UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Smart Liveable Neighbourhoods

in Lake Macquarie and City of Sydney

Project Report

TULIP

A project of the Technology for Urban Liveability Program (TULIP)

This report was written and produced solely by the University of Technology Sydney and opinions and positions discussed are not the official positions of project partners.

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Executive Summary

The Smart Liveable Neighbourhoods project was a Smart City pilot project at the leading edge of experimentation and innovation, led by the University of Technology Sydney. The project ran from 2017 to 2019 with major support from the Australian Government. UTS worked collaboratively with Lake Macquarie City Council and the City of Sydney to explore the intersection of emerging smart city technologies, applied methodologies, city operations, community participation, and urban development agendas that prioritise sustainability, liveability and resilience outcomes. Central to the project was the development of the UTS Technology for Urban Liveability Program (TULIP), which combines applied technology with community-centred and outcomes-focused design. The lessons learned through the project have supported a growing understanding of best practice for distributed low-cost urban microclimate monitoring, positioning UTS as a national leader in the field.

Project partners and funding

Lead organisation

University of Technology Sydney

Faculty of Engineering and IT
Institute for Sustainable Futures

Principal funding partner

The Australian Government

Smart Cities and Suburbs
Program, round 1 grant recipient

Local government partners

Lake Macquarie City Council

City of Sydney Council

Technology partners

Nokia

Bosch

Total project value

$866,000

Project period

November 2017 to June 2019

Technology for smart liveable neighbourhoods

Over the past decade, the concept of the Smart City has risen to prominence in Australia and around the world. While initially characterised by the application of rapidly emerging communications, computing, internet of things and big data management technologies to the urban environment, the Smart City has transcended a purely technological definition and is now generally understood to occupy the intersection of technology, societal, environmental and governance considerations of city development. The aim is to produce tangible positive outcomes for citizens in the context of significant intersecting challenges.

Cities worldwide face enormous challenges and these are expected to increase dramatically in coming decades. Cities are under strain from rapid population increase and densification, with over two thirds of the global population expected to live in cities by mid-century (United Nations, 2015[1]). This places increasing strain on existing infrastructure and services, as well as on the health of the urban environment, resulting in increasing pressure upon the lives and wellbeing of city dwellers[2]. The impacts of climate change by 2050, while still dependent upon the degree of mitigation achieved in coming years, are projected to significantly intensify the challenges faced by cities, even under best case scenarios. In Australia and around the world, extreme heat, bushfires and smoke are a growing concern for public health, infrastructure and city economies. Flooding, intense storms and coastal erosion have also increased in recent decades, with increasing future impacts that are directly attributable to climate change[3],[4].

The challenges faced by cities underscore an urgent need for dramatic changes to urban thinking, with a more holistic, systemic and long-term perspective gaining increased prominence. In the past two decades, the role of ICT has risen as a powerful new tool in the urbanist playbook, with trends of widespread interconnectivity and data-driven outcomes forming the technological backbone of a rising smart city agenda. It is argued that the complexity of the urban system and its interrelated co-dependent parts, demands the complex information processing and operational outcomes promised by a rapidly evolving suite of smart technologies[5]. These technologies promise to increase efficiency, reduce redundancy, connect disparate parts of a complex urban system and as such, address foundational sustainability challenges faced by cities.

A *Climate Responsive Neighbourhood* is a term that describes a location where strategies are available to enable the monitoring of and adaption to changes over time. In its broadest sense these can include various social, technological, environmental and political factors that can impact a neighbourhood and the wellbeing of its residents. At the heart of this concept is the practical application of low-cost smart sensor technologies to the urban environment. Advances in sensors, micro-processing, communications and big data management technologies are heralding a new paradigm that is enabling interested parties to capture detailed real-time hyper-local environmental data that was previously unavailable. The ways in which this data might be used to improve urban liveability, promise to redefine almost every aspect of how we design and manage our cities over the coming years.

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[1] United Nations (2015). World urbanization prospects. The 2014 revision. New York: Department of Economic and Social Affairs, http://esa.un.org/unpd/wup/Publications/Files/WUP2014-Report.pdf (accessed 22.1.2017).

[2] Desa, U.N., 2016. Transforming our world: The 2030 agenda for sustainable development.

[3] Climate Council, 2017. *Intense Rainfall And Flooding: The Influence Of Climate Change*. [online] Climate Council. Available at: <https://www.climatecouncil.org.au/uploads/5dafe61d7b3f68d156abd97603d67075.pdf> [Accessed 27 August 2020].

[4] Steffen, W., Hunter, J. and Hughes, L. (2014). *Counting the costs: Climate change and coastal flooding*. [online] Climate Council. Available at: https://www.climatecouncil.org.au/uploads/coastalflooding.pdf [Accessed 7 Mar. 2020].

[5] Bibri, S.E. and Krogstie, J., 2017. Smart sustainable cities of the future: An extensive interdisciplinary literature review. *Sustainable cities and society*, *31*, pp.183-212.

An overview of specific project activities and deliverables

Open access LoRaWAN for community participation and scalability

The project trialled the deployment of three Meshed LoRaWAN gateways which make use of The Things Network, an open access free-to-use community IoT service that provides open connectivity for both Council and community devices. This has directly enabled community engagement with Council's smart city development via project initiatives such as the *Smart Liveable Neighbourhoods Challenge* and *Adopt-a-sensor*.

Exploring and understanding low-cost sensor options

We procured a broad range of commercially available devices and tested them for functionality, reliability and the ability to integrate and manage them successfully with a city-wide network. This practical experimentation has supported a deep working knowledge of the operational considerations and constraints of working with a variety of commercially available devices.

Developing our own multi-sensor device

Working with ARCS Group, we developed the TULIP EMS to deliver a combination of environmental data and functionality that was not available anywhere else. The process of developing our own monitoring solution has deepened our understanding of smart city sensors and provided Council partners with a robust scalable solution. Additionally, we have developed an integration between the EMS and a solid-state weather station (Lufft WS10) to provide extended meteorological telemetry, all with a self-contained solar/battery system and LoRaWAN connectivity.

Benchmarking sensors

Researchers at UTS have benchmarked the performance of commercially available environmental sensors against high-end equipment in a controlled lab environment. We built our own test chamber to carry out this work and have begun work defining a benchmarking protocol and device categorisation framework. The TULIP EMS has been a major focus, with the benchmarking work helping to validate the performance of our new device.

Designing and delivering sensor networks to generate new data

We have deployed over 100 sensors that remain active after the end of the project, measuring temperature, humidity, air quality, noise, weather and people counts. We have explored a range of practical and experimental considerations relating to the choice of location and mounting options and the capturing and management of associated metadata. The data which these networks are now generating is unprecedented in Lake Macquarie and Sydney. Our extensive review of smart city literature has confirmed that the scale of these new networks is both nationally and internationally significant.

Building an open modular data architecture

We have built TULIP as an example of an open modular data architecture, integrating four separate cloud-based data platforms. It is one answer to the proliferation of closed proprietary smart city systems that Councils are accumulating. In this project, TULIP is drawing data from multiple sensor types on multiple networks. It is providing a single onboarding and management solution for all of these devices, displaying all of the data in a single location and making it available to a range of different users, in a controlled and sophisticated way. This is done not through one mega-platform solution, but via an ecosystem of collaborators filling different niches. The modular nature of the platform gives Councils greater freedom to work with multiple partners and build an architecture that best suits their needs.

Understanding the role of data models to facilitate interoperability and data sharing

A data model is the framework, language and rules that govern how data is interpreted, stored, labelled, accessed and share. TULIP has developed a shared data model between all of our platform partners. It has enabled us to capture and manage the complex metadata required to support rigorous environmental data science. It also allows interoperability and user functions that leverage capacities from multiple platforms simultaneously.

The project has generated an open public data portal and an open public API for sharing live data with the world. At the heart of this capacity lies a data model that in part references existing standards and in part, through necessity, offers new structures and approaches that might have wider relevance.

Understanding and testing use cases for smart sensor technology

Too often, smart city projects end up being led and defined by technology. This project was designed by exploring use cases, placing the needs of Council and community front and centre. We have learnt a great deal about the collaborative design processes that underlie human-centred smart city initiatives and we have identified a broad range of practical use cases for environmental sensor technologies. This project has enabled us to explore some of these use cases, while many others have planted seeds across Council for future attention.

Developing Council's operational capacity (device deployment and management)

The scale of the sensor networks deployed in this project has demanded that we develop an operational practice for planning, deployment, and device management. We have developed scalable procedures for identifying deployment locations, prepping devices and mounting kits for installation, capturing metadata, testing and verifying devices and monitoring them for issues. These lessons and new capabilities provide Council with a practical operational foundation from which to scale smart city device deployments in future.

Data actuated installations for place-making and engagement

Working with Newcastle-based start-up Newie Ventures, we developed the TULIP Rosella, a versatile open-source device that responds to live data from the TULIP platform and generates custom LED light patterns. The Rosella has been adapted to drive three data-actuated public artworks in Lake Macquarie which each respond to some combination of temperature, rain, wind and weather warnings. The artworks activate public space, bring data to life, and engage communities with the dynamic nature of the environment and with technology.

Understanding user requirements for environmental data platform functionality

Detailed project design brought together Council end users with platform developers to explore what an ideal environmental data platform might look like. The process has helped Council to understand and prioritise their own needs and has helped the commercial partners to understand things from a functional client perspective. Many assumptions about the relative importance of particular functionality have been put aside and many critical new functions have come to light that were not previously apparent.

Exploring new environmental data for better city living

The sensor networks have begun to generate usable environmental data, enabling researchers at UTS to begin to make sense of it. Three teams have explored urban heat, air quality and noise data in turn. The work has been necessarily limited due to the small amount of data accumulated so far, however we have been able to begin the process of verifying data quality and identifying significant trends and patterns. Perhaps the most useful output of this early data research is an assessment of what the new data might mean for Council going forward, with a number of future avenues of inquiry identified.

Engaging community with smart technology: building ownership, digital literacy and environmental awareness

The Smart Liveable Neighbourhoods Challenge was a community competition to design and build a working LoRaWAN device that connected to The Things Network via one of the new LoRaWAN gateways funded by the project. Participants were challenged to create solutions that might be deployed in public spaces to benefit the whole community. Five finalists presented working devices with functions such as measuring noise, counting people, and monitoring sports fields.

The Adopt-a-Sensor program was a major part of device deployment for the Smart Liveable Neighbourhoods project. Ten schools, four sports facilities, a scout hall and fifteen local residents have been gifted devices by Council and deployed them on their properties. These devices all connect to the TULIP platform, alongside Council devices. This model demonstrates a potential emerging model for distributed community ownership of environmental sensors. There is potential here for future scalability. In the shorter term the approach has proven to be a highly effective way of engaging people with the project, the technology and the environmental liveability challenges that we are addressing.

Exploring future scalability and business models

A guiding approach of TULIP has been to design and test systems and operations that can be scaled to support much larger device deployments and more complex data utilizations than those undertaken within the scope of this project. A challenge has been that business models which might support scaled commercial activities have not always been apparent to Council while things are smaller scale and experimental. The agile and experimental nature of the project has given Council the freedom to explore multiple complex aspects of the technologies, use cases and user requirements. Ideas have been tested, and knowledge generated through practical engagement. Now these learnings are directly informing strategic discussions as Council considers the next phase of its smart city journey.

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Project Information

The Smart Liveable Neighbourhoods for Lake Macquarie and City of Sydney project was delivered by the University of Technology Sydney (UTS) in partnership with Lake Macquarie City Council (LMCC) and the Council of City of Sydney, with major funding from the Australian Government.

The Australian Government's $50 million Smart Cities and Suburbs Program (SCSP) supports the delivery of innovative smart city projects that improve the liveability, productivity and sustainability of cities and towns across Australia.

This project was one of 49 *round one* SCSP grant recipients and had a total delivery value of $866,000.

The project commenced on the 17th of November 2017 and ran to the 30th of June 2019.

This report has been produced by UTS in collaboration with project partners as a comprehensive overview of project activities and outcomes.

UTS executive statement

The University of Technology Sydney (UTS), is pleased to have led the Smart Liveable Neighbourhoods Project in partnership with Lake Macquarie City Council (LMCC) and City of Sydney (CoS), under the Australian Government's Smart Cities and Suburbs Program. The project aligns well with the university's 2027 vision, notably: our precinct and community partnerships; our digital partnerships; and our connected research.

The project offered UTS a unique opportunity to pull together a multi-faculty team and work collaboratively with technology partners and Councils. Our work leveraged technology, data and research to:

- Improve the liveability and sustainability of cities, suburbs and towns through the application of smart technology solutions to economic, social and environmental challenges;
- Open public and private data sets to support citizen engagement, unlock innovation, and create new business opportunities;
- Increase innovation and capability in local governments through collaboration and smart city innovation ecosystem development;

Moreover, the project enabled the setup of "Digital Living Labs" that enable Councils to experiment with data sources, data sharing, analytics and applications. In our view, this type of open-ended collaborative experimentation is an essential capability needed by cities in a rapidly emerging smart city landscape.

UTS gained many valuable outcomes and insights that have lifted our understanding and knowledge in the creation and development of smart city culture and capability, including:

- The use of open community networks, such as The Things Network
- The variability in low-cost sensor quality, which UTS researched through benchmarking and ultimately supported the development of an Australia-designed and made low-cost environmental monitoring system (in partnership with The ARCS Group).
- The benefits and challenges of open architecture and functionally separated data collection, transformation, distribution, storage, analysis and visualisation – supported by research on smart cities standards and the evolution of the UTS smart city "TULIP" architecture.
- The importance of education participation and co-design in engaging council and communities
- The complexities of data model flexibility across domains and the value of:
- separation of data storage from application
- deep data and information ontology underpinnings to provide meaningful output for diverse stakeholders and inform metadata requirements
- capabilities and flexibility for interoperating between local and internal technology partners

UTS is thankful for the Commonwealth's investment in Smart Cities and Suburbs which has realised important and enduring insight and developments which promise to deliver real benefits for our community and for Australia.

Frank Zeichner
Director, Business Development (Smart Cities),
Faculty of Engineering and IT, University of Technology Sydney

Lake Macquarie City Council Executive Statement

Lake Macquarie is a natural playground for progress and possibility that is connected by new ideas and life by the lake. Historically, the City's economy has been fuelled by coal and electricity generation, which has supported local manufacturing, real estate, community facilities, environmental leadership and social wellbeing. We are acutely conscious that coal's ability to do the economic heavy lifting for the city will not continue indefinitely. Our City's economy is changing, so we must adapt and diversify or risk impacting our community.

We see our future benefiting from new economic drivers. A City that is the first-choice location for innovators that want to work with like-minded collaborators, supported by the infrastructure and reputation that will allow them to take their ideas as far as they desire. Innovators that want to enjoy an enviable, affordable lifestyle while they help build our City's knowledge economy. TULIP is a project that can support our progress towards an innovation ecosystem.

TULIP is an example of taking Smart City principles and applying them to real aspirations. It supports our fundamental City values of protecting and enhancing our natural environment, increasing our resilience and adaptability and connecting people within our community.

The environmental data collected by the TULIP project is helping us better understand the urban heat island effect. This is having an input into resilience and urban planning strategies for the City. Air quality data is being used to measure the effect of recent bushfires and people counting sensors are being used to inform planning and service delivery, such as public toilet cleaning schedules. The project has been able to directly engage the public and local schools through the adopt a sensor program and Council has learnt a great deal about data sharing, security and opening data to the public.

The collaboration with our partners on the TULIP project, especially University of Technology, Sydney and City of Sydney, has contributed to our corporate knowledge about Smart Cities. It has shown us that we can work with the best and that there is real value for the community in pursuing these types of experimental, capacity building projects. The Commonwealth's investment in Smart Cities and Suburbs is to be congratulated and promises to reap huge benefits for our community and Australia.

Tony Farrell
Deputy Chief Executive Officer, Lake Macquarie City Council

City of Sydney Executive Statement

The City of Sydney is committed to harnessing technology and data to enable collaborative innovation and create a thriving, inclusive and resilient future for all. One of the strategic outcomes we are seeking to achieve with smart city initiatives is to future-proof our environment and bolster resilience. In addition, the City understands the importance of working collaboratively with academia, business and the community to design, test and iterate smart solutions to the problems faced by the city.

The Smart Liveable Neighbourhoods project has provided the City with the opportunity to work constructively with a number of partners to develop a technology and data solution for the problems of urban heat, poor air quality and noise in the city. The cost and size of environmental sensors is rapidly reducing and the the smart city platforms that support them are increasingly versatile and sophisticated. The City of Sydney became involved in this project to better understand the technologies available for monitoring environmental information, as well as emerging ways to facilitate open access to environmental data.

Increasingly cities are installing liveability sensors to better inform urban liveability strategies. For Sydney, measuring urban heat is important to monitor local conditions and to assess the effectiveness of treatments like cool roofs, vegetation, and water projects on bringing down local temperatures. These treatments are needed to keep our city cool as ambient temperatures are forecast to increase by 2 degrees in coming decades. Air quality too is of rising concern to our communities and has become all the more topical given the recent impacts of bushfire smoke. The City is aware of many cities around the world experimenting with low-cost air quality sensing. The City of London for example, is installing a massive array of local air quality sensors and the City of Sydney has engaged with them regarding their approach and insights.

The Smart Liveable Neighbourhoods project has seen deployment of low-cost air quality, noise and heat sensors across the city. Through the City's partnership with UTS, we are seeing data emerge from our new networks that has been shown to be consistent with data from previously installed larger and more costly monitoring units managed by the City. It is hoped that as we build our understanding of urban liveability data from these new types of sensor network, we will discover useful insights about environmental conditions impacting the wellbeing of our communities. These insights may then help to inform City decisions around urban heat mitigation, transport policies, environmental advocacy, community engagement, and other measures that will help to keep our communities clean, cool and quiet.

Kate Deacon
Executive Manager, Strategy & Urban Analytics, City of Sydney

Nik Midlam
Manager Carbon Strategy, City Sustainability, City of Sydney

Project Foundations

Image: 1 - TULIP petal diagram

TULIP (Technology for Urban Liveability Program)

TULIP is the University of Technology Sydney's leading smart city project delivery program. It is a joint initiative from the Institute for Sustainable Futures (ISF) and the Faculty of Engineering and IT (FEIT). TULIP is represented at FEIT through the Knowledge Economy Institute (KEI).

TULIP focuses on environmental monitoring for urban liveability and was founded in 2016 by UTS and a consortium of affiliated industry partners. A pilot program with the City of Sydney established a basic approach and vision for TULIP and provided important foundational expertise in the space.

TULIP has been significantly developed in the context of the *Smart Liveable Neighbourhoods* project, working closely with Lake Macquarie City Council and the City of Sydney.

The core capacity of TULIP is an open, modular and flexible data architecture that represents a departure from the standard vendor-controlled proprietary data stack. UTS recognises the importance of developing a collaborative ecosystem of many technology partners, each playing to different strengths. The TULIP platform does exactly this, providing councils with access to and flexibility with all levels of the data architecture, from device management, up through ingestion, to data storage, analytics, visualisation and actuation.

TULIP has the capacity to manage and ingest data from multiple device types across multiple networks, standardise data formats and labelling and collate a broad range of outputs in one place. The platform is designed to be as open and accessible as possible, at all levels, meaning that new capacities can be continually added or indeed removed.

The longer-term vision for TULIP is to build capacity and knowledge in the smart city space through real-world experimentation and active collaboration with government and industry to help establish UTS as a leading authority on smart city research and development in Australia.

Image: 2 - Charlestown, Lake Macquarie

Project foundations in Lake Macquarie

Charlestown Innovation Precinct (ChIP)

Lake Macquarie City Council is upgrading Charlestown's Pearson Street Mall to create a new and inviting smart space, which will form part of the Charlestown Innovation Precinct (ChIP). In 2016, Council adopted the Lake Mac Smart City, Smart Council Digital Economy Strategy 2016-20, after asking the community how they thought technology could be used to make our City more connected and sustainable, how City services could be provided more efficiently and conveniently, and how the City could create new jobs and retain innovative, talented people. Key initiatives include piloting new technologies in the public realm, to understand the possible role of new technologies in creating fun, inviting and safe places for people to eat, meet, work and play.

At Pearson Street Charlestown, Council established a co-working space - the Dantia Smart Hub, or DaSH- in partnership with Dantia, the Lake Macquarie Economic Development Company. DaSH has recently expanded to accommodate more people and is now also home to one of four regional incubator sites supported by the University of Newcastle to help start-ups grow and create new employment opportunities.

Council allocated funds to revitalise the ageing Pearson Street Mall. The recent expansion of DaSH and the mall upgrade are part of the broader vision for Charlestown to grow as an ‘innovation precinct’ as a key site for the community and Council to test new ideas while providing new spaces to eat, meet, work and play.

Charlestown is the City's major commercial and public transport hub, contributing significantly to the Lake Macquarie economy. ChIP is helping to strengthen this economic activity, assist in creating new diverse employment opportunities for the area and supporting the implementation of Council's Digital Economy Strategy.

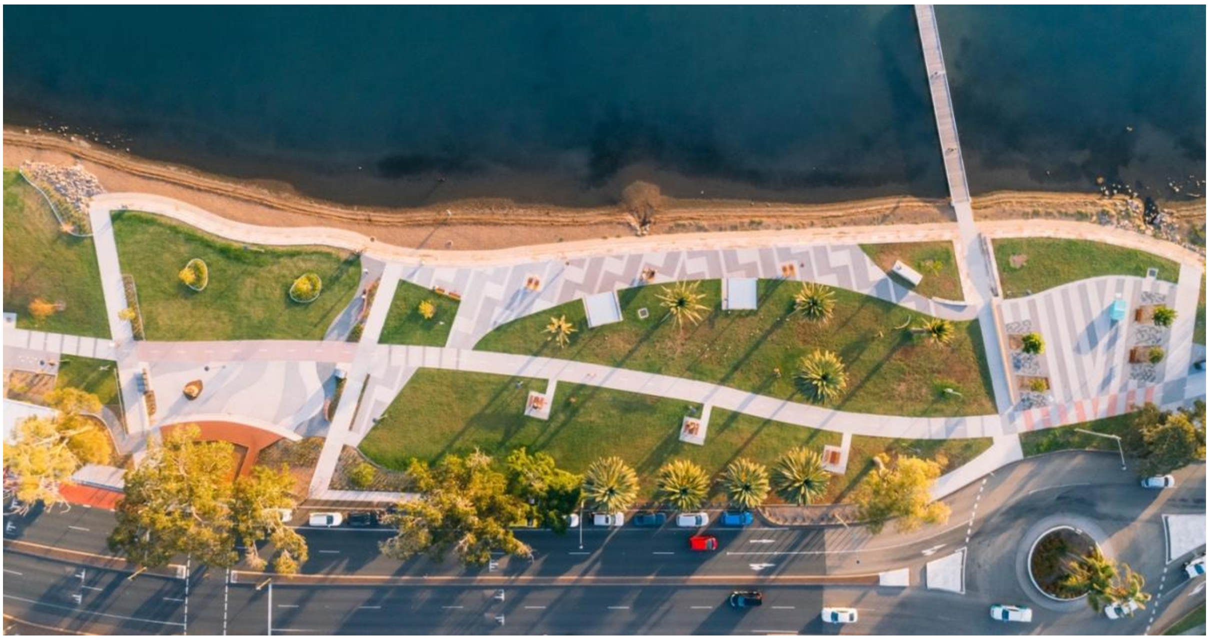

Image: 3 - Aerial view of Lake Macquarie

Supporting strategies and policies in Lake Macquarie

Lake Macquarie City Council has a number of strategies and policies in place that directly supported the establishment of the project and are critical to ongoing project activities.

