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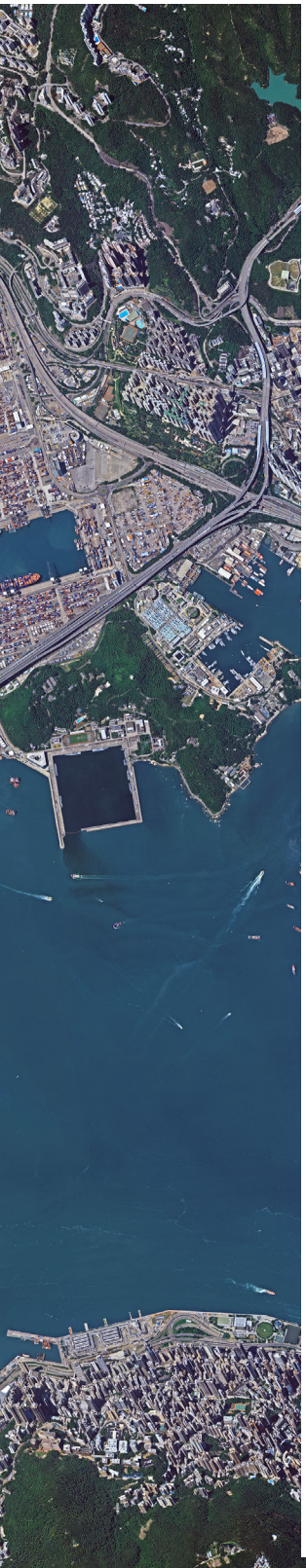
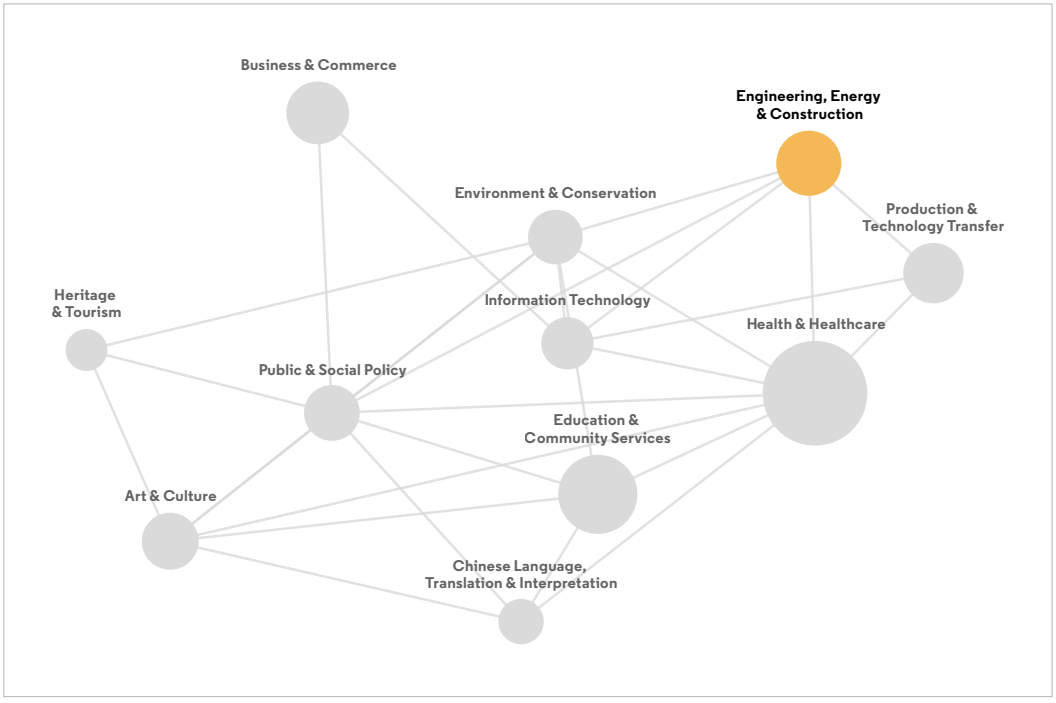


