabled staff to apply for specific resources including equipment and travel funding to facilitate their research and impact projects.

We have had considerable success in winning internal funding: eight projects in the Knowledge Exchange, Impact and Public Engagement Scheme (up to £10k each) to develop relationships between academia and industry, five ODA-related projects (up to £13.7k) addressing challenges in economic development and wellbeing faced by developing countries, four projects to support the development of impact (up to £9.3k), three projects on developing research partnerships with India (up to £10k), one project for ECR funding (£2k), and one project from the internal Industrial Strategy Challenge Fund (£25k).

2.3.3 Mentoring, training, advice and peer review

Research group meetings give opportunities for staff to discuss and develop their own research and impact ambitions with colleagues working in similar areas. As a focal point for these groups, the LSA Research and Knowledge Exchange committee shares recent research successes,

upcoming events, information on upcoming calls for research grants, REF preparations and PGR development. Research groups provide support to staff through partnerships and by sharing research strategies, methodologies, successful grant proposals and experiences. The lunchtime LSA research seminar series allows staff to share their research with other groups and benefit from peer review in an informal setting.

All staff have a research mentor from the professoriate who can give advice on publications, grant applications and research and impact strategies. Mentoring has helped develop the research profiles of ECRs by reviewing draft research publications and advising on publication strategies, grant applications and potential collaborations. Due to potentially long lead-in periods for impact, staff are encouraged to log evolving evidence on the intranet (Elements). This facilitates the mentoring of impact case study authors and identifies aspects that would benefit from funding, such as HEIF impact support.

Procedures are in place to maintain and improve the quality of external grant applications with formal reading and review programmes. Grant proposals are peer-reviewed at departmental level and also by senior staff from other departments prior to submission. Several staff members are peer-reviewers for external grant awarding organisations (e.g. AHRC, EPSRC). Their experience is brought back into the University through internal review boards and is valuable in developing applications from early-career researchers. This has helped us increase the number and value of successful grants.

Our staff have access to University networks which provide career support and foster equality and diversity on campus; these include BAME, LGBT, Carers, Parents, Women in Science and Engineering and Female ECR networks. Our Faculty has established an HSS ECR Network for new lecturers, postdoctoral researchers and PGR students with a series of events on funding, policy, consultancy work and impact. For ECRs there is a dedicated intranet site and newsletter providing information on training, funding opportunities and events.

The University provides postgraduate supervision workshops for new staff, which they attend within one year of appointment. ECRs are encouraged to become secondary supervisors for PhD students to gain the experience needed to become primary supervisors once they have seen a student through to successful completion in their secondary supervisor role. As a result of these support processes, the majority of staff have supervised PGRs during this REF period. For supervisors at all levels of experience, the PGR Supervisors Network provides training and development opportunities.

The Head of Department has overarching responsibility for REF preparation at a strategic level with the REF lead overseeing preparation at operational level on outputs and the environment, and a REF Impact lead overseeing preparation of the impact case studies. REF committees have representation from at least one ECR. The REF lead runs the rolling reading programme to formally evaluate research outputs that are submitted by staff. This evaluation is carried out by two senior members of staff (using a third reader where needed), to give a single rating and review that is fed back to staff with transparency as to who carried out the review. The REF Impact lead convenes a separate group that assesses the impact case studies and provides feedback from at least four reviewers within LSA as well as considering reviews provided at Faculty level.

2.3.4 Professional qualifications

We continue to recruit research staff who are professionally qualified with over 57% of our staff being trained architects or chartered engineers (e.g. RIBA/ARB and CEng). This supports our strategy of increasing research relevance and impact through shared good practice and professional engagement as well as facilitating research-led teaching. Existing staff are encouraged to seek professional qualifications where it benefits their personal development and research.

2.3.5 Research ethics

Staff undergo compulsory research ethics training and LSA staff are active in assessment committees and as reviewers at University level and in the School of the Arts. Staff and PGR students have access to drop-in sessions to discuss aspects of their research ethics applications.