- **Lake Mac Smart City, Smart Council Digital Economy Strategy (2016-2020)**

  This strategy was tied directly to The Hunter Smart Specialisation strategy, which uses an OECD assessment framework for the whole region. This means that the LMCC smart city strategy aligns with the City of Newcastle's smart city strategy, creating a coherent regional positioning. Superseded by the Innovators Support Strategy 2019

- **Lake Macquarie Economic Study 2018 - Informing the vision for Lake Mac 2050 and Beyond: Planning for the economy of the future**

  Contains detail on building a digital and knowledge economy.

- **Let's Imagine - Innovators Support Roadmap (2019)**

  Replaces the Smart City strategy with a sharper focus.

- **The City of Lake Macquarie Environmental Sustainability Action Plan 2014-2023**

  Provides a framework for sustainability planning, decision-making and action, to achieve improved environmental sustainability for the City of Lake Macquarie.

- **City Data Policy [working title] (forthcoming: 2020)**

  Developed during the project period, partially in response to new challenges identified by project activities. Scheduled for release in 2020.

Image: 4 - Central Park, Sydney

Project foundations in the City of Sydney

The origins of TULIP

The Technology for Urban Liveability Program (TULIP) began as a small pilot initiative in 2016 that grew out of a multi-stakeholder forum called Smart Locale, hosted by the UTS Institute for Sustainable Futures (ISF) in collaboration with the Total Environment Centre and a range of tech start-ups. Smart Locale supported tech-focused collaborations around Ultimo and Pyrmont and leveraged the capacity of the university and the various partners. In mid 2016 the ISF invested in a single Meshed LoRaWAN gateway, which was deployed on a campus rooftop. Seeking to explore the gateway's potential uses and build internal smart city capacity and knowledge, the ISF worked with Smart Locale partners to compile a document which outlined potential use cases for LoRaWAN sensor networks in the City of Sydney and forwarded this to the City of Sydney for consideration. In September 2016, seeking to explore ideas further, the ISF and Meshed co-hosted a workshop for Smart Locale partners and a broader range of interested parties. Following that workshop, a group was formed that would grow into TULIP. At this time the UTS Faculty of Engineering and IT became involved, establishing a cross-faculty collaboration that still continues. The focus from the start was to deploy environmental sensors to measure the health of the city, with the broad aim of creating liveability outcomes.

By late 2016 TULIP had an identity and modest funding for a pilot initiative from the City of Sydney and Insurance Group Australia totalling $10,000. TULIP remained a collaborative project at this stage, though the ISF provided administration of finances.

Image: 5 - TULIP urban heat monitoring trial

City of Sydney urban heat monitoring trial

In 2017, TULIP deployed LoRaWAN temperature and humidity sensors in partnership with the City of Sydney (CoS) in locations across Chippendale and Redfern, to monitor urban heat. The aim was to trial the new technology and to establish its viability against existing temperature sensors owned by the City. The existing models (supplied by a provider called Ajenti) are large arrays mounted on custom fixed poles that were installed with relatively significant capital works. The Ajenti sensors provide real time data via 3G connectivity and are costly to maintain. Together with their bulk, this makes any upscaling to a larger sensor network impractical. The TULIP devices used cost around $400 per device[6], roughly one-tenth of the cost of the existing sensor installations. The first three TULIP devices were deployed in Chippendale and Redfern on the same poles as the existing Ajenti sensors. A further three sensors were then deployed in nearby locations such as Prince Alfred Park in Surry Hills.

The goal for this trial project was to test the performance of the new LoRaWAN temperature and humidity sensors against the older Ajenti sensors. TULIP saw value in longitudinal monitoring and expansion of the sensor network in order to inform urban heat monitoring and strategic heat responses in the Sydney CBD. With their low cost and low maintenance fees, small size, self-contained nature (requiring no electrical wiring) and ability to quickly and easily attach them to existing poles, LoRaWAN temperature and humidity sensors have the potential to form the basis of an affordable expanding network across the city, replacing the existing Ajenti technology. In order to explore this further, the decision was made to analyse data from both sensor types, investigating longitudinal trends from the Ajenti transmissions as well as any differences apparent in the TULIP transmission from a similar time period. This data analyse work was undertaken within the scope of the Smart Liveable Neighbourhoods project and established an evidence-based rationale for the large scale sensor network in Sydney.

6 It is worth noting that in the two years since these devices were procured, equivalent temperature and humidity sensors have halved in cost, shrunk in size and gained more sophisticated functionality

Image: 6 - View of the City of Sydney

Supporting strategies and policies in the City of Sydney

The City of Sydney has a number of strategies and policies in place that directly supported the establishment of the project and are critical to ongoing project activities.

Current:

- Sustainable Sydney 2030 (2008)
- Environmental Strategy and Action Plan (2015)
- Adapting for Climate Change A long term strategy for the City of Sydney (2015)
- Digital Strategy (2017)

Forthcoming (2020):

- Sustainable Sydney 2050
- City of Sydney Smart City Strategy [working title]

2 Design and collaboration approach

- High-level project co-design approach and use case development
- Detailed design and delivery: an agile and iterative approach
- Adapting project deliveries for the City of Sydney
- Key learnings and future considerations

High-level project co-design approach and use case development

The grant proposal committed project partners to a co-design process to explore alignment of the project with other urban management challenges and to raise awareness of the possibilities enabled by a new low power wide area network (LPWAN), specifically, long range wide area network (LoRaWAN), being deployed as part of the project.

The co-design process resulted in an adjustment to the scope of the project to focus on the following public place typologies:

- Streets and plazas
- Amenities blocks
- Parks and play facilities (pools, sports fields)
- Schools and community centres

The aim of the co-design process was to develop detailed designs for use cases and living labs:

Use cases

Smart city use cases are technology deployments, designed to address specific real-world challenges. Integrated technologies are positioned as a set of tools for the achievement of defined outcomes.

Living Labs

Aligned with use cases are *Living Labs*. A Living lab is a less targeted and more open-ended technology deployment, designed to create the infrastructure for experimentation and innovation in the smart city context. Living labs are a response to the understanding that it is not possible to anticipate all of the most useful or relevant outcomes and use cases for an emerging technology, particularly in a space that is highly collaborative. A living lab is location-specific. A wide range of complimentary smart technologies are deployed in a location. Relationships between data (including both sensor data and more qualitative data relating to human experience of and interaction with space), may be analysed and new relationships may become apparent. These relationships may inform urban design for liveability, service provision, council operations, communications, user-directed data and machine to machine data use cases.

The co-design process began with a focus on identifying existing challenges from a Council operations perspective. The Lake Macquarie City Council Business Transformation Team has been engaging staff from across the organisation for the past two years. The results of digital surveys were recorded and made available to the project team as a significant collection of text-based ideas from staff, relating both to operational challenges and potential solutions. These results were grouped into rough categories and then translated into a series of challenge statements. This provided an invaluable starting point for developing use cases and living lab concepts.

Liveability challenge statements, distilled from digital surveys of council staff

1. *Main roads and adjacent areas have poor liveability and are not places that people want to be in. We want to change that but there are so many factors involved its hard to know where to start.*
2. *We're not well equipped to understand how well the design outcomes for public space (e.g. Pearson St Mall) are actually met.*
3. *We don't know enough about how people use existing cycling/pedestrian infrastructure and this limits our ability to effectively plan for the future.*
4. *We don't know when public amenity blocks require cleaning or maintenance and we have no way of obtaining feedback from the public about their experiences as users. We'd like to design and run them better.*
5. *Council planners and designers do not currently know where to place street furniture (seats, benches, bins, bubblers) to maximise its use and the liveability of a target area.*
6. *Council has no strategy for managing trees or increasing tree cover. What species should we plant, and where? How often should we water and maintain them?*
7. *Council spends a lot of time and money mowing the grass. Creating appropriate and efficient grass mowing schedules is complicated, with many factors to consider.*
8. *Council would like to transform public spaces to make them more fun, engaging, informative and connected.*
9. *A lot of people choose to drink bottled water when they're out and about. Given the environmental impacts of this, Council wishes to actively support the community to drink tap water instead.*
10. *Poor quality storm water pollutes the Lake, resulting in ecological and human health impacts. Council would like to clean storm water up by minimising run-off and sediment loss at key catchment locations.*
11. *Lake Macquarie is one of the highest risk communities for sea level rise in the country. Property and infrastructure is under threat. Community concern is growing. We need an informed practical strategy now, and into the future.*
12. *Development approvals take a long time relative to other LGAs. Council would like to update its DA process to make it easier, quicker and deliver better outcomes, without compromising on social, environmental or economic priorities.*

The above challenge statements were considered in terms of how new smart city technology and how data might be utilised to help address them. They formed the starting point for a cross-council high-level co-design workshop, which then produced the high-level design plan for the project.

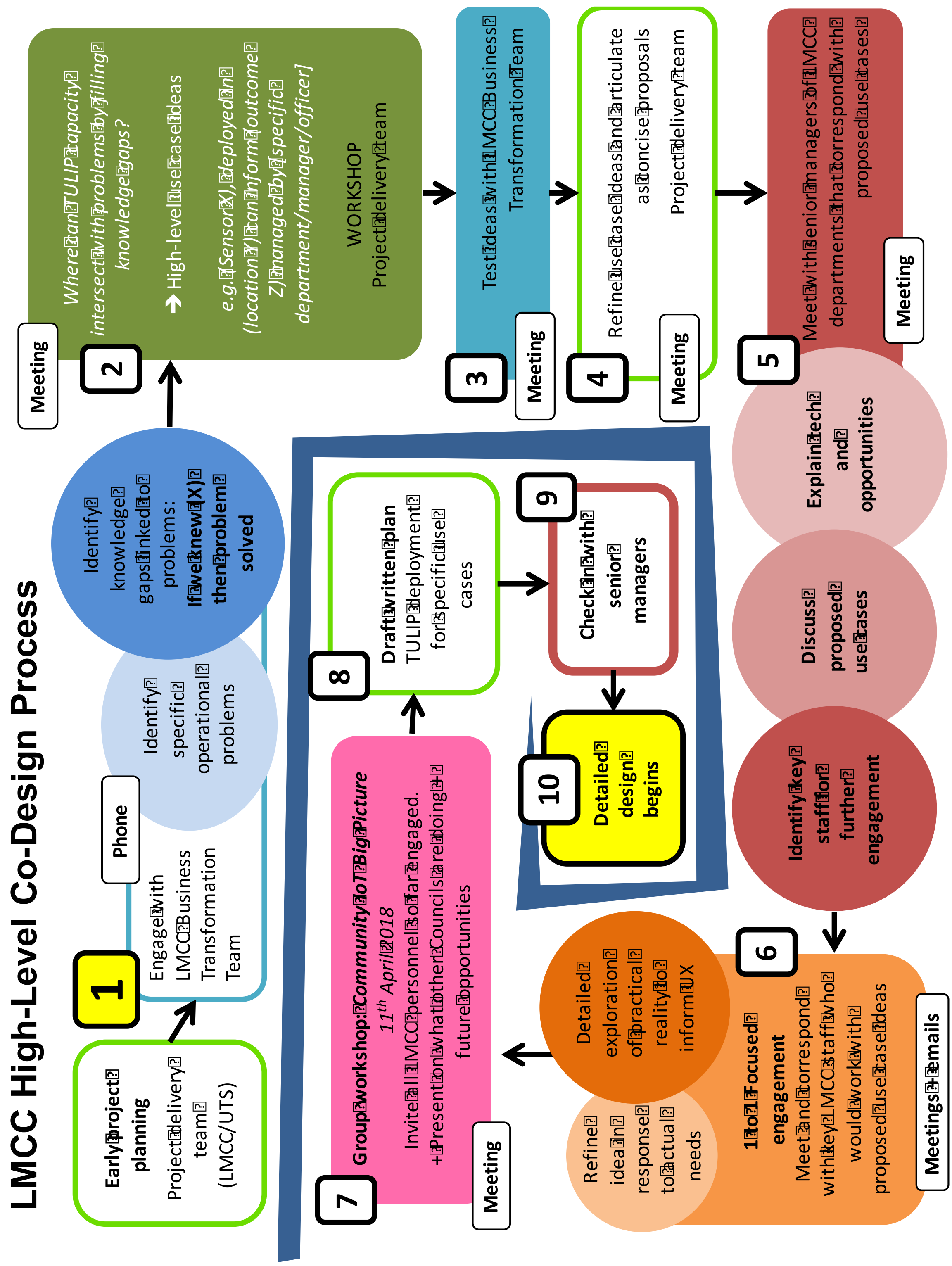

Image: 7 - LMCC co-design process

Adapting project deliveries for the City of Sydney

A majority of the project design process occurred in collaboration with Lake Macquarie City Council through the processes described above. The areas of focus that emerged, as well as the more detailed design considerations, directly influenced the smaller network deployment in Sydney, which came towards the end of the project period.

The TULIP team engaged with City of Sydney staff to identify which areas of focus identified for Lake Macquarie were of particular interest in Sydney. These were:

Undertake trial deployments to better understand emerging smart city technologies for monitoring environmental information and new open ways to transmit and access the data.

Explore urban heat, air quality and noise variations relating to land use and traffic density in the inner city.

Specific sites for sensor deployment were chosen to provide a mix of location types. Major roads with high volumes of traffic were of high interest, including major bus routes such as Broadway and Elizabeth Street. The mitigation impact of parks and pedestrian precincts was also of interest, meaning that pairs of sites were chosen to provide a juxtaposition, allowing comparison between a busy roadside and a quieter or greener location a short distance away.

The process of identifying, discussing and shortlisting sensor sites made heavy use of Google Maps. UTS made an initial list of options, with subsequent passes by City of Sydney and the TULIP team. Signal strength tests and field observations narrowed the list considerably. There were also unforeseen restrictions, for example all poles in the new light rail corridor have not yet passed into City of Sydney ownership, ruling out sites on George Street and much of the area around Central Station.

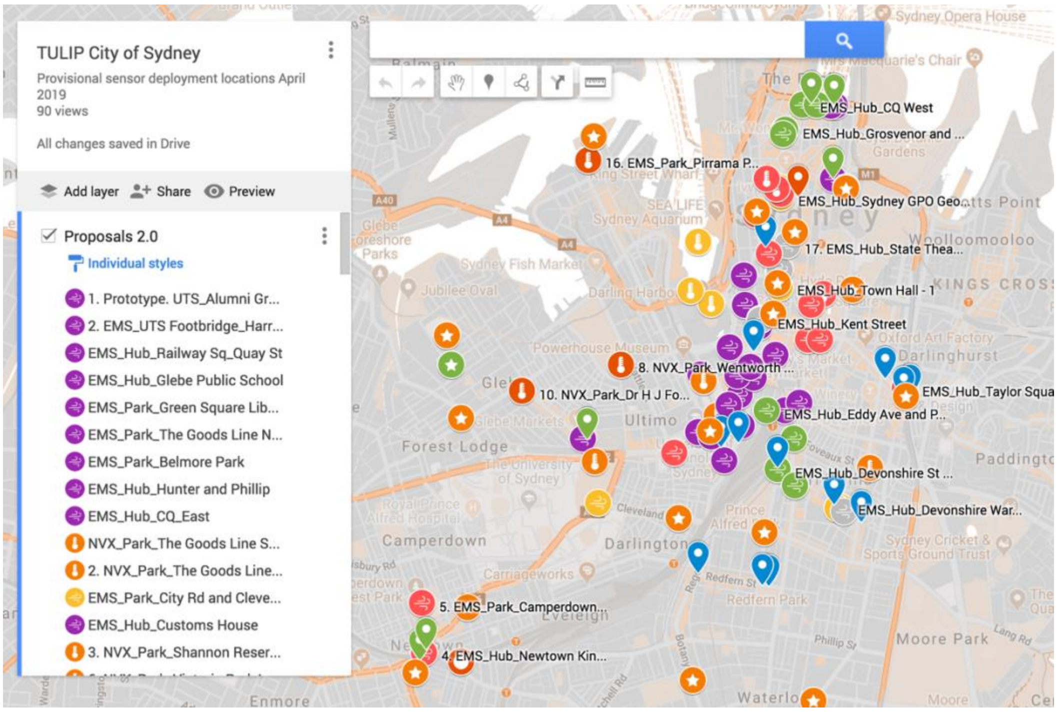

Image: 8 - Screenshot of the Google Map used for Sensor deployment planning in the City of Sydney

Detailed design and delivery: an agile and iterative approach

The approach to detailed design of project deliverables was largely synonymous with the approach of Action Research. Traditional project management approaches have tended to involve creation of a complete plan of delivery at the start of a project, delivering that plan to the letter, and then finally reporting on the outcomes. This linear design and delivery approach does not leave much room for experimentation and may stifle innovation and learning. Action Research adopts a cycle of planning, action, observation and reflection. It allows the detailed design and delivery of a project to evolve during the project. This approach is particularly appropriate in situations that involve many complex integrated components, partners, outcomes and challenges.

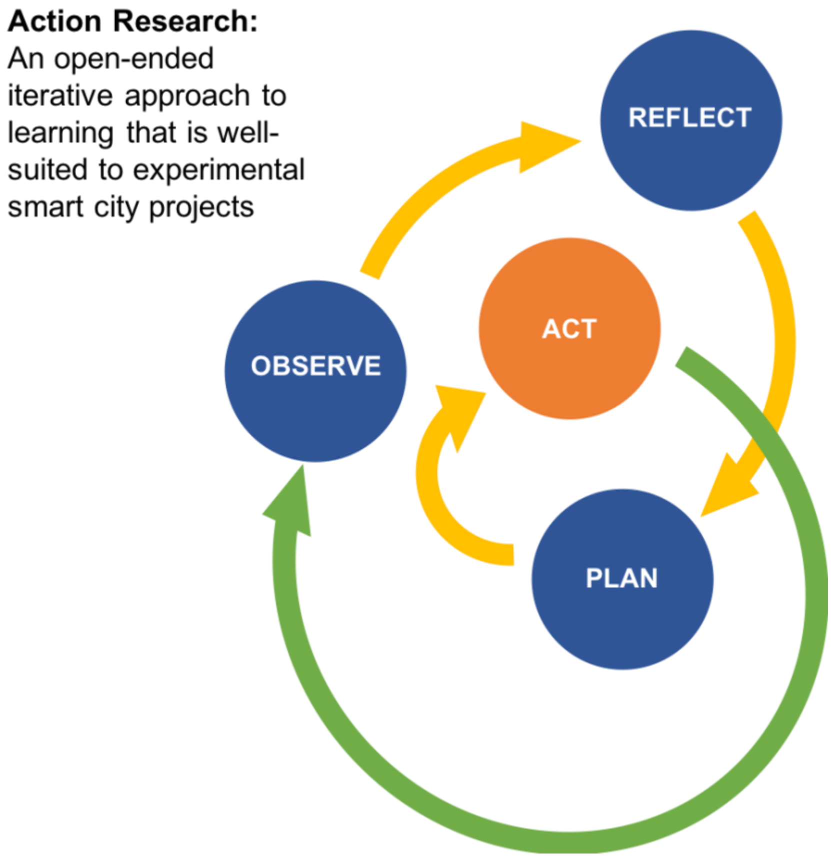

Image: 9 - Action Research diagram

The living lab model as an operational sandpit

The Living Lab approach detailed on previous pages makes use of technology in an experimental setting to generate an iterative series of insights. The emphasis of these insights tends to be on data-driven outcomes. For example, a living lab might draw upon environmental data, pedestrian movements and public transport data to learn new things about how people use public space during a heatwave. The design of the Smart Liveable Neighbourhoods project aimed to begin this sort of exploration and the installed networks of sensors in Lake Macquarie and the City of Sydney may certainly be characterised as newly established Living Labs. However it is worth noting that the principle insights that have so far emerged do not generally relate to data-driven insights. The initial value of the Living Lab approach has undoubtedly been at a more practical and operational level. As new smart technologies are becoming accessible, Councils have the challenge of getting to grips with what works and what doesn’t, in various contexts and combinations. Early exploration with the Living Lab model has offered a learning environment where it is possible for Councils to undertake rapid prototyping and deployment, ‘fail fast’, and generally work through a wide range of design and operational challenges in a contained environment. As Councils begin to consider how to scale smart city solutions and grapple with more far-reaching strategic positioning, the lessons learnt from these smaller projects look to be invaluable.