The societal impact of research undertaken by Hong Kong universities:

Engineering, Energy & Construction

A synthesis of the RAE 2020 impact case studies



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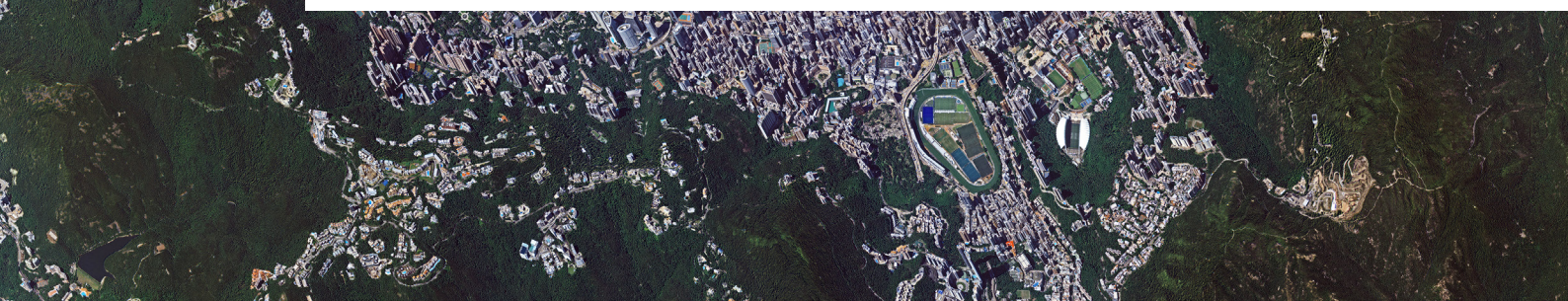