2.4 Postgraduate researchers

2.4.1 Expansion of PhD cohort

The increase in staff numbers and expansion of research expertise has allowed us to increase the size of our PhD cohort by 91% from 35 students at the point of submission in REF 2014 to 67 at the end of this REF period (average over this REF period was ≈ 58 students). PhD completions per Category A submitted FTE have increased by 45% from 1.19 in REF 2014 to 1.72 now.

At the beginning of this REF period, we started co-supervising PhD students with staff at Xi'an Jiaotong-Liverpool University (XJTLU) in China (the partnership between the University of Liverpool and Xi'an Jiaotong University). This has steadily built up, such that in 2020 we have 18 registered students. Their PhD research topics align with the LSA research groups, and during their study they spend up to three months at Liverpool to integrate with the Liverpool cohort.

Over this REF period, our cohort comprised (on average) 68% international students (Canada, China, Egypt, Germany, Greece, Indonesia, Italy, Japan, Jordan, Kuwait, Malaysia, Mexico, Morocco, Nigeria, Oman, Portugal, Russia, Saudi Arabia, South Korea, Spain, Thailand, Turkey) and 32% home/EU students. The female:male ratio has been (on average) 1:2.0 which is similar to the ratio of our Category A submitted FTE which is 1:1.7.

As part of our strategy to develop and support the next generation of interdisciplinary researchers, interdisciplinary research topics are encouraged through shared supervision across different departments in the University, as well as with XJLTU. In this REF period we have had joint supervisory arrangements with Civic Design, Communications and Media, Computing Science, English, Engineering, Geography, Management and Psychology.

2.4.2 Environment

PGR students are represented in our discussions and decisions on Departmental and School matters. At Department level, they have representation in the Staff/Student Liaison Committees. These are chaired by a student member and include student representatives from all Levels (undergraduate and postgraduate). The Head of LSA is a standing member and all staff involved in postgraduate research supervision and the Director of Postgraduate Research attend Committee meetings. Meetings are held three times a year and a postgraduate student represents all postgraduate students in LSA.

The School of the Arts Postgraduate Research Committee oversees the management of PGR students, ensuring that its discussions are informed by consultation with the students themselves. The Committee is chaired by the School Director of Postgraduate Research and members include Departmental Directors of Postgraduate Research from each Department and student representatives from the five Departments in the School.

2.4.3 Research opportunities and outcomes

Research groups arrange presentations by PhD students of their research to other students working in similar research fields (including those in the MA and MSc) and to staff. This gives our students experience of presenting in a conference style with questions and feedback. Each year there is a PGR conference where all students give a progress presentation as part of the evaluation process.

To promote the research of doctoral students outside the University, all PGRs are encouraged to apply to the School PGR Support Fund for research expenses that support presentations at conferences and workshops. These funds can also be used for fieldwork, archival work, and

research materials that cannot be funded from other University sources. Full-time students can apply for up to £300 per annum (pro rata for part-time students) for their expenses.

PGRs can apply for financial support in organising workshops, symposia or small conferences with an academic staff member acting as a sponsor. Full-time students can apply as a collective or as an individual with the maximum value of a single bid being £1k (pro-rata for part-time students) for the reimbursement of expenses.

To give PGRs the opportunity to establish themselves as researchers, and hone the writing skills needed for a research career, supervisors support and encourage their students in the submission of conference and journal publications during, or at the end of their research period. This resulted in our PGR cohort producing an average of 17 conference papers and 9 journal papers per year.

2.4.4 PGR development and training

Each year our PGR students make a professional and personal development plan (Development Needs Analysis) to advance their research progress and meet longer-term personal and professional ambitions. This is formulated in consultation with students' supervisors and considers communication skills, research methods, impact, ethic, employability and entrepreneurship. Within three months of registration, students are encouraged to reflect and review their abilities and to plan the acquisition of new skills and professional competences. This plan is used by students and supervisors to identify priorities for development and training. To inform this discussion, the student considers the training and development opportunities in the School of the Arts, Faculty and Liverpool Doctoral College. The student and supervisory team agree a programme of professional development which is reviewed annually. Within the University, students can choose from development themes ranging from communications skills, personal resilience, research productivity, creative and critical thinking, public engagement, leadership skills and career planning. Students record developmental activities in an online Portfolio of Activity.

