ACKNOWLEDGEMENTS

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The Australian Research Council (ARC) Industrial Transformation Research Hub for Nanoscience-based Construction Material Manufacturing (the Nanocomm Hub) is a multidisciplinary Research Hub for the construction materials industry. Led out of Monash University in Victoria, the Hub is a network of 13 Australian and three overseas universities and 47 industry partners across Australia, New Zealand, China, Singapore and South Korea. The Hub explores the construction materials industry to inspire technological innovation throughout the sector with the overarching goal of creating lighter, more resilient materials, ultimately contributing to a more efficient, sustainable and liveable Australia.
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1.1 DIRECTOR’S MESSAGE

ARC Review Panel gives Hub the thumbs up

We are pleased to announce that, following a successful performance review, the ARC has confirmed funding for the Nanocomm Hub through 31 December 2021. On behalf of the Hub, I would like to wholeheartedly thank everyone who contributed to this excellent outcome.

As part of the review process, an ARC Review Panel conducted a site visit to the Hub on 31 July 2018, interviewing key personnel and stakeholders. Additionally, the Hub facilitated submissions from 13 university partners, 47 industry partners and five other organisations. After considering all relevant discussions and documentation, the Panel determined that, since the Hub’s establishment in 2016, we have met our milestones and key performance indicators, as well as ARC and Hub objectives.

The Review Panel comprised two ARC executive directors, an ARC secretary and two technical experts (from the University of Sydney and the University of Adelaide). In the ARC review report, released on 21 November 2018, they made various recommendations to ensure our continued success. In general terms, we were advised to adopt a more corporate approach to our operations, such as those involving internal reporting, monitoring and future direction – all of which we promptly undertook to address.

PwC conducts Hub economic impact study

In recent months, we have put into motion various initiatives to build the strongest possible foundation for the future – one that will carry the Nanocomm Hub well beyond its current lifespan. As part of this ongoing effort, we engaged Pricewaterhouse Coopers Consulting (PwC) to analyse the actual and potential impacts of our research projects on the Australian economy, and this study now informs how we market our work to prospective funders.

Using robust economic modelling, PwC examined a range of research outcomes over a 30-year period, quantifying their effect on gross domestic product, consumption, investment, labour market and value added at the industry level. Direct impacts on targeted industries and flow-on impacts on associated industries were both evaluated. In other words, an economy-wide framework underpinned PwC’s report.

To facilitate this analysis, we elucidated the nature and goals of our research, the probability and timeframe of commercialisation of new technologies, and how and when industry might benefit from our projects. Such background information enabled PwC to produce model outputs comparing a shock scenario (where the ‘shock’ reflects the economic impacts of a new technology) with a baseline scenario without the shock.

The Hub and PwC also held an intensive workshop to not only examine relevant features of our various projects, but to discuss factors that affect technology transfer, such as regulatory hurdles and public perception of risk, across the construction, mining, aquaculture, waste and transport industries. Key players from the Hub attended this workshop, including Dr Kwesi Sagoe-Crentsil, Deputy Director (Operations), Dr Anna Paradowska of the Industry Advisory Committee, Prof Vute Sirivivatnanon of the Steering Committee, Prof William Young, Chief Investigator, and myself.
Dr Robert Mun, Executive Director of Engineering and Information Sciences at the ARC, and Mrs Halina Oswald, Director of Monash Research Office, provided advice to support us in this early phase of the PwC process. Also, industry partners and chief investigators completed a questionnaire, enabling us to relay to PwC the societal and economic potential of specific projects. And lastly, the Hub Steering Committee met to develop and review strategies to obtain additional input data needed by PwC to successfully conduct its analysis.

After absorbing our specifics and doing a desktop literature review, PwC produced a comprehensive summary report, featuring both probable and possible impact scenarios for nine Hub projects. From 2020 to 2050, the overall estimated impacts include an increase of $400-1870 million in gross domestic product, $155-$560 million in real wages, $110-490 in household consumption, $160-$790 million in investment, and $180-590 in Australian exports. These exceptional findings clearly attest to the Hub’s enormous potential. They will help us more effectively market our work to all our stakeholders, and convince industry to use our technologies and products on a large scale, ensuring a promising future for the Hub.

Wenhui Duan
Director, ARC Nanocomm Hub

We have put into motion various initiatives to build the strongest possible foundation for the future – one that will carry the Nanocomm Hub well beyond its current lifespan.
1.2 About the Nanocomm Hub

Australia’s continued prosperity depends on the construction materials industry, which manufactures and distributes cement, concrete, aggregates such as gravel and crushed stone, polymer composites used, for example, in fibre-reinforced polymer composites, and chemicals. All in all, this massive industry contributes nearly $12 billion to our gross domestic product (GDP). Further, it employs 18,000 Australians directly and 85,000 indirectly.

To drive economic growth and enhance the quality of life of Australians, we must create sustainable and resilient infrastructure – infrastructure that requires less maintenance and can resist extreme weather conditions and even terrorist attacks. That’s why the Federal Government has committed a record $50 billion to infrastructure from 2014-15 to 2019-20. Combined with state, territory and private sector investment, this initiative will likely have spurred over $125 billion of infrastructure spending nationwide by 2020.

To realise investors’ ambitions, we need a steady supply of innovative construction materials from local sources. But can our construction materials industry meet Australia’s substantial infrastructure needs? Although historically a major source of jobs and revenue, the industry has recently been challenged by declining employment, rising energy costs and competition from low-cost Asian imports. Responding to these challenges, the Hub has undertaken the development of high-value products and specialised manufacturing operations that will keep the industry ahead of the game.
As a world-class research centre, the Nanocomm Hub seeks to develop materials and technologies that will elevate the global competitiveness and profitability of the Australian construction sector.

**HUB STRUCTURE**

The Hub’s network of 13 Australian and three overseas universities, along with 47 industry partners, including state government, creates a vast collaboration to truly innovate infrastructure systems. Partners from the construction materials industry – many of which are small and medium enterprises (SMEs) – operate across Australia, New Zealand, China, Singapore and South Korea.

Our research spans four areas: nanoscience, construction materials, green structures and asset management. In nanoscience, which overlaps chemistry and physics, we focus on the fundamentals at the molecular level. With construction materials, we explore how to bind together individual elements, such as cement, concrete, adhesive, glass, metal, timber, fibre-reinforced plastic, and pavement materials. When developing green structures, we cover everything from buildings, bridges, roads and dams to tunnelling, sensor technology and structural health monitoring for damage detection. Asset management involves entire infrastructure systems, such as national road networks, where we aim to optimise the performance of assets.

Together Hub teams probe the full spectrum of the construction materials industry to inspire technological innovation throughout the sector. Our overarching goal is to create lighter, more resilient materials, ultimately contributing to a more sustainable and liveable Australia.

**MEETING OUR GOALS**

To advance the development of construction materials and infrastructure systems, the Australian Research Council (ARC) awarded the Hub $5 million. This government funding has been complemented by $10 million invested by universities ($3.8 million) and industry ($6.2 million), in Australia and overseas. This means that our current industry-to-ARC cash matching ratio is 1.24, well above the ARC requirement of 0.75. Thanks to this strong industry commitment, the Hub has financial leeway.

In our ARC project proposal, we outlined five primary objectives. All five remain front and centre today. Collectively, the Hub’s 37 research projects align with the first three: reducing energy consumption and CO₂ emissions in the manufacture of construction materials; developing high-performance, high-durability construction materials and structures; and creating materials and structures that can resist extreme conditions and terrorist attacks. Our 25 research fellows (RFs), early career researchers (ECRs), research assistants (RAs) and 61 higher degree by research (HDR) students meet the fourth objective: boosting the engineering capability of Australian industry with an innovative, skills-based workforce. Our fifth objective to link Australian companies to the enormous infrastructure opportunities in Asia will be reached via the Monash Suzhou (China) and Sunway (Malaysia) campuses.

Officially launched on 20 November 2017, the Hub has made enormous strides in achieving its goals.
1.3 Vision
As a world-class research centre, the Nanocomm Hub seeks to develop materials and technologies that will elevate the global competitiveness and profitability of the Australian construction sector.

1.4 Mission
By promoting collaboration among Australia’s best minds in academia and industry, we aim to advance the construction materials and technologies through nanoscience and nanoengineering, while providing hands-on experience to our future workforce.
CONSTRUCTION

2
Revolutionise civil engineering with modular construction and nanoengineered high-performing and durable cementitious materials.
2.1 MODULARISATION IN CONSTRUCTION

2.1.1 PROJECT IMPACTS

Observed impacts:
Construction moves much more quickly with modular methods like 3D printing and precast fabrication. For instance, it can take 20% less time with precast concrete than with standard on-site concrete. Modular construction methods also significantly reduce construction and maintenance costs.

Probable industry impacts:
The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

- 85% commercial viability
- 5% reduction in cost of labour and materials to the commercial construction sector owing to increased speed and efficiency in construction
- market entry in 2030
- 15% market penetration.

Nanocomm Hub researchers are developing extrusion-based 3D printing techniques for micro-cable-reinforced geopolymer composites that will transform the Australian infrastructure construction industry.
2.1.2 BACKGROUND

Formwork makes up around 53% of building construction costs. This has prompted a growing interest in minimising the cost of formwork through modular construction, along with a push towards high-performance buildings. Modular construction involving off-site precasts can be enhanced by 3D-printing techniques, as well as by building formwork into the finished product. Such methods offer greater efficiency and speed in construction.

Widely used in landscape and garden structures, 3D construction technology has experienced a recent surge in other prefabricated structures – this includes full-scale applications such as a 3D-printed house built by Apis Cor in a mere 24 hours. The Hub project could reduce the cost of house construction by up to 40% when compared with building a conventional concrete house.

Laboratory testing and numerical simulations were used to investigate the axial-flexural behaviour of AFS-Logicwall and AFS-Rediwall columns. This led the researchers to propose a numerical model for computing axial-flexural interaction curves of AFS-encased columns, with reduced reinforcement ties. Their work incorporated sophisticated material constitutive laws and finite element procedures.
2.1.3 AIMS AND GOALS

» Enhance the applicability of 3D-printed cementitious materials through material design, printability study, and finding construction applications.
» Identify axial-flexural performance of concrete columns encased with an AFS stay-in-place formwork system.
» Calculate nominal axial-flexural interaction curves according to calibrated numerical models and compare the results with design interaction curves proposed in AS3600:2018.
» Identify the performance of U bars as transverse reinforcements in AFS-encased columns in lieu of standard detailing set out in AS3600:2018.
» Identify the contribution of AFS encasements to confine concrete core against premature spalling and longitudinal bars against premature buckling.

2.1.4 INNOVATIONS

It is expected that the proposed research on 3D concrete printing will transform the Australian infrastructure construction industry through the development of functional, smart, and high-performance concreting materials. The project is likely to lead to the creation of new manufacturing technology in the renewable energy industry.

Structural performance of the participating stay-in-place concrete formwork system was numerically modelled and calibrated using experimental lab tests. Finite element procedures, with sophisticated material constitutive law and interface elements, were successfully employed to predict the actual performance of AFS-encased columns. The calibrated model was then effectively utilised to predict nominal axial-flexural interaction curves for AFS-encased columns.

Testing the failure of an AFS wall sample in a Western Sydney University research laboratory

Nanocomm Hub researchers use a 3D-printing technique to fabricate wave-shape cementitious element for electromagnetic wave absorption.
2.1.5 KEY FINDINGS
Nanocomm Hub researchers found that:

» Enhancement methods improve the printed specimen’s compressive performance with faster strength gaining capacity and improved mechanical performance, with a 40% improvement in standard compression and a 34% improvement in prism compressive strength at 7 days.

» The printed specimen creates a flexural strength of 5.74 MPa, 10.6 MPa and 13 MPa at 3-7- and 28-day status, presenting 17%, 27% and 52% increments compared to cast samples. Apart from the optimised squeezing effect, the aligned fibre by printing technology increased toughness and reduced micro-cracks initiation and propagation at the tensile stress zone in weak interfaces.

» The enhancement methods have been shown to diminish visible cold joints and micro voids from 17.47% to 11.13% with more narrowly distributed void size (medium void size at 22 nm).