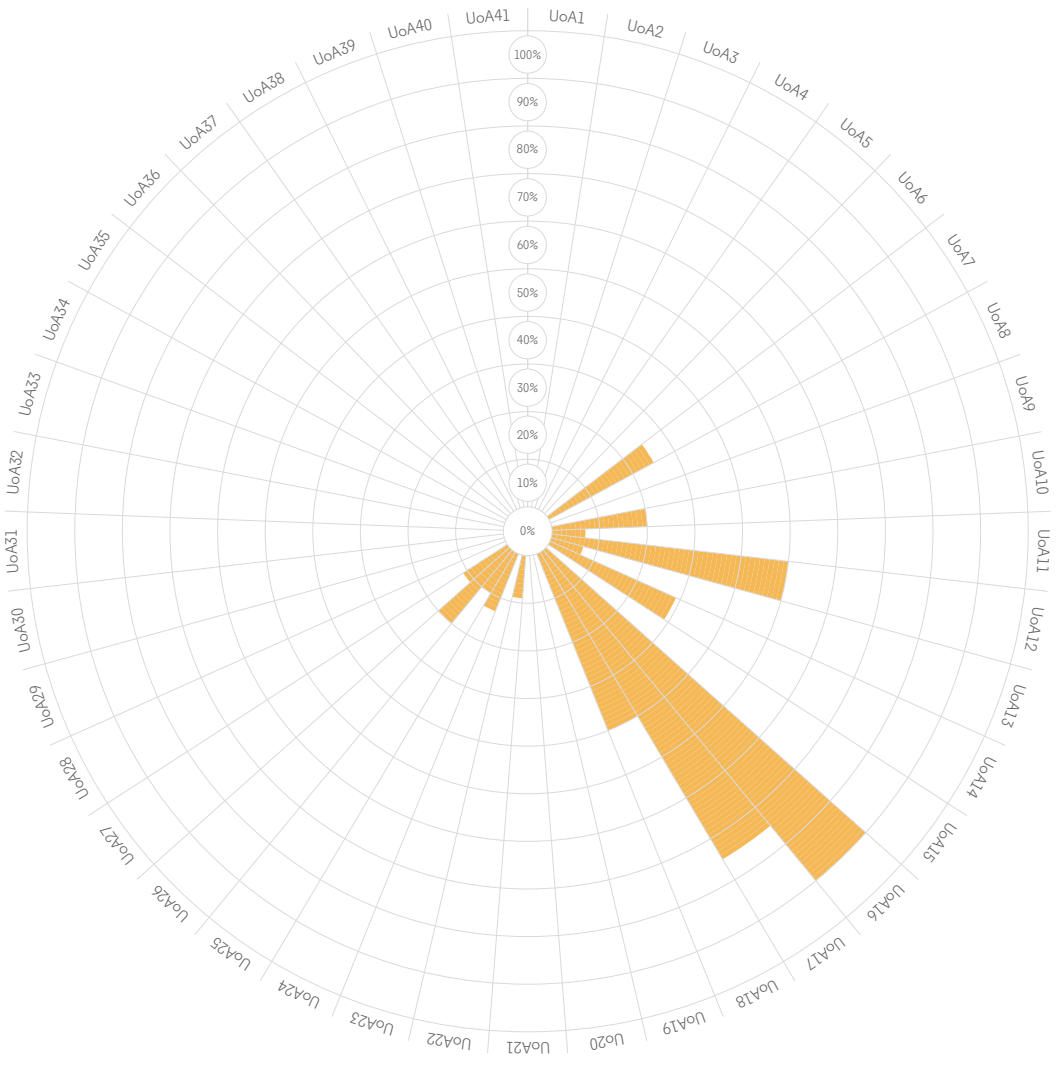
This report is part of a series of outputs that examines the impact of research arising from eight universities based in Hong Kong and funded by the University Grants Committee (UGC). The report focuses on the Impact Case Studies (ICS) produced by the UGC-funded universities as part of their response to a Research Assessment Exercise (RAE) in 2020. The overarching report - *The impact of research undertaken by universities in Hong Kong: A synthesis of the RAE 2020 impact case studies* – is accompanied by 11 thematic reports that examine the nature of research impact in different areas, ranging from Arts & Culture to Health & Healthcare. The 342 impact case studies that are analysed through this body of work are also available on a searchable database that is posted on the UGC's website.

The Engineering, Energy & Construction cluster contains 36 impact case studies (ICS) from four primary topics identified in the topic modelling. The cluster represents 11% (i.e. 36/342) of the total ICS submitted to RAE 2020.

The impact wheel in Figure 1 illustrates how the Engineering, Energy & Construction cluster is distributed across the 41 Units of Assessment (UoAs) used for RAE 2020. For example, not surprisingly, for UoA 16 (civil engineering and building technology), nine of the ten (=90%) submitted to this UoA were in the Engineering, Energy & Construction cluster.

Overall 14 of the 41 UoAs made a contribution to this cluster including: UoA 7 (physics & astronomy); UoA 10 (earth sciences and other physical sciences); UoA 11 (mathematics and statistics); UoA 12 (electrical & electronic engineering); UoA 13 (computer studies/science); UoA 14 (mechanical engineering, production engineering, textile technology and aerospace engineering); UoA 16 (civil engineering and building technology); UoA 17 (architecture); UoA 18 (planning and surveying); UoA 22 (business); UoA 24 (psychology); UoA 25 (political science); UoA 26 (geography); and UoA 27 (sociology & anthropology).

Figure 1: Impact wheel for the Engineering, Energy & Construction cluster (n=36)



[1] See methodological annex for details.

The impact of Hong Kong universities' research: **Engineering, Energy & Construction**

Table A shows the most salient features of the case studies in terms of beneficiaries, location, type of impact and time lag. It gives the percentage of case studies in this cluster that were tagged with sub-codes under these code headings, as well as the percentage of case studies tagged with those sub-codes in the entire sample of 342.