Overview of detailed design tasks

a) Detailed technology deployment design and delivery

- Identification of suitable locations for LoRaWAN gateways and their subsequent installation. The third TTN gateway was not installed until late in the project as the decision about its location was left open. The coverage and use of the first two gateways allowed a more informed decision to be made about the placement of the third.
- Identification and procurement of specific devices that produce the telemetry types required and fulfil a range of practical and operational specifications. An exploratory approach, with some appetite for risk, saw the procurement of a number of devices that were tested but not ultimately deployed at scale.
- Identification of specific locations and assets for mounting devices in the areas of interest. This included practical considerations that favoured or excluded various options, as well as approval processes for mounting on certain assets (e.g. privately owned street poles). Many locations had devices deployed, only to have them subsequently removed due to factors such as poor signal or insufficient sunlight for solar power. Knowledge about what constitutes an appropriate location for a certain type of device was generated through a certain amount of practical trial and error, with changes in approach continuing right through to the end of the project.
- Design and procurement of appropriate mounting equipment, in line with the needs of asset owners, Council policy and installation contractors. The specific solutions changed with each combination of device type and mounting asset. Some devices were deployed in staggered batches and lessons learnt about mounting solutions from a first batch were able to be implemented in the subsequent batch.

b) TULIP architecture and data modelling

- Identifying and engaging platform partners to deliver critical layers of the overall TULIP architecture
- Integrating architecture layers in a reliable functional framework through the design and establishment of multiple APIs
- Defining and agreeing upon a schema for device telemetry and metadata that was shared between the key platform partners (Nokia, Reekoh and Urban Institute). This schema was updated multiple times in response to changes in deployment design and the practical realities of device deployments as they occurred.

c) User interfaces/dashboards

- Collaborative design of the public and Council dashboards to allow access to and visualisation of live sensor data. This process was drawn out over a 12 month period and saw significant changes in what the platform partner (Urban Institute) was offering. These changes were in part a result of the underlying platform technology evolving in response to developments outside of the project, and partly in. response to the evolving needs of the project itself. A number of experimental versions of dashboard were explored by the project team, with subsequent versions built in response to feedback on the previous version. The final version of public dashboard was a product of more direct engagement between Lake Macquarie City Council and Urban Institute, allowing the design to respond in a more focused way to the precise needs of the user.

d) Community engagement programs

- Specific community engagement activities were developed iteratively as the project progressed. For example:

- Installation of the TTN LoRaWAN network triggered the Smart Liveable Neighbourhoods Challenge, where community members built DIY devices that made use of the new Things Network connectivity
- Lessons learnt from the Challenge informed the design of the Adopt-A-Sensor initiative
- The design of Adopt-A-Sensor itself developed and adapted to changing circumstances as the project progressed and the initiative continues to evolve past the end of the project.

e) Design of data analytics

- Data analytics for the project was split into three distinct pieces of work: air quality, urban heat and noise. Each of these had a brief that was initially designed based upon an understanding of existing literature and methodologies. Following deployment of devices and the generation of data, new insights emerged and briefs were refocused in response.

Project timeline: tracking iterative changes

Project inception (early 2018)

Pearson Street Mall + ChIP

The focus of the project was primarily the redevelopment of Pearson Street Mall in Charlestown, which formed the core of the original project proposal. ChIP was the 'Charlestown Innovation Precinct', which expanded project focus from the mall redevelopment, out into the surrounding town centre.

Critical activities and idea progression (January to June 2018)

Exploring use cases with LMCC

A series of engagements with Lake Macquarie City Council (LMCC) centred around a full-day workshop with managers from multiple areas of council operations. This promoted the project internally, helped to raise understanding and basic literacy and broadened the thinking around how the technologies might be used, and by whom.

Beyond environmental sensors

The use cases that were emerging to justify environmental monitoring were also demanding exploration of people counting and asset monitoring, which were increasingly understood as providing a context to environmental data and informing urban design decisions, making them a vital part of the broader liveability question explored by the project.

Planning LoRaWAN deployments

This included negotiation of dual networks (Meshed community network of three gateways, plus partial support for the NNNCo commercial network). Decisions about placement of Meshed gateways brought Speers Point into focus for the first time.

Practical engagement on Pearson St Mall upgrade

Engagement with the project manager and landscape architect for the Pearson Street Mall upgrade. Incorporation of ideas emerging from the project design process with plans for the upgrade.

Sensor procurement research

Discovery that appropriate commercial options were far more limited than initially anticipated. Amongst other things, this led to conception of the sensor benchmarking program and a decision to partner with ARCS Group to develop the TULIP Environmental Monitoring System (EMS).

Developing the TULIP platform architecture

Industry partners were brought on board (including Reekoh and Urban Institute) and the fundamental open modular architecture of TULIP was first established. Critically, this saw the emergence of the aim for the architecture to be vendor, network and device agnostic, with maximum flexibility and the ability to ingest many different data sources.

Early exploration of actuation options

A high-level review was undertaken into data-actuated installations in smart city contexts around the world. Findings were presented to Lake Macquarie City Council and directly informed ideas for the planned mall upgrade. In parallel, technical discussions began regarding how best to build an actuated device and integrate it into the emerging TULIP architecture. A post-graduate mechatronics intern was provided with equipment to build and test a simple prototype. The device worked in isolation, however integration with TULIP was not achieved, in part because the core architecture of the platform was still under discussion and in part because the intern was not able to gain direct access to the platform layers.

Delays to the mall upgrade

News of a delay to the Pearson Street Mall upgrade timeline to early 2019. This compressed the available time for installation of smart components in the mall within the project timeframe and opened up the opportunity to undertake complimentary activities, expanding the focus of the project.

A rethink for City of Sydney collaboration

The project agreement with the City of Sydney specified the use of an existing environmental data platform in use by the City for hosting of TULIP sensor data, with direct support from the City's technical staff. As the TULIP platform architecture took shape it became apparent that the proposed integration was not workable. Critically, it was clarified that the City's existing platform was not able to ingest real-time data and could not be retrofitted to do so. Thus it was established that the planned collaboration with the City of Sydney required a radical rethink. Discussions at the time concluded that the project delivery should focus on Lake Macquarie delivery until late 2018 with the understanding that a clearer set of alternative options should emerge in the interim.

Expanded vision (June 2018)

Six months into the project, stakeholder engagements, high level design considerations, early insights and some emerging practical constraints around the initial concepts caused a general broadening of focus and ambition. Aims outlined in the July 2018 project milestone report were wide-ranging and in hindsight, were overly ambitious. At this time, the project was being led primarily by a collaborative design process and a flexible experimental approach. It was yet to be constrained by more fundamental practical realities of delivery.

At this time, the planned deliveries were as follows:

Pearson Street Mall upgrade, detailed design focus

- Environmental monitoring (heat, air, noise)
- People and asset monitoring (silent wifi people counting; smart furniture/bins/bubblers)
- Actuated installations (Addressable LED lighting incorporated into furniture and landscaping; projectors for evening/night time activation of the space, with live data responsiveness; an actuated water/mist feature that responds to sensor data)
- Staging platform for pop-up events and art (featuring fibre, power, modular components)

Pearson Street and central Charlestown

Environmental monitoring throughout central Charlestown, placing Pearson Street Mall in a broader context.

City-wide environmental monitoring

A new aim to expand environmental monitoring across the LGA, with Speers Point as a second centre of focus, in direct comparison to Charlestown, plus deployments around the lake, including Redhead, Swansea and Morisset. This broader deployment plan was made possible by factoring in the NNNCo network, the growing Things Network coverage in the area, and the ability for the TULIP platform to ingest from both networks as well as from 3G devices.

Actuated public art at Charlestown Skatepark

The upgrade of Pearson Street Mall was always intended to include data-actuated public art for the purpose of creative data interpretation and place-making. With the delayed delivery of the mall upgrade a decision was made to develop actuation capacity ahead of the upgrade through initial focus on *Antenna*, a newly installed public artwork at Charlestown skatepark. Funding was re-allocated from the Pearson Street Mall budget for development of the TULIP Rosella, which was to be designed as a versatile device that could be adapted for use in Pearson Street Mall, following initial deployment and fine-tuning in Antenna. The idea was to get a head start so that requirements for actuation were better understood, allowing additional installations to be more easily delivered to the Mall within the now constricted Mall upgrade timeframe in early 2019.

Smart parks and play

Charlestown Oval and Speers Point Park were identified as areas for experimentation, moving beyond just environmental monitoring to include people counting and use of public amenities. These locations were envisaged as living labs. Parks and playgrounds were chosen because of their relevance to the public as part of a deliberate move to ensure that project activities could be easily aligned community interests.

Smart swim centre

Emerging directly from the engagements with LMCC staff, a focus on Speers Point Pool emerged. The pool was the focus of an aligned Council initiative to trial smart energy and water metres. The project was positioned to compliment this by adding environmental and people counting devices. The aim was to use the new data to help develop real-time operational responses for the pool, including energy and water management, public engagement, building management and staffing. Analysis and responsiveness to multiple heterogeneous data sets in such a context is highly complex and demands significant development work and additional software support. Though this is now better understood, it was not factored into the planning at the time.

Critical activities and idea progression (July to November 2018)

Engagement of a Technical Program Manager

From September 2018 a Technical Program Manager joined the UTS team to take on the mounting workload of technical management tasks. This role covered provisioning of devices and development of the TULIP platform through liaison with technical partners and coordination of collaborative workflows.

Sensor procurement developments

Various devices arrived from vendors (many significantly late) and critical lessons were learnt, including the possibility for:

- the elastic nature of lead times for new-to-market products;
- the lack of 'out-the-box' functionality (regardless of vendor claims);
- the inadequacy of official documentation (or its complete absence);
- poor interoperability;
- physical design flaws;
- lack of critical functionality;
- the difficulties of dealing with international vendors, often via local intermediaries
- The project team began to speak informally with individuals undertaking similar procurement explorations at other Australian councils and heard similar experiences and frustrations. It became clear that the current market for low cost smart city sensors was relatively immature, somewhat restricted in terms of choice and almost entirely unstandardized. A shortlist of appropriate sensors was ultimately selected for scaled project deployment, but only after many false starts.

Delivery of the first TULIP EMS prototypes from The ARCS Group

The first two TULIP Environmental Monitoring Systems (EMS) arrived from The ARCS Group in September 2018, along with detailed documentation. One unit was assigned to benchmarking and the other was deployed in Lake Macquarie. It is worth noting that the latter was incorrectly deployed, through a lack of clear process, an outcome of which was the development of the first device provisioning procedure (see below).

Device benchmarking program begins

A research lead for device benchmarking was designated at UTS and initial exploration began into the Libelium Smart City Pro particulate monitor and the performance of the first TULIP EMS prototype. Progress was hindered due to delayed arrival of devices and, with the Libelium, an inability to configure the device for correct operation (due to poor documentation and lack of vendor support). The first EMS prototype also had some bugs, delaying early investigations. However, a test facility for controlled exposure of devices was designed and built at this time, along with a rigorous methodology, and by November a clear plan was in place for an extended benchmarking program in early 2019.

Phase 1 Actuation

Newcastle-based start-up Newie Ventures was engaged in August 2018 to create an actuation driver for LED lighting that connected to the TULIP platform. The device, named the TULIP Rosella, was developed for use in a public artwork called Antenna; a 6m steel and glass obelisk situated in the newly commissioned Charlestown skatepark. The Rosella would cause lights in the sculpture to respond to real-time temperature and weather data from TULIP and from the Bureau of Meteorology (BOM). The initial expense for development of the Rosella was justified because the design brief stipulated that the device should be versatile enough that it could be easily adapted to other actuations. The design was also made fully open source.

The Urban Institute was also engaged regarding the integration of the Rosella with a custom actuation command module that UI would build and host. An outline for this was developed and a separate commercial contract was raised for delivery.

The initial timeframe for delivery of Antenna was significantly delayed at multiple stages. The most notable was access to accurate local rain data, which proved to be unavailable from third party sources as the nearest BOM weather station was over 6km away. Ultimately, a decision was made to develop a custom LoRaWAN weather station that could be situated in Charlestown, though delivery of this (and eventual completion of Antenna) did not occur until the end of the project. However, the Rosella prototype was completed on time and established a basis for further actuation deliveries in early 2019.

Architectural deep dive

With platform partners such as Nokia, Reekoh and Urban Institute in place, ideas for an open modular multi-partner data architecture took shape with the first data flowing from devices through all layers of the TULIP data stack by July 2018. As complexity was added (e.g. the use of the Ansible orchestration engine by Nokia, as part of the device provisioning process), UTS decided to explore the emerging TULIP architecture through a dedicated piece of research lead by the School of Software in the Faculty of Engineering and IT. The work positioned TULIP against best practice and related architectures detailed in academic literature and established the overall approach being taken as appropriate and significant.

Data model explorations

As the detailed design for the project took shape, lists of sensor telemetry and device metadata emerged. At the same time, the multi-platform data architecture demanded a commonly agreed data model that allowed all parties to handle and share data effectively through stack. Early explorations of the challenge considered the demands of rigorous deployment design as well as future scalability needs and produced an ambitious ‘ideal’ model that accommodated metadata categories for devices, sensors, locations, users and use cases in a complex arrangement of connected tables. It became clear that this ideal was not practical for immediate implementation and so, in collaboration with partners, a simpler ‘interim’ data model was developed and agreed to.

At this time, existing standards and frameworks were explored for potential incorporation with TULIP. The Hypercat data labelling system developed in the UK and initially noted in the project plan was discarded due to a perceived lack of broader uptake as well as feedback from platform partners. The emerging Fiware model, which has seen significant uptake in European smart city projects, was considered but not ultimately incorporated.

In light of the deep exploration of data model requirements at this time, an independent contractor (Surround Australia) was engaged to review the ‘interim’ TULIP data model and provide a roadmap for future data model development. Concern was raised about inflexibility of the TULIP data ontology as well as significant manual coding in the model adopted. Feedback from

Surround was instructive, indicating high-value longer term strategic directions, however the project continued to operate on the agreed ‘interim’ model due to immediate practical needs.

Platform functionality and UX development

In August 2018, a multi-partner workshop was hosted at UTS with Urban Institute, Reekoh and Nokia, plus representatives from Lake Macquarie City Council (LMCC). The workshop explored complex functionality and desired features for the TULIP platform, from the level of device onboarding and management, to a broad range of user experience functions for the Urban Institute dashboard. Features and functions were itemised, categorised and prioritised through group discussion. A new technical management platform was brought into use to capture the emerging consensus and manage the ensuing workflow.

Following the workshop the list of idealised platform and UX functionality was found to be overly ambitious. A sub-set of critical deliveries was identified for a November delivery and agreed to by technical partners. Other ‘high priorities’ were shifted to December and March delivery deadlines and a significant number of ‘ideal’ features were dropped as targets within the scope of the project, reducing the overall list of development tasks to a more manageable level. LMCC were active participants in this re-prioritisation exercise.

Multi-partner collaboration challenges

In the second half of 2018, a growth was seen in collaborative tasks involving multiple technical partners, in line with the growing complexity of the TULIP platform. As initial open enthusiasm for the project transitioned into practical delivery requirements and intersecting deadlines, a new phase of partner engagement began. Partners came to the project from quite different backgrounds and disciplines and as collaboration became more directly critical to task delivery, confusions often arose through a lack of shared language. Such confusions were navigated, though the importance of face-to-face meetings (as opposed to teleconferences) became clear to everyone involved.

Two core partners (Reekoh and Urban Institute) are start-ups and as such were under all the usual stresses and strains that start-ups face. Working with start-ups brought great benefits to the project. Response times were very fast, close working relationships were formed with senior management and an appetite to experiment and collaborate was hardwired into them. Involvement with a university research project was clearly understood by both businesses to be strategically beneficial to their mid to long-term aims and things worked well when TULIP development tasks were seen to directly align with the needs of their current commercial clients. However, the time allocated to custom development for TULIP was in direct competition with time spent on commercial contracts. Given that the platform license and custom development fees charged to the project by both partners were essentially at cost, project tasks were often delayed in favour of higher priority clients paying commercial rates. One consequence of this that quickly became clear was that the idealised ‘needs’ of the platform (for example, the ‘ideal’ data model, or the full list of functionality that emerged from the September platform functionality workshop) needed to be reduced down to a much smaller set of practically achievable tasks that aligned with the strategic directions of the partners.

The tensions between project and commercial work for a single partner were compounded for tasks that required two or more partners to work together – for example, to onboard a new type of device to the system. If one partner was delayed for a week due to other commercial commitments, this would hold up the progress of others. The following week, a different partner might be unavailable. Tasks that should theoretically have taken a couple of days would often take some weeks to accomplish. It became clear that the collaborative multi-partner approach, for all that it was necessary for creation of an open modular data architecture, was fundamentally challenging in its execution. Towards the end of the project a deeper strategic response to this challenge was formulated, however late 2018 to early 2019 was undeniably characterised by these tensions.

Development of an operational model

As the project moved from planning to practical delivery a need for an operational model came quickly to the fore. The following distinct areas of focus arose:

a) Data model updates

b) Device type onboarding

c) Device pre-provisioning

d) Device provisioning

e) Trouble-shooting (missing telemetry, incorrect telemetry, etc.)

f) Platform down-time and upgrade management

Procedures in all of these areas began in response to direct need and grew iteratively as the project progressed. Despite discussion and best effort, some areas were only partially addressed by the end of the project, highlighting the need for ongoing work.

Pearson Street Mall upgrade is pushed beyond the project timeframe

By late 2018 it was apparent that the timeframe for the Pearson Street Mall upgrade was pushed back beyond the timeframe for the project, meaning that all project deliveries would need to occur independent of the upgrade. This constituted a notable departure from the original concept and rationale for the project, requiring negotiation between UTS and LMCC in the first instance, followed by a process of amending official delivery requirements under the grant agreement (a negotiation with the Australian Government).

The core of the project was concerned with 'better city living', exploring use cases associated with urban heat, air quality and noise. The context for this exploration was initially the upgrade of Pearson Street Mall, and it was in this context that Council had agreed to contribute significant funding ($240K) to the project. With the mall upgrade removed from the picture, the focus became ChIP (the Charlestown Innovation Precinct), with a secondary focus on Speers Point. The latter is the site of the second Meshed LoRaWAN gateway and the Council administration offices. It is also a green lakeside suburb with large areas of parkland; a notable contrast to Charlestown, which is a high density town centre. This shift of focus constituted a shift of Council expenditure away from the Mall upgrade and into more general 'Smart City' activities. This aligned with the emerging Council focus on smart cities, and was justified as such, however at the time it amounted to unplanned additional expenditure. This was because the allocated funds, originally intended for the mall, were directed elsewhere, however the mall upgrade (now scheduled for late 2020) will ultimately require those funds to be a part of its budget. It is perhaps testament to LMCC's commitment to a smart city agenda, and to the kind of open and iterative innovation engendered by the project, that the transition of project focus from Pearson St Mall to a wider set of environmental monitoring deliveries was able to occur relatively quickly and smoothly. The Australian Government, for their part, were very accommodating of the shifted focus. A detailed plan for changed deliverables was drawn up by UTS and LMCC and officially approved.

Early community engagements

The project had a presence at a number of community events, culminating in the Sustainable Neighbourhoods Challenge, a competition to design, build and connect a DIY LoRaWAN device. This focused on an activation of the Meshed community LoRaWAN gateways and The Things Network. The exercise proved the existence of a niche group of technically competent enthusiasts in the Lake Macquarie area and was a conceptual pre-cursor to the adopt-a-sensor initiative.

The final push to project completion (December 2018 to June 2019)

A new City of Sydney collaboration plan

The original high level agreement between UTS and the City of Sydney positioned the City as a $50K project contributor. The original understanding was that UTS would work with Council to integrate live data from some of their existing environmental sensors (delivered by UTS in 2017), with an existing data platform in use by the city. As the TULIP data architecture and broader technical understanding evolved through work in Lake Macquarie, it became clear that this original plan was not feasible, notably because the data platform initially identified was not capable of ingesting and managing live data. While this was apparent throughout the second half of 2018, a decision about how to proceed was deferred until early 2019. This was mostly so that the design decisions of the project could be worked through in the Lake Macquarie context, allowing UTS to approach the City of Sydney with a stable proposition.

The plan that was agreed to with the City of Sydney in early 2019 saw approximately half of their project commitment assigned to capital expenditure, with the purchase of fourteen sensors for deployment in the City. The remaining commitment went towards their staffing costs to support the planning and rollout of the sensors. Data from these devices was directed into the same TULIP platform instances as the LMCC data, effectively allowing the City of Sydney to 'piggy back' on the core project infrastructure. The deployments in Sydney were positioned as a trial that allowed the City to explore the practical realities of low-cost environmental sensing while keeping their exposure to risks at a minimum. The UTS engagement with the City has continued after the project, with ongoing support and assistance with the sensor network. With the upcoming release of a City of Sydney Smart City Strategy in 2020, there is certainly a good basis for ongoing collaboration.

All detailed Lake Macquarie deployments finalised

Final procurement decisions for scaled device deployment in Lake Macquarie were made, with orders placed between December 2018 and February 2019. This occurred somewhat later than originally planned, due mainly to the initial frustrations finding appropriate device options. With uncertainty surrounding the few options for temperature and humidity monitoring devices a decision was made to procure three different commercially available models in order to spread the risk associated with any one option.

The initial order for EMS units from ARCS Group was expanded and an extended integration of the EMS with a solid state weather station (the Lufft WS10) was negotiated. This would provide localised meteorological data in Charlestown and Speers Point. It was hypothesised that this would prove critical for analysing telemetry from the sensor networks in these locations, as well as being needed for integration with the actuated public artworks (Antenna and Chimera).

Site surveys and detailed deployment design

In early 2019, a large amount of work by UTS and Council staff went into the detailed deployment design for the sensor networks, in Lake Macquarie and in the City of Sydney. This included extensive site surveys, with hundreds of potential deployment locations identified and assessed for suitability. Attention was paid to a range of practicalities and a great deal was learnt about critical factors to consider, approvals processes, mounting solutions, and delivery timeframes. This first-hand practical knowledge has proven invaluable for both Councils and UTS. Councils developed a frontline understanding of deployment design and operations, which relates to their own future resourcing needs in the space. UTS has developed a deep working knowledge of delivery that is not unreasonably comparable to that of a specialist contractor. This knowledge, and the tools and processes developed in the project, has gone on to directly influence the delivery of other projects (e.g. with the City of Parramatta).

Adopt-a-sensor program gets underway

The Adopt-a-Sensor program was originally conceived in late 2018, as a critical sub-set of the network deployments. It was only in early 2019 that plans really got underway. A new Council officer (from Integrated Planning) was assigned to the task, with assistance from a schools liaison officer. Council was able to manage their public outreach effectively and recruited a range of residents, schools and community groups to participate. This process was very much embedded in the broader deployment design for sensor deployments in Lake Macquarie. UTS was able to work closely with the newly assigned Council staff.

LMCC Staff turnover

In early 2019, the two critical lead staff at LMCC moved on from their roles, within the space of a couple of months. This was something of a setback to the project because a great deal of technical knowledge was held by those individuals. Furthermore, while the relationship between UTS and LMCC extended to executive level, and while a number of other individuals were engaged, a large amount of the working relationship, and the trust that underlies successful partnerships, was tied to those two individuals. This situation highlights a major risk to smart city pilots such as this project. A pilot project delivered at the level we were working, while enjoying executive approval, was not embedded in the wider operations of council, and as such, was inherently reliant upon a handful of individuals. Smart city knowledge, whether technical or more outcomes focused, lay with those individuals.

Two new staff were assigned to work on the project, most notably the officer who was managing the Adopt-a-Sensor program. This meant some degree of continuity as he had been working alongside the staff members who left, meaning that some transferal of knowledge and partner relationship was possible. Work continued effectively, but no doubt some time and efficiency were forfeit in the changeover.