» Based on the experimental lab tests and numerical finite element modelling, the AFS-encased columns containing reduced complex reinforcing steel ties will achieve compliance to AS3600:2018, provided the concrete strength is lower than 25 MPa.

» In order to achieve AS3600 compliance for higher strength concrete, either the size or the spacing of ligatures needs modification to provide sufficient concrete core confinement.

2.1.6 TEAM

Leading CI: Dr Yimiao Huang

Yimiao Huang\(^1\) and Guowei Ma\(^1,2\)

1. Department of Civil, Environmental and Mining Engineering, the University of Western Australia, Australia

2. School of Civil and Transport Engineering, Hebei University of Technology, China

Leading CI: Prof Bijan Samali

Reza Ardalan, Zahra Nouri Emamzadeh, Maryam Ghodrat, Babak Abtahi and Bijan Samali

Centre for Infrastructure Engineering, Western Sydney University, Australia
2.2 LOW CARBON & ENVIRONMENT-FRIENDLY CONSTRUCTION MATERIALS

2.2.1 PROJECT IMPACTS

Observed impacts:
Adding nanomaterials to cementitious composites could significantly enhance their performance. The following improvements have already been established:

» compressive strength increased by 17-109%
» flexural strength increased by 7-88%
» tensile strength increased by 15-79%.

With a need for less cement, these improvements make it possible to achieve the same or better performance of concrete. The manufacture of cement accounts for 8-9% of global anthropogenic CO₂, which means this also could minimise its adverse effect on the environment.

Probable industry impacts:
The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

» 85% commercial viability
» 20% increase in the asset life of all new civil engineering assets owing to more durable construction materials
» market entry in 2030
» 15% market penetration.

Nanocomm Hub research team has found that the addition of nanomaterial refines the microstructure of cementitious material to a denser state due to the nucleation effect.
Nanocomm Hub researchers apply 2D nanomaterials as high efficient reinforcing materials for cement. The scanning electron microscopy image shows the crack bridging effect of 2D nanosheets in cementitious composites.

Nanocomm Hub researchers developed a novel nano-modification method to enhance the dispersion of 2D nanomaterials in cement composites. By coating cement on graphene surface, the agglomeration of graphene is significantly reduced, enabling its use in large concrete structures. This is another promising advance from the Nanocomm Hub in the use of nanotechnology for sustainable infrastructure.

2.2.2 BACKGROUND

With an escalation in construction activities worldwide, particularly in Asia and South America, a significant increase in concrete usage is anticipated over the next five years. The impact of increased concrete production on CO₂ emissions and water contamination puts enormous pressure on the environment.

Improving the performance of construction materials will help minimise this environmental impact, and developing ultra-high-performance concrete sets a standard. 2D nanomaterials, such as graphene oxide and boron nitride nanosheets (BNNSs), are among the most efficient reinforcing materials for cementitious materials. Although nanomaterial-reinforced concrete costs 30% more than materials currently in use, its cost curve would be subject to economies of scale that would reduce its cost in production. A case in point: The global nanosilica market size was estimated as 3,348.3 kilo tons in 2015, but its applications in concrete, rubber and other areas mean that it is expected to grow at a CAGR of 7.6% from 2016-2025.

The arch is one of the most efficient structures and widely used in modern engineering designs. Aerospace and military engineers have adopted the arch as the major structural element to support the overall structural skeleton.
Nanocomm Hub researchers have developed an easy method of fabricating graphene-oxide-coated fibre at large scale under mild conditions to reinforce the interface between fibre and cement matrix.

2.2.4 INNOVATIONS

Exfoliation and dispersion of 2D nanomaterials are among the major challenges for the fabrication of nanocomposites. Current methods for exfoliating 2D nanomaterials (e.g., BNNSs) are still lacking in efficiency.

The dispersion of 2D nanomaterials such as graphene oxide (GO) is challenging in an alkaline cement environment. To eliminate the negative effects of GO agglomeration on cement performance, a nano-coating technology has been developed specifically for nano-additives in cementitious composites.

By coating cement on the graphene surface, the agglomeration of graphene is significantly reduced, enabling its use in large concrete structures. This is another promising advance from the Nanocomm Hub in the use of nanotechnology for sustainable infrastructure.

A three-step dip-coating was developed to maximise the performance of 2D-nanomaterial-reinforced polymer-cement composites. In the first two steps, positively charged polymer was coated on the fibre surface. Then negatively charged GO was attracted due to electrostatic force, and bonded by chemical bond onto the fibre surface.
2.2.5 KEY FINDINGS

BNNS large-scale production via water ultrasonification
   » With only about a 0.003% addition of BNNSs, the compressive strength and tensile strength of Ordinary Portland Cement were improved by 13% and 8%, respectively.

Coating 2D nanomaterials for enhanced dispersion
   » The interfacial interaction between fibre and cement was modified with graphene-based 2D nanosheets.
   » Cement matrix was densified by this modification, which strengthened the fibre-reinforced composites.
   » The interface between fibre and cement was tailored, which improved the flexural toughness.

Improved performance via GO-coated polyvinyl alcohol (PVA) fibres
   » Nanocomm Hub researchers recently found that their newly developed GO-coated PVA fibres could improve the tensile strength of fibre-reinforced cementitious composites (FRCCs) by 35.6% compared with that of pristine PVA FRCCs, without compromising compressive strength.
   » Functioning as a double-sided tape, GO significantly improves the chemical bond between fibre and cement.

2.2.6 TEAM

Leading CI: Prof Wenhui Duan
Wei Wang, Junlin Lin, Xupeøi Yao, Shu Jian Chen, Felipe B de Souza, Bailin Wu and Wenhui Duan

Department of Civil Engineering, Monash University, Australia,
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Leading CI: Prof Wei Gao
Zhanpeng Liu¹, Chengwei Yang¹, Wei Gao¹, Di Wu¹ and Guoyin Li²

1. Centre for Infrastructure Engineering and Safety, School of Civil and Environmental Engineering, The University of New South Wales, Australia
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3. Future Innovative Technology Pty Ltd, Australia

Annual Report 2019
Future road towards more durable, resilient and secure infrastructure networks
3.1 SURFACE DAMAGE INVESTIGATION

3.1.1 PROJECT IMPACTS

Observed impacts:

Good welding not only can reduce maintenance costs by 30-40%, it can extend the service life of tracks and provide greater passenger comfort.

Probable industry impacts:

The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

- 90% commercial viability
- 1.5% increase in the asset life of all new road and rail assets owing to new technologies and more effective use of maintenance budgets
- Market entry in 2025
- 15% market penetration.

Nanocomm Hub researchers measure the mechanical properties, plastic deformation and failure behaviour of rail flashbutt welds, produced from several high-strength rail steels, with different welding process parameters used in heavy haul railway systems in the Australian mining industry.
3.1.2 BACKGROUND

Rail welding is critical in designing railways, and it can affect their overall performance. This project aims to initialise and mitigate the localised surface damage of rail welds in heavy haul railways, thereby enhancing the productivity of rail assets. This will provide insight into the formation of microstructures and the performance of different premium rail steel grades when used as rail flash-butt welds.

3.1.3 AIMS AND GOALS

» Experimentally measure the mechanical properties, plastic deformation and failure behaviour of rail flashbutt welds, produced from several high-strength rail steels, with different welding process parameters used in heavy haul railway systems in the Australian mining industry.

» Characterise the metallurgical microstructures of the rail welds and develop a metallurgical model to predict weld material characteristics.

» Establish the relationship of the microstructures, the macroscopic behaviour and the welding conditions of the rail welds.

» Numerically simulate the ratcheting behaviour of rail welds during cyclic rolling contact in heavy haul railway systems and develop a reliable tool to predict the initiation life of the localised surface damage at rail welds.
3.1.4 INNOVATIONS AND OUTCOMES

Nanocomm Hub researchers measure the mechanical properties, plastic deformation and failure behaviour of rail flashbutt welds produced from several high-strength rail steels with different welding process parameters used in heavy-haul railway systems in the Australian mining industry. This project will enhance our understanding of the formation of microstructures and the performance of different premium rail steel grades at rail flash-butt welds. More importantly, the outcomes will be applied directly by rail welding companies to optimise welding procedures. Also, rail infrastructure owners can mitigate the extent of localised surface fatigue damage at rail flash-butt welds – they can do so by modifying wheel/rail contact conditions and the associated rail maintenance strategy to grind the damaged rail welds (by taking into consideration the cyclic deformation behaviour and the fatigue initiation life of rail welds).

3.1.5 TEAM

Leading PI: Dr Anna Paradowska

Hang Su¹, Wenyi Yan¹, Chung Lun Pun², Peter Mutton², Qianhua Kan³ and Anna Paradowska⁴

1. Department of Mechanical and Aerospace Engineering, Monash University, Australia
2. Institute of Railway Technology, Monash University, Australia
3. School of Applied Mechanics and Engineering, Southwest Jiaotong University, China
4. Australian Nuclear Science and Technology Organisation, Australia
3.2 ROBOTICS AND SENSOR TECHNOLOGIES

3.2.1 PROJECT IMPACTS

Observed impacts:
Robotic systems with artificial intelligence have so far been shown to successfully detect structural damage with 97.7% specificity, 91.9% sensitivity and 96.6% accuracy.

By detecting defects with greater accuracy, autonomous robotics systems and techniques allow for better use of maintenance budgets and, consequently, longer asset lives.

» Using similar technologies, Sydney Water achieved a 25% reduction in the annual cost of their critical water mains (CWM) renewal program.

» Additionally, semi-autonomous robots reduced the cost of bridge inspections by 30-40%, while improving the safety of inspectors. The robots also made it easier to track the aging of bridges.

Probable industry impacts:
The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

» 90% commercial viability
» 1.5% increase in the asset life of all new road and rail assets owing to new technologies and the more effective use of maintenance budgets
» market entry in 2040
» 15% market penetration.

3.2.2 BACKGROUND

Australian governments spend over $7 billion each year maintaining and renewing the road systems, with states spending over $5.5 billion and local governments $1.5 billion. To reduce expenditure, Australia needs more durable, resilient and secure infrastructure – infrastructure that can resist extreme events.
3.2.3 AIMS AND GOALS

Develop next-generation pavement testing and inspection facilities, including:

» design for novel pavement materials
» robotics for pavement maintenance
» robotic system hardware
» mechatronic device.

3.2.4 INNOVATIONS AND OUTCOMES

The collaboration between ARRB and Monash to envisage, design, manufacture and implement the robotic transverse profiler (RTP) for routine, high-quality research data collection has been exceptional. The collaboration shows what is possible and demonstrates the value of bringing together multidisciplinary experts. ARRB had a clear need for the RTP.

While ARRB’s expertise in civil and infrastructure engineering is first-class, expertise in robotics was lacking. The successful collaboration has not only developed the RTP, but has brought ARRB and Monash closer together for future similar initiatives. It has also formed the basis for discussions about potential improvements and also future developments for the next generation of more sophisticated RTPs.

This technology extends the agricultural robotic system. A depth camera is used to detect the fruits from the current working space. The detection algorithm is based on deep learning which has shown superior performance and robustness in real picking environments.

3.2.5 TEAM

Robotic systems which utilise artificial intelligence, developed to date, have been successful in detecting structural damage with 97.7 per cent specificity, 91.9 per cent sensitivity and 96.6 per cent accuracy. By using autonomous robotics systems and techniques, defective assets can be identified with greater accuracy allowing for more effective use of maintenance budgets and therefore longer asset lives.

— PricewaterhouseCoopers (PwC)

Michael Stanley¹, Logan Vesty¹, Kee Tee¹, Wenhui Duan² and Chao Chen¹

¹. Department of Mechanical and Aerospace Engineering, Monash University, Australia
². Department of Civil Engineering, Monash University, Australia
3.3 TECHNOLOGIES FOR FUTURE ROADS

3.3.1 PROJECT IMPACTS

**Observed impacts:**

More durable, resilient and secure concrete can reduce the maintenance costs of infrastructure networks. And making such improvements increases the capacity of concrete to resist extreme events. This project examines how local aggregates can reduce the incidence of cracking commonly known as concrete cancer.