The 36 case studies in this cluster benefited three key sectors under the classification of the Hong Kong Standard Industrial Classification: Construction (42%), Transportation, storage, postal and courier services (28%) and Electricity and gas supply (17%). The key decision taker groups that were involved were the private sector (28%) government departments/agencies (11%), and NGOs/third sector (6%). Beyond Hong Kong (81%), the Greater Bay Area (6%) and Mainland China (6%), these case studies primarily had an impact in the United States (25%) and the United Kingdom (14%). The most salient type of impact was informing procedure, practice or protocol (39%), patents (31%), improving workflows (25%), and informing guidelines or strategy (22%). On average, the research in this cluster was started in 2010, compared to 2006 for the whole sample.

The median publication date for this cluster was 2014, slightly earlier than the median for the whole sample (2015).

The impact wheel (Figure 1) confirms the expectation that the ICS in this cluster would likely be grouped around the physical and engineering sciences. Four dominant subthemes emerged from reading these case studies: first, sustainability, whether focused on transport, energy use or construction; second, standards, guidance, and accreditation; third, health and safety; and fourth, designing buildings to withstand natural disasters such as earthquakes, landslides and tropical storms. On pages 6 and 7 we use these themes to describe some of the ways that research in Hong Kong has had a significant societal impact on engineering, energy and construction.

Table A: Some salient features of research impact identified in the Engineering, Energy & Construction cluster (n = 36)

Beneficiaries of impact (top mentions)	**% of cluster impact case studies**	**% of all impact case studies**
Hong Kong Standard Industrial Classification		
Construction	42%	5%
Transportation, storage, postal and courier services	28%	5%
Electricity and gas supply	17%	2%
Sociodemographic group		
Children (under 18)	3%	20%
Elderly	3%	4%
Decision taker group		
Private sector	28%	30%
Government departments/agencies	11%	31%
NGOs/third sector	6%	17%
Location of impact	**% of cluster impact case studies**	**% of all impact case studies**
Hong Kong	81%	75%
Greater Bay Area (excluding Hong Kong)	6%	3%
Mainland China (excluding Hong Kong and GBA)	6%	12%
United States	25%	32%
United Kingdom	14%	17%
Type of impact (top mentions)	**% of cluster impact case studies**	**% of all impact case studies**
Inform procedure, practice or protocol	39%	52%
Patent	31%	15%
Improve workflows	25%	15%
Inform guidelines or strategy	22%	27%
Elapsed time	**Cluster**	**All**
Median year of research commencement	2010	2006
Median year of publication date	2014	2015

Sustainability

A handful of ICS described the ways that research originating in Hong Kong universities had helped to manage and reduce energy consumption in buildings. Buildings contribute over 40% of overall energy consumption worldwide, and over 80% of the overall energy consumption and over 90% of electricity consumption in Hong Kong. A team of researchers from The Hong Kong Polytechnic University's Building Energy Group, for example, describe how they advised on over twenty building projects – including a number of signature buildings such as the International Commerce Centre, the tallest super-high-rise building in Hong Kong, and the redevelopment of New World Centre. Drawing from their research on the optimal design of air conditioning systems, the integration of renewable energy and the development of smart energy efficient control strategies they claim to have delivered energy savings ranging from 15% to 42% totalling over 25 million kWh annual savings, currently valued at about HK$25 million (cUS$3.2m).

There were further examples of how research has been used to manage energy consumption including the use of machine learning approaches to support large scale energy management systems for street lighting that have resulted in energy savings of around 20-40%. This research, by the Smart Energy Conversion and Utilization Research group at City University of Hong Kong has resulted in a spin-off company, e.Energy Technology Ltd, which has productized the patented dimming technology for the lighting management systems. The Hong Kong University for Science and Technology also developed a number of products, including an energy efficient adsorption cooling system and a small-scale wind power system. Both innovations are now in manufacture by companies in Mainland China, generating total revenues in excess of RMB7m (cUS$1m).