Phase 2 Actuation

Following the refocus of the project deliverables in Lake Macquarie, away from Pearson Street Mall and into Charlestown and Speers Point more generally, a significant reallocation of funds for capital expenditure was open for discussion. It was agreed that a majority of these funds, originally designated for 'smart' infrastructure in the upgraded mall, should be directed at data-actuated public art of the sort trialled by the Antenna project in Charlestown Skatepark. This led to a deeper engagement by UTS with the LMCC public art team, resulting in the project to actuate the Chimera artwork on the shore of Lake Macquarie. As with Antenna, this involved engaging with an existing artwork that was being commissioned within the timeframe of the project, thus presenting an opportunity to collaborate. Chimera was already designated to be lit with LED lights and Council had a wider plan to invest in smart and interactive lighting along the lake shore. The two projects were able to mutually leverage off each other to produce outcomes that would not have been possible under just one of the budgets. That said, it should be noted that this process was not without its difficulties. Standard Council process for public art involves working with an artist from start to finish, with close attention paid to supporting an artist's vision for a work. Our project was seen as an imposition upon this standard process. UTS involvement with Chimera and the public art team was likely mandated from the Council executive as part of the move away from the Pearson Street Mall delivery. UTS was able to work directly with the public art team but there was no direct contact with the artist. This led to tensions that were not always clear to UTS. It was an irregular set of circumstances, handled well by all concerned, but nonetheless a departure from standard operations.

It has been noted that the project followed an iterative delivery pathway, responding agilely to changing requirements, and the scenario with Chimera is an example of how this occurred. It is a testament to Council that they were willing and able to adapt to such changes and the challenges inherent in them, to work outside of standard process, and to produce an outcome that worked for the project and for the public art agenda.

In addition to Chimera, options for a third actuation were considered. While the Mobile Beacon was the eventual delivery, a number of other options were explored, including a concept for a Smart Mural in Charlestown centre, which progressed to an advanced planning stage. It was ultimately found that the Smart Mural concept was not feasible within the project budget and timeframe. With the deadline for the grant agreement looming, a last minute decision was made to deliver the Mobile Beacon, within budget constraints. The concept for this was somewhat rushed, to meet that deadline. The final product was an effective demonstration of the Rosella technology and the actuation capabilities of TULIP, as well as a practical public engagement tool. However, the notable point here is that the process, which was rushed through in line with the grant deadline, did not align with a Council approach for developing a public engagement tool. That approach would have been more consultative and would likely have engaged an artist to produce a more polished product. As it stands, the Mobile Beacon is more of a technology prototype that demonstrates capability. The result is that Council did not feel able to take on the Mobile Beacon as a working asset for public engagement and instead decided to relinquish ownership to UTS. The Mobile Beacon thus became a UTS asset that can be used to visualise live data from Lake Macquarie, City of Sydney, or any future TULIP project. In many ways this is a more appropriate home for this type of prototype demonstration device. If there is a lesson here it is that Council were able to be flexible to a point (see Chimera), but the reality of hard deadlines and budgets ultimately found immovable barriers. The entire scenario can be traced back to the delays with the Pearson Street Mall redevelopment, with management of deliveries in 2019 exacerbated by staff turnover and multiple technical delays.

Research brief development

Development of the research briefs for the three areas of environmental enquiry: heat, air quality and noise. These briefs were strongly influenced by the insights developed from the design and practical delivery of the sensor network, which placed constraints on what we could explore and provided a methodological context for data analysis.

Post project wrap-up and reflections

All aspects of the project were officially delivered by June 2019, however a number of tasks required ongoing support from UTS to councils in order to reach a stage of full completion. Aspects of the project continued through late 2019 and into 2020. Certain activities detailed in this report were not fully completed, as funding and resources ran short following the official end of the project. A great deal was attempted with this project and one lesson learned is the importance of embedding activities into the operations and budget of an organisation to ensure ongoing support. A common criticism of smart city projects is that they often fall over when the initial delivery is completed. The challenge of sustainable integration is a significant one.

While not all initiatives explored in this project have continued with full support, many have, and many more have made a lasting impact on Council engagements with smart city technology and environmental monitoring. As of August 2020 (14 months after official project completion), the following can be said:

Lake Macquarie post-project stock-take, August 2020

- Almost all of the devices deployed are currently operating and collecting data and have done so continuously since completion of the project. A few EMS and Netvox R712 devices are still awaiting deployment due to some last minute changes of plans. The Lufft weather stations have not been fully commissioned due to decisions made by Council to reallocate them to alternative locations. The Bosch weather station has been decommissioned due to prohibitive costs and technical issues.

- Data analytics on urban heat, air quality and noise has finally been undertaken against extended data sets, with reports published in the second half of 2020.

- All three TTN LoRaWAN base stations deployed for the project continue to operate, with growing community user bases. Council has been so impressed by the TTN model that they have now rolled out an LGA-wide network of TTN gateways in partnership with Meshed, moving away from the Dantia-led NNNCo network.

- Concepts developed for the TULIP platform were taken into the Smart Beaches project, a round two Smart Cities and Suburbs project led by Lake Macquarie City Council. UTS and LMCC were able to continue the ideas and solutions first explored in the Smart Liveable Neighbourhoods project. Since the completion of Smart Beaches in June 2020, LMCC chose to extend the second generation TUILP platform in ongoing partnership with UTS.

- UTS and LMCC have signed an MOU to support ongoing collaboration in this space and a number of new business development opportunities are being followed at the time of writing.

City of Sydney post-project stock-take, August 2020

- Despite significant delays and redeployments, all City of Sydney devices were deployed and active by 2020. In August 2020, twelve out of sixteen devices are deployed, fully active and collecting data. Three are deployed but experiencing technical issues and one has been recalled, due for redeployment.

- Due in part to the early work demonstrated by TULIP, the City of Sydney has committed to a 'Breathable Sydney' program, supported by a Mayoral minute from July 2020. There is now a commitment to continue City collaboration with UTS through extension of the TULIP program. Ongoing support for the existing network is being negotiated, as well as the procurement and deployment of additional EMS devices. UTS is working with Council to develop a Breathable Sydney roadmap that aligns with broader strategies, including Sustainable Sydney 2050 and the City's new Smart City Strategy 2020.

Key learnings and future considerations

Design and collaboration approach

1) Executive buy-in was critical

In Lake Macquarie and City of Sydney, executive Council officers were directly engaged with the project planning and delivery. This proved to be important for ensuring that project deliveries aligned with broader Council strategy. Furthermore, it has laid the foundations for discussing how the legacy systems of the project will be taken forward into the future.

2) The importance of internal champions

Each Council assigned staff to the project to ensure delivery. At Lake Macquarie, this was several key individuals from the Integrated Planning department as well as senior project officers from Sustainability. At the City of Sydney, the key point of contact was from the Sustainability team. All of these individuals showed a strong personal engagement with the project and support for what it sought to achieve and may be thought of as internal champions. The process of project delivery was complex, iterative, somewhat drawn out and at times frustrating as new challenges were negotiated. The dedication of these internal champions was likely critical to the success of this sort of early adoption trial.

3) Knowledge gaps and resulting time investment required

The design and implementation of the technical solutions delivered by the project required familiarity with many concepts and vocabularies that were new to many of the Council staff assigned to the project. We found that there were significant technical and conceptual knowledge gaps within both Councils. Over the course of the project, Council staff built their knowledge and understanding of the new technologies. However this meant that progress, particularly during the earlier design stages, was slower than expected. We feel that it is vital for Councils to ‘come on the journey’ and take full ownership of smart city technologies of the sort that TULIP delivers. For this to happen effectively, it is important that enough time is allocated to the design and discovery phases of a project.

4) Iterative experimentation is a welcome but challenging new mode of operation for Councils

The project has been a highly experimental foray into the use of new technologies and how they might be applied within urban communities. Approaches have been open ended, design and delivery has been iterative and many activities have been undertaken without full understanding of the outcomes. Delays and hurdles have appeared where they were not anticipated. It is fair to say that both Councils have learnt a great deal as a result of the project and that the open experimental approach has been critical to this. However, such a mode of operation is challenging for Councils, who are more familiar with clearer and more linear project design and delivery. The iterative approach is now being recognised as valuable and is increasingly being incorporated into smart city strategies. Projects like this may be understood to be part of a wider shift in how councils operate as they negotiate the challenges of an increasingly complex and evolving world of technology.

5) The rewards and challenges of multi-stakeholder collaboration

The smart city concept has evolved from early technology-focused concepts of urban innovation and development, to have a more human-centred design focus, characterised by broad stakeholder collaboration and a more outcomes driven approach to things like liveability and sustainability. A model for smart city knowledge and value creation has been established based upon the Triple Helix model for knowledge based economic development[7]. The model emphasises the combined role of universities, industry and government in smart city learning and innovation. A fourth strand, alternately identified as civil society, citizens, or simply 'end users' of a smart city, has expanded the model into the Quadruple Helix[8]. The emphasis is on the formation of a collaboration ecosystem as a means to achieve appropriate and effective outcomes for citizens, while boosting the economic and sustainability performance of the city.

Multi-stakeholder collaboration was baked into the foundations of the project as a pre-requisite of the Smart Cities and Suburbs grant program, underscoring this emphasis on innovation as a primary aim of activities. The project fitted the Quadruple Helix model, with the inclusion and participation of community groups in Lake Macquarie.

The rewards of working with multiple stakeholders in a genuinely open and collaborative process have been great:

- From a university perspective, UTS was forced to keep tightly focused on the real operational needs and practical realities of our Council partners. This ensured that the project stayed very well grounded in real world problems and the delivery of genuinely valuable solutions.
- From a Council perspective, UTS brought a large amount of knowledge to the table, but also the capacity of a university to engage with learning. Universities operate at the forefront of knowledge and are used to shouldering the risk that goes with experimentation, meaning that such risk could be distanced from Council and their rate payers. As cities explore the front lines of smart city ecosystem development, they must tread a line between innovation and over-reach. By partnering with a university, a city can get more deeply involved in an experimental space while minimising their exposure.
- UTS and Council worked with industry partners to deliver vital technical services and capacities for the project. Much of what was provided by external partners could theoretically have been done internally at UTS. However, it was recognised from the start that the project needed to explore solutions that were scalable, commercially viable, and could be continued after the life of the project. By building relationships with commercial partners UTS and Council learnt about the commercial realities of the space we were exploring and ensured that our efforts were taking us in a sustainable direction. From a UTS perspective, we were also freed up from a great deal of the nuts and bolts work of the project, allowing us to focus on the development of ideas and learning, which is the most valuable contribution that a university can bring to the table.
- From the perspective of the various industry partners, a great deal of value came from association with the project. For start-ups, it was an opportunity to test and refine ideas and products in a functioning ecosystem, as well as offering exposure to new relationships and opportunities. For larger corporate partners, the project was an opportunity to explore novel new applications of new products in the rapidly emerging smart city domain, providing insights into the use of their systems and how they might fit within a broader ecosystem.
- For schools and community members in Lake Macquarie, the project was an opportunity to engage with Council on issues like urban heat and air quality. The true benefits and outcomes of this are hard to confirm at this stage.

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7 Etzkowitz, H. and Leydesdorff, L., 1995. The Triple Helix--University-industry-government relations: A laboratory for knowledge based economic development. EASST review, 14(1), pp.14-19.

8 Schuurman, D., Baccarne, B., De Marez, L. and Mechant, P., 2012. Smart ideas for smart cities: Investigating crowdsourcing for generating and selecting ideas for ICT innovation in a city context. Journal of theoretical and applied electronic commerce research, 7(3), pp.49-62.

The challenges of a multi-stakeholder process are:

- Competing agendas – all stakeholders pursued slightly different outcomes from the project. This tended to align but there are always points of difference where small frictions can occur. In addition, there were often underlying agendas, and these could change throughout the course of the project.

  Some examples:

  - UTS had a focus on growing the TULIP platform and model, and building a working knowledge of the technical aspects of the work. This technology-centred view could sometimes pull in a different direction to Council's far more human-centred view. The best results were when the two views combined and complimented each other.
  - Council would often have opaque reasoning behind decisions and positions. This was perhaps linked to the broadly cross-departmental nature of the project delivery, which touched many aspects of Council operations. It also included politics around the allocation of funds to certain areas of focus that would be up for debate by the project control group.
  - Commercial partners tended to have certain goals that included the development of strategically useful products on project time. When designing a dashboard for example, progress could be fast on a task that was deemed to be of value outside the project, but slow on something that was seen as too bespoke.

The real take-away from the multi-stakeholder experience of this project is the importance of establishing a clear business requirements document at the start of the project, with full participation and buy-in from all parties. This learning was actually acted upon by UTS in round two Smart Cities and Suburbs projects, with noticeable improvements to the governance and collaboration process.

6) The ongoing role of universities in the smart city space

The project has highlighted a number of things about the role of a university in the smart city space and will likely prove to be influential in UTS' ongoing smart city engagements. Some key take-aways include:

- Universities need to engage in multi-stakeholder partnerships to deliver smart city projects. The benefits far outweigh the challenges (see above).
- Universities engaged in smart city projects with local government need to find ways to distance themselves as much as possible from operations while remaining fully connected to the design and evolution of operational solutions. The key is to minimise the repetition of established task and the responsibility of ongoing service delivery while maximising creative input and research outcomes. The caveat is that operations and service delivery must be kept firmly in focus as a critical aspect of smart city research that keeps things grounded in practical reality.
- Universities need to recognise smart city research as a transdisciplinary endeavour that draws upon multiple faculties. This project was overwhelmingly focused on technology, through the Faculty of Engineering and IT. As human-centred approaches to smart cities rise, it is vital that researchers in the humanities, sustainability, health, design, arts, business and the natural sciences engage in the space. This is the only way to shift research in the smart city space out of the technology-centric paradigm that it currently sits.

7) Business models and scalability

- Vendors do not currently have business models designed for working in multi-vendor ecosystems like TULIP. There is an appetite to develop such models because there is recognition of inherent value in collaboration, particularly in the context of small-scale experimental projects.
- Councils are keen to experiment in the space but require lower barriers to entry. Most vendors are positioned to deliver complete commercial solutions, however these tend to require significant upfront Council buy-in.
- There are a range of emerging use cases for smart city technology. Some of these have clear revenue generation associated with them (e.g. smart parking, bins and lighting), meaning that they can be justified with a projected return on investment (ROI). However, many use case do not have such clear cut short to medium-term returns and environmental monitoring is one such area. Councils have a clear interest in environmental monitoring, and can justify it according to strategies and charters, with an understanding that the return on investment may be a fairly long one. However, the jump from a small sensor trial to a scaled monitoring network is much harder to justify when compared to the more established smart city revenue generators. On the one hand, costs are dropping rapidly and it is reasonable to expect this to continue in the near to mid-term. However, Council appraisal of this situation is about more than cost of entry. Part of the complication here comes down to risk. A great many uncertainties and challenges exist in the current approach to distributed smart sensor networks, which are arguably more complex to plan, maintain and extract value from than a smart parking or smart bin system. When this risk is added to a lack of clear short-term ROI, the proposition for scaling of a sensor network may be a hard sell. A reduction in risk, via ongoing research and collaboration, adds more certainty to longer term ROIs and it is perhaps this certainty, driven by a maturing methodology, that will prove to be the strongest driver of scaled environmental monitoring capacity.
- Councils want to get their hands dirty – access to back ends, flexible and customisable platforms. This leads to the possibility of a more self-serve business model for platform providers, which in term can bring down costs. Note that UI has identified this as a preferred direction and Reekoh are providing this access, however neither was able to offer that sort of usability during the project itself.

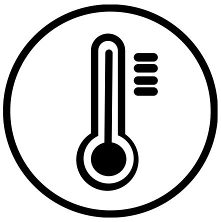
3

Project focus, and high level design

- Better City Living: Environmental data for more liveable communities
- Monitoring urban microclimates
- Project aims and guiding questions

Better City Living: Environmental data for more liveable communities

Better city living is enabled through analysis of hitherto unavailable hyper-local temperature, air quality and noise pollution data that drives research and urban environmental design improvements.



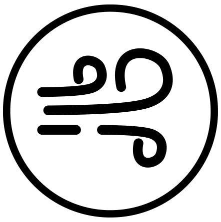
Monitoring & mitigating urban heat

Urban heat is a serious risk to the health and wellbeing of communities and compromises liveability, especially for vulnerable populations. The hazard posed by heat is due to two distinct causes; an increase in the number and/or intensity of heat waves, and the urban heat island effect (UHI) in which urban landscapes have increased temperatures due to buildings and paving, dark surfaces and lack of vegetation.

In Australia heat waves cause more deaths than other natural disasters (Steffen et al. 2015[9]). With the number of days above 35°C projected to increase (Adapt NSW, 2015[10]) and projected increases in the density and population of cities, the number of heat-related deaths is projected to grow.

UTS studies in Penrith have revealed considerable spatial heterogeneity in the distribution of observed heat within each suburb with surface temperatures ranging from around 30°C through to almost 55°C.

Hyper-localised environmental data and applied data science will inform strategies for UHI mitigation, “cool route” wayfinding, urban design and citizen awareness and warnings.



Monitoring & improving urban air quality

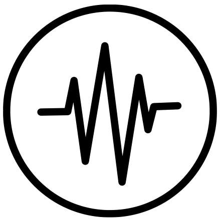
There is a strong variation in air quality between suburbs and even specific locations in cities and suburbs, impacted by local wind and temperature patterns, as well as point or line sources such as major roads. Poor air quality has been linked to a range of health impacts, respiratory and also cardiovascular, in Australian cities.

The network of air quality measurement stations in Australian cities, is sparsely located, particularly those that measure the full range of parameters including the particulates, PM10 and PM2.5. The more widespread deployment of sensors proposed by this project will enable a greater level of awareness and better datasets of air quality conditions.

This data, combined with noise data, available traffic count data, opt-in data from road users and public transport users will support councils, planning authorities and citizens in data driven urban design and governance for improved liveability.

9 Steffen, W.: Quantifying the impact of climate change on extreme heat in Australia, Report by the Climate Council of Australia, available at: http://www.climatecouncil.org.au/uploads/ 00ca18a19ff194252940f7e3c58da254.pdf (last access: 30 October 2016), 2015.

10 NSW OEH (2015), Minimising the impacts of extreme heat: A guide for local government



Monitoring & mitigating urban noise pollution

Urban noise pollution in Australian cities comes from many sources, including road traffic, aircraft, rail corridors, construction and various commercial and industrial activities.

Persistent and pervasive noise pollution has a direct negative impact on human health, resulting in increased levels of stress and reduced amenity, including sleep disturbance and even cardiovascular impacts. Some studies show that chronic exposure to levels above 60 dBA increase the risk of cardiovascular disease.

Currently, urban noise pollution is not extensively measured. TULIP provides better noise measurement which may help to improve transport planning and mitigation strategies.

It may also enable baseline measurements prior to new developments, monitor the impact of trends such as electric vehicle uptake, and test the impact of measures to mitigate urban noise such as sound barriers, new road surfaces and improved urban design.

Informing and improving urban design, planning and policy

Creating liveable and thriving urban places requires high-quality urban design, planning and policy. Cities must mitigate urban heat, improve air quality, and minimise noise pollution. These outcomes can be achieved through improved land use and transport planning, vegetation of the urban environment and use of water in the landscape, with world-leading sustainable urban design, planning and policy informed by strong community input.

Monitoring urban microclimates

Microclimates: understanding the climate where we live

Existing standards and expertise from the World Meteorological Organisation (WMO) provides guidance on how to collect *representative* climate data and avoid landscape features that may affect measurements (Oke, 2006[11]; WMO, 2012[12]). Representative data aims to provide an indication of conditions across a wide area. Microclimate monitoring is far more localised and data is specific to a particular location.

There is also growing recognition from the WMO of urban air quality at micro climate scales and its relationship to the UN Sustainable Development Goals (WMO 2018). However, this is an emerging area of research and climatic monitoring of micro scales is yet to be standardised. There are also challenges for how to integrate data for specific micro climates into existing climate models that operate on a larger scale (WMO 2018).

Conditions on the ground can vary across a neighbourhood, from busy roads to tranquil parks. There is growing interest in capturing this variation to gain new insight into the impacts of climate and urban design upon the liveability of our cities at the human scale. For example, monitoring the climate at the micro scale can answer questions like ‘just how concentrated is the pollution for a cyclist or a pedestrian on or near a busy road?’. It can also consider how this pollution diffuses before reaching an adjacent school. Similarly, monitoring of heat impacts from road and building surfaces around a retirement village can inform mitigation decisions to reduce impacts on elderly residents.

The important characteristic of this type of monitoring is that it aims to capture the highly localised variations caused by landscape features. In comparison, traditional climate monitoring from government agencies seeks to avoid or average out the variation from micro climate features to produce a more representative average for the area.

11 Oke, T. R. (2006). Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites In. Geneva: World Meterologial Organisation.

12 WMO. (2012). Guide to Meteorological Instruments and Methods of Observation, 2008 Version Updated 2010. In: World Meteorological Organization.