**Probable industry impacts:**

The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

- 90% commercial viability
- 1.5% increase in the asset life of all new road and rail assets owing to new technologies and the more effective use of maintenance budgets
- market entry in 2022
- 15% market penetration.

Nanocomm Hub CI Prof William Young attending the 3rd International Conference on Transportation Infrastructure and Sustainable Development 2019
Nanocomm Hub researchers are developing protocols for minimising deleterious alkali-silica reaction (ASR) with the use of aggregates. This alternative ASR mitigation methods improve the durability of concrete with potential to be applied worldwide.

3.3.2 BACKGROUND

The way we connect has been rapidly changing – even the way we physically connect by road. Because Australia’s $250 billion road network was created for our past, we now need a social licence for the future so that road design, management and maintenance fulfill community needs and expectations. To understand how 25 million daily road users think and choose, we must touch base with them regularly. This requires continual systematic engagement – direct and indirect – with users.

Alkali-silica reactivity (ASR) can cause concrete to expand then crack. Unless the cracking is contained, the concrete will lose functionality. This then requires repair, rehabilitation and possible decommission of the damaged structure. To avoid such problems, asset owners might limit their use of potentially reactive aggregates. Or they might inhibit concrete expansion by routinely applying surface treatments to prevent moisture ingress.

Such measures unfortunately can add a huge cost to concrete, as well as tax the environment owing to the scarcity of non-reactive aggregates. Dr Kirk Vessalas, Deputy Head of the School of Civil and Environmental Engineering at the University of Technology Sydney (UTS), has therefore embarked on devising novel strategies for the use of potentially reactive aggregates in concrete.

3.3.3 AIMS AND GOALS

» Develop strategies for use of reactive aggregates in concrete without using supplementary cementitious materials (SCMs).

» Develop novel mitigation techniques for minimising deleterious ASR in concrete.

» Determine alkali threshold limits for New Zealand aggregates and concrete mixes.

» Assess aggregate combinations for effective mitigation of deleterious ASRs.

» Identify causative components in reactive aggregates and their effect on the extent of ASR.

» Increase the strength of stabilised soil and maintain the material stiffness over moisture fluctuation.
3.3.4 INNOVATIONS AND OUTCOMES

The adoption of guidelines focused around the RILEM Recommendations for the Prevention of Damage by Alkali-Aggregate Reactions in New Concrete Structures has proven to be particularly effective in ascertaining the reactivity potential of different rock types and aggregate combinations that are used in concrete.

The incorporation of physical expansion tests, petrographic examination, dissolution studies and elemental analysis to determine the presence of deleterious ASR allows variations in alkali limits and aggregate combinations to be trialled and investigated.

Combining a potentially reactive aggregate with a non-reactive aggregate in concrete highlights a sustainable approach in minimising the risk of deleterious ASR. Also, this study will substantially benefit geotechnical applications including cost-effective and sustainable road constructions.

3.3.5 TEAM

Leading CI: Prof Kirk Vessalas
Elsie Nsiah-Baafi¹, Kirk Vessalas¹, Paul Thomas⁴, Vute Sirivivatnanon⁴, James Mackenzie⁵ and Sue Freitag

Leading CI: Prof William Young
William Young¹, Michael Shackleton² and Alexa Delbosc³

Leading CI: Dr Dilan Robert
Jaspreet S Pooni¹, Filippo Giustozzi¹, Dilan Robert¹, Sujeeva T Setunge¹ and Brian O’Donnell²

1. School of Civil and Environmental Engineering, University of Technology Sydney, Australia
2. School of Mathematical and Physical Sciences, University of Technology Sydney, Australia
3. Concrete New Zealand
4. School of Civil and Environmental Engineering, University of Sydney, Australia
5. School of Mathematical and Physical Sciences, University of Sydney, Australia

Nanocomm Hub CI Dr Kirk Vessalas
3.4 BRIDGE MANAGEMENT

3.4.1 PROJECT IMPACTS

Observed impacts:

The Central Asset Management System (CAMS), a GIS-integrated functional bridge management system, provides a comprehensive inventory with the capability to filter data of different bridges and components. It can also forecast the life cycle cost of bridge components, optimising maintenance management. Cloud hosted on Amazon servers in Sydney, CAMS is protected by all the security provisions required by Australian government agencies. CAMS currently predicts the future condition and life cycle cost of 3800 bridge structures in Victoria.

This project aims to develop a deterioration model and a prioritisation tool to predict future conditions of bridge components, as well as a maintenance budget. It will also improve assessment of risk associated with current budget levels, and prioritise bridges for maintenance, repair or replacement.

Nanocomm Hub researchers are developing modelling for bridge deterioration and prioritisation. This approach can predict the condition of bridge components and optimise maintenance management.
3.4.2 BACKGROUND

In Victoria, only 72% of concrete bridges and 35% of timber bridges are considered to be in good condition. Because road authorities have trouble predicting when materials and structures of aging infrastructure will degrade, their maintenance decisions are often reactive rather than proactive.
3.4.3 AIMS AND GOALS

Develop a working deterioration modelling tool, including all VicRoads road structures.

» Incorporate models into an existing bridge management system.

» Implement Central Asset Management System (CAMS) for bridges developed by RMIT University.

Nancomm Hub researchers at RMIT, in collaboration with Dr Koay and Dr Alam from the Department of Transport in Victoria, have also developed a comprehensive bridge prioritisation methodology by establishing a model for evaluating the value of a bridge to the network.

3.4.4 INNOVATIONS AND OUTCOMES

Deterioration of bridge components has been established using data analytics of the Level 2 bridge inspection data captured by the Department of Transport in Victoria. A combination of artificial intelligence and stochastic modelling, based on the Markov chain theory, has been used to derive deterioration curves for 75 bridge components representing all the elements of bridges in Victoria. The modelling covered reinforced concrete, prestressed concrete, steel, timber and other materials, such as masonry bridges.

Research is in progress to convert the data-driven stochastic deterioration models into nanoscience-based physical degradation models. This is a great example of the Nanocomm hub linking the nanoscience-based technologies to system-level forecasting.

The prioritisation model is developed by evaluating the impact on the road network when a bridge is closed for traffic. The cost associated with the bridge closure is established by considering the detour length, speed change, detour time, impact on the community, accidents, air pollution, access to emergency services, etc. The model is built based on the data collected from literature, the Department of Transport in Victoria, and the Australian Bureau of Statistics. A traffic simulation model is used to establish the change to traffic flow when a bridge is closed to traffic.

3.4.5 TEAM

Leading CI: Prof Sujeewa Setunge

Sujeewa Setunge¹, Huu Tran¹ and Yew-Chin Koay²

1. School of Engineering, RMIT University, Australia
2. VicRoads

Annual Report 2019
Turning “waste” into “wealth”
4.1 WASTE BENEFICIATION AND REDUCTION

4.1.1 PROJECT IMPACTS

Observed impacts:

Commercialisation of several new technologies is now underway in the areas of brown coal fly ash beneficiation and utilisation, including:

- replacement of clay bricks with geopolymer ones (for example, in underground mine stoppings and dams)
- reuse fly ash by extracting high-purity nano-minerals from brown coal combustion waste.
Probable industry impacts:
The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

» 60% commercial viability
» $16.5 million reduction in imports owing to domestic fly ash production and existing stockpiles replacing fly ash imports. $16.5 million is equivalent to Australia’s current imports of black coal fly ash (150,000 tonnes per annum worth $90 to $130 per tonne on average).
» market entry in 2030
» market penetration implied above.

4.1.2 BACKGROUND

There has been a growing recognition in recent years that the use of renewable resources in the construction industry is paramount to achieving carbon neutrality and environmental sustainability. Geopolymers present an environmentally friendly alternative to Portland cement. They are made by reacting materials containing aluminate and silicate, such as coal fly ash and slag, with a highly alkaline activator. Using fly ash produced by brown coal combustion, the Nanocomm Hub aims to test the feasibility, and optimise the method of manufacturing, of a novel geopolymer masonry product. Replacing Portland cement with such geopolymers not only would help eliminate waste, it could potentially reduce CO₂ emissions by 25-45%.

As the world’s fourth largest producer of brown coal, Australia has an economically recoverable reserve of 37 billion tonnes – that’s 25% of worldwide resources, with significant reserves in Russia, Germany and the US. Each year over one million tonnes of fly ash (primarily from brown coal) are generated in Victoria alone. Mainly stored in ponds or sent to landfills, fly ash adversely affects the environment, contaminating groundwater among other things.

As an eco-friendly construction material, magnesium oxychloride cement (MOC) has attracted much research interest in recent decades. In Australia, there are plenty of magnesite resources (320.48 million tonnes), as well as seawater, from which both magnesium oxide (MgO) and magnesium chloride (MgCl₂) are readily accessible.
4.1.4 INNOVATIONS AND OUTCOMES

A comprehensive experimental study has investigated the geopolymerisation and compressive strength development of mortar made from brown coal fly ash recovered from two distinct locations in the storage ponds at Loy Yang Power Station in the LaTrobe Valley, Victoria. The team designed an optimised mix, based on the compressive strength, for the geopolymer mortar. They performed an in-depth analysis of the development of its microstructure/pore-structure development over an initial 90-day period to gain an understanding of the geopolymerisation process.

The Loy Yang–A (LYA) geopolymer mortar showed an increase in strength of approximately 30% whereas the Loy Yang–B (LYB) one showed a decrease in strength of approximately 18% over a 7- to 90-day period. However, both geopolymer mortars initially achieved a similar 28-day strength of approximately 23 MPa.

This increased strength of the LYA mortar correlates with an increase in the quartz phases, coupled with a decrease in the moganite phase. Formation of sodium carbonate due to atmospheric carbonation of unreacted sodium hydroxide also contributed to the increased strength of the LYA geopolymer.

4.1.3 AIMS AND GOALS

» Develop an alternative binder material for use in concrete that will ultimately replace Ordinary Portland Cement.

» Mitigate adverse environmental impact (e.g. decrease groundwater contamination and CO₂ emissions).

» Investigate the geopolymerisation and compressive strength development of mortar made from brown coal fly ash from two distinct locations in an Australian power plant’s storage ponds.

» Promote HCl regeneration rate from the abundant, mixed waste of brown coal combustion.

» Improve the mechanical properties and water resistance of MOC.

Nanocomm Hub research team at RMIT is investigating the feasibility of using geopolymers as a binder in the manufacture of masonry bricks. The replacement of Portland cement by geopolymers is expected to reduce CO₂ emissions by 25-45%. Image shows the morphology of Loy Yang Power Station gel.
Facilitated by silica and steam, HCl has been successfully recovered from the copyrohydrolysis of alkaline-earth-metal chlorides (CaCl\(_2\) and MgCl\(_2\)). A double-sided effect from the addition of MgCl\(_2\) has been revealed for the first time.

The influences of fly ash on the physical and mechanical properties of MOC, especially after being attack by water, have been investigated. Incorporating fly ash up to 30% the weight of the MgO in the MOC paste reduces the fluidity, retards the setting time, improves the water resistance and, most importantly, enhances the mechanical properties, including compressive strength, flexural strength and elastic modulus. Adding fly ash has significantly increased the flexural strength retention coefficient under water attack.

The addition of fly ash optimises the pore structure of hardened MOC to get a compact structure, and the formed magnesium silica hydrate (M-S-H) gel-like phase contributes to the water repellence of MOC. The interlock and combination of MOC and fly ash particles improve the stability and water resistance of MOC.

4.1.5 TEAM

Leading CI: Assoc Prof Lian Zhang
Tahereh Hosseini, Binbin Qian, Song Zhou, Anthony De Girolamo and Lian Zhang

Leading CI: Prof Sujeeva Setunge
Muhammed Khodr, David Law, Chamila Gunasekara, Robert Brkljaca and Sujeeva Setunge

Leading CI: Assoc Prof Yixia Zhang
Yingying Guo1, Yixia Zhang1,3, Khin Soe4, Wayne D. Hutchison2, Heiko Timmers2 and Myra R. Poblete2

1. School of Engineering and Information Technology, UNSW, Australia
2. School of Science, UNSW, Australia
3. School of Engineering, Western Sydney University, Australia
4. UBIQ PTY LTD, Australia
4.2 GREEN CONCRETE

4.2.1 PROJECT IMPACTS

Observed impacts:
The widespread use of geopolymer concrete as a construction material has many benefits, including:

» primarily using industrial waste products, such as fly ash and slag, as the binder in concrete
» minimising the carbon dioxide emissions of cement manufacture (owing to the partial replacement of Ordinary Portland Cement) and reducing construction costs
» stabilisation of soil slopes and roads using natural pozzolan-based geopolymers, which strengthen slopes at less cost than traditional cement-like binders
» using geopolymer concrete in pipes can reduce their thickness with little or no reinforcement – a big advantage for precast pipe manufacturers.