In addition to a focus on energy consumption, other examples of universities' research are supporting sustainability and the 'greening' of the economy, including research on battery technology for electrical vehicles, the development of analytical models to optimise the pedestrianisation of urban spaces and modifying manufacturing process to reduce the weight of steel in car production.

Standards, guidance and accreditation

The development of standards that are then accepted and used by industry is one of the key requirements for the diffusion and adoption of new technologies. One illustration of this was the development of the technology that laid the foundation for the Qi Standard for wireless charging of mobile telephones and other products. The pioneering work of a research team at City University of Hong Kong in developing wireless charging technology is documented in more than 55 patents and a number of influential academic publications. Most of the patents were licensed to a start-up company that was instrumental in founding the Wireless Power Consortium. Starting with initially eight companies in 2018, the Consortium rapidly increased to nearly 600 partners by 2019. The Consortium adopted the Qi Standard and this became the world's first industrial standard for certifying wireless charging. Today, millions of mobile devices, including more than 3,000 products from popular smartphone brands such as Apple, Samsung, Huawei, and Xiaomi, have adopted the Qi Standard wireless battery charging feature.

Other ICS informed standards and accreditation in the construction industry. For example, researchers from The Hong Kong Polytechnic University improved the structural performance of civil engineering structures through innovative materials, advanced computational/design methodologies and improved performance monitoring technologies. The research has had a significant impact on structural engineering internationally via the adoption into company design codes and guidelines in countries including China, UK, USA, Australia and Germany. In a similar vein, researchers from The University of Hong Kong conducted extensive lifecycle assessments of materials used in the construction industry and from this research assessed the carbon footprint of the materials based on specific manufacturing processes and local energy sources. The carbon assessment scheme was adopted in 2014 by Hong Kong's Construction Industry Council (CIC) for its Carbon Labelling Scheme for Construction Products. The Scheme has been taken up by the construction industry and is referred to in guidelines issued by the Government and in the certification requirement of the Hong Kong based Building Environmental Assessment Method (BEAM).

Finally – and in part related to the next group on health and safety – another group of researchers also from The University of Hong Kong developed a set of evidence-based guidelines requiring breaks for construction workers. Based on two years of fieldwork on 34 construction sites across Hong Kong, a model was developed that could predicted heat strain when combined with weather forecasts. This informed the "Guidelines on Site Safety Measures for Working in Hot Weather" issued by the CIC in 2013. The guidelines are now mandated by the Hong Kong Housing Authority requiring a morning break and extended lunchtime breaks in air conditioned or fan assisted cool areas to reduce core body temperature and the effects of heat stress.

Health and safety

Continuing the theme of working in hot weather, an ICS from researchers at the The Hong Kong Polytechnic University investigated the cooling properties of different types of fabrics and used these empirical data to make recommendations for clothing for construction workers that would protect them from heat stress. The resultant uniform offers a 29% reduction in heat storage and a 14% improvement in thermal comfort. The uniform was licensed to the CIC (2015) and then specified by the Government as standard work wear for all public works contracts (2018). To date, over 116,000 anti-heat stress shirts and 36,000 pairs of trousers have been sold to over 100 organisations. The garments have been adopted by other work sectors including cleaning, gardening, and logistics in Hong Kong, Macao, Cambodia, and Saudi Arabia.

Health and safety were also the focus of a very different ICS from The Hong Kong Polytechnic University. This example of research improving health and safety focuses on identifying deficits in railway tracks using an optical fibre-based predictive monitoring (OFPM) system. The research group developed special optic fibre sensors that could be used to anticipate potential faults. The patented technology has been adopted not only for MTR network but also the Singapore SMRT metro network. In addition to averting potential accidents, the OFPM system improves train availability, service quality and safety. It provides operators with real-time train and track information so that they can act promptly in case of a fault and thus further reduces maintenance costs. Another train-based maintenance system was described by a researcher from City University of Hong Kong Department of Computer Science. This ICS recounts how an artificial intelligence (AI) system was developed to automatically schedule engineering works for MTR. Automatic dispatching of engineering works is estimated to save 30 minutes per night compared to manual dispatching and a US$1 million annual productivity gain. The significance and unique application of this AI system was reported in the New Scientist (2014) leading to other media articles on AI and its impact on MTR.