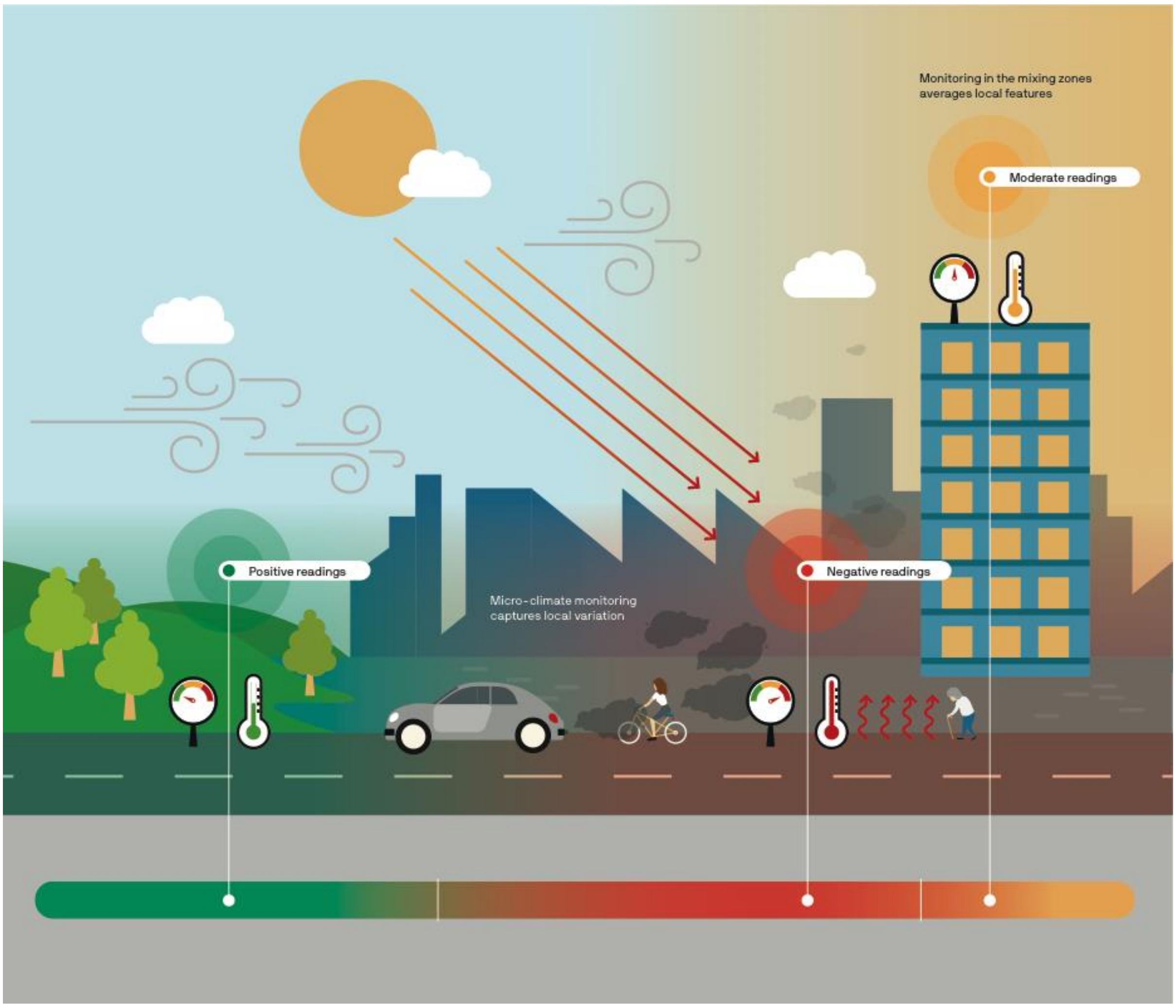


Image: 10 - Microclimate monitoring infographic

New technology to measure and respond to challenges

A breakthrough for distributed microclimate monitoring has been enabled by low-cost devices, combined with new communications and data management technologies. One such technology is Long Range Wireless Area Network (LoRaWAN), which connects many small distributed devices to a central 'gateway' via periodic radio transmission.

An advantage of LoRaWAN is its low power requirement, a result of low bandwidth (i.e. small amounts of data sent), and high latency (i.e. data is sent at intervals, such as every 15 minutes, rather than as a stream). This allows some devices to function for months or years on batteries. Battery-optimised devices expand the options for deployment locations in the urban environment and can help avoid lengthy approvals associated with connection to mains power. Solar PV can be integrated to support more power-hungry sensor types.

The graphic opposite summarises the components of the TULIP system deployed in Lake Macquarie and the City of Sydney: monitoring devices host sensors and communicate with a nearby LoRaWAN gateway that relays the signal through the internet to an environmental data platform, where it is stored, processed, analysed and communicated to the user.

Community engagement in local environmental monitoring

Community participation is supported by low cost technology, ease of deployment, open access networks and the ability to focus on particular locations of public interest. Example initiatives vary from centrally organised models where data is made open to the public, through to programs where a community designs a project, choosing locations of interest, deploying devices and analysing the data.

Around thirty TULIP environmental sensors were deployed in Lake Macquarie as part of Council's 'adopt-a-sensor' initiative. Devices were donated to residents, schools, and community groups and connected to the TULIP data platform, allowing participants to share live data with each other. The initiative points the way towards a grassroots multi-ownership model for distributed environmental monitoring. By inviting local people to actively participate, the project supported digital literacy and encouraged community to take ownership of the technology and its outcomes.

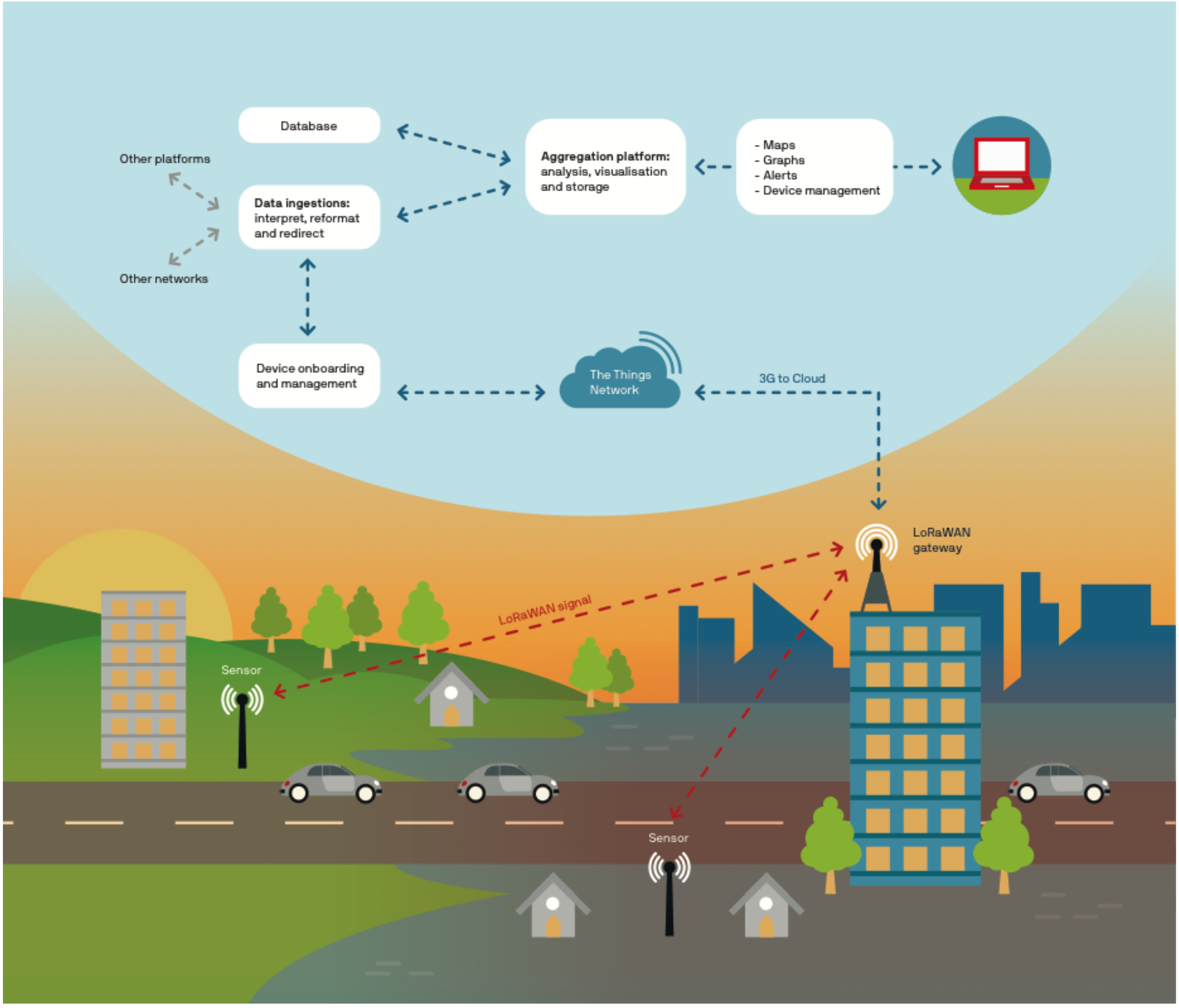


Image: 11 - LoRaWAN sensor network infographic

Project aims and guiding questions

INFORM CITY STRATEGY

How can new data insights inform design, planning, policy and public service provision to improve urban liveability in response to changing environmental conditions?

IMPROVE CITY OPERATIONS

How can new data insights inform the management and maintenance of public spaces and facilities help to improve Council's operational efficiency and resilience in response to changing environmental conditions?

UNDERSTAND PEOPLE

How do changing daily environmental conditions shape people's use of public spaces and infrastructure?

CHANGE BEHAVIOUR

How can new data insights and data-driven engagements help shape more sustainable behaviour in the community?

INFORM, EDUCATE AND EMPOWER

How can Council raise awareness of city data and its value for improving urban liveability? How can Council meaningfully engage people as smart technology users and collaborators in Lake Macquarie?

UNDERSTAND VALUE PROPOSITION OF SMART CITY MONITORING

How valuable and how practical is it for local government to deploy and maintain low cost sensor networks, supporting infrastructure and data services?

BUILD SMART CITY KNOWLEDGE AND CAPACITY

What can Council learn through practical experimentation and collaboration with smart city technologies and how might the resulting knowledge and capacity help to shape future digital and innovation strategy?

5 Device Procurement

- Considerations for device procurement
- Overview of all devices deployed at scale

Considerations for device procurement

A number of attributes were critical when choosing suitable devices for scaled deployment. These were as follows:

A) Non-proprietary devices

A majority of low-cost monitoring devices on the market are sold as part of a complete proprietary service. The user pays a software license fee, which generally recurs on an annual basis, and this is the only way to access data from the device. Although the device itself is owned it cannot be used outside of the closed ecosystem of the manufacturer. This is problematic for a number of reasons:

ii. The data cannot be aggregated with other data sources on a centralised platform

iii. The devices cannot be onboarded and managed as part of a mixed network of device types

iv. Options to customise the device settings are often limited

v. There is a recurring fee that ties assets to an ongoing vendor lock-in

For this project, we sought non-proprietary devices. Options are not that abundant, particularly when other requirements are considered as well. However, by choosing non-proprietary devices we were able to:

- Build the TULIP platform so that it aggregates data from many different device types.
- Explore the relative pros and cons of different device types without having to manage multiple platforms.
- Create a single device onboarding and management process that worked for multiple device types.
- Get hands on with devices and their settings, truly understand how they work, and therefore better understand the data they produce.
- Provide fixed assets to Councils without tying them to ongoing vendor relationships.

B) LoRaWAN devices with The Things Network compatibility

The TULIP platform is designed to work with data from many sources, including multiple device types and networks, and third party data streams, and this flexibility was demonstrated through project deliveries. However, our focus was on devices that could be configured to work with an open community platform called The Things Network (TTN), a global, open, free-to-access initiative that began in the Netherlands in 2016 and has since spread to hundreds of countries around the world. It enables non-commercial users to connect devices to TTN-configured LoRaWAN gateways and access the data at no cost. A TTN gateway can support thousands of devices at once and may facilitate widespread community engagement and innovation. In Australia, there has been a rapid uptake of TTN in recent years.. Local government has embraced TTN as an experimental technology that is a relatively low-cost investment and at the time of writing there are over 50 Councils around the country that manage one or more TTN gateways. All of the devices deployed for the project at scale were TTN configured. This was a limiting factor in terms of procurement options, however it meant that we were able to:

i. Connect most devices at no marginal cost

ii. Manage multiple device types via a single simple user interface (the TTN console) that was not at risk of any vendor lock-in

C) Self-sufficient power

All project devices were battery optimised and could either last with one battery for two or more years, or had built in solar power that recharged the batteries. The reason we chose to do this was to minimise the complexity of installation and maximise the options available to us for mounting locations.

Only a small sub-set of potential mounting locations has mains power available. A significant proportion of devices deployed for the project are on street poles that do not have 240V power in them. Devices deployed in schools and on residential properties were also in locations without power. Self-sufficient power opened up a lot of options.

Many street poles used do have power available. However the administrative complexity of accessing it, plus the additional cost of installation, would have taken a lot more time and money than was necessary. Self-sufficient power saved us both time and money.

Self-sufficient power was not without its downsides. Some devices that used solar to recharge (notably the TULIP EMS), were initially placed in locations that did not receive enough sunlight. This was a particular issue in the city of Sydney, where many locations of interest in the CBD had a lot of building shadow. The result was that the locations that were used were restricted to more open and sunlit ones, such as city parks and large intersections. The manufacturer of the TULIP EMS (ARCS Group) is now working on a mains-powered version of the device for use in these inner city situations. There are also some indications that Council has a preference for low 'pole clutter', meaning that removal of a solar panel could ultimately be viewed favourably, once the administrative process for gaining power access is streamlined.

D) Compact and aesthetically appropriate

Devices chosen needed to be small. The rule of thumb was 'no larger than a shoebox'. They also needed to be compact overall, with minimal extra parts distributed outside the main device. We found that some devices were not designed for civic deployment and comprised a central node with all manner of external sensors, radiation shields and solar power plugged in. This gives a somewhat messy look that is not aesthetically appropriate for public spaces. The devices we chose were as self-contained as possible and though was given to how they would look in public, with emphasis on small size, low profile, and neatly housed components.

E) Low cost

The definition of low cost devices is not standardised. For our purposes, low cost smart city monitoring devices are $10,000 or less. The upper end of this bracket is predominantly air quality monitors. This bracket covers all commercially available devices in the same class – for example, including most particulate monitors that use a nephelometer (optical counter), as opposed the much more expensive and bulky TEOM style sensors. State-run air quality monitoring stations are essentially small sheds full of high-end equipment and cost many hundreds of thousands of dollars. There is a mid-range class in the $10k-$50k bracket though we will not define it here.

For practical purposes, the project only dealt with devices that cost less than $5000. This was mostly to ensure that enough devices could be procured and deployed within the available budget.

Overview of all devices deployed at scale

Device procurement for the project occurred in two phases:

1. Phase 1 procurement consisted of a range of commercially available devices that measured variables critical to identified use cases. These devices were procured in order to test functionality, integration with the TULIP platform and suitability for more widespread deployment in phase 2.

2. Phase 2 saw scaled procurement of certain devices found to be suitable during phase 1. It also saw the procurement of new devices not tested in phase 1[13].

Choosing a suitable low-cost temperature and humidity sensing device

Of note was the phase 2 option for a low-cost temperature and humidity sensor. The phase 1 device tested (Winext) proved unsuitable as it did not have the ability to automatically re-join the LoRaWAN network in the event of a gateway outage. With very few remaining options and a tight timeframe for phase 2 procurement, the decision was made in late 2018 to purchase three device types for basic urban heat monitoring, thus spreading the risk of an unsuitable or otherwise problematic device three ways and with the added bonus of comparing their performance and functionality, thus increasing our working knowledge of device options.

Two of the three device types chosen proved to be successful (Netvox R712 and the DecentLab Temperature and Humidity node). The third device (Sensedge ‘SenseStick’, AKA ‘Microclimate.One’) proved to have technical issues relating to its the functionality on the Australian LoRaWAN band and was ultimately dropped in favour of additional Netvox R712s.

The following list of devices covers Phase 2 procurements (deployed at scale). For the more extensive list of Phase 1 procurements, please refer to APPENDIX C.

13 Due to delayed deliveries and longer than expected periods for testing and integration, some decisions were made about phase 2 device procurements that risked working with untested devices.

Image: 12 - TULIP EMS

TULIP Environmental Monitoring System (EMS)

Manufacturer	The ARCS Group (in collaboration with UTS)
Device name	TULIP Environmental Monitoring System (EMS)
Telemetry	- Temp - Humidity - PM1/2.5/10 - CO - NO_2 - O_3 - Noise - GPS - Battery voltage
Quantity procured	2 prototypes Subsequent 11 more for LMCC, 2 for UTS campus and 7 for City of Sydney
Use case	Heat, air quality and noise monitoring
Notes	Two prototypes delivered: 1) One device deployed in Lake Macquarie. Initial signal issues at site. Subsequent successful onboarding on Council Admin building rooftop. 2) Other device underwent initial benchmarking at UTS. Early feedback informed updates in development of first batch of EMS for scaled delivery.
Verdict	Performed well. Some bugs detected, which were then ironed out for the main batch delivery. **Proceeded to scaled phase 2 deployment**

Image: 13 - Lufft WS10

TULIP EMS + Lufft WS10 solid state weather station extension

Manufacturer	The ARCS Group (in collaboration with UTS) + Lufft
Device name	TULIP Environmental Monitoring System (EMS) + Lufft WS10 solid state weather station
Telemetry	- All EMS telemetry + - Barometric pressure - Wind speed - Wind direction - Precipitation type - Precipitation intensity - Precipitation 24hr avg. - Light (Lux)
Quantity procured	2 (LMCC only)
Use case	Weather data for actuated sculptures + Local reference for environmental data science
Notes	A decision was made to explore this extension to the standard EMS quite late in the project, once phase 2 was going. It was realised that local weather data would likely be critical for wider data analysis from the networks. Furthermore, the designs developed for data actuated public art required local rain and wind data.
Verdict	The two devices developed for the project were a trial extension of the EMS design. Final delivery of the Lufft weather stations has proven critical to project outcomes.

Image: 14 - Netvox R712

Netvox R712

Manufacturer	Netvox
Device name	R712 Outdoor temperature and humidity monitor
Telemetry	- Temperature - Humidity - Battery voltage
Quantity procured	Initially: 15 (14 for LMCC; 1 for benchmarking); 7 units for CoS Subsequently (following failure of the SenseStick): +40 units for LMCC Total procured for project: 62
Use case	Urban heat monitoring Benchmarking
Notes	The R712s were procured following failure with the Winext device (above). With time running low, a risk was taken by procuring 15 at once, though they came recommended by Meshed, who had worked successfully with them before. They turned out to work well, and were easily onboarded to TULIP. The robust solar shield, combined with low price point, were identified as positive aspects. An additional 40 devices were procured to replace the SenseSticks, following technical issues with the latter.
Verdict	Successful trial. Very good performance for the cost. Best option for scaled deployment of a temperature and humidity sensor. **Proceeded to scaled phase 2 deployment**

Image: 15 - DecentLab temperature and humidity sensor

DecentLab temperature and humidity

Manufacturer	DecentLab
Device name	Air temperature and humidity node, with radiation shield
Telemetry	- Temperature - Humidity - Battery voltage
Quantity procured	15 (14 for LMCC; 1 for benchmarking)
Use case	Urban heat monitoring
Notes	These devices worked perfectly and are manufactured to a very high quality. Very strong performance in device benchmarking tests. Some concern about the quality of the mounting bracket (risk of rust) led to development and manufacture of a stainless steel replacement later in the project. This was only deployed in the City of Sydney
Verdict	You get what you pay for – these devices were over three times the cost of the other temperature and humidity nodes used. This did however make them less attractive for more scaled deployment. If you want the gold standard, use these. If you want a larger network or have a limited budget, use the Netvox R712.

Image: 16 - SensEdge SenseStick

Sensedge SenseStick (AKA Microclimate.One)

Manufacturer	Sensedge
Device name	SenseStick (AKA Microclimate.One)
Telemetry	- Temperature - Humidity - Pressure - Battery voltage
Quantity procured	40 (all returned to manufacturer)
Use case	Urban heat monitoring
Notes	UTS was the first major customer for this device and there was a known risk associated with what amounted to a relatively large batch procurement. The device was in the final stages of prototyping and commercial development as our order was being met. Tests of the device in Slovenia, where SenseEdge are based, showed that it worked correctly. Difficulties occurred when attempts were made to configure devices to the Asian AS923 LoRaWAN band plan, which is the primary band used in Australia (AU915 is on its way out). Ultimately, following many months of delays, the order had to be cancelled. The devices may well have the technical creases ironed out in time and if so, their design, compact size and low cost would make them an attractive option for scaled deployment.
Verdict	Not able to configure for use in Australia within the timeframe of the project. Despite a phase 2 order, a full refund was sought. All 40 devices were then replaced with Netvox R712s

6 Technology deployment

- Meshed open community LoRaWAN network for Lake Macquarie
- NNNCo commercial LoRaWAN network
- Device deployment planning
- Sensor site selection considerations
- Urban microclimate monitoring networks in Lake Macquarie and the City of Sydney
- TULIP deployment stories
- People and asset monitoring trials in Lake Macquarie
- Data actuated public art installations

Meshed open community LoRaWAN network for Lake Macquarie

Overview of Meshed

UTS approached Meshed to install 3 LoRaWAN AS923 gateways at Charlestown and Speers Point in Lake Macquarie, for delivery of core connectivity for the project. Meshed were chosen due to the open community access model that they use. Their gateways are configured to connect the The Things Network (TTN), a global movement for community IoT connectivity. By installing Meshed gateways in Lake Macquarie we have enabled community to connect devices to the network at no direct cost to individuals. Use of The Things Network, which parses the data from the gateways, requires all device use cases to be non-commercial. This arrangement aligns best enables deployment of council trial use cases for the purposes of experimentation via a living a lab model; activation of community IoT with emphasis on citizens capturing and sharing environmental data; and the delivery of a city-wide scalable data architecture that will facilitate both of these activities and manage all data in one place, under one data model.

Commercial use cases can be activated through the Meshed network but this sits outside of the scope of this project and is subject to different commercial arrangements.

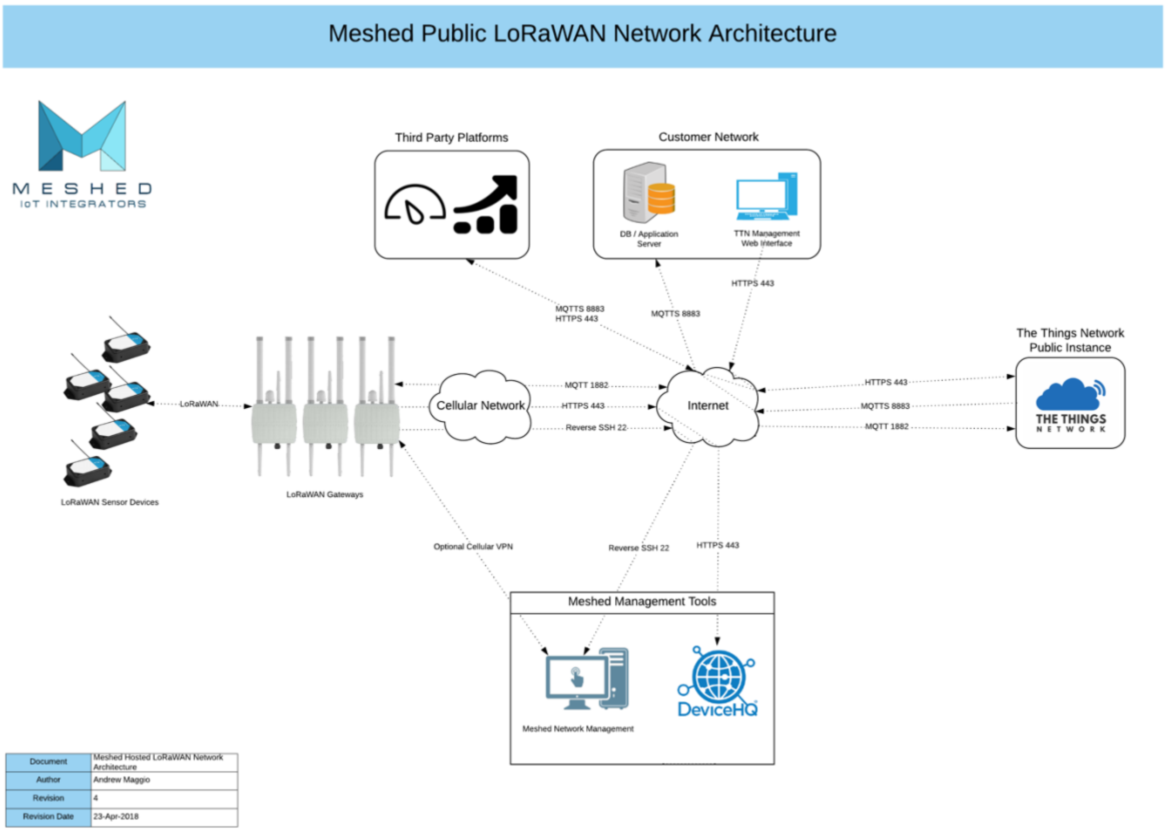


Image: 17 - Meshed public network architecture

Overview of Things Network Gateway installations

Gateway hardware: 3x Multi-tech Conduit LoRaWAN gateways

A number of potential sites were considered for installation of the three gateways, including locations in Charlestown, Cardiff, Warners Bay, Whitebridge and Speers Point. Charlestown was of highest priority and it was decided that Speers Point, which is home to the Council administration building and a number of major public facilities, was also of key importance.