Researchers at the University of Melbourne have conducted an in-depth study of the behaviour of AAMs in acidic environments. The results have facilitated the development of more durable construction materials for sewerage systems.
4.2.2 BACKGROUND

The acid-rich environment of sewage and drainage wastewater can severely damage concrete sewer pipes, which must then be repaired or replaced. In the single state of South Australia, it is projected that each year about $48 million will be spent on the maintenance of underground wastewater structures. The high cost makes it imperative that we develop more durable building materials that can withstand such a highly aggressive environment.

An alternative to standard cementitious materials are alkali-activated materials (AAMs) made by mixing aluminosilicate precursors (such as metakaolin, ground granulated blast furnace slag and/or fly ash) with alkaline activators. AAMs hold promise as an environment-friendly binder to replace those based on Ordinary Portland Cement.

Designing precast concrete components

With the current push towards sustainable materials in construction, AAMs have gained traction owing to their excellent durability properties. Compared with Ordinary Portland Cement, they have a greater resistance to alkali-silica reaction, freeze-thaw, acid attack and sulphate attack. That makes AAMs ideally suited as a binder for precast concrete components, such as culverts and pipes.
4.2.3 AIMS AND GOALS

» Produce AAMs resistant to mineral acids, such as sulphuric acid and phosphoric acid.

» Reduce cost of repairing sewerage systems.

» Experimentally investigate the resistance of alkali-activated slag/fly ash-based geopolymer pastes and compare them to Ordinary Portland Cement-based pastes when exposed to phosphoric acid with different pH values (pH = 2, 3 and 4) for 150 days.

» Develop a novel powder-based geopolymer (a collaboration between Hub researchers at the University of Technology Sydney and Cement Australia).

» Overcome production issues related to liquid activators in geopolymers.

» Determine the influence of a sodium-based retarder on setting time, heat release, workability and compressive strength development of dry powder fly ash/slag-based geopolymer pastes and mortars.

» Reduce greenhouse gas emissions in Australia.
4.2.4 INNOVATIONS

The experimental results revealed that alkali-activated slag/fly ash-based pastes are more resistant to phosphoric acid attacks compared with Ordinary Portland Cement-based pastes.

The theoretical model developed in this study predicts that, under strong phosphoric acid conditions for a period of 50 years, alkali-activated slag/fly ash-based pastes could potentially reduce the degradation depth by around 70–80% in comparison with Ordinary Portland Cement-based pastes.

This study suggests that a sodium-based retarder can be used effectively in dry powder (or one-part mix) geopolymer mortar based on fly ash/slag to control the setting time to desired levels. Compressive strength reduced considerably with the increase of retarder content regardless of the curing regime. The reason for this result is not entirely understood.

Optimal amount of retarder is 2-6%, in terms of setting time, workability and compressive strength.

4.2.5 TEAM

Leading CI: Assoc Prof Lihai Zhang
Jie Ren, Rackel San Nicolas and Lihai Zhang

Department of Infrastructure Engineering, the University of Melbourne, Australia

For precast products, a curing process consisting of sealing the exposed surfaces and steam curing at 60°C for six hours is recommended. Hub researchers at the University of Melbourne have studied in depth the behaviour of AAMs in acidic environments. The results have assisted the development of more durable construction materials for sewerage systems.

Leading CI: Prof Vute Sirivivatnanon
Sumita Dangol, Paul Kidd, Pre De Silva, Tran Huyen Vu, Nadarajah Gowipalan and Rijun Shrestha

School of Civil and Environmental Engineering, UTS, Australia

Optimal amount of retarder is 2-6%, in terms of setting time, workability and compressive strength.

Leading CI: Prof Zhong Tao
Zhong Tao¹ and Zhu Pan¹

¹Centre for Infrastructure Engineering, Western Sydney University, Australia

Nanocomm Hub CI Prof Tao Zhong

School of Science, Australian Catholic University, North Sydney, NSW, Australia

Cement Australia Pty Ltd, Australia
5

AQUACULTURE
5.1 FLOATING FOREST

5.1.1 PROJECT IMPACTS

Observed impacts:
To assess scientific and engineering concepts relevant to this project, a feasibility study was conducted. Additional research now in progress examines:

» the viscous effect
» various design parameters
» a floating forest model.

Probable industry impacts:
The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

» 55% commercial viability
» $26 million increase in output in the seafood industry owing to improved protection for fish farms and expansion of their operational space. The seafood sector is expected to exceed $5 billion by 2040, with innovation from the Hub assumed to contribute 1% of the increase
» market entry in 2025
» market penetration implied above.
5.1.2 BACKGROUND

Increasingly strong winds and waves caused by extreme weather events can seriously damage beaches, boats and coastal infrastructure. To counteract these forces, a floating breakwater-windbreak has been designed with an arched shape and inclined concrete deck to dissipate wave energy, and with hollow tube “trees” on top to reduce wind speed.

The “floating forest” creates a calm, protective environment for fragile shorelines, fish farms, marinas, port terminals and other large floating structures. Inventors on this patent include Hub Chief Investigators, Professor Chien Ming Wang from the University of Queensland and Professor Wenhui Duan from Monash University, and Partner Investigator Dr Kwanghoe Jung from Hyundai Engineering and Construction, South Korea.

5.1.3 CHALLENGES

Nanocomm Hub researchers from the University of Queensland address the following challenges:

- nonlinear wave run-ups
- structural safety under extreme wave conditions
- viscous effects and waves breaking near the structure
- wind-wave coupling analysis
- non-steady zero displacement plane for wind analysis
- 3D turbulence modelling
- balance between economic concerns and effectiveness.

5.1.4 INNOVATIONS

This mega floating structure adopts an arched shape with an inclined deck to keep concrete structures under compression during wave action and to allow wave run-ups for more efficient wave energy dissipation. As a breakwater, it can be used in various water depths, providing suitable sea-keeping systems.

The structure’s windbreak capability is enabled by artificial “tree” columns on the deck, installed in arrays that create air flow turbulence to dissipate wind energy. The combination of energy extraction by the structure and divergence of flow leads to a large wake region behind the structure, with a significant reduction in wind speed.

This novel structure has the ability to create calm water on its downstream side for the preservation of marinas, seaplane landing strips, fish farms, recreational sea activities, and large floating structures that carry buildings and infrastructure.
5.1.5 OUTCOMES

A windbreak could be made up of real vegetation, but that would be difficult to maintain and manage because it would be offshore. Instead, we’ve chosen to build the tubes out of plastic and concrete, placing them in a formation that provides the most resistance to wind, thereby dissipating its strength.

The floating structure would be around one kilometre long, with the tubes standing at 20m tall. A smaller version may be constructed in places that are hit by severe cyclone seasons, such as Bangladesh, Mozambique, Taiwan and the Philippines.

Nanocomm Hub researchers working with industry partners are generating some incredibly innovative research and ideas. The patent taken out by the researchers allows them to claim ownership of this idea and to work further on the invention, with the possibility of it being commercialised and shared with coastal communities around the world.

5.1.6 TEAM

Leading CI: Prof Chien Ming Wang

Chien Ming Wang1, Mengmeng Han1, Junwei Lyu1, Wenhui Duan2, Kwanghoe Jung³ and Sara Kang1,2

1. School of Civil Engineering, The University of Queensland, Australia
2. Department of Civil Engineering, Monash University, Australia
3. Hyundai Engineering and Construction, R&D Division, South Korea
Towards safe and environment-friendly mining with cutting-edge nanotechniques and innovative structure design
6.1.1 PROJECT IMPACTS

Observed impacts:
Ultra-thin graphene-based material offers separation and acid recovery nearly four times that of current commercial dense membranes. When the Asarco Globe refinery installed a nanofiltration (NF) membrane, the volume of water required for precipitation was reduced by 75%.

Probable industry impacts:
The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:
» 90% commercial viability
» 0.4% reduction in costs to the coal sector owing to a 20% reduction in water waste via solution-based processing (comprising 2% of total costs)
» market entry in 2025
» 15% market penetration.

Nanocomm Hub researchers use graphene-based membrane for acid waste water treatment. The developed graphene-based membrane exhibits a superior capacity for separation and acid recovery, significantly improving overall performance.
6.1.2 BACKGROUND
Freshwater consumption by the industrial and mining sectors has been rapidly growing – a problem compounded by the massive quantities of acidic wastewater these sectors produce. The inadequate treatment of this wastewater before discharge can bring about severe contamination, adversely affecting the aquatic environment and threatening community health. Over the past decade, wastewater recovery, as an additional water resource, has emerged as a sustainable path – not only does this diminish environmental pollution, it alleviates the problem of freshwater scarcity.

6.1.3 CHALLENGES
Despite the serious consequences of inadequate treatment, the drawbacks of current acid waste treatment limit its employment. This leads to:
- massive accumulation of hazardous acidic waste
- high energy consumption when recycling acidic industrial wastewater in a closed loop
- severe environmental pollution
- wastage by not recycling potentially valuable byproducts, including acid and precious metals.
6.1.4 INNOVATIONS
A new class of graphene-based ion exchange membrane (IEM) has been developed at Monash University. Its unique architecture features an ultra-thin dense nanoporous layer of only a few dozen to a few hundred nanometres. This charged asymmetrical graphene-based IEM, driven by the rapid flow of ions through its membrane, has led to a sustainable and continuous acidic wastewater treatment. By contrast, commercial IEMs consist of a thick dense nanoporous layer of 100,000 nanometres. The newly developed graphene-based membrane exhibits a superior ability for separation and acid recovery, significantly improving the

6.1.5 KEY FINDINGS
Our results show that this unique graphene-based membrane comprises an ultra-thin dense nanoporous layer of 30 nanometres to no more than 350 nanometres across – in other words, it’s about 300 to 3000 times thinner than commercial IEMs.

Accordingly, ions can be quickly and directly transported from the bulk of the solution to the IEM’s surface, without the hindrance and resistance of the external ion-depletion region, which normally occur in dense commercial IEMs. This allows for fast and continuous acidic wastewater treatment.

6.1.6 TEAM
Hanaa Hegab, Huanting Wang
Department of Chemical Engineering, Monash University, Australia

Leading Ct: Prof Huanting Wang
6.2.1 PROJECT IMPACTS

Observed impacts:

The risk of serious injuries has been minimised by redesigning the platform on continuous miners and bolting rigs, limiting distances reached in underground coal mines during drilling and bolting.

Various protective structures have undergone laboratory and numerical testing for use on continuous miners to help improve construction safety.

A case study at Coal India Ltd revealed a loss of approximately 12% of coal production due to ground control problems. The Hub project aims to develop technology that will avoid such problems and help boost mineral industry output.

Auxetic panels, which will be used in the Hub's protective structure, have displayed extremely good protective properties. To demonstrate their stress resistance and energy absorption, a dynamic impact test was carried out at the University of Wollongong.
Probable industry impacts:
The economic impact of this project was estimated using parameters based on the Hub’s expertise and the available academic research:

- 90% commercial viability
- 0.1% reduction in costs to the iron ore, coal, copper and nickel mining sectors owing to fewer mine collapses
- market entry in 2025
- 15% market penetration.

6.2.2 BACKGROUND
Coal or rock burst is a sudden and violent failure of coal or rock caused by dynamic loading in underground mines. Not only can such hazards damage a mining system, they can seriously injure workers. In Australia, two burst-related fatalities have occurred while using a continuous miner during development of an underground gate-road. The industry has expressed an urgent need for a protective structure that can be installed on continuous miners used in mines susceptible to coal or rock bursts. According to IBIS 2018, the coal mining sector generates $61.8 billion of revenue in Australia.