Designing safe construction

A group of ICS reported on research to improve the structural resilience of buildings under adverse conditions such as extreme wind, mudslides or earthquakes. For example, researchers from the Department of Civil Engineering at The University of Hong Kong described how their research on a novel plate-reinforced composite (PRC) coupling beam has improved the safety of high-rise buildings. Coupling beams are used to connect walls at the base of a structure with the aim of reducing its movement, especially when exposed to external pressures such as high wind. The team developed a novel PRC coupling beam, which is fabricated by embedding a steel plate into a conventional reinforced concrete beam and using shear studs to couple the steel plate and the concrete. Research showed that the PRC beam was better able to withstand extreme loads in comparison with conventional reinforced concrete coupling beams. As a result, guidelines for the PRC coupling beam were published in 2009 and have since been used worldwide in the construction of tall buildings, such as Trump International Hotel, Waikiki, Hawaii.

A similar ICS was submitted by The Chinese University of Hong Kong, but this time focused on developing a lightweight building system designed for regions that are prone to earthquakes. The researchers developed a series of building systems that were lightweight, modular and flexible as well as being relatively cheap and developed from sustainable materials. One of the systems was used to support the development of Checked Playrooms, an architectural product developed jointly with Beijing Western Sunshine Rural Development Foundation (an NGO). Over 100 schools have benefitted from a stimulating and safe study environment using the spatial panel system in preschool playrooms.

The characteristics and translation of the underpinning research

Table B provides the salient features of the underpinning research. It provides bibliometrics as well as information on the impetus for the research and mechanisms/channels of dissemination.