Given that exact coverage of a gateway cannot be easily understood until after it is installed, the project team decided to install two of the three gateways in the first instance, at Charlestown Oval and at the Council Admin Building at Speers Point. The third gateway was installed at Lisle Carr Oval later in the project, following clearer understanding of coverage from the first two gateways.

Location	Model	Serial Number	LoRaWAN EUI	Location
Speers Point	MTCDTIP-LEU1-266A	19618476	00800000A00026BE	Roof of Council Admin Building, Speers Point
Charlestown Oval	MTCDTIP-LEU1-266A	19618477	00800000A00026BB	Light pole at Charlestown Oval, Charlestown
Lisle Carr Oval	MTCDTIP-LEU1-266A	19618478	00800000A00026BA	Lisle Carr Oval, Whitebridge

Table 1 - Details of TTN gateways installed for the project

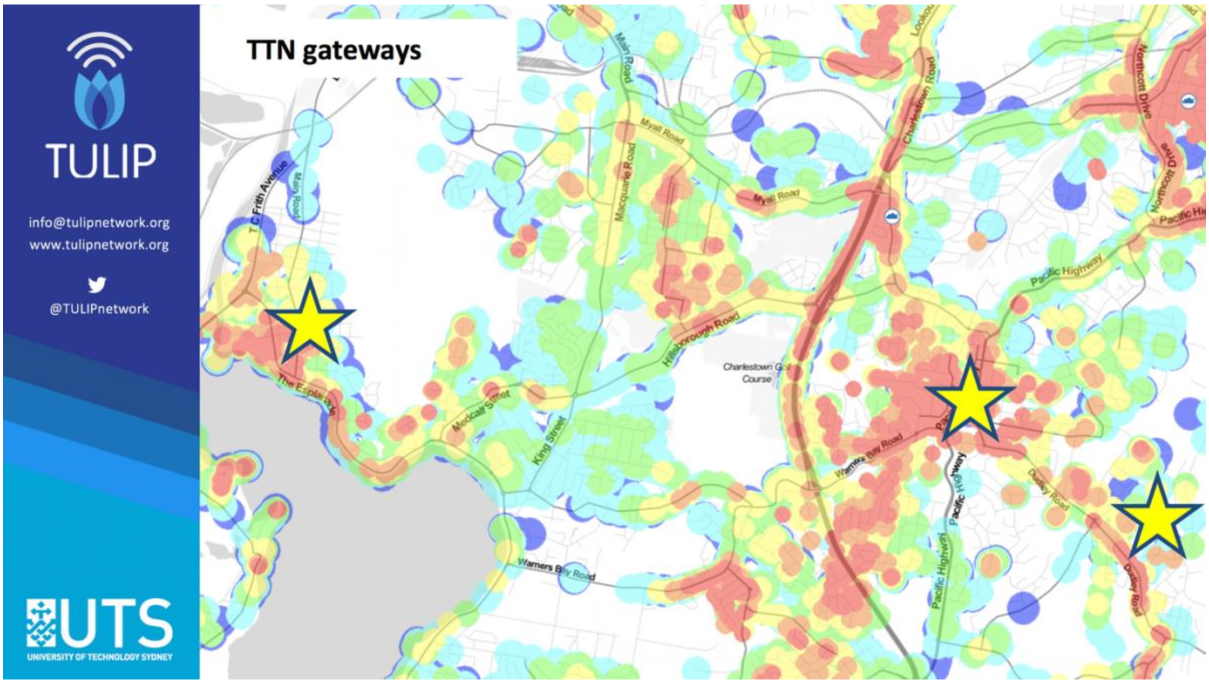


Image: 18 - Map showing the location of the three TTN gateways installed with project funds

Gateway signal coverage mapping

Following installation of the first two gateways, coverage was mapped using two suitably configured LoRaWAN GPS trackers (Digital Mapper Guppy), which were assigned to kerbside waste collection vehicles for a number of weeks. The devices report at regular intervals and the strength of their signal connection can be shown on a map at https://ttnmapper.org/. Due to the extensive movement of the vehicles through residential streets the result has been a comprehensive heat map of gateway coverage. Map 1 shows coverage for the Charlestown gateway. Red and orange indicate strong signal, while blue indicates weaker signal.

Map 2 shows the Speers Point and Charlestown gateways on the left and right of the image respectively. The gateway visible to the north is a community TTN gateway, one of many in the area. The Things Network is open access, so the project is deploying devices that make direct use of such community gateways, just as community members are able to deploy their own devices through LMCC gateways with no barriers to connectivity.

The TTN coverage map was used to assist with use case development and detailed deployment planning. Due to the open access nature of the TTN Mapper tool, anyone can view the coverage map via the URL above.

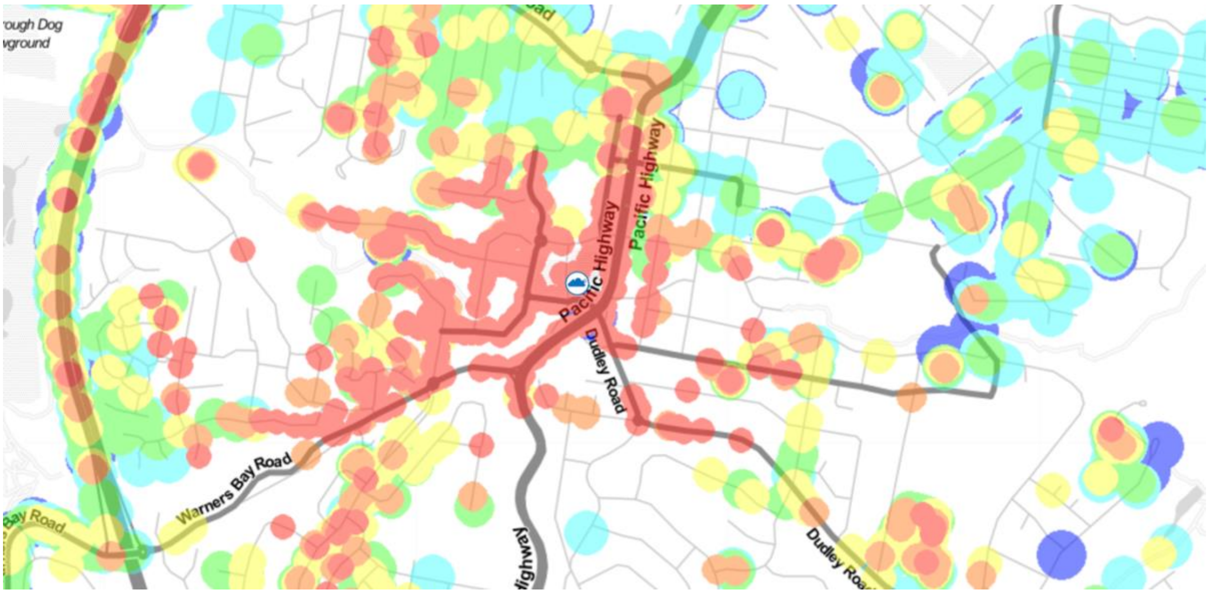


Image: 19 - Map 1, TTN gateway signal coverage in Charlestown

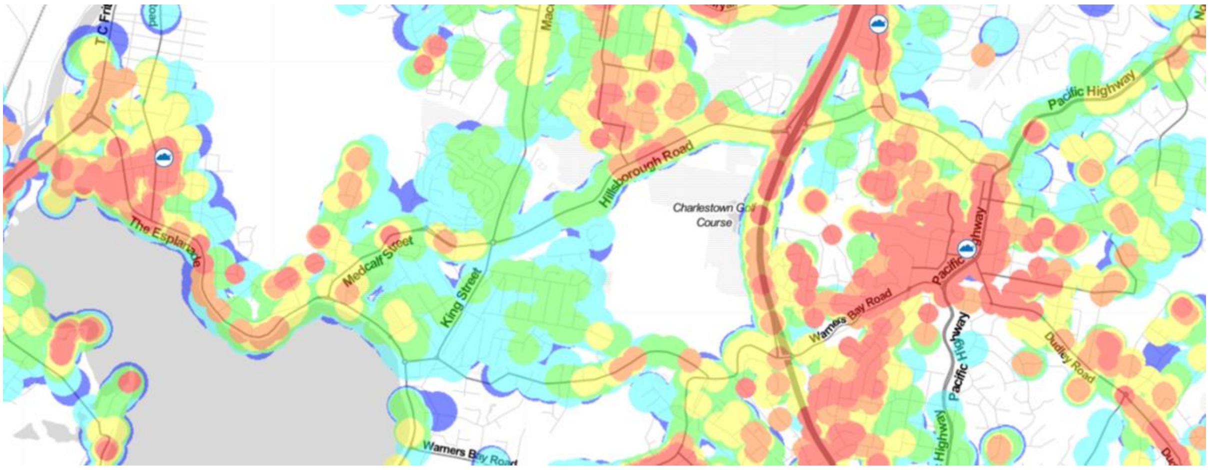


Image: 20 - Map 2, TTN gateway signal coverage for multiple gateways at the northern end of Lake Macquarie

Meshed open community LoRaWAN network for City of Sydney

The project included deployment of LoRaWAN-connected sensors in the City of Sydney. However, unlike in Lake Macquarie, no new gateways were procured for the project using project funds. All device deployments in Sydney made use of existing TTN gateways, predominantly an AS923 gateway installed on the UTS Broadway campus.

The location of the UTS gateway restricted the locations that device s could be deployed in the City of Sydney. A majority were deployed around Haymarket and Broadway. No signal coverage was evident to the east of Elizabeth street due to topology. Signal strength also became too weak much north of Townhall. The red areas on the heat map below show some strong coverage in the north of the CBD, however this was not associated with the UTS gateway. Private gateways in the city appear to be somewhat intermittent in terms of being turned on and active so the decision was made to avoid dependence upon them and ensure that all devices were in range of the UTS gateway.

The City of Sydney has taken ownership of the devices deployed in the LGA, following completion of the project. What is interesting, and in some ways unique, is that the devices communicate via an open public communications network that is not owned or maintained by the City and which sits entirely outside of Council control. Many local governments around Australia are choosing to invest in Things Network gateways in order to have a greater degree of control over LoRaWAN communications. This affords them the ability to deploy devices more strategically, by ensuring that they can provide coverage to locations of specific interest. It also gives extra assurance that the gateway will continue to operate. All gateways have recurring annual costs and relying upon a third party to cover those costs in order for your own sensor network to run is a risk. Given the rapid uptake and popularity of The Things Network and the strong coverage in the city centre from multiple private gateways, these concerns are minimised in this particular scenario. One way of viewing the situation is that the City has chosen to shoulder a small amount of risk in the context of a pilot project in order to reduce expenditure and exposure to a relatively unproven technology.

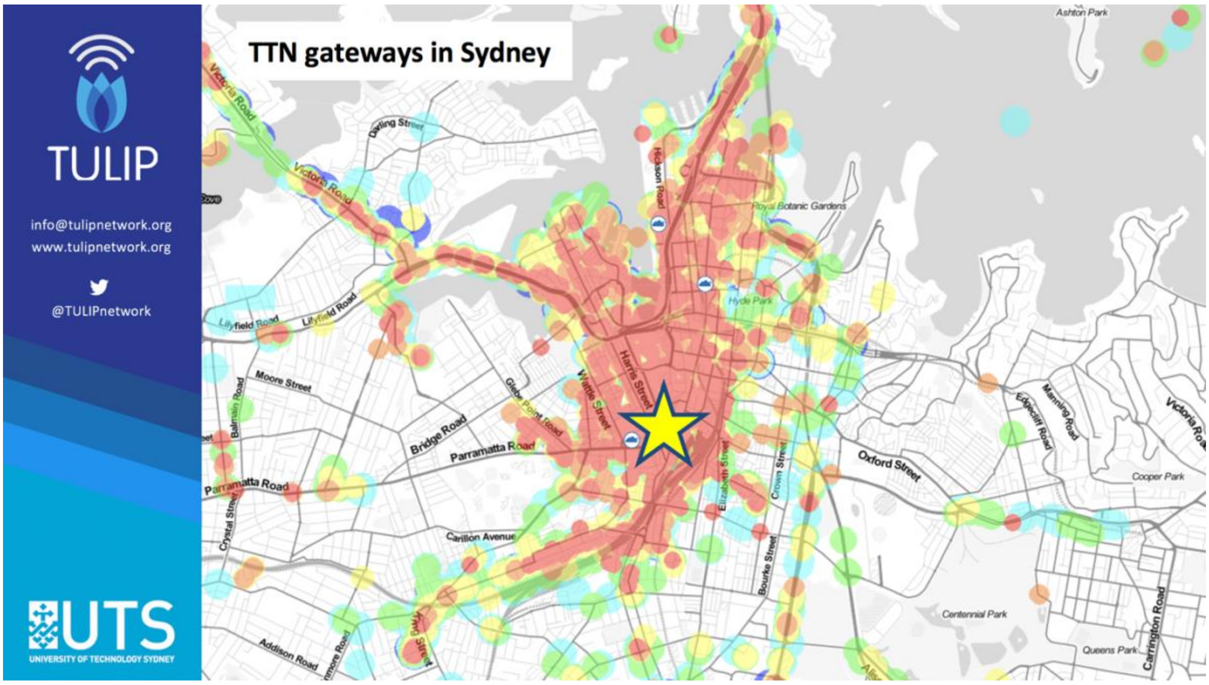


Image: 21 - Map 3, TTN signal coverage in the City of Sydney

NNNCo commercial LoRaWAN network

NNNCO is a commercial LoRaWAN network provider that is in the process of installing LGA-wide coverage in Lake Macquarie, in partnership with the publicly managed Dantia economic development company. Lake Macquarie City Council required that a portion of project funding ($50,000) was contributed to Dantia to support the creation of this network. This represented a significant portion of the overall funding for the NNNCo network.

The NNNCo network delivers commercial services and operates with a per-device connection fee. This differs to The Things Network (TTN), which has no connection fees. Simple connection of private devices is not possible on the NNNCo network, whereas there are no barriers to this on TTN.

For the purpose of this project, the TTN model of LoRaWAN provision was most appropriate, particularly because of our emphasis on community participation (e.g. see 'Adopt a Sensor' program). However, an aim of TULIP is to explore hybrid and modular systems that maximise flexibility and choice for Councils. The use of the Reekoh data ingestion platform as a critical centre piece of the TULIP data architecture meant that data from more than one network type could be ingested into TULIP. It was therefore understood as a valuable exercise to connect some sensors through the NNNCo network, with their data pointed at Reekoh. It was decided that two TULIP EMS sensors would be reconfigured to operate on the NNNCo network . This would demonstrate flexibility of the EMS and of the TULIP platform.

The work required to integrate NNNCo communications with TULIP focused on integration of the TULIP EMS with the NNNCo network and the integration of the NNNCo network server with Reekoh. This work proved to be more challenging than initially anticipated and significant delays occurred. By the end of the project, this work was still pending.

UPDATE (August 2020):

Lake Macquarie was a recipient of round two Smart Cities and Suburbs funding through the Smart Beaches project. UTS and NNNCo were partners in this project and the EMS was included in project delivery. The challenge of integrating the EMS with TULIP via NNNCo was readdressed through this project and the task was successfully completed in 2020.

Device deployment planning

Process

- **Engage** with project stakeholders, particularly Council
  - Identify areas of interest
  - Develop use cases and match to actual locations
- **Review** TTN Mapper for coverage in areas identified
  - Discount locations with no coverage
  - Consider areas with strong coverage that may not have been considered and discuss their relevance
- **Conduct site visits** in shortlist of locations
  - Check signal strength at actual proposed deployment locations and record
  - Take photographs of proposed deployment locations
  - Assess other site specific attributes that may impact the decision to deploy
- **Propose** a draft list of deployment locations
  - Make use of Google Maps and a corresponding spreadsheet to store details
  - Ensure more locations are proposed than are needed.
  - Work through the list with Council to identify priorities and challenges
  - Create a revised final plan
- Revisit finalised locations and capture all relevant **metadata**

Tools

https://ttnmapper.org/heatmap/	Visual reference for local LoRaWAN coverage
Digital Matter Oyster GPS tracker	For populating the heatmap in TTN Mapper
Multitech LoRaWAN site survey device	Assess LoRaWAN RSSI and SNR at specific locations
Netvox R712	Alternative signal strength assessment tool to Multitech due to the accessible reset button on the front. More cumbersome to use but given some technical faults we experienced with the Multitech device, this proved to be a more reliable solution throughout the project.
Google Maps (My Maps)	Store proposed and final deployment locations and maintain a visual record of their spatial spread.
Excel / Google Sheets	Track information about proposed and confirmed deployment locations, including a large amount of location-specific metadata.

Table 2 - Tools for device deployment planning

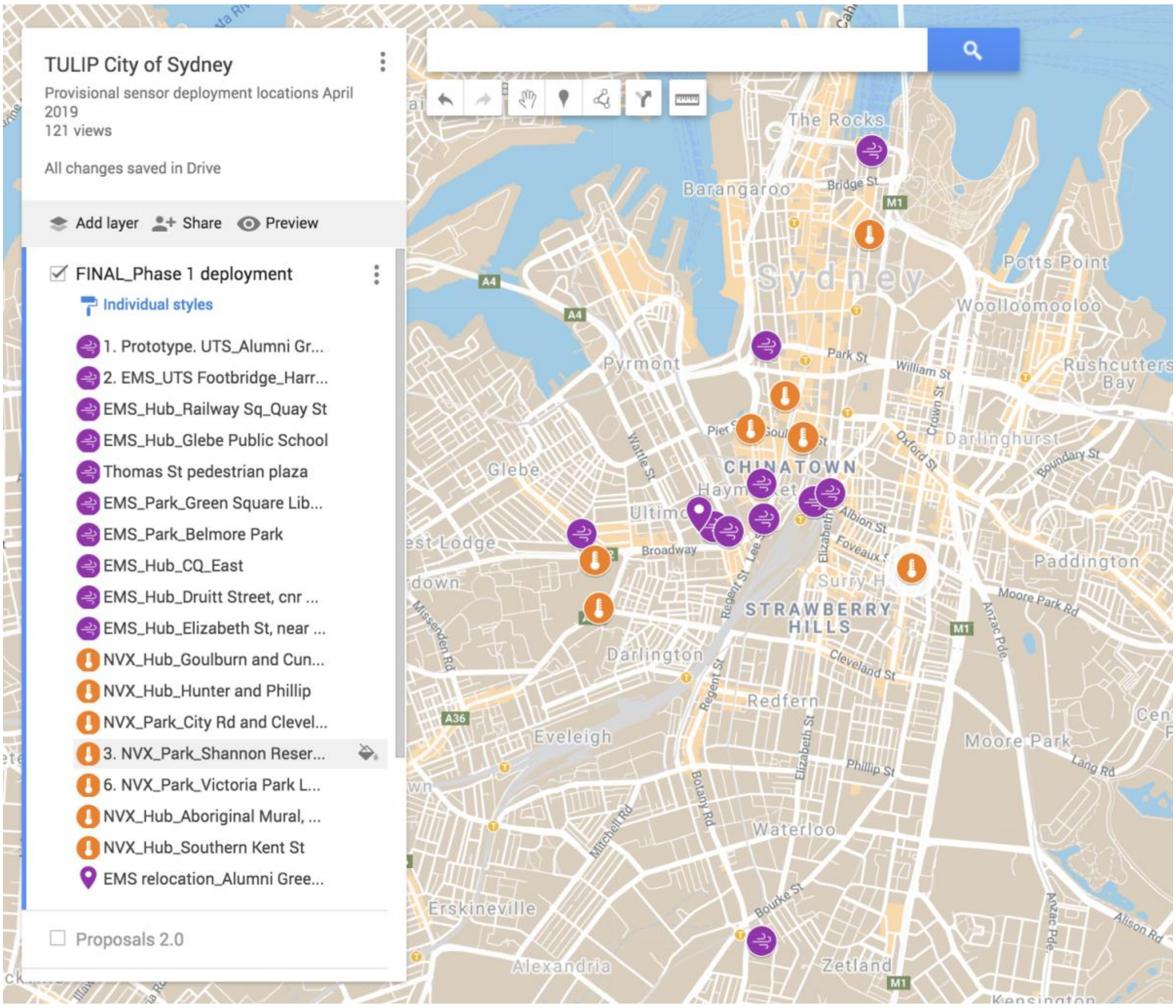


Image: 22 - Map showing deployment locations in the City of Sydney. The 'My Maps' function of Google Maps proved to be an invaluable planning tool for planning deployments. Multiple layers can be made, showing first ideas, then a succession of refined shortlists.