The coal fragments generated by tests are analysed through digital image processing to study fragment size distribution (FSD) and fragmentation energy of a coal burst.
6.2.3 AIMS AND GOALS

Safety, energy release

» This project aims to design, manufacture and implement an innovative protective structure for continuous miners in underground coal mines where a coal burst or outburst can occur when developing roadways in highly stressed and gassy coal seams.

» Quasi-static and dynamic loading tests have been designed to assess energy release and transformation during a coal burst incident. Numerical models have been developed to study the influence of coal cleat and joint systems on the dynamic failure of coals under various loading conditions.

» To demonstrate the stress resistance and energy absorption ability of auxetic panels, the dynamic impact testing was carried out at the University of Wollongong.

6.2.4 INNOVATIONS

The energy scale associated with a coal burst is an important parameter when designing a structure to protect against coal ejection. The rationale behind a supportive or protective design is to dissipate or absorb the kinetic energy of ejected coal, based on energy analysis and fragmentation study.

The experiment conducted in this project is called the “coal ejection test”. This has been modified based on a uniaxial compression test, which aims to understand the energy dissipation and failure pattern of coal samples prone to bursts.

The energy scale of a coal burst has been determined through testing and analysis. Our research shows that the scale of kinetic energy released by a coal burst in underground roadways can reach over 10^7 J high, which can eject coal with over 24 m/s velocity. In future research, the material property of a protective structure could be tested according to the scale of energy.

6.2.5 TEAM

Ting Ren¹, Alex Remennikov¹, Peter Holt², Xiaohan Yang¹, Lihai Tan¹ and Dulara Kalubadanage¹

¹ School of Civil, Mining and Environmental Engineering, University of Wollongong, Australia
² Ironclad Mining Machinery, Australia
7

EQUITY
To date, 21% of our members are female, with representation across all levels of the Hub.
Diverse teams are known to perform better than those with gender and cultural uniformity, and we recognise that the Hub will benefit from a diverse milieu in terms of productivity, creativity and efficiency.
The Nanocomm Hub seeks talented staff and students, irrespective of social or economic circumstances, while striving to build a connected community that is deeply engaged with the wider government, business, industry and public communities.

Further, we believe every individual has the right to be treated equally and fairly regardless of gender, race, religious belief or any other personal characteristic. We foster equity and fairness by promoting diversity within the Hub. After all, diverse teams are known to perform better than those with gender and cultural uniformity, and we recognise that the Hub will benefit from a diverse milieu in terms of productivity, creativity and efficiency.

To date, more than 21% of our members are female, with representation across all levels of the Hub. Among those industries that suffer a serious gender imbalance, this percentage is considered relatively good. Although a 50-50 blend of women and men in the construction area may seem out of reach, Nanocomm Hub has put into place various strategies to attract more women into our research.

In strong support of the ARC Gender Equality Action Plan 2018, we have undertaken to:

• monitor gender balance during recruitment of Hub members
• raise awareness of unconscious bias by highlighting it in our staff training
• create an inclusive workspace that is female- and family-friendly
• support current female Hub members and increase their overall participation via mentoring, scholarships and travel allowances
• provide opportunities for female Hub members to speak at conferences and workshops
• establish a school work experience program that engages girls
• organise a community outreach program to inspire girls to study engineering.

The table below shows the breakdown of roles currently held by women at the Hub.

<table>
<thead>
<tr>
<th>NANOCOMM HUB ROLE</th>
<th>FEMALE</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partner Investigators</td>
<td>7</td>
<td>48</td>
<td>15%</td>
</tr>
<tr>
<td>Chief Investigators</td>
<td>11</td>
<td>48</td>
<td>23%</td>
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<tr>
<td>Research Fellows, ECR &amp; RA</td>
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<td>25</td>
<td>20%</td>
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<tr>
<td>HDR Students</td>
<td>15</td>
<td>61</td>
<td>25%</td>
</tr>
<tr>
<td>Overall</td>
<td>38</td>
<td>182</td>
<td>21%</td>
</tr>
</tbody>
</table>
8.1 MANAGEMENT TEAM

HUB DIRECTOR
PROF WENHUI DUAN

DEPUTY DIRECTOR (OPERATIONS)
DR KWESI SAGOE-CRENTSIL

DEPUTY DIRECTOR (SYDNEY)
PROF VUTE SIRIVIVATNANON

DEPUTY DIRECTOR (BRISBANE)
PROF SRITAWAT KITIPORNCHAI

DEPUTY DIRECTOR (MELBOURNE)
PROF SUJEeva SETUNGE

PROJECT OFFICER
DR BILLY CHANG
8.2 ADVISORY COMMITTEE

The Advisory Committee consists of the Hub Director, Hub Deputy Directors, and other academic and industry experts in the specific fields related to the research. The purpose of the Advisory Committee is to:

- Provide strategic advice, opinions and recommendations on the direction of Research Programs
- Provide industry input to the Hub Director
- Promote the objectives and outcomes relating to industry and engagement

8.2.1 SCIENTIFIC ADVISORY COMMITTEE

- PROF YIU-WING MAI (Chair)
  University of Sydney
- PROF DAVID NETHERCOT
  Imperial College of London
- PROF JOSE TORERO
  University College London

8.2.2 INDUSTRY ADVISORY COMMITTEE

- PROF SER TONG QUEK
  The National University of Singapore
- PROF ROSE AMAL
  The University of New South Wales
- PROF MARK BRADFORD
  The University of New South Wales
- MR MENNO HENNEVELD
  Menno Henneveld Consulting
- MR RICHARD KELL
  Cardno
- PROF WENHUI DUAN (Chair)
  Monash University
- DR PHILLIP ARENA
  Fortis
- DR ANNA PARADOWSKA
  Ansto
- DR WARREN SOUTH
  Cement Concrete and Aggregates Australia (CCAA)
- DR RICHARD YEO
  ARRB
8.3 STEERING COMMITTEE

The Steering Committee has four sub groups, i.e. Chief Investigator (CI) group, Partner Investigator (PI) group, Research Fellow (RF) group and HDR student group. Each group has one facilitator to promote the collaboration amongst hub members from different participant organisations and to provide advice to the Management Team on any concern/opportunities from CI, PI, RF and HDR.

PROF WENHUI DUAN
Monash University

PROF SUJEEVA SETUNGE
RMIT University

PROF VUTE SIRIVIVATNANON
University of Technology Sydney

PROF SRTAWAT KITIPORNCHAI
The University of Queensland

DR KWESI SAGOE-CRENTIL
Monash University

PROF BIJAN SAMALI
Western Sydney University

DR WARREN SOUTH
Cement Concrete and Aggregates Australia (CCAA)

DR SHERRY QIANHUI ZHANG
Monash University

ZAHRA NOURI EMAMZADEH
Western Sydney University
HUB MEMBERS

8.4 CHIEF INVESTIGATORS

PROF WILLIAM YOUNG
Monash University

PROF JIAN ZHAO
Monash University

PROF WENHUI DUAN
Monash University

DR QIANBING ZHANG
Monash University

DR AMIN HEIDARPOUR
Monash University

A/PROF MOHAN YELLISHETTY
Monash University

DR COLIN CAPRANI
Monash University

DR CHAO CHEN
Monash University

MR PETER MUTTON
Monash University

A/PROF LIAN ZHANG
Monash University

PROF HUANTING WANG
Monash University

A/PROF RUIPING ZOU
Monash University

DR HUI HUANG
Monash University

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GOVERNANCE

PROF SRITAWAT KITIPORNCHAI
The University of Queensland

PROF CHIEN MING WANG
The University of Queensland

DR YIMIAO HUANG
The University of Western Australia

PROF YAN ZHUANGE
University of South Australia

DR EMRE ERKEMEN
University of Technology Sydney
8.5 PARTNER INVESTIGATORS

DR QUNYING WANG
China Huadian

DR PHILLIP ARENA
Fortis

DR RICHARD YEO
ARRB

PROF TONGBO SUI
Sinoma

DR JUN GANG CAI
Tritech

MR MARK MUZZIN
OneAtom 12

DR ANNA PARADOWSKA
Ansto

PROF GUOZHENG KANG
Southwest Jiao University

PROF SER TONG QUEK
NUS

A/PROF CLAIRE WHITE
Princeton University

PROF SUREN德拉 SHAH
Northwestern University

MR BRIAN O’DONNELL
CPEAP

DR YEW-CHIN KOAY
VicRoads

Annual Report 2019
8.6 RESEARCH FELLOWS & ECRS

DR HUU TRAN
RMIT University

DR CHAMILA GUNASEKARA
RMIT University

DR BAIQIAN DAI
Monash University

DR SAEED MIRAMINI
The University of Melbourne

DR HONG ZHANG
Beijing Institute of Technology

DR VAN THUAN NGUYEN
The University of Queensland

DR PAN ZHU
Western Sydney University

DR BOB ABTAHI
Western Sydney University

DR KAMYAR KILDASHTI
Western Sydney University

DR EZZAT SHAMSAEI
Monash University

DR SHERRY QIANHUI ZHANG
Monash University

DR ASGHAR HABIBNEJAD KORAYEM
Iran University of Science and Technology

DR SHUJIAN CHEN
The University of Queensland
8.7 RESEARCH ASSISTANTS

YUGUO YU
University of New South Wales

DR CUONG TRAN
Western Sydney University

MR WEIWEI DUAN
University of South Australia

DR PHUONG PHAM
University of South Australia

DR YANG YU
University of Technology Sydney
8.8 HDR STUDENTS

ERFAN AMIRI
RMIT University

RINTU RENJITH
RMIT University

JASPREE SINGH POONI
RMIT University

MUHAMMED KHODOR
RMIT University

SHA JI
Deakin University

VAN MANH PHUNG
Swinburne University of Technology

XIAOXIAO XU
Swinburne University of Technology

BABAR NASIM KHAN RAJA
The University of Melbourne

DANDAN SUN
The University of Melbourne

JUNFEI ZHANG
The University of Western Australia

JUNWEI LYU
The University of Queensland

REZA BANI ARDALAN
Western Sydney University

ZAHRA NOURI EMAMZADEH
Western Sydney University

YINGYING GUO
University of New South Wales, Canberra

BINBIN QIAN
Monash University

QIAOQIAO ZHOU
Monash University

GOVERNANCE
GOVERNANCE

MR XIAOHAN YANG
University of Wollongong

LIHAI TAN
University of Wollongong

XUPEI YAO
Monash University

HAO SUI
Monash University

JUNLIN LIN
Monash University

FELIPE BASQUIROTO DE SOUZA
Monash University

AFIFA TAMANNA
Monash University

YUBING OUYANG
Monash University

ZUNARIRA NASEEM
Monash University

ZIJUE CHEN
Monash University

JIALU ZHENG
Monash University

SAMEERA PITAWALA
Monash University

SAREH BAHROLOOLOOM
Monash University

JUNBO SUN
The University of Western Australia

MIAO LIU
The University of Western Australia

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ARC Nanocomm Hub
9.1 Key Performance Indicators

The Australian Research Council Industrial Transformation Research Hubs scheme has developed a key performance indicator (KPI) system to stimulate the translation of technological innovations from academia to industry. The system relies on 27 KPIs across six categories:

- research training and education
- research links and networks
- outputs
- outcomes
- end-user links
- benefits.

These occur in three phases: talent, excellence and impact (see diagram to right). Research training and education, research links and networks, and outputs combine to bolster excellence in university research, whereas outcomes, end-user links and benefits support the commercialisation of innovations by industry. By catering to the needs of both universities and industry, the KPI system maintains a balanced and mutually beneficial relationship between them.
2019 Key Performance Indicators

NETWORKING
- Overseas visits: 120%
- Nat and int'l visitors: 150%
- Workshops held: 400%

TRAINING AND EDUCATION
- KPI: 100%
- HDR courses attended: 138%
- PO mentors: 179%
- Mentoring programs: 179%
- Postgrad completions: 114%
- HDR in PO: 250%

OUTPUTS
- Invited talks: 240%
- Commentaries: 300%
- Industry reports: 300%
- Research outputs: 405%

END-USER LINKS
- KPI: 100%
- Industry visitors: 109%
- Public talks: 260%
- End user briefings: 650%

OUTCOMES
- New processes and products arising from research: 200%

BENEFITS
- KPI: 100%
- ROI: 113%
9.2 Research Training and Education

The Nanocomm Hub deeply values the professional development of our research team. We work hard to prepare our members for future success wherever their career may take them, whether they choose to pursue academic research or to enter the industrial workforce.