LSA has seven PhD students registered through formalised doctoral training routes. These include four in the AHRC North West Consortium Doctoral Training Partnership, one in the EPSRC and ESRC Centre for Doctoral Training on Quantification and Management of Risk and Uncertainty in Complex Systems and Environments, and two in an EU Marie Curie Innovative Training Network. These provide additional training opportunities (ranging from general workshops on thesis writing or entrepreneurial skills to specific training on sustainable materials); this training is also available to our PGR cohort. Koeck is the institutional lead for Transformation NW, a doctoral training programme applying design and creative techniques to enhance growth and prosperity for businesses in the North West in which he supervises two students.

Advanced interdisciplinary and innovative methodological training is provided for PGR students from the ESRC North West Social Science Doctoral Training Partnership and the AHRC North West Consortium Doctoral Training Partnership. engage@liverpool represents the University of Liverpool's contribution to 'Methods NorthWest', a research and methods collaboration involving a range of institutions across the North West of England; for our students working on social science this has involved an initiative to pioneer theoretical and methodological innovation.

During this REF period, we have had four funded PhD studentships from Low Carbon Eco-Innovatory (LECI) and one with Eco-I NW where our students work alongside businesses (Urban Splash, Fifth Sector, Knowsley Safari, Base Energy, Fielden Clegg Bradley Studios) to reduce energy consumption, reduce carbon emissions and produce sustainable building solutions. This provides their research with ecological validity along with the benefit of vocational experience.

2.4.5 Employability and skills development

To enhance the employability of our PGR students (and delivering on the Concordat to Support the Career Development of Researchers), they are given the opportunity to take a 15-day placement outside academia (public, private and charity sectors) for which a £500 bursary is available from the Liverpool Doctoral College. Our students have taken this opportunity to gain experience and new skills with Arup, Bluecoat, Crowberry Consulting, Drome Architects, FACT, National Museums Liverpool, Open Eye Gallery, Red Ninja, 20th Century Society and RIBA North-West.

3. Income, infrastructure and facilities

3.1 Research income

We have increased our research income by 67% from £1,397,675 in REF 2014 to £2,344,738 in REF 2021. This has been achieved by building upon previous funding streams, the strategic creation of our Heritage group and through the expertise and international standing of our staff that has expanded the range of funding sources. Staff are supported in all aspects of preparing grant proposals at Department, School and Faculty levels in terms of costing, peer-review and advice on embedding impact. The research groups targeted different National and International funding sources as indicated below.

Architectural and Urban History

This group targeted Leverhulme Trust funding to allow expansion with postdoctoral researchers and to consolidate their research strengths. Shasore won a Leverhulme Early Career Fellowship on 'Architecture, Civic Design and the Municipal Project in Britain, 1919–1979' (2017–2020: £87k).

This project fits exceptionally well with our 20th century expertise, particularly the 'Architecture and Welfare State' project instigated by Swenarton, and the work undertaken by Pepper, Richmond, and Dunne. Building on the research undertaken in Ghana and Nigeria as part of the 'Fry and Drew Project' (2011–2014 Leverhulme Trust), I. Jackson won funding from the British Academy on 'Architecture and Planning in the Tropics: From Imperial Gold Coast to Tropical Ghana' (2015: £30k). His most recent grant success with the Leverhulme Trust will investigate the architecture of the United Africa Company. Working in collaboration with archivists at Unilever, the project will focus on the buildings, plans, and mercantile projects in West Africa, 1872–1960. This will fund 2.5 postdoctoral research positions for two years (2020–2022: £298k).

In this REF period we have sought funding for major monographs. Calder's earlier research and funding on Brutalism and Concrete was critical in developing his ideas on energy and architectural history, and was pivotal in securing a British Academy Mid-Career Fellowship Scheme on 'Energy in the History of Architecture' (2018: £103k) for his latest monograph 'Architecture and Energy: From pre-history to climate crisis'. N. Jackson's substantial monograph (235,000 words, 200 illustrations) 'Japan and the West: An Architectural Dialogue' also benefitted from Getty Research Institute (2014: ≈£11k) and Great Britain Sasakawa Foundation (2017: £3k) grants.