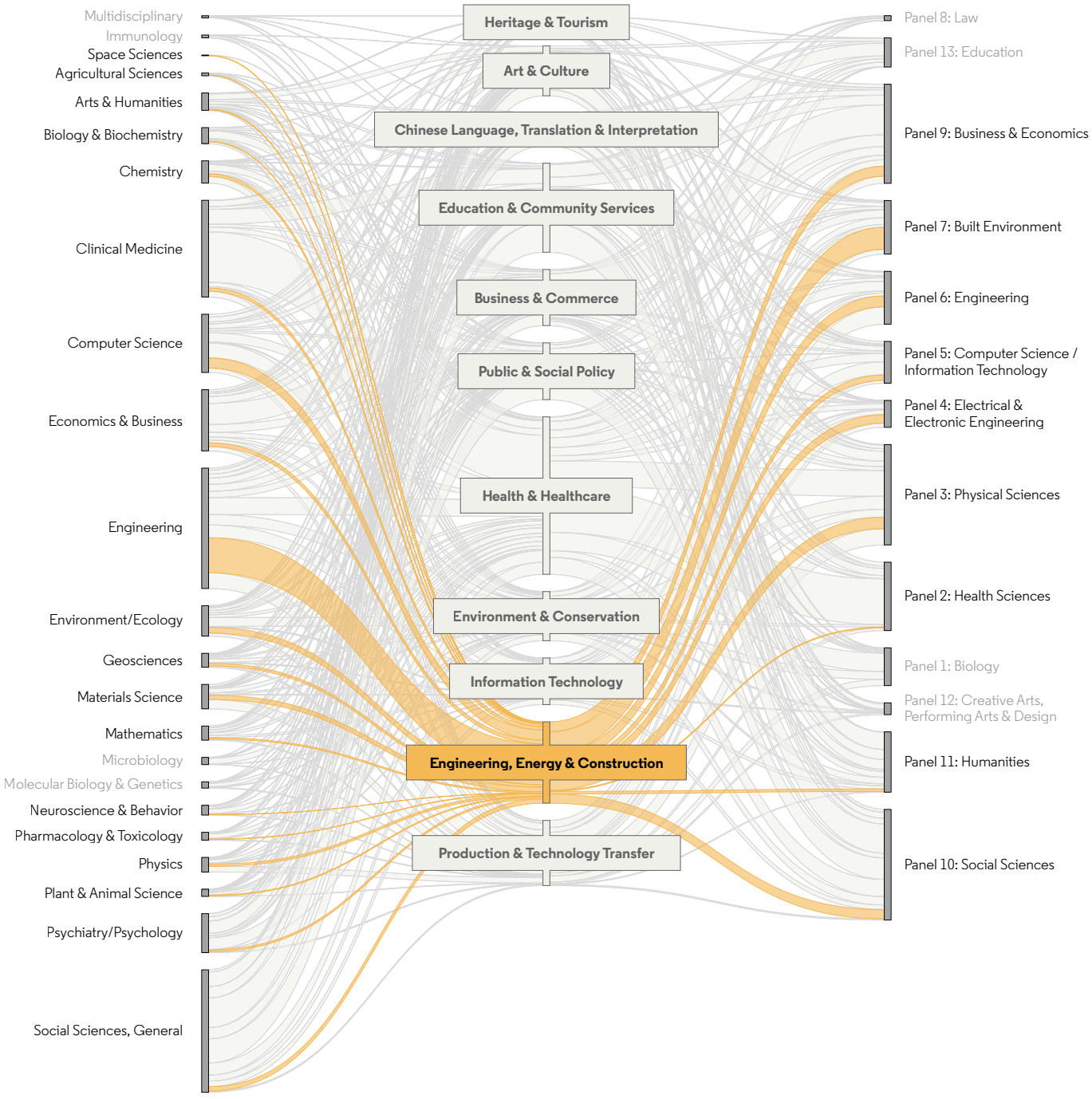
189 outputs from this cluster are indexed on the Web of Science, which have a mean citation score of 3.32. The median citation score is 1.62, which is slightly higher than the median of 1.59 for all case studies. Key international collaborators included the United States (11%), the UK (9%) and Australia (5%). 31% of the research was commissioned, and 14% was in response to demand for better protocols, practices, and policies. The research was driven by external advances creating new questions in 3% of cases. The main forms of co-production and collaboration were academic and industry partnership (36%) and academic and public sector partnership (8%). The researcher was involved in the impact by being referenced as an expert or advisor (17%) and through co-producing new technology or products (3%). The research findings were disseminated primarily through media coverage (19%) and through non-academic presentations (14%). Many ideas and products arising from the research were given prizes and awards (44%) and were patented (28%).

Table B: Some salient features of the underpinning research identified in the Engineering, Energy & Construction cluster (n = 36)

Analysis of underpinning research	**Cluster impact case studies**	**All impact case studies**
Bibliometrics indicators		
Number of outputs indexed on Web of Science	189	1445
Mean citation score	3.32	4.45
Median citation score	1.62	1.59
Collaborators location (top mentions, excluding China)		
USA	11%	18%
UK	9%	8%
Australia	5%	5%
Impetus for research (top two mentions)	**% of cluster impact case studies**	**% of all impact case studies**
Pull factors		
Commissioned	31%	16%
Demand for better innovation & technology	14%	11%
Push factors		
External advances creating new questions	3%	6%
Mechanisms/channels of impact (top mentions)	**% of cluster impact case studies**	**% of all impact case studies**
Coproduction & collaboration		
Academic - industry partnership	36%	23%
Academic - public sector partnership	8%	17%
Researcher involvement		
Referenced as expert, practitioner or adviser	17%	33%
Co-produced new technology/product	3%	9%
Dissemination of research findings		
Media coverage	19%	48%
Non-academic presentation (incl public lecture)	14%	36%
Codification of impact eg prizes, patents etc.		
Prizes and awards	44%	33%
Idea/product patented	28%	11%

The alluvial diagram in Figure 2 links the underpinning research (as classified by discipline using the 23 Web of Science, Essential Science Indicators (ESI), journal categories) to the 11 clusters identified through the topic modelling and the 13 Panels used in RAE 2020. The Engineering, Energy & Construction cluster has been highlighted, with the impact pathways for the other clusters greyed out. Figure 2 illustrates the multidisciplinary nature of research impact; multiple journal categories feed into the cluster and the cluster contributes to ICS submitted to a range of RAE panels.