We encourage our members to attend seminars, workshops and short courses to enhance their professional development. These opportunities help Hub members build a broad range of skills, which will maximise their career options in a competitive environment. Also, we urge participation of research fellows and HDR students, as well as collaborators and industrial partners, so that they gain exposure to the latest technology in the field.

<table>
<thead>
<tr>
<th>EVENT TITLE</th>
<th>EVENT TYPE</th>
<th>VENUE</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual CCAA-UTS ASR Research Workshop</td>
<td>Workshop</td>
<td>UTS Tech Lab, Sydney NSW</td>
<td>17 Jan 2019</td>
</tr>
<tr>
<td>CCAA/UTS ASR Research Workshop</td>
<td>Research Development</td>
<td>Sydney NSW</td>
<td>17 Jan 2019</td>
</tr>
<tr>
<td>First South Asia Conference on Earthquake Engineering</td>
<td>Conference</td>
<td>Pakistan</td>
<td>11 Feb 2019</td>
</tr>
<tr>
<td>Transforming Recycled Waste to Engineered Materials and Solutions Industrial Transformation Training Hub</td>
<td>Professional Development</td>
<td>Monash University, VIC</td>
<td>14 Feb 2019</td>
</tr>
<tr>
<td>CCAA Academics Forum 2019</td>
<td>Symposium</td>
<td>Sydney NSW</td>
<td>26 Feb 2019</td>
</tr>
<tr>
<td>RILEM SMSS 2019</td>
<td>Conference</td>
<td>Hotel Lone, Rovinj Croatia</td>
<td>20 Mar 2019</td>
</tr>
<tr>
<td>ACS National Meeting 2019 Spring</td>
<td>Conference</td>
<td>Orlando, Florida, USA</td>
<td>2 Apr 2019</td>
</tr>
<tr>
<td>World Conference on Floating Solutions 2019 sets sights offshore</td>
<td>Conference</td>
<td>Singapore</td>
<td>22 Apr 2019</td>
</tr>
<tr>
<td>3rd International Conference on Artificial Intelligence, Automation and Control Technologies (AIACT 2019)</td>
<td>Conference</td>
<td>X’ian, China</td>
<td>26 Apr 2019</td>
</tr>
<tr>
<td>Global AI Product &amp; Application Expo 2019</td>
<td>Exhibition</td>
<td>Suzhou China</td>
<td>11 May 2019</td>
</tr>
<tr>
<td>UTS-Boral Workshop</td>
<td>Workshop</td>
<td>UTS Tech Lab, Sydney NSW</td>
<td>4 Jun 2019</td>
</tr>
<tr>
<td>Department of Civil Engineering 3-Minute Thesis</td>
<td>Symposium</td>
<td>Monash University, VIC</td>
<td>14 Jun 2019</td>
</tr>
<tr>
<td>ANSTO-HZB Neutron School</td>
<td>Workshop</td>
<td>ANSTO, Sydney</td>
<td>25 Jun 2019</td>
</tr>
<tr>
<td>Laboratory of Construction Materials Monthly Meeting</td>
<td>Seminar</td>
<td>Ecole Polytechnique Fédérale de Lausanne, Switzerland</td>
<td>10 Jul 2019</td>
</tr>
<tr>
<td>Cement Concrete &amp; Aggregates Australia: Concrete Technology Course</td>
<td>Professional Short Course</td>
<td>Sydney NSW</td>
<td>27 Aug 2019</td>
</tr>
<tr>
<td>International Conference on Transport Infrastructure and Sustainable Development</td>
<td>Conference</td>
<td>The University of Da Nang, Vietnam</td>
<td>1 Sep 2019</td>
</tr>
<tr>
<td>Concrete 2019</td>
<td>Conference</td>
<td>ICC Sydney, NSW</td>
<td>11 Sep 2019</td>
</tr>
<tr>
<td>Concrete 2019 Biennial Conference</td>
<td>Professional Development</td>
<td>Sydney NSW</td>
<td>11 Sep 2019</td>
</tr>
<tr>
<td>UWA HDR Conference</td>
<td>Conference</td>
<td>UWA, WA</td>
<td>25 Sep 2019</td>
</tr>
<tr>
<td>Indian Geotechnical Society</td>
<td>Seminar</td>
<td>Multi-cities, ndian</td>
<td>30 Sep 2019</td>
</tr>
<tr>
<td>Advancements in modern prefabricated and modular buildings - R&amp;D FORUM, 3rd OCT 2019</td>
<td>Forum</td>
<td>The University of Melbourne</td>
<td>3 Oct 2019</td>
</tr>
<tr>
<td>Concrete New Zealand Conference 2019</td>
<td>Conference</td>
<td>Dunedin Centre, New Zealand</td>
<td>10 Oct 2019</td>
</tr>
<tr>
<td>EVENT TITLE</td>
<td>EVENT TYPE</td>
<td>VENUE</td>
<td>DATE</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>ASCP Pavements Sydney Forum 2019</td>
<td>Forum</td>
<td>Ryde Eastwood Leagues Club, NSW</td>
<td>21 Oct 2019</td>
</tr>
<tr>
<td>2019 International Conference on Advances in Civil Engineering and Materials (ACEM2019) and 2nd World Symposium on Sustainable Bio-composite Materials and Structures (SBMS2)</td>
<td>Conference</td>
<td>Fuzhou, China</td>
<td>26 Oct 2019</td>
</tr>
<tr>
<td>Annual CCAA-UTS ASR Research Workshop 2019</td>
<td>Workshop</td>
<td>UTS Tech Lab, Sydney NSW</td>
<td>12 Nov 2019</td>
</tr>
<tr>
<td>CCAA/UTS Annual Research Workshop</td>
<td>Workshop</td>
<td>Sydney NSW</td>
<td>12 Nov 2019</td>
</tr>
<tr>
<td>ARRB NTR Award and Gala Dinner</td>
<td>Award</td>
<td>Melbourne VIC</td>
<td>15 Nov 2019</td>
</tr>
<tr>
<td>2nd PITCHCAMP - STRUCTURES ENGINEERING</td>
<td>Workshop</td>
<td>Melbourne VIC</td>
<td>19 Nov 2019</td>
</tr>
<tr>
<td>World Engineers Convention 2019</td>
<td>Conference</td>
<td>Melbourne VIC</td>
<td>20 Nov 2019</td>
</tr>
<tr>
<td>Smart Construction</td>
<td>Professional Short Course</td>
<td>UWA, WA</td>
<td>28 Nov 2019</td>
</tr>
<tr>
<td>2019 Civil Postgrad Conference</td>
<td>Conference</td>
<td>Monash University, VIC</td>
<td>29 Nov 2019</td>
</tr>
<tr>
<td>2nd ANZ Smart Farms and Agtech Forum</td>
<td>Forum</td>
<td>Melbourne VIC</td>
<td>3 Dec 2019</td>
</tr>
<tr>
<td>10th International Conference on Structural Engineering and Construction Management 2019</td>
<td>Conference</td>
<td>Kandy, Sri Lanka</td>
<td>14 Dec 2019</td>
</tr>
</tbody>
</table>
9.3 Research Networks

To boost Australian research, and to link Australian companies to the enormous opportunities in the Asian infrastructure market, we have set out to build national and international networks across industry and educational organisations.

9.3.1 VISITING STUDENTS AND FELLOWS

Inviting students and fellows to the hub from other universities has proved the most effective way to form strong bonds with our academic partners. In 2019, we have a total of 12 visiting students and fellows.

<table>
<thead>
<tr>
<th>NAME</th>
<th>INSTITUTION</th>
<th>DATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professor Zhenyu Liu</td>
<td>Beijing University of Chemical Technology</td>
<td>10 Feb 2019</td>
</tr>
<tr>
<td>Dr Yang Zhou</td>
<td>Southeast University</td>
<td>11 Feb 2019</td>
</tr>
<tr>
<td>Professor Jianbiao Bai</td>
<td>China University of Mining and Technology</td>
<td>13 Feb 2019</td>
</tr>
<tr>
<td>Dr Peter Waclawik</td>
<td>The Czech Academy of Sciences</td>
<td>11 Mar 2019</td>
</tr>
<tr>
<td>Professor Tao Zhang</td>
<td>Xi’an University</td>
<td>3 Jun 2019</td>
</tr>
<tr>
<td>Mr Yuan Gao</td>
<td>China University of Mining and Technology</td>
<td>1 Sep 2019</td>
</tr>
<tr>
<td>Mr Sina Fouladi</td>
<td>Iran University of Science and Technology</td>
<td>1 Sep 2019</td>
</tr>
<tr>
<td>Professor Lawrence Sutter</td>
<td>Michigan Technological University</td>
<td>6 Sep 2019</td>
</tr>
<tr>
<td>Professor Chung Bang Yun</td>
<td>Zhejiang University</td>
<td>2 Dec 2019</td>
</tr>
<tr>
<td>Professor Jung-June Roger Cheng</td>
<td>Zhejiang University</td>
<td>2 Dec 2019</td>
</tr>
<tr>
<td>Professor Jiaping Liu</td>
<td>Southeast University</td>
<td>3 Dec 2019</td>
</tr>
<tr>
<td>Dr James Mackechnie</td>
<td>University of Canterbury</td>
<td>12 Dec 2019</td>
</tr>
</tbody>
</table>
9.3.2 VISITS TO OVERSEAS LABORATORIES

The Hub offers members opportunities to visit top facilities at various educational organisations overseas. During these visits, Hub members learn about state-of-the-art research laboratories, as well as technology advancements in their field. Also, they get a chance to establish a connection with our international collaborators and engage with different world-leading research teams.

<table>
<thead>
<tr>
<th>LABORATORY/FACILITY</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concordia University Lab</td>
<td>12 Jul 2019</td>
</tr>
<tr>
<td>University of Ottawa Lab</td>
<td>12 Jul 2019</td>
</tr>
<tr>
<td>Laboratory of Construction Materials, Ecole Polytechnique Fédérale de Lausanne</td>
<td>12 Jul 2019</td>
</tr>
<tr>
<td>Southeast University Laboratory</td>
<td>26 Aug 2019</td>
</tr>
<tr>
<td>Laval University Lab</td>
<td>10 Oct 2019</td>
</tr>
<tr>
<td>Hebei University of Technology</td>
<td>10 Dec 2019</td>
</tr>
</tbody>
</table>
9.3.3 NATIONAL AND INTERNATIONAL EVENTS HELD/SPONSORED BY THE HUB

The Hub holds events, such as innovation dinners, seminars, workshops and short courses, to encourage communication between participants. All events offer great networking opportunities and are capable of sparking strategic alliances matching research capacity with construction industry ambition.

The events hosted, organised or sponsored by the Hub include:

<table>
<thead>
<tr>
<th>EVENT TITLE</th>
<th>EVENT TYPE</th>
<th>VENUE</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018 Hub Annual Report Launch</td>
<td>Seminar</td>
<td>Monash University, VIC</td>
<td>7 Jun 2019</td>
</tr>
<tr>
<td>Nanocomm Hub Exhibition at Concrete 2019</td>
<td>Exhibition</td>
<td>ICC Sydney, NSW</td>
<td>9 Sep 2019</td>
</tr>
<tr>
<td>ARC Nanocomm Hub ANSTO Tour &amp; Nanocomm Hub Annual Meeting</td>
<td>Seminar</td>
<td>ANSTO, Lucas Heights NSW</td>
<td>12 Sep 2019</td>
</tr>
<tr>
<td>National Transport Research Awards</td>
<td>Symposium</td>
<td>South Wharf, Melbourne</td>
<td>15 Nov 2019</td>
</tr>
<tr>
<td>Future Women Leaders Conference</td>
<td>Conference</td>
<td>Monash University, VIC</td>
<td>18 Nov 2019</td>
</tr>
<tr>
<td>2019 International Symposium on Mine Dust and Gas</td>
<td>Symposium</td>
<td>UoW, Wollongong NSW</td>
<td>22 Nov 2019</td>
</tr>
<tr>
<td>IAPS-AUS 2019</td>
<td>Workshop</td>
<td>Perth, WA</td>
<td>25 Nov 2019</td>
</tr>
<tr>
<td>11th Australian Network of Structural Health Monitoring (ANSHM) Workshop</td>
<td>Workshop</td>
<td>Griffith University Gold Coast Campus, Queensland</td>
<td>2 Dec 2019</td>
</tr>
<tr>
<td>EASEC16</td>
<td>Conference</td>
<td>Brisbane, Queensland</td>
<td>3 Dec 2019</td>
</tr>
</tbody>
</table>
9.3.3.1 NANOCOMMHUB LEAVES BIG FOOTPRINT ON CONCRETE 2019

The Concrete Institute of Australia recently held Concrete 2019 in Sydney. This 29th biennial national conference revolved around the multidisciplinary theme “Concrete in Practice - Progress through Knowledge”. Among the 60 exhibitors, 170 speakers and 530 delegates present, the Nanocomm Hub clearly stood out.