Centre for Architecture and the Visual Arts (CAVA)

Building on trans-disciplinary design principles developed in CAVA, Koeck won funding from Innovate UK (Design Foundations competition) with Spark Compass UK to develop intelligent, real-time, hyper-local screen-based Out-of-Home (OoH) marketing innovation (2017–2018: £30k). Koeck's links with China led to three UKRI/AHRC UK-China Creative Industry Partnerships projects (2019: £25k, 2020–2022: £253k, 2020–2021: £75k) with Aardman Animations, Shanghai Theatre Academy and the Shanghai Media Industry Association. These break new ground by dissolving traditional boundaries between cinema screen and audience, creating a responsive and immersive environment with real-time content driven by games technology and AI.

Heritage

A major grant won by Bandyopadhyay was from the Qatar National Library (with Alsalloum and Quattrone) to establish the world's largest digital archive for Gulf architecture and urbanism (The Gulf Architecture Project, GAP, 2019–2020: £737k). Bandyopadhyay, with Quattrone, won funding for researching and developing management strategies for vernacular heritage sites in Oman from the Ministry of Heritage and Culture, Oman (2015–2018: £83k), as well as from a private benefactor for the rehabilitation and restoration of an 18th century merchant house (2016–2017: £31k), which have allowed them to continue research and impact work on oasis settlements and architecture in the Arabian Peninsula. These projects resulted in enhanced understanding of the

cultural landscape of the southern Arabian Peninsula, and its relationship with the Western Indian Ocean region.

Expanding on digital surveying methodologies that Webb used in his PhD at Liverpool, and expertise in medieval history (Buchanan, History), a number of small grants (Lambarde fund, Paul Mellon Centre for Studies in British Art) were used to develop the proof-of-concept needed to win an AHRC Early Career Grant proposal (Webb (PI) jointly with Buchanan (History, Co I)), 'Tracing the past: analysing the design and construction of English medieval vaults using digital techniques' (2018–2020: £199k).

Environment, Sustainability and Technology in Architecture (ESTA)

To bring research on new ceramic materials into practice, Urbano Gutiérrez won funding from the Spanish Association of Ceramic Tile Manufacturers (ASCER) (2014–2019: £44k).

Acoustics Research Unit (ARU)

The combined experience of Hopkins and Lee on the measurement, prediction and subjective evaluation of impact sound insulation in heavyweight buildings that are common in Korea led to research funding from the Korean government and the Korean Institute of Civil Engineering and Building Technology (Hopkins and Lee, 2014–2018: £222k). This led to further funding for Lee from the Korean Institute of Civil Engineering and Building Technology on perceptual modelling of floor impact sound (2014–2015: £44.9k); psycho-physiological assessment of floor impact sound (2015–2016: £35k); development of guidelines for dealing with noise complaints (2016–2017: £30k); and the perceived stress due to noise exposure inside buildings (2017–2018: £24k). These projects provided an ideal platform to research the European context where lightweight buildings often provide poor insulation against heavy impacts; this was funded within an EU Marie Curie ITN project 'ACOUTECT' in a consortium of five academic and five industry participants across Europe (Hopkins and Lee, 2017–2019: £372k).

Sustained links with an SME (Primasonics) through consultancy work led to KTP funding from the Technology Strategy Board on the acoustic cleaning of cargo ship holds (Seiffert and Hopkins, 2014–2016: £92k). Previous UK government funding on speech security in buildings during REF 2014 led Hopkins to develop further projects with other government department on maintaining the confidentiality of speech (2016–2019: £157k).

3.2 Doctoral training income

Full scholarship funding has been won for PhD students (2014–2020: ≈£347k) through AHRC, EPSRC and ESRC centres for doctoral training and the ERDF Low Carbon Eco-Innovatory fund. Success with the latter has led to further funding for five studentships (2020–2023: ≈£254k).

3.3 Consultancy and CPD income

Consultancy allows increased interaction between our researchers and industrial/commercial/government sectors for which the University provides administrative support to staff. Income from ArCHIAM, ARU, CAVA and ESTA was ≈£135k.

Provision of CPD by the ARU has bought in £160k from courses on acoustics for industry and the UK Institute of Acoustics. This facilitates knowledge exchange with practitioners and provides a dissemination route for research.