Sensor site selection considerations

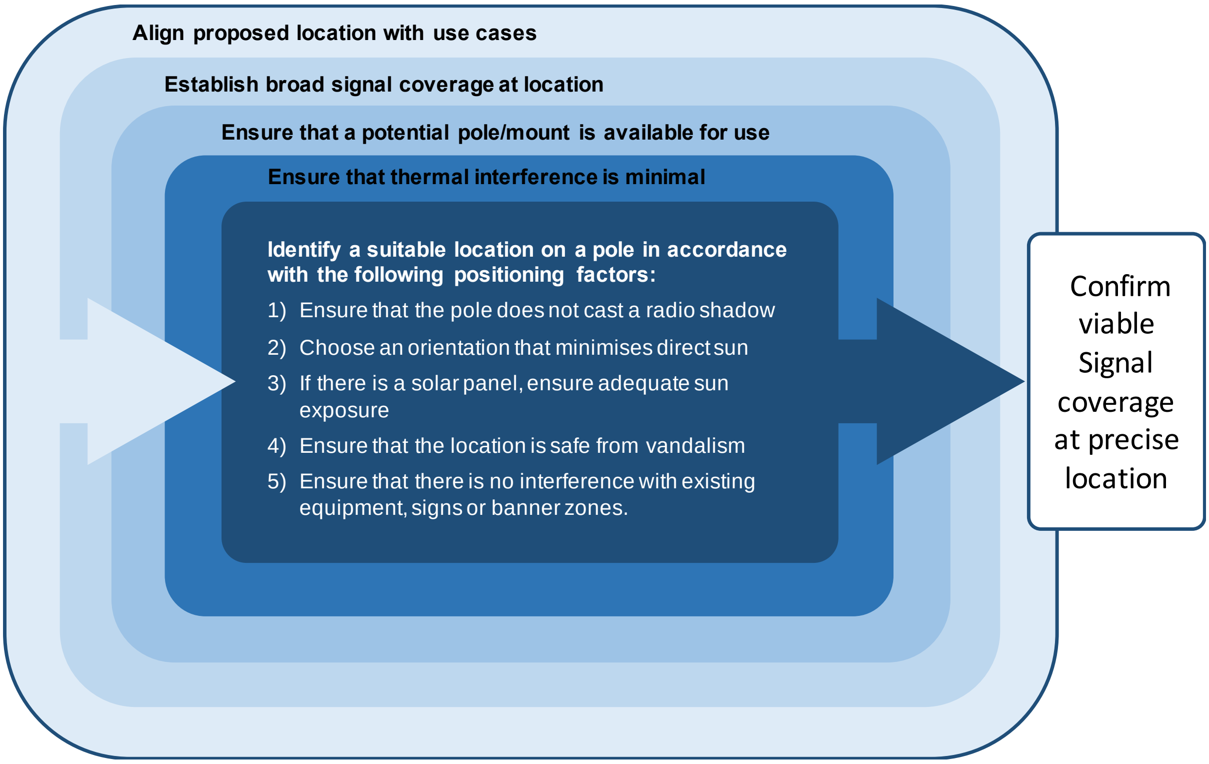


Image: 23 - Diagram of decision-making for sensor site selection

Alignment with identified use cases

A fundamental consideration for sensor site selection is whether the proposed deployment will help to deliver against a recognised use case or broader strategy. Initial discussion of potential sites always begins by considering which locations might provide the most useful data.

Broad signal coverage at location

Perhaps the first practical assessment of a proposed site is whether it broadly falls within known signal coverage. LoRaWAN coverage in Lake Macquarie and the City of Sydney was roughly mapped using LoRaWAN GPS devices. In Lake Macquarie, the devices were assigned to Council waste collection vehicles, while in Sydney, a device was taken around most inner city streets by bicycle. An open source initiative called TTN Mapper (https://ttnmapper.org/heatmap/) allows every successful connection by a specific LoRaWAN GPS device to The Things Network to be viewed as a point on the map. The signal strength is colour coded. The net effect of many hundreds of points is a heat map that roughly indicates the extent of gateway coverage. This rules out whole areas that receive no viable signal as a result of terrain. For example, initial GPS signal mapping in Sydney showed that signal drops off sharply to the east of Pitt Street, as well as confirming that Newtown is entirely outside of current signal range. These areas could then be discounted, allowing focus on areas with known strong coverage.

Owner of pole/mount

Cities have many poles, owned by many organisations. In Lake Macquarie the project has worked with Council-owned poles and Ausgrid poles. In the City of Sydney, the project was restricted to deploying on Council-owned poles only. Working with Ausgrid provided a great number of options in Lake Macquarie. In the City of Sydney, Hub smart poles are restricted to major intersections and retail areas but are largely missing in residential streets where only Ausgrid poles are found. While some devices were deployed on non-Hub poles in Sydney parks, roadside deployments were restricted to Hub poles and were thus limited to main thoroughfares only. Not all Hub poles were available either. For example, all poles inside the new light rail corridor in Sydney's CBD have not yet passed into City ownership, meaning that George Street, Devonshire Street and much of the area around Central Station was not available.

Thermal mass

Walls and large steel poles can heat up in the sun and radiate heat through the afternoon and evening, creating interference with ambient temperature readings. For this reason, temperature sensors are not placed on walls. Some poles may also be positioned close to walls and if these are north facing they are also avoided. Certain device designs such as the DecentLab Temperature and Humidity sensor are mounted closer to the pole than others so for this reason they are mounted on wooden poles only, avoiding the interference that might occur from a steel pole.

Direction of gateway

A wide pole may block signal if it lies between a sensor and the gateway, so knowing the direction of the nearest gateway is critical when assessing a site. Wide poles essentially rule out about 90 degrees of orientation resulting from a radio shadow caused by the pole.

Solar interference

The temperature and humidity sensors deployed for the project are fitted with solar radiation shields that help to prevent interference with readings by direct sunlight. However, if a pole allows for a device to be deployed on its south side, particularly if it is a larger pole, it means that the device stays in shade for a greater proportion of the day, particularly during midday and early afternoon when the sun is hottest. Choosing a southern orientation where possible is a preference (except for the EMS).

Solar power requirements

There is a need to ensure that some devices (namely the TULIP EMS) receive enough sun to power their solar panels. The EMS is best deployed on the north side of a pole for this reason. It turns out that the angle at which the solar panel is mounted actually provides direct shade to the sensor unit mounted below it, ensuring that the EMS is shielded from direct solar interference at the same time as maximising solar collection.

The side of the street is also a significant consideration for solar powered devices, particularly in more built up areas like city centres. On streets running east to west, the southern side receives the most sun, however some such locations remain unviable due to deep overshadowing amongst very dense high-rise. Streets running north to south allow a device to be orientated north, with a much higher chance of midday sun. Overshadowing by trees is a further consideration.

Vandalism

Devices for this project were deployed at three metres, or just above, whenever possible. In an ideal world, sensors would be at human head height because the primary interest is in liveability impacts of environmental variables. However, to avoid tampering and vandalism, devices must go just out of reach. Three metres is the lowest height that is deemed ‘safe’ from vandalism, while remaining as close to human height as is feasible. In certain locations, a decision was made to deploy a device at four metres, inferring some assumed degree of additional safety. These are locations of high strategic interest that have a heightened concern about vandalism (e.g. known past activity in the area, particularly inner-city parks).

Overhang

Some poles are set back from the road by a metre or more while others are positioned right on the road side. Generally speaking, items attached to a pole should not overhang the road. A device attached to a pole that is located very close to the road side should not face the road, but should rather face up or down the street, or away from the road.

Pole space

Many poles in town and city centres are cluttered with signs, traffic lights, cameras and communications technologies. Busy intersections with many poles may not have any with space for sensor. Even where there is space, a device must not block line of site to a sign, traffic light or camera from any direction. On top of this, many city poles also carry banners. Banner zones constrict the area on a pole where anything can be attached, causing signs and other existing equipment to be concentrated in the 3-4 metre zone, with no remaining space for a sensor.

Signal coverage at precise location

Once a pole is identified in a location with known coverage, with an appropriate space for mounting a sensor, a final signal check is required. Due to the complex way in which radio signals propagate through dense inner city environments, it is possible for radio shadows or blind spots to occur within a general location that otherwise has broad coverage. The only way to be certain that a chosen mounting location is suitable is to carry out a final signal check in that precise location.

Sensor deployment operations

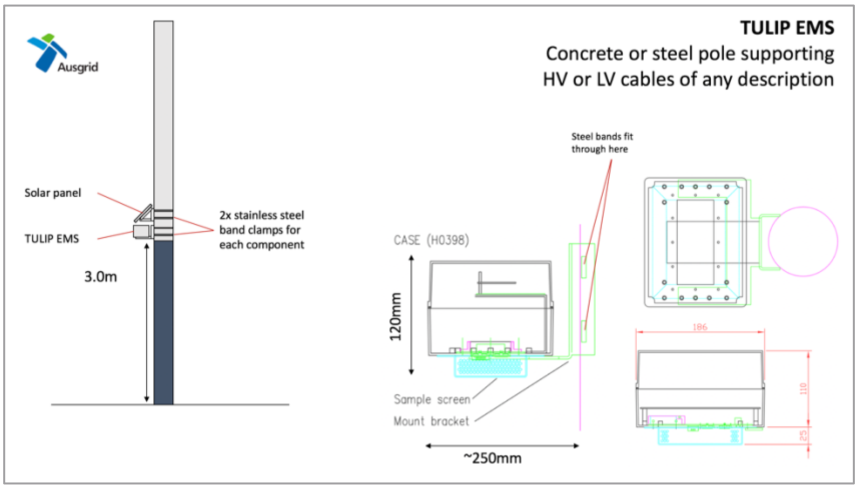


Image: 24 - Example of schematic provided to Ausgrid as part of approvals process

A) Asset types and approvals

In the context of device deployment and for our purposes here, an 'asset' refers to the fixed asset to which a device is attached. For this project, the majority of such assets were street poles.

Assets such as street poles can be owned by a variety of organisations and be situated on land owned by a range of different entities. The two most common asset owner classes in the project were Councils (LMCC and CoS), and an electricity infrastructure provider (specifically Ausgrid). All Council-owned poles are situated on Council land, however not all poles on Council land are Council owned. The boundaries of Council land are also often complex, making it difficult to know whether certain poles are Council owned. For example, in the City of Sydney, the RTA owns major roads and most poles on them, making them state owned rather than Council owned. An electricity company like Ausgrid has poles on Council land, state land and private land.

Navigating the complexity of asset ownership is necessary for gaining approval for device deployments. Many similar smart city projects keep things simple, for example by only deploying on Council owned poles. Indeed, this is the approach that was taken in the City of Sydney. In Lake Macquarie, we found that deployment options were severely limited by sticking to Council poles only, hence we reached out to Ausgrid. We also wished to explore the operational reality of working with multiple land and asset owners to deploy a sensor network as we feel that it sets a precedent for increased complexity and flexibility in future projects.

It is worth briefly noting the Ausgrid approval process. Our request (to deploy around 40 small battery-powered devices on their poles) was fairly unique. The fact that we were conducting research rather than a commercial activity worked strongly in our favour and we found relatively swift support. The fact that the devices were self-sufficient for power and did not need to be wired up to the poles was also a major help, as was the small size and weight of the devices. The approval required us to submit detailed schematics of each device type and how it would be deployed on each pole type. Given that there were several pole types and several device types and each combination required a slightly different mounting solution, this amounted to extensive drawings and supporting information. Consideration was given to size, weight and wind loading. We also needed to submit detailed information about every specific deployment location, provided as a series of annotated photographs and accompanying notes. The approval process was a significant body of work and added a couple of months to the overall timeline of device deployments.

B) Mounting solutions

Commercially available sensors tend to have a single standard mounting solution that may or may not be suitable for some mounting needs and is almost never versatile enough to work with multiple asset types. As a result, various custom mounting solutions had to be developed during the project. Some of these were more DIY in nature and some were designed and fabricated commercially. Notable examples are detailed here.

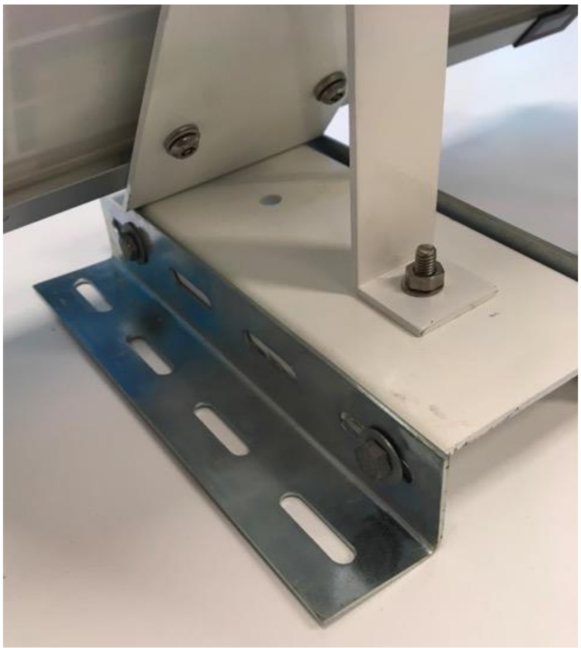
'Universal bracket adapter'

Sections of galvanised steel 'slot bar' (available from Bunnings) were cut to two, three and four slot lengths, filed and given an outer coating of galvanic spray paint to seal the cuts against rust. The slots allowed the sections to fit with a variety of sensor mounting systems. For example, when bolted to the EMS, the brackets enabled coach screws to be used to fix the device to a wooden power pole. When attached to a Netvox R712 the brackets enabled the device to be strapped to a steel light pole by passing ties through the slots.

By the end of the project we had developed more professional integrated mounting solutions for both the EMS and the Netvox, allowing us to avoid the need for future DIY construction and resulting in improved aesthetics.

Custom stainless steel Hub Pole bracket

The City of Sydney owns a large network of 'Smart Poles' that utilise a system of external channels for mounting a flexible variety of equipment, from signage to traffic lights. UTS worked with the pole manufacturer (Hub) to develop a custom mating bracket that fits between one of their standard pole fixings and two of our most used sensor types – the TULIP EMS and the Netvox R712.



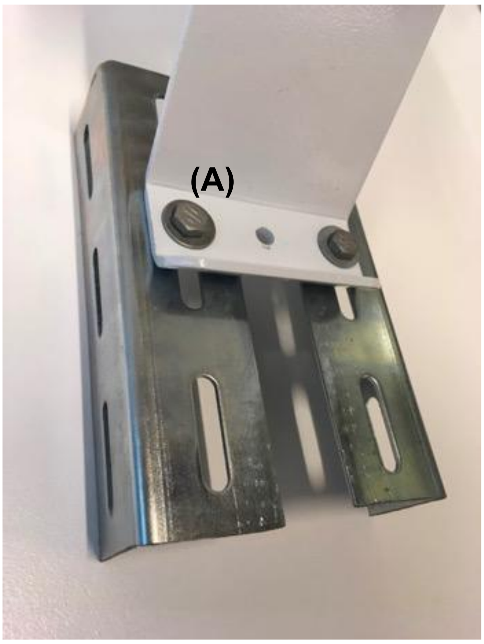
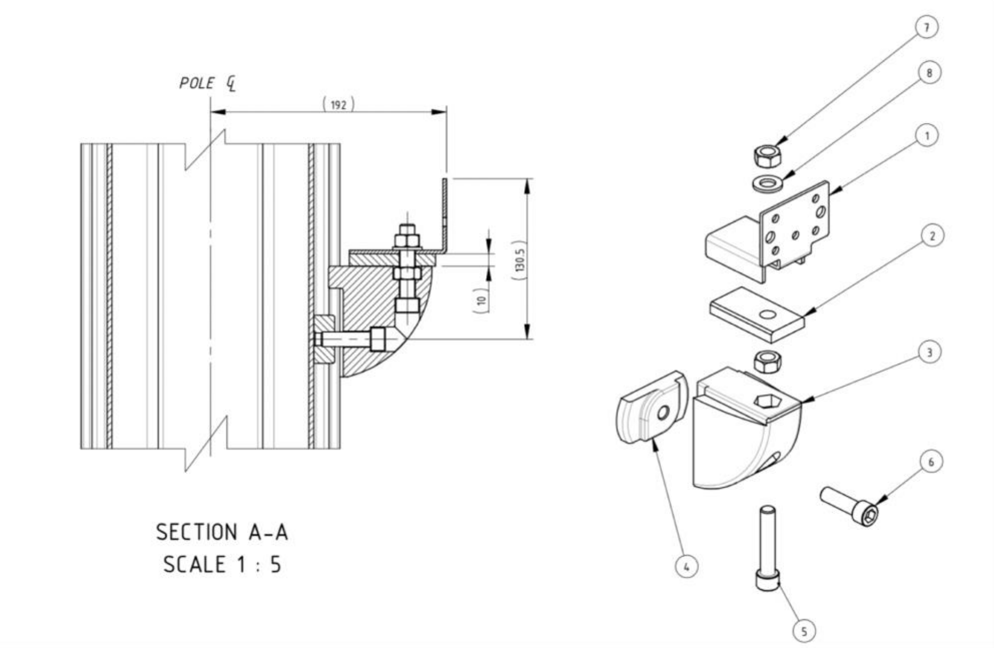
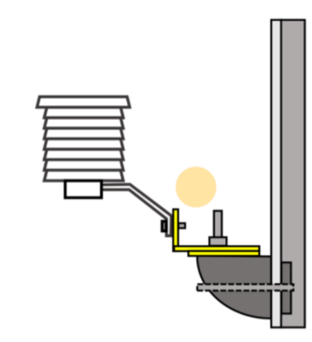
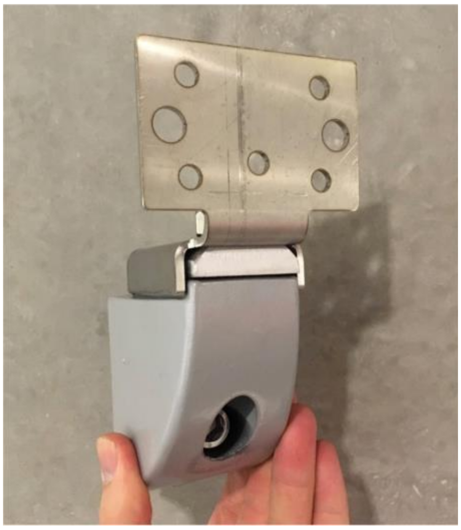


Image: 25 - Prototype EMS with slot brackets (left); Netvox R712 with slot brackets (right). Credit: UTS



Custom stainless steel Hub Pole bracket for TULIP EMS and Netvox R712





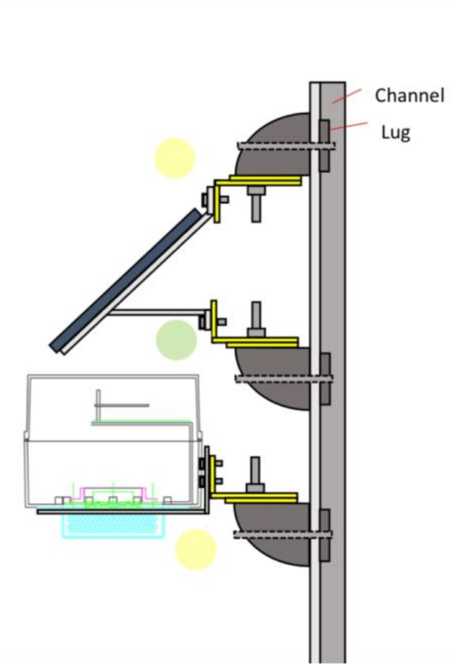


Image: 26 - Custom stainless steel Hub Pole bracket for TULIP EMS and Netvox R712

C) Deployment procedure

The deployment procedure refers to the process by which a device is received from a manufacturer, configured, onboarded, lab-test, assembled with mounting equipment, labelled, administrated, redistributed to installation contractors, installed, field-tested, and ultimately commissioned.

This process can be split into two parts:

1 – Pre-provisioning = configuration, onboarding and lab testing of a device

2 – Provisioning = assembly, physical installation, metadata capture and supporting administration

UTS had to develop processes, materials and administrative systems to manage all aspects of device deployment for the project. This was necessary for managing around 100 devices deployed as part of the project. It was also emphasised as an exploration of scaled deployment operations that may serve as a useful reference to others.

Full details of pre-provisioning and provisioning procedures can be found in APPENDIX E

Urban microclimate monitoring networks in Lake Macquarie and the City of Sydney

Image: 27 - Installing a Netvox R712 in Lake Macquarie

The deployment of scaled microclimate monitoring networks was one of the critical deliverables of the project. This section details what was deployed and where, for Lake Macquarie and the City of Sydney.