Global leaders in the concrete industry gathered at the conference to probe all aspects of concrete materials and structures - from research and design to construction, maintenance and repair. Engineers, scientists, researchers, academics and industry professionals from 20 countries around the world came together to share their innovative ideas and latest advances. During the three-day conference, Hub members gave nearly two dozen different talks. A few highlights include Professor Vute Sirivivatnanon (University of Technology Sydney) addressing the mitigation of alkali-silica reaction (ASR) which can cause serious cracking in concrete, Professor Zhong Tao (Western Sydney University) presenting recent developments in the engineering of hybrid basalt-polyvinyl alcohol (PVA) fibre-reinforced concrete, and Dr Kwesi Sagoe-Crentsil (Monash University) providing a promising update on Hub research.

9.3.3.2 A DAY TRIP TO ANSTO INFORMS AND INSPIRES

On 12 September, Nanocomm Hub members, along with other Concrete 2019 delegates, spent an action-packed day at the Australian Nuclear Science and Technology Organisation (ANSTO) in Sydney. The visit offered them an in-depth look at how ANSTO’s landmark research infrastructure performs at nanoscale to advance the construction industry.

ANSTO leads Australia in the use of neutron scattering and x-ray techniques to solve complex research and industrial problems in many important fields, including materials engineering. The Hub and ANSTO plan to engage in a variety of structural integrity investigations, with an aim to develop modern engineering processes.

“Visiting ANSTO not only gave us further insight into its capabilities, but an opportunity to explore future collaborations,” says Professor Wenhui Duan, Director of the Nanocomm Hub. “We see enormous potential there for characterisation and process development, materials testing, new materials development and optimisation, as well as structural analysis and assessment.”
9.3.3.3 THE INTERNATIONAL SYMPOSIUM ON COAL MINE DUST AND GAS CONTROL

Hub co-sponsored the International Symposium on Coal Mine Dust and Gas Control on 21-22 November at the University of Wollongong (UoW) in New South Wales. This successful event attracted more than 70 participants from both industry and academia, including 30 postgraduate students and Early Career Researchers. Hub Chief Investigator Assoc Prof Ting Ren from UoW served as Symposium Chair, as well as gave an illuminating talk. Hub HDR student Mr Xiaohan Yang from UoW took on the role of Symposium Secretariat.

9.3.3.4 IAPS-AUS 2019 WORKSHOP

The Hub had sponsored the International Association of Protective Structures (IAPS) Australian Chapter’s workshop at Curtin University in Perth. Academics and engineers from government, industry, universities and research institutions around Australia engaged in technical presentations and open discussions on new materials and structural designs for improved protection of structures against extreme dynamic loads.
9.3.3.5 AUSTRALIAN NETWORK OF STRUCTURAL HEALTH MONITORING (ANSHM) WORKSHOP

Around the same time, we also sponsored the two-day Australian Network of Structural Health Monitoring (ANSHM) workshop at the Gold Coast campus of Griffith University in Queensland. ANSHM members came together to share their research achievements, structural health monitoring implementations and data mining strategies. About 10 Hub members took part in the workshop, with an eye to collaborative research opportunities. I myself gave a talk entitled “Impact Analysis of Nanocomm Hub and Future Plan”.

9.3.3.6 THE 16TH EAST ASIA-PACIFIC CONFERENCE ON STRUCTURAL ENGINEERING & CONSTRUCTION (EASEC-16)

In yet another endeavor, the Hub sponsored the 16th East Asia-Pacific Conference on Structural Engineering & Construction (EASEC-16) on 3-6 December in Brisbane. Chaired by Hub Chief Investigator Prof Chien Ming Wang of the University of Queensland, the conference provided a forum for professional engineers, academics, researchers and contractors to present recent research and developments. Hub members served on the International Steering, Scientific and Local Organising Committees, as well as took centre stage as keynote speakers and opening ceremony emcee. About 30 postgraduate students and Early Career Researchers attended the conference.
9.4 Research Outputs

The Hub records research outputs as a measure of our contribution to technological innovation. Research outputs include journal article publications, industry reports and publications, as well as invited talks, papers and keynote addresses. The hub published 38 journal articles, 26 conference papers and 5 book chapters in 2019.

9.4.1 PUBLICATIONS

38 Journal Publications:

Gowripalan, N.; Vu, T.; De Silva, P.; Sirivivatnanon, V. Concrete in Australia 2019, 45 (2), 41-46.
Nguyen, T. Nhu; Yu, Y.; Li, J.; Gowripalan, N.; Sirivivatnanon, V. Computers and Concrete 2019, 24 (6).
Cao, J.; Gowripalan, N.; Sirivivatnanon, V.; South, W. Concrete in Australia 2019, 45 (No 2), 37- 40.
Zhao, Y.; Huang, Y.; Du, H.; Ma, G. Advances in Structural Engineering 2019, 136943321989159.
Tao, Z.; Pan, Z. NED University Journal of Research 2019, 2 (Special Issue on First SACEE’19), 113 - 128.


26 Conference Papers:


Khodr, M.; Law, D. W.; Gunasekara, C.; setunge, S. In Concrete 19 – Concrete in Practice-Progress through Knowledge; Concrete 19 – Concrete in Practice-Progress through Knowledge; Sydney, 2019.


Thomas, P.; Hau, V. Ha; Vessallas, K.; Sirivivatnanon, V.; South, W. In Concrete 2019; Concrete 2019; Concrete 2019: Sydney, 2019.


Nsiah-Baafi, E.; Vessallas, K.; Thomas, P.; Sirivivatnanon, V. In Concrete 2019; Concrete 2019; Concrete Institute of Australia: Sydney, Australia, 2019.

Dangol, S.; Shrestha, R.; Sirivivatnanon, V.; Kidd, P.; Perry, B. In Concrete 2019; Concrete 2019; Concrete Australia: Sydney, Australia, 2019.

Nsiah-Baafi, E.; Vessallas, K.; Thomas, P.; Sirivivatnanon, V. In Concrete NZ Conference; Concrete NZ Conference; Concrete New Zealand: Dunedin, New Zealand, 2019.

Vu, T.; Gowripalan, N.; Sirivivatnanon, V.; De Silva, P.; Kidd, P. In Concrete 2019; Concrete 2019; Concrete Australia: Sydney, Australia, 2019.

Tapas, M. Joshua; Vessallas, K.; Thomas, P.; Sirivivatnanon, V.; Kidd, P. In Concrete 2019; Concrete 2019; Concrete Institute of Australia: Sydney, Australia, 2019.
Nguyen, T. Nhu; Yu, Y.; Li, J.; Gowripalan, N.; Sirivivatnanon, V. In Concrete 2019; Concrete 2019; 2019.
Yu, Y.; Nguyen, T. Nhu; Li, J.; Sirivivatnanon, V. In Concrete 2019; Concrete 2019; 2019.
Cao, J.; Gowripalan, N.; Sirivivatnanon, V.; South, W. 2019.
Pan, Z.; Tao, Z.; Cao, Y. Fang; Chaudhary, M. Proceedings of the 29th Biennial National Conference of the Concrete Institute of Australia, 2019.
Sui, H.; Zhang, Q.; Sagoe-Crentsil, K.; Duan, W. In World Engineers Convention 2019

5 Book Chapters:

In Data Mining in Structural Dynamic Analysis; Data Mining in Structural Dynamic Analysis; 2019.
Guo, Y.; Zhang, Y.; Soe, K. In Lecture Notes in Civil Engineering; Lecture Notes in Civil Engineering; 2019; Vol. 37.
### 9.4.2 INDUSTRY REPORTS AND PUBLICATIONS

- Reliability of extending AS1141.60.1 and 60.2 test methods to determine ASR mitigation
- Structural investigation of Logicwall and Rediwall columns under eccentric axial load by means of experimental test and numerical simulations
- Axial-flexural interaction curves for AFS-Logicwall columns
- Structural Investigation of AFS-Logicwall and AFS-Rediwall Columns under Concentric and Eccentric Axial Loads using Experimental Test and Numerical Simulations
- Balanced alkali limit in concrete production
- Development of Protocols for the Use of Aggregate Minimising the Likelihood of Potentially Adverse Alkali Silica Reaction (ASR)
- Design development for geopolymer concrete in precast engineered component applications
- Assessing the performance of ASR affected structures
- Brown Coal Fly Ash Geopolymer Progress Report – Testing of Brown Coal Fly Ash Geopolymer Products
- Closing The Gap Between Design and Reality of Building Energy Performance
- Separation of magnesium from Yallourn fly ash
- Pyrolysis of waste scrap tyre for the co-production of multiple products
- Future of road changes in the next 30 years
- The Future of Roads Biggest Issues
- Roads and their future: The public’s view by region
- Future of road changes: The public’s views by age
- Future of roads: the view of people of different employment status
- Future of roads: View of different mode users

### 9.4.3 INVITED TALKS/PAPERS/KEYNOTE ADDRESSES

<table>
<thead>
<tr>
<th>PRESENTER</th>
<th>EVENT NAME</th>
<th>DATE</th>
<th>ORGANISOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhong Tao</td>
<td>First South Asia Conference on Earthquake Engineering</td>
<td>11 Feb 2019</td>
<td>NED University</td>
</tr>
<tr>
<td>Wei Gao</td>
<td>3rd International Conference on Artificial Intelligence, Automation and Control Technologies, Xi’an, China.</td>
<td>26 Apr 2019</td>
<td>Xi'an University; Xi'an; China</td>
</tr>
<tr>
<td>Kirk Vessalas, Vute Sirivivatnanon</td>
<td>Cement Concrete &amp; Aggregates Australia: Concrete Technology Course</td>
<td>27 Aug 2019</td>
<td>Cement Concrete &amp; Aggregates Australia</td>
</tr>
<tr>
<td>William Young</td>
<td>International Conference on Transport Infrastructure and Sustainable Development</td>
<td>01 Sep 2019</td>
<td>Da Nang Administrative Centre</td>
</tr>
<tr>
<td>Dilan Robert</td>
<td>Indian Geotechnical Society</td>
<td>30 Sep 2019</td>
<td>Multiple India Universities</td>
</tr>
<tr>
<td>Nadarajah Gowripalan</td>
<td>Advancements in modern prefabricated and modular buildings - R&amp;D FORUM</td>
<td>03 Oct 2019</td>
<td>The University of Melbourne</td>
</tr>
<tr>
<td>Kirk Vessalas, Nadarajah Gowripalan</td>
<td>ASCP Pavements Sydney</td>
<td>21 Oct 2019</td>
<td>Australian Society for Concrete Pavements</td>
</tr>
<tr>
<td>Chien Ming Wang</td>
<td>The International Conference on Sustainable Civil Engineering and Architecture</td>
<td>24 Oct 2019</td>
<td>ICSCEA</td>
</tr>
<tr>
<td>Zhong Tao</td>
<td>2019 International Conference on Advances in Civil Engineering and Materials (ACEM2019) and 2nd World Symposium on Sustainable Bio-composite Materials and Structures (SBMS2)</td>
<td>26 Oct 2019</td>
<td>Fujian Agriculture and Forestry University</td>
</tr>
<tr>
<td>Chien Ming Wang</td>
<td>16th East Asia-Pacific Conference on Structural Engineering &amp; Construction</td>
<td>3 Dec 2019</td>
<td>The University of Queensland</td>
</tr>
<tr>
<td>Yimiao Huang</td>
<td>16th East Asia-Pacific Conference on Structural Engineering &amp; Construction</td>
<td>5 Dec 2019</td>
<td>The University of Queensland</td>
</tr>
</tbody>
</table>
9.4.4 OTHER MEDIA

The research of the Hub has captured much attention ever since its launch. In 2019, the hub has been mentioned 12 times in various media, including television and online publications. With such a high degree of exposure, public awareness of the Hub has grown markedly.