3.4 Infrastructure

A significant enhancement to our existing accommodation will be the new £23M extension to the existing Leverhulme Building. Reflecting the vitality and sustainability in LSA, it will accommodate staff and researchers along with laboratory and workshop facilities. The extension will be fully accessible with all mobility issues in mind. An international competition was won by Architects O'Donnell+Tuomey in 2019 with staff and students fully-involved in the early selection stages. Research centres will have designated areas and every individual researcher will have their own office space.

LSA were involved in the University of Liverpool in London (2014–2020) which enhanced and expanded the range of professional and industry links for staff that we now maintain from Liverpool.

3.5 Facilities

In 2017/18 Architecture used a significant part of its endowment funding (David Foster Wicks) to enhance AV facilities in the Leverhulme Building for research and teaching. This resulted in the installation of new PCs, visualisers, projectors, speakers, webcams, microphones, screens, and lecture-capture equipment. Endowment and LSA funds supported the purchase of an Unmanned Aerial Vehicle (UAV) and 3D laser scanning equipment (£53k) to enable field research and impact generation in the Heritage group, software licenses, immersive technologies for research and research-led teaching, a heliodon (£18k) to investigate solar impact on buildings and neighbourhoods, a robotic arm (£23k) to support new research on automated fabrication and refurbishment of the semi-anechoic acoustic chamber (£8k). These initiatives are linked to a broader development strategy for digital and cross-disciplinary research and allied curriculum development. To support research into digital architecture there has been an investment into equipment and software (£350k over a three-year period).

For research and dissemination that requires models for exhibitions and conferences, our workshop facilities have significantly improved since 2014 with new, replacement or updated equipment. LSA now has two fully-equipped workshops with four new laser cutters, a new XYZ machine and two assembly rooms. This was complemented by a commensurate increase in technical support staff with ten dedicated production resource staff.

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

4.1 Collaborations, networks and partnerships

Collaborations with academics, architects, planners, government and industry help us identify new research areas which satisfy the needs of practitioners. International perspectives are provided by our research collaborations on outputs and grants involving academics in 52 universities in 26 countries.

4.1.1 Advisory roles

Our staff expertise has led to advisory roles at international, national and local levels.

International: Collaborations on urban morphology with Southeast University in China led to Yangzhou municipal government (China) inviting F. Chen to join a judging panel for a new town master plan (2014). Bandyopadhyay is heritage advisor to the Ministry of Tourism, the Ministry of Heritage and Culture in Oman, helping them to develop regional heritage strategies, and two museums in Oman, to build their permanent collections and exhibits (2014-present). For the National Museum in Oman, Quattrone designed two bilingual educational workshop booklets in child-friendly formats. ArCHIAM's collaboration with the Qatar National Library is now helping them build a major digital archive.

National: Koeck presented CAVA's Open Planning demonstrator app at the Houses of Parliament, having been chosen as a best practice project by the All-Party Parliamentary Design and Innovation Group (2015). Developed with public and private sector partners, it allows instant access to planning updates in a specified area to ensure a fairer, accessible and democratic public planning process. Finnegan is an invited academic on the University forum of the UK Green Building Council which reviews relevant government policies.

Local: Liverpool council have declared a climate emergency and set a zero-carbon deadline for the city. To help achieve this, Finnegan is working with National Museums Liverpool (who own and operate seven museums/galleries) and the Everyman & Playhouse Theatre to create action plans to achieve Net Zero Carbon status. Finnegan's industrial links in sustainability in

construction and operation enabled three PhD studentships with the ERDF Low Carbon Eco-Innovatory fund that were financially supported by Egg Homes, Urban Splash and Knowsley Safari Park. The latter linked to Finnegan's research to help Knowsley become the world's first zero carbon safari park at zero cost with an advisory role to Lord Derby on establishing a ground-mounted solar PV array for the estate. This led to collaborations with Sensor City (University Enterprise Zone, Liverpool) to implement a new prototype WiFi that allows energy data to be collected across the entire zone.

Support for academic publishing is evidenced by staff holding ten editorial roles in academic journals, book series editor (Historic England and Liverpool University Press) and the majority of staff have reviewer roles for academic journals and publishers.