Figure 2: Alluvial diagram linking underpinning research with clusters and panels.



Methodological annex

This synthesised impact report presents a cross-cases analysis of the salient features in 342 impact case studies (ICS) provided by Hong Kong universities as part of the RAE 2020 evaluation. A sequential multi-method approach was employed. The first component involved quantitative topic modelling, followed by directed content analysis. This approach allowed the essence of the impact generated by Hong Kong universities to be captured and synthesised. It is important to note that the analysis and conclusions of these reports are based on the impact as described in the ICS. That is, the authors of this report took the case studies at face value and did not verify or question the narratives provided. A summary of the methodology is given below. For more detailed information on the methodological elements of this study, please see the overarching impact report.

Quantitative topic modelling

Quantitative topic modelling was used to identify overarching topics in the ICS. Topic modelling is a language processing technique applied to document sets to understand the different combinations of words or phrases (topics) that are present. It is a data driven approach, meaning results are not dependent on pre-conceived notions of structure, but are instead derived from the data itself.

Python, Scikit Learn, and Gensim packages were used to implement the topic modelling. Text from section 4 (Details of Impact) from the ICS was normalized (i.e. removal of punctuation and special characters), and domain specific stop-words were removed (i.e. words that are used frequently across the case studies). Various implementations of the topic modelling algorithm were tested, and the Non-negative matrix factorization [NMF] was found to produce the most usable results. After testing multiple models using this algorithm, and manual review by the authors, the number of topics was set to 35 to provide a balance between the breadth of groupings and granularity of topics.

In discussion with UGC, the research team developed an initial taxonomy by grouping similar topics into broader ‘clusters’. For example, the topics ‘finance’, ‘accountancy and governance’, and ‘economics’ were grouped into a cluster titled ‘business & commerce’. Topic clusters were set at the outset of the analysis to ensure cognitively similar cases were read together, thereby improving the quality of coding, analysis, and impact reports. This classification system then informed the coding and testing of case studies.

Directed content analysis

Qualitative directed content analysis was then used to elucidate the salient characteristics of the impact narratives. This involved an iterative process of examining case studies and developing a code book to categorise their inherent features. The code book was derived from the existing literature and the domain expertise of the authors. It included four overarching categories: a) research, which captured funding source and impetus for research; b) time lags, which captured the elapsed time between the research and its impact; c) mechanisms/channels of impact, which included forms of collaboration and dissemination; and d) impact, which included beneficiary groups (e.g. young people, women, ethnic minorities), location and reach (e.g. Hong Kong, Mainland China, elsewhere), and the nature of impact (e.g. commercial, policy, practice).

Using the cloud based qualitative analysis software, Dedoose, each case study was read, and relevant excerpts were 'tagged' with the relevant codes. Multiple codes and subcodes were attributed to individual case studies. This allowed all case studies that had been tagged with a particular code (e.g. a particular beneficiary group) to be considered as a group. Two of the study's authors undertook the reading and coding (JG and KW). Inter coder reliability was ensured by double coding 10% of the cases (i.e. each author codes the same case study) and through regular coding meetings that were used to compare code applications and adjust the code book as required. The code book was thus a 'living document' that was reviewed and revised iteratively. This process allowed for cross case analysis that was the basis of synthesised impact reports. A code co-occurrence matrix was used to identify where the overarching codes intersect (for example, instances where particular topics are associated with particular beneficiary groups). The properties of the ICS were systematically examined, and evidence was gathered by assigning segments of text to unique codes within the broader coding categories. This process allowed for cross case analysis that formed the basis of this synthesised impact report.

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