<table>
<thead>
<tr>
<th>TITLE</th>
<th>MEDIA NAME</th>
<th>TYPE</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tullamarine Freeway sign may have fallen due to sustained wind pressure, engineering experts say</td>
<td>ABC News Melbourne</td>
<td>Online</td>
<td>16 Jan 2019</td>
</tr>
<tr>
<td>An Introduction into the Building Industry for Graduate Civil and Structural Engineers</td>
<td>Western Sydney University</td>
<td>Online</td>
<td>5 Mar 2019</td>
</tr>
<tr>
<td>Floating homes, parks, facilities - a reality in Singapore that’s closer than you think?</td>
<td>channelnewsasia</td>
<td>Online</td>
<td>27 Apr 2019</td>
</tr>
<tr>
<td>University of Queensland wins at global engineering awards</td>
<td>Prime Creative Media</td>
<td>Print, Magazine</td>
<td>1 May 2019</td>
</tr>
<tr>
<td>China’s Economy has Potential, Kinetic Energy to Speed up Transformation</td>
<td>China Central Television</td>
<td>Television</td>
<td>9 May 2019</td>
</tr>
<tr>
<td>Artificial Intelligence Products and Application Solutions Unveiled in EXPO Suzhou 2019</td>
<td>China Central Television</td>
<td>Television</td>
<td>10 May 2019</td>
</tr>
<tr>
<td>the floating cities and floating forest</td>
<td>ABC Tardis</td>
<td>Radio</td>
<td>6 Jun 2019</td>
</tr>
<tr>
<td>Central Pier in Melbourne’s Docklands vacated after it is deemed unsafe by engineers</td>
<td>Hyperlocal News, Melbourne</td>
<td>Online</td>
<td>29 Aug 2019</td>
</tr>
<tr>
<td>Impact of climate change on the integrity of the superstructure of deteriorated U.S. bridges</td>
<td>NewScientist</td>
<td>Online</td>
<td>6 Sep 2019</td>
</tr>
<tr>
<td>Green cement a step closer to being a game-changer for construction emissions</td>
<td>ARCHITECTURE &amp; DESIGN</td>
<td>Online</td>
<td>14 Nov 2019</td>
</tr>
<tr>
<td>Australian Company Servicing the Growing Industrial Clean Up Market</td>
<td>raisebook</td>
<td>Online</td>
<td>16 Nov 2019</td>
</tr>
<tr>
<td>University of Queensland: A double-skin tubular arch bridge system</td>
<td>Composites Australia</td>
<td>Print, Magazine</td>
<td>23 Dec 2019</td>
</tr>
</tbody>
</table>

To reach an even wider audience, we have used various digital platforms to spread the word on the Hub, with the main emphasis on our ground-breaking research.

To engage with more professionals and the general public, the Hub has established a presence on LinkedIn and Twitter. We use both to deliver news about research, events and activities relevant to Hub members. Such forms of social media forge alliances between Hub members from different nodes, communicate the Hub’s research outcomes to the public and attract potential collaborators.

In addition to external communication tools, the Hub has been developing an internal newsletter with up-to-date news and events for all members. We envision that, upon publication of our first issue, cohesion across the Hub will progressively improve.
9.5 Research Outcomes

9.5.1 INTELLECTUAL PROPERTY FILINGS

<table>
<thead>
<tr>
<th>TITLE</th>
<th>TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FGO based AEM for acid recovery</td>
<td>Patent</td>
</tr>
<tr>
<td>Floating breakwater and windbreak structure</td>
<td>Patent</td>
</tr>
</tbody>
</table>

9.6 End-user Links

Research end users are the individuals, communities and organisations outside academia that will directly benefit from our research. End users will continue to support our research only if they can see its value. Hence, the Hub advocates for transparency in research outputs and outcomes.

To engage end users, the Hub has delivered several government, industry and business community briefings, invited industry visitors to the Hub, as well as given talks open to the public. In this way, we can highlight the benefits of our research to those who have funded it, as well as to those who will ultimately benefit from it. Additionally, such engagement attracts potential collaborators for future projects.

9.6.1 GOVERNMENT, INDUSTRY AND BUSINESS COMMUNITY BRIEFINGS

<table>
<thead>
<tr>
<th>BRIEFING</th>
<th>PRESENTER(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability of extending AS1141.60.1 and 60.2 test methods to determine ASR mitigation</td>
<td>Prof. Vute Sirivatvananon</td>
</tr>
<tr>
<td>Structural investigation of Logicwall and Rediwall columns under eccentric axial load by means of experimental test and numerical simulations</td>
<td>Dr. Kamyar Kildashti</td>
</tr>
<tr>
<td>Axial-flexural interaction curves for AFS-Logicwall columns</td>
<td>Dr. Kamyar Kildashti</td>
</tr>
<tr>
<td>Structural Investigation of AFS-Logicwall and AFS-Rediwall Columns under Concentric and Eccentric Axial Loads using Experimental Test and Numerical Simulations</td>
<td>Dr. Kamyar Kildashti</td>
</tr>
<tr>
<td>Balanced alkali limit in concrete production</td>
<td>Dr. Paul Thomas</td>
</tr>
<tr>
<td>Development of Protocols for the Use of Aggregate Minimising the Likelihood of Potentially Adverse Alkali Silica Reaction (ASR)</td>
<td>Dr. Kirk Vessalas</td>
</tr>
<tr>
<td>Design development for geopolymer concrete in precast engineered component applications - report no 2</td>
<td>Dr. Rijun Shrestha</td>
</tr>
<tr>
<td>Assessing the performance of ASR affected structures, Progress Report No:2, January</td>
<td>Dr. Nadarajah Gowripalan</td>
</tr>
<tr>
<td>Brown Coal Fly Ash Geopolymer Progress Report – Testing of Brown Coal Fly Ash Geopolymer Products</td>
<td>Dr. David Law</td>
</tr>
<tr>
<td>Closing The Gap Between Design and Reality of Building Energy Performance</td>
<td>Dr. Morshed Alam</td>
</tr>
<tr>
<td>Separation of magnesium from Yallourn fly ash</td>
<td>A/Prof. Lian Zhang</td>
</tr>
<tr>
<td>Pyrolysis of waste scrap tyre for the co-production of multiple products</td>
<td>A/Prof. Lian Zhang</td>
</tr>
<tr>
<td>Outlined progress in the study to members of ARRB and interested researchers.</td>
<td>William Young</td>
</tr>
</tbody>
</table>
### 9.6.2 Industry Visitors to the Hub

<table>
<thead>
<tr>
<th>Visitor(S)</th>
<th>Institution</th>
<th>Date(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oneatom 12 team</td>
<td>Oneatom 12</td>
<td>22 Jan 2019</td>
</tr>
<tr>
<td>Tim Song</td>
<td>Solar E</td>
<td>15 Mar 2019</td>
</tr>
<tr>
<td>Acarp visitros</td>
<td>Acarp</td>
<td>28 Mar 2019</td>
</tr>
<tr>
<td>Dr Ramesh Mashelkar</td>
<td>India National Innovation Fundation</td>
<td>12 Apr 2019</td>
</tr>
<tr>
<td>Coal Energy Australia visitors</td>
<td>Coal Energy Australia</td>
<td>12 Aug 2019</td>
</tr>
<tr>
<td>Surface Design Consulting visitors</td>
<td>Surface Design Consulting</td>
<td>6 Sep 2019</td>
</tr>
<tr>
<td>Concrete NZ visitors</td>
<td>Concrete New Zealand</td>
<td>10 Sep 2019</td>
</tr>
<tr>
<td>ARRB team</td>
<td>ARRB Group</td>
<td>10 Sep 2019</td>
</tr>
<tr>
<td>VicRoads visitors</td>
<td>VicRoads</td>
<td>10 Sep 2019</td>
</tr>
<tr>
<td>WSP Opus visitors</td>
<td>WSP Opus</td>
<td>10 Sep 2019</td>
</tr>
<tr>
<td>ARRB team</td>
<td>ARRB Group</td>
<td>18 Sep 2019</td>
</tr>
<tr>
<td>Ms Junping Guo</td>
<td>China Building Materials Academy</td>
<td>16 Dec 2019</td>
</tr>
<tr>
<td>TALK TITLE</td>
<td>PRESENTER</td>
<td>DATE</td>
</tr>
<tr>
<td>---------------------------------------------------------------------------</td>
<td>---------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>ARC Nanocomm Hub: Full Utilisation of Resources for ASR Mitigated Structures – A Multifaceted Approach</td>
<td>Kirk Vessalas</td>
<td>26 Feb 2019</td>
</tr>
<tr>
<td>Synthesis of advanced nano-sized zinc sulfide from tyre char for the upgrading of bio-oil</td>
<td>Lian Zhang</td>
<td>2 Apr 2019</td>
</tr>
<tr>
<td>New Era of Civil Engineering: When It Meets Artificial Intelligence</td>
<td>Wei Gao</td>
<td>26 Apr 2019</td>
</tr>
<tr>
<td>Secret for long-lasting concrete on a tip of a pencil</td>
<td>Felipe Basquiroti de Souza</td>
<td>14 Jun 2019</td>
</tr>
<tr>
<td>The role of the public in next generation asset management</td>
<td>William Young</td>
<td>1 Sep 2019</td>
</tr>
<tr>
<td>Investigating the Alkali Threshold of Potentially Reactive Aggregates for Use in ASR Risk-Free Concretes</td>
<td>Elsie Nsiah-Baafi</td>
<td>9 Sep 2019</td>
</tr>
<tr>
<td>Mechanistic Role of Supplementary Cementitious Materials (SCMs) in Alkali-Silica Reaction (ASR) Mitigation</td>
<td>Marie Joshua Tapas</td>
<td>11 Sep 2019</td>
</tr>
<tr>
<td>The Development of Wave Shaped EMW Absorbing Concrete using 3D Printing Technology</td>
<td>Junbo Sun</td>
<td>13 Sep 2019</td>
</tr>
<tr>
<td>Soil Stabilization in Unsealed Road Pavements</td>
<td>Dilan Robert</td>
<td>3 Oct 2019</td>
</tr>
<tr>
<td>Investigation of Alkali Threshold Limits and Blended Aggregate in ASR Risk-Assessed Concretes</td>
<td>Nadarajah Gowripalain</td>
<td>10 Oct 2019</td>
</tr>
<tr>
<td>Recent research efforts towards development of sustainable houses</td>
<td>Zhong Tao</td>
<td>26 Oct 2019</td>
</tr>
<tr>
<td>Floating Solutions for Problems facing Humanity</td>
<td>Chien Ming Wang</td>
<td>7 Nov 2019</td>
</tr>
<tr>
<td>Artificial Intelligence based Smart Mixture Design for Functional Concrete</td>
<td>Yimaio Huang</td>
<td>27 Dec 2019</td>
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</tbody>
</table>
### 9.7 Hub Finance

<table>
<thead>
<tr>
<th>REPORTING PERIOD</th>
<th>2019</th>
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<tbody>
<tr>
<td><strong>INCOME</strong></td>
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<tr>
<td>ARC</td>
<td>1,067,645</td>
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<tr>
<td>Universities</td>
<td>721,654</td>
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<tr>
<td>Industry Partners</td>
<td>1,357,544</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td>3,146,844</td>
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<tr>
<td><strong>EXPENDITURE</strong></td>
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<tr>
<td></td>
<td>2,708,194</td>
</tr>
</tbody>
</table>

ARC Nanocomm Hub

Performance