4.1.2 Networks

Networking with other researchers provides us with new routes for dissemination, research collaborations and joint PhD supervision.

Gibbs heads up the EPSRC-funded Special Interest Group on Vibro-acoustics in the UK Acoustics Network (2018-2020) with over 170 members; this brings together researchers from different areas of acoustics, providing a focus for collaboration and innovation, as well as promoting the impact of acoustics research.

To bring together research from engineering, physical and life sciences, management, and social sciences, Sharples and Hopkins belong to the Liverpool Institute for Risk and Uncertainty, a unique interdisciplinary national centre. This led to joint PhD supervision with other disciplines in the University.

Triggered by a mobility grant to research modern Ghanaian architecture, I. Jackson has developed strong links with the University of Legon and KNUST (Ghana). With colleagues at the University of Manchester and Manchester Metropolitan University, he subsequently founded the research network, West African Rapid Urbanisation and Heritage, with colleagues in Ghana, Nigeria and Togo. I. Jackson established the Transnational Architecture Group blog as a forum for scholars investigating the export of architectural ideas and forms between regions; since 2014 this has attracted over 46,000 visitors from 120 countries.

4.1.3 Team working

Collaborating with colleagues from Archaeology, Classics and Egyptology and Modern Languages and Cultures, Bandyopadhyay has been Co-I on two AHRC Newton fund projects: 'Dhiban:

Valuing sites through valuable stories' and 'Hugli river of cultures'. The latter resulted in collaborations with historians, history of literature specialists, anthropologists, social historians, museum experts, filmmakers and local volunteer researchers to develop an integrated understanding of the changing nature and role of the erstwhile colonial house within a wider civic and urban setting. The resulting management plan combined research findings with strategic directions for the West Bengal Heritage Commission.

The Heritage group have five visiting International fellowships to collaborate with researchers based at targeted institutions in Syria, India, Iraq and Ghana. Our staff provide mentoring around key heritage themes and facilitate collaboration, networking, and grant bids, with a view to developing joint future projects and outputs.

Lee collaborated with workplace and wellbeing analysts at Mitie, the UK's leading facilities management and professional services company to assess speech privacy in their portfolio of open-plan offices and help them develop a strategy to achieve privacy through innovative workplace design.

Koeck produced an award-winning documentary with researchers from the University of Cambridge on their hospital ventilation strategies to reduce the concentration of SARS-CoV-2 (the virus causing COVID-19). This film won the 2020 Impact DOCS Award and the 2020 TVE Global Sustainability Award for the use of digital innovation and AI, and was presented to WHO and health authorities worldwide.

4.1.4 Training

Our research expertise provides a strong basis for the provision of training courses for professionals and specialists. F. Chen was invited by the China Ministry of Housing and Rural Development to give a training programme for Chinese civil servants on urban morphology, drawing on her research on Chinese urban design (2014). Bandyopadhyay, Alsalloum and Quattrone developed a ten-lecture series funded by the Aga Khan Trust for Culture on an alternative approach to Islamic architectural history. This is freely available via the MIT website (archnet.org) to reach a wide audience (including academics and professionals). In addition, the Getty Conservation Institute (Bandyopadhyay) and the Barakat Trust (Quattrone, Alsalloum) financially supported the training of heritage and conservation professionals from 12 countries in urban heritage management.

4.2 Professional bodies and recognition

Support for the professions is evident in the majority of staff belonging to one or more professional bodies relating to architecture, building industry or engineering (usually with Chartered status). Our standing in these bodies is evidenced by N. Jackson being President of the Society of Architectural Historians of Great Britain (2017–2020) and Gibbs being President of the Institute of Acoustics (2018–2020) which has a membership of ≈3000. Recognition of research excellence by the profession is evidenced by the medals awarded by the UK Institute of Acoustics (IoA) to Gibbs (R.W.B. Stephens medal, 2015) and Hopkins (IoA Engineering medal, 2016).