An overview of the deployed network in Lake Macquarie

Manufacturer	Model	Telemetry	Quantity
The ARCS Group	TULIP EMS	- Temp - Humidity - PM1/2.5/10 - CO - NO_2 - O_3 - Noise - GPS - Battery voltage	12
The ARCS Group	TULIP EMS + Lufft weather station	- All EMS telemetry + - Barometric pressure - Wind speed - Wind direction - Precipitation type - Precipitation intensity - Precipitation 24hr avg. - Light (Lux)	2
Netvox	R712	- Temperature - Humidity - Battery voltage	54
DecentLab	Air temperature and humidity sensor with radiation shield	- Temperature - Humidity - Battery voltage	14

Table 3 - Deployed devices in Lake Macquarie

(Green = EMS; Orange = Netvox; Blue = DecentLab)

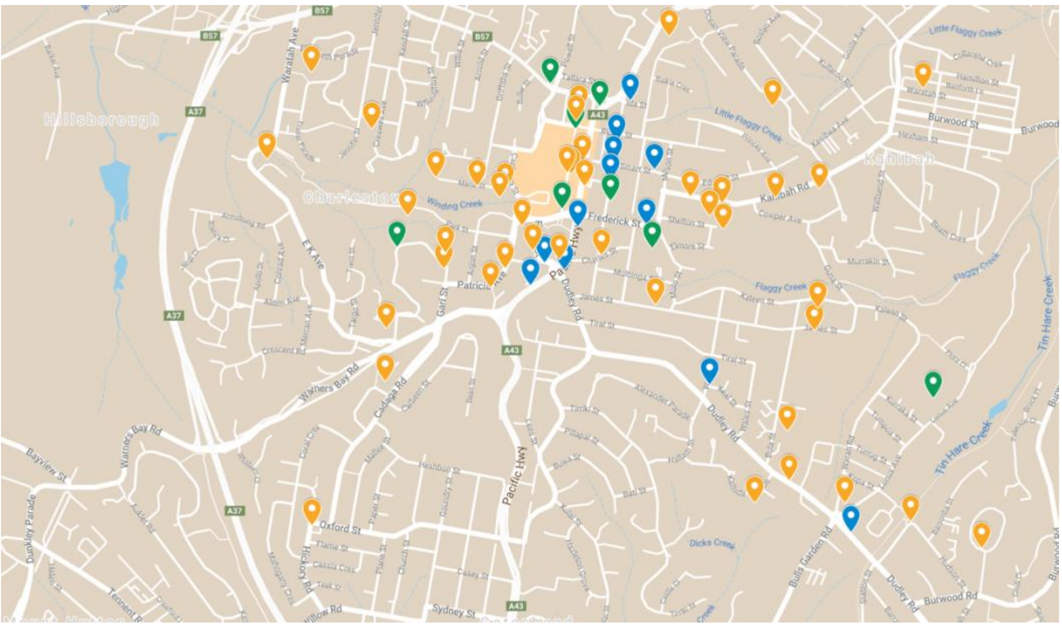


Image: 28 - Charlestown deployments

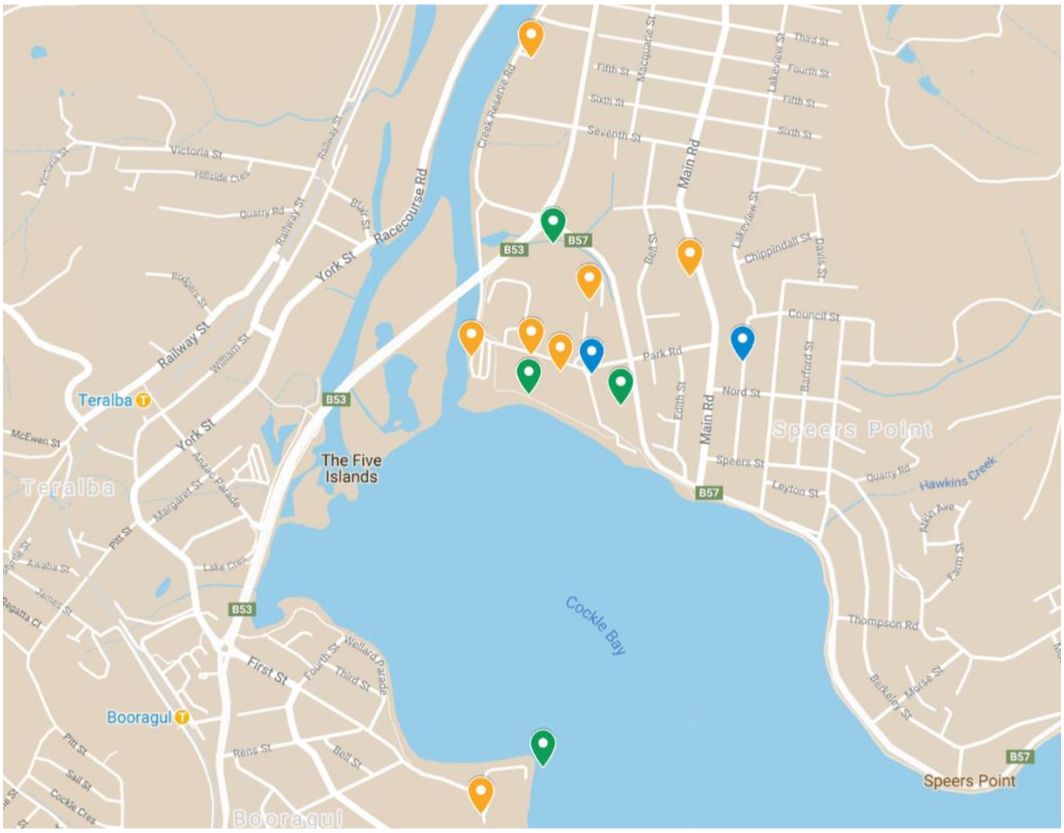


Image: 29 - Speers Point deployments

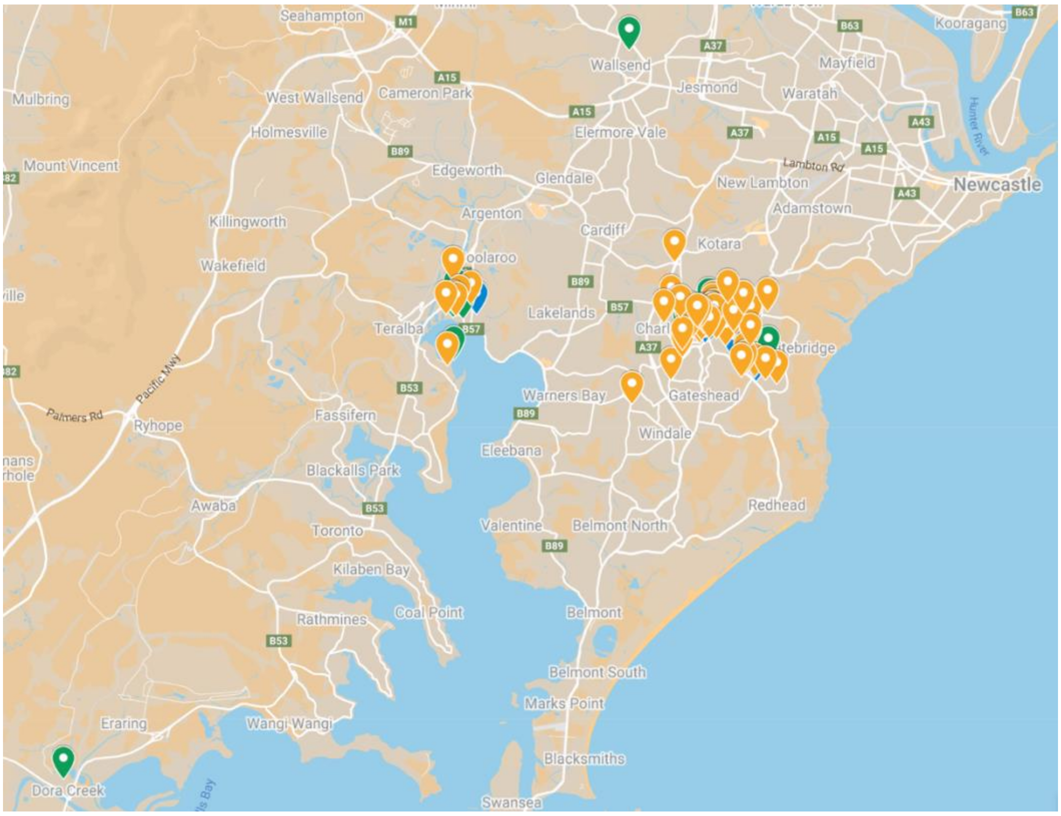


Image: 30 - The entire LMCC network

An overview of the deployed network in City of Sydney

Manufacturer	Model	Telemetry	Quantity
The ARCS Group	TULIP EMS	- Temp - Humidity - PM1/2.5/10 - CO - NO_2 - O_3 - Noise - GPS - Battery voltage	7 (CoS owned) 2 (UTS owned)
Netvox	R712	- Temperature - Humidity - Battery voltage	7 (CoS owned)

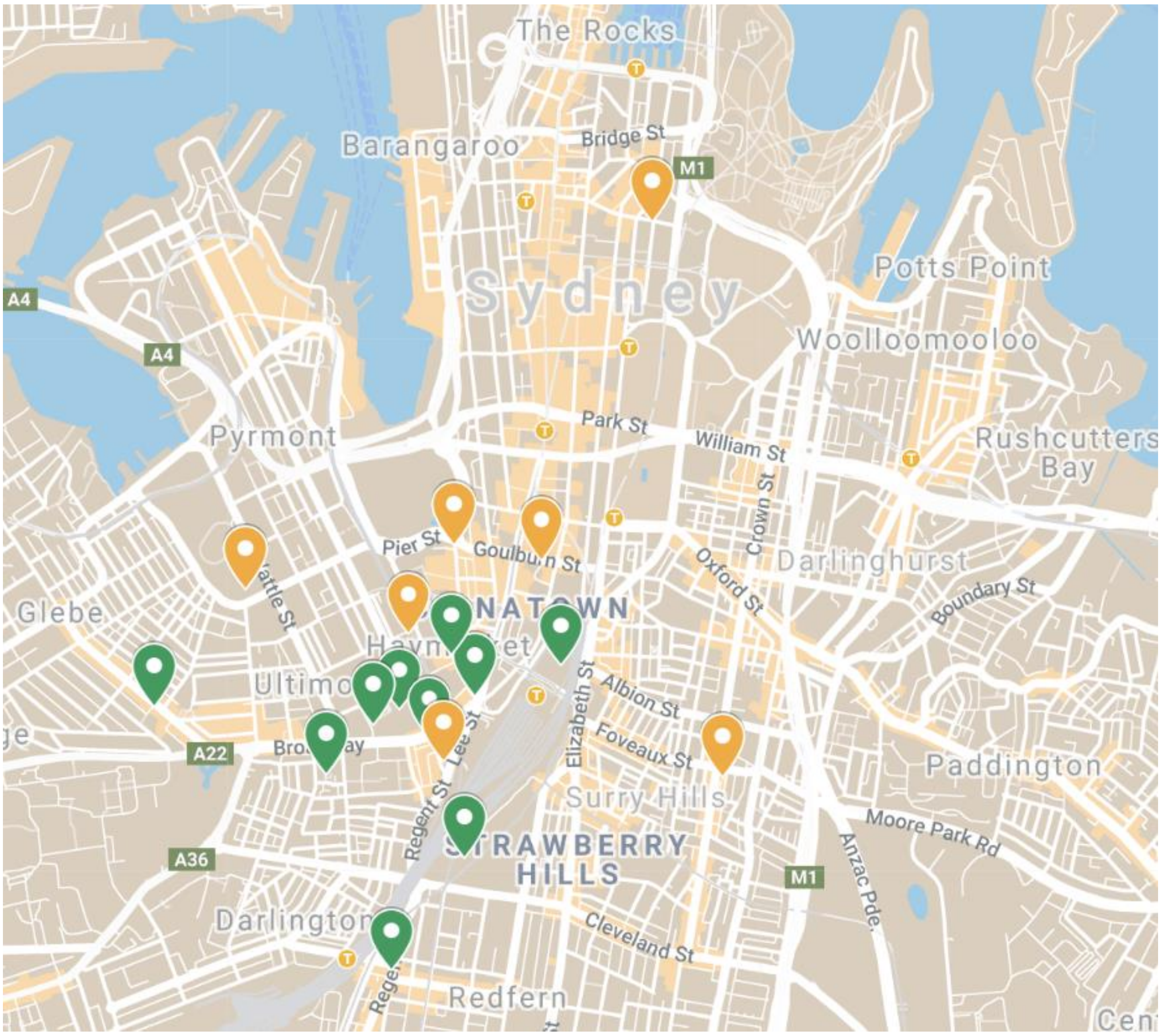


Image: 31 - Map of Sydney city centre deployments (phase 1)

Note: This map details phase 1 deployments in Sydney. Many of these devices were subsequently redeployed in 2020 due to a variety of issues with the original locations, particularly marginal LoRaWAN signal strength and overshadowing of solar panels.

TULIP deployment stories

Image: 32 - Green Square Library, Sydney

At a microclimate scale, everything is contextual

The deployment of any single monitoring device within a distributed microclimate sensor network is highly contextual and each site differs from others with its own unique combination of local factors. Currently data science is unable to reliably and accurately predict a microclimate reading at a location between two sensors, based upon the data from those sensors – an analytics technique called spatial interpolation. This is because the specific local context of that mid-point is not known and even if it were, it would be different to the recorded contexts of the deployed sensors to either side. What this means is that we cannot currently create accurate heat maps from environmental data tied to fixed points in the urban environment, at least at a microscale scale. The microclimate of urban environments is extremely complex and dynamic and until highly sophisticated multi-parameter 3D geospatial models are created that are able to make use of sensor data, spatial interpolation will remain beyond our grasp.

Grids don't make sense – we have to tell stories

When choosing deployment locations, a broad spread of sensors across an area is sought. However, spacing devices within a fixed grid is not an approach that was used because a grid incorrectly presupposes uniform spatial variation of environmental factors at the microclimate scale. As explained above, this uniformity is not present and air quality, heat and noise may vary across distances of several metres. Furthermore, deployment locations are limited to appropriate mounting infrastructure and this rarely occurs in standardised grids.

Therefore, a majority of deployment locations were chosen based upon their relevance to the stories they might tell, either on their own, or in reference to other locations. Working from the use cases identified in the high level design process, and operating within a number of practical constraints (including signal strength, site accessibility and available mounting infrastructure), five types of story were developed that guided the sensor deployments.

Image: 33 - Central Charlestown

Story #1: Mapping a town centre: Charlestown centre and Pearson Street

Central Charlestown is a busy retail, services and transport hub, with high vehicle traffic and high numbers of pedestrians. The area measures approximately 1km by 500m with Pearson Street and the Pacific highway running north to south. Thousands of people live work and play in the area and environmental liveability is a critical concern of Council.

Air quality, noise, temperature and humidity monitors have been deployed on Pearson Street at the north and south entrances to the large Charlestown Square shopping centre, with another five in the surrounding area. A weather station has also been deployed to provide accurate local meteorological data to interpret readings from the whole Charlestown sensor network. A further thirty two temperature and humidity sensors have been deployed throughout the area.

Aims:

- Understand how heat, air quality and noise vary spatially and temporally at a microclimate scale across central Charlestown
- Use insights from geospatial and temporal trends to inform mitigation strategies
- Establish a baseline against which future mitigation initiative may be compared

A key question:

- Where and when are people most exposed to peaks in heat, poor air and noise pollution in Central Charlestown?

Image: 34 - Traffic in Lake Macquarie

Story #2: Highways and back streets

Highways are understood to be one of the greatest sources of air pollution and noise in urban areas. Large expanses of exposed asphalt and concrete are also significant contributors to the urban heat island effect. Devices have been deployed to collect data along the side of highways, with a spread of other devices positioned through surrounding back streets up to a distance of 700m. Back streets in Charlestown tend to be residential and host public facilities such as schools and sports centres. Back streets in Sydney are busy pedestrian precincts and 'village' centres. By comparing the data on the side of highways to the data collected at intervals back from them, insights can emerge about how highways negatively impact the broader environment that they run through. Critical highways for focus are the Pacific Highway in Charlestown and Broadway in Sydney.

Aims:

- Understand how air and noise pollution spreads away from highways into surrounding streets and how different land uses might help to mitigate this.
- Understand the impact of highways on the urban heat island effect experienced in surrounding residential streets.

A key question:

- During rush hour traffic, under various weather conditions, how far from a highway does a pollution peak stretch and how long does it remain in place?

Image: 35 - Rugby in Lake Macquarie

Story #3: Community hotspots: sensing at the human scale

A specific sensor deployed in an urban microclimate provides data that is most relevant to its immediate vicinity. It can tell us about what the lived human experience of that place might be like, but it is much harder, using only the data from that sensor, to predict what conditions might be like 20m away. Therefore, the location chosen matters a great deal because the highest level of certainty and insight that we can gain will be tied to the specific deployment location.

Distributed sensors allow data to be gathered in the places that matter – where people gather and spend time exposed to the outdoor environment. Bus stops mark the sites of many sensor deployments throughout Charlestown because people are likely to spend significant periods of time in those locations. In Lake Macquarie, the Adopt-a-Sensor program has seen air quality, noise, temperature and humidity devices deployed at eighteen schools, sports facilities and clubs, including three pre-schools, six primary schools, two high schools, two sports fields, two swim centres, two bowling clubs and a scout hall. In the City of Sydney, Glebe Public School and Blackfriars Childcare Centre are focus points.

TULIP has created a platform for community data sharing. Schools and community groups now have open access to their own live and historical environmental data, allowing people to understand what they and their families are exposed to and to compare this with other locations in their area and further afield. The implications for advocacy and grassroots innovation may well be significant.

Aims:

- Understand the impact of air quality, noise and heat on schools and community facilities throughout the day and year and how peaks overlap with periods when people are exposed.

Key questions:

- How exposed to air pollution are certain schools and public facilities, particularly those adjacent to known pollution sources such as highways or power stations?
- How will schools and community groups respond as they gain access to this new data?

Image: 36 - Urban bushland in Lake Macquarie

Story #4: Urban Microcosms: hyper-local variations and urban design

Distributed microclimate monitoring allows a focus on urban microcosms. Urban heat island effect, air quality and noise can all vary significantly over just tens of metres, depending on multiple intersecting aspects of the urban environment. Building shadow, tree canopy, porous surfaces, building density, types of façade, wind tunnelling and distance from point and line sources of pollution can all create highly localised variations.

Examples:

- Pearson St Mall in Charlestown is a well-used tree-covered pedestrian thoroughfare and gathering place. Two temperature and humidity devices were deployed at either end of the mall to compare localised heat with the surrounding area. The mall was scheduled for an upgrade in late 2019, with trees replaced and new surfaces installed. Initial temperature and humidity data will provide a baseline against which the upgrade can be compared.

- Pearson Street in Charlestown runs north to south. Buildings along the street create shading on the eastern side of the street in the morning and on the western side of the street in the afternoon. Two temperature and humidity devices were deployed on opposite sides of the street to explore the microclimatic variations between shaded and sun-lit locations.

- Belmore Park is 25,000m^2 of parkland in front of Sydney's Central Station. One air quality monitor has been placed in the centre of the park while another has been placed at nearby Railway Square, which experiences high bus and other vehicle traffic. Variations in data between the two sites will illustrate how air quality can vary significantly over short distances.

Aims:

- Generate data to support new or existing understanding of urban design choices at a highly granular level, regarding their ability to either mitigate or exacerbate urban liveability outcomes.

Key questions:

- Can new data-driven insights be used to advocate for design decisions in the areas being monitored?
- Can the same insights help build a case for broader policy changes (e.g. increased canopy targets, more small parks, water sensitive urban design)?

Image: 37 - Lake Macquarie at sunset

Story #5: How's the serenity?

Town centres such as Charlestown are known to have an Urban Heat Island Effect that makes them warmer than surrounding areas. Concentrated traffic and civic works in a town centre may also result in heightened air and noise pollution. A less developed area such as Speers Point, with its large areas of green space adjacent to Lake Macquarie, may be significantly cooler, cleaner and quieter than Charlestown. However, there are other factors in play; Lake Macquarie has multiple coal-fired power stations, the closest to Speers Point being 17km south at Dora Creek, with a clear line of site down the lake. Pollution from the power station may well impact air quality at Speers Point more than at Charlestown, which is further away, elevated and sheltered by topography. The Lake Macquarie sensor network includes sensors at multiple sites in Charlestown and Speers Point and will enable a direct comparison of both locations.

Aim:

- Understand how environmental liveability varies between town centres and outlying areas, with insights about the relative impacts of land use and activities.

Key question:

- Is Speers Point Park cooler, cleaner and quieter than central Charlestown and can we understand the various land uses and activities that explain observed trends?

People and asset monitoring trials in Lake Macquarie

The insights that can be gained from highly localised environmental data increase when we have corresponding data about how people use space and facilities. For this reason, the project conducted two limited trials of smart people counting technology. These were not intended to be scaled within the scope of the project. Rather, they enabled Council to undertake limited low-risk experimentation in an emerging field with direct cross-over relevance to core project activities.

Image: 38 - The Living Smart Festival in Lake Macquarie, where Meshed nCounter technology was trialled as part of the project

Trial 1: Silent wifi pedestrian counting

'Silent wifi' is a sensing technology that projects a wifi field and counts the number of devices that attempt to connect to it. There is no internet connection involved – wifi is simply used to detect wifi-enabled devices. Given that most adults have an active smart phone in their pocket, this provides a proxy count of people in the radial zone covered by the sensor, which can be adjusted between 10m to around 50m. The count is not perfectly accurate in terms of precise numbers of people but it does provide a reliable trend and is particulatly useful for understanding changes over the course of a day. The nCounter by Meshed uses LoRaWAN to communicate the results of its silent wifi counting in 15 minute updates. No personal information is captured or transmitted, only a count of devices entering and leaving the zone.

The project procured three nCounters for a trial in Lake Macquarie. The first field test was undertaken at the 2018 Living Smart Festival at Speers Point, testing the concept of using the device as a portable crowd counter for major events. The trial was successful and data obtained matched observations of visitor numbers by staff and volunteers on the day.

Council deployed two nCounters at either end of Pearson Street Mall in early 2019. They have successfully gathered pedestrian data over a year, prior to the planned upgrade of the mall. The plan is to continue nCounter monitoring after the upgrade and explore changes in pedestrian traffic.

Image: 1 - An amenity block in a Lake Macquarie park

Trial 2: Amenity block visitation monitoring with Infrared motion detection

Proximity Infrared (PIR) sensors detect nearby motion within an invisible light cone. This technology has been combined with LoRaWAN communications to create a number of commercially available devices which count proximity alerts and transmit them at regular intervals (in this case, every 15 minutes). The project procured two LoRaWAN-enabled PIR sensors from Elsys (ERS model) and these were deployed in the public amenity block at Speers Point (not shown in above image). Council was interested in monitoring how the facility is used throughout the day and through the week. The devices have produced a rich continuous data record that has been analysed by Council's business analytics team. The information has already assisted them in understanding visitation and helped them to improve the timing of their cleaning schedule.

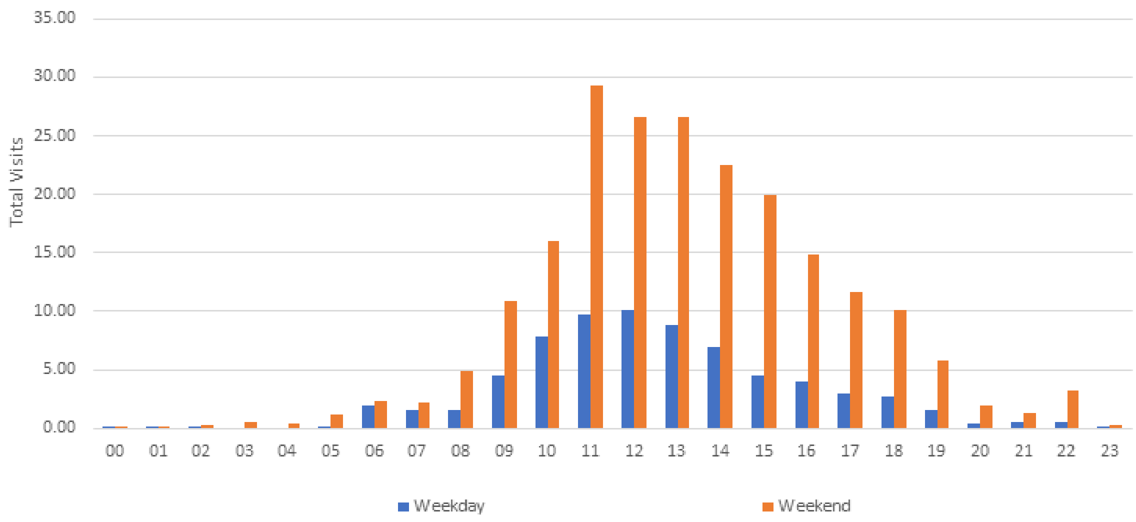