4.3 Consultancy

Consultancy opens up opportunities for increased interaction with industry, commercial and government sectors which facilitates impact and brings in new research ideas and opportunities. ArCHIAM research on the Wilayat Al Hamra Project (Oman) led to them being sub-contracted to supervise a Muscat-based company (Architectural Wall Systems) to ensure the design scheme developed in the research was faithfully executed. ARU were commissioned by museums in Birmingham and Liverpool to assess the effect of vibration on exhibits caused by the proposed HS2 route and a pop concert inside a museum. The latter resulted in a successful concert with no exhibits damaged, and attracted interest in the museum sector for a viable new income stream. Morgan Industries approached the ARU to carry out sound absorption measurements which led to research funding on the acoustic performance of their ceramic fibre blankets at high temperatures. For Liverpool City Council, CAVA produced the official RIBA Heritage Tour of Liverpool with a bespoke content management system that drives a progressive web app walking tour and an Augmented Reality installation at RIBA North.

4.4 Exhibitions

In this REF period, staff produced 11 exhibitions that engaged a broader cross-section of the public and facilitated conversations between researchers, practitioners and the public.

International events include Iuliano's co-curation of the exhibition "Eternal City. Roma nella collezione fotografica del Royal Institute of British Architects" in Rome (2018). With over 110,000 visitors, this brought together carefully selected images from RIBA of Rome, from its landscape to close archaeological detail, through the intermediate scale of architecture. Bandyopadhyay curated "Architecture on the Fringes: Cultural Topography of Oman" at the Aga Khan Documentation Centre at MIT (Cambridge, Massachusetts) (2016). I. Jackson's research on Nek Chand was shown at the Kohler Arts Center (USA) with his drawings now forming part of the permanent collection (2017).

Nationally, our exhibitions at RIBA North have included Swenarton's exhibition on "Cook's Camden" (2018–19) and Schmiedeknecht on the representation of modern architecture in children's books in the UK (2019), and the ECAlab exhibition Cerámica at RIBA North (2017–18) featuring full-scale prototypes of light-diffusing facades and ceilings attracting over 14,000 visitors. We celebrated the 30th Anniversary of Tate Liverpool (designed by Stirling, Wilford & Partners) with Iuliano's workshop "Tate Architecture Studio – From James Stirling to public engagement: Circa 1958 – Beyond 2018" (2018). Urbano Gutiérrez's research on the production of sustainable building components led to the exhibition PlatFORM (2018) at Tate Liverpool with over 8,000 visitors, and a workshop bringing together architects, artists, engineers and researchers to discuss the future of ceramics. This led to an invitation to be part of the "Hand Held to Super Scale Exhibition" at The Building Centre in London (2019–20) with over 40,000 visitors.

4.5 Design

Our digital research translates into creative design. Agkathidis applied algorithmic modelling techniques to represent, design and fabricate gravitational lens effects (astrophysical theory of dark matter) in the form of a garden pavilion for the Royal Horticultural Society's Chelsea Flower Show. This was awarded the gold medal for 'Best Fresh Garden' (2015).

CAVA led a team of local creative industry partners to develop a ground-breaking participatory and immersive mixed reality experience at St George's Hall in Liverpool (2019). Based around the famous court case of Florence Maybrick (accused of poisoning her husband), the immersive mixed reality experience allows participants to experience the Victorian prison and justice system. With the support of Microsoft's Mixed Reality team (USA), this became the world's first volumetrically filmed (3D holograms) UNESCO heritage experience using the HoloLens system.

4.6 Media

Engagement with the media allows our researchers to reach a wider audience. N. Jackson was interviewed on BBC1 Breakfast (2016) on the restoration of the Elizabeth (clock) Tower at the Palace of Westminster with an estimated audience of 8.5 million viewers. Regional aspects of our research such as Kronenburg's co-authored book 'Liverpool's Musical Landscapes' has led to two appearances on BBC Radio Merseyside (2018, 2019). Social media also plays a role, with Calder promoting his research on Brutalism through Twitter with over 8,800 followers. Shepperson worked as an archaeology blogger for The Guardian on the Science Blog Network series, The Past and the Curious, publishing 13 articles on archaeology, history and cultural heritage protection.

By establishing a broad, dynamic research base that has benefitted from continued investment over the REF period, we have actively contributed to the development and impact of the discipline, locally, nationally and internationally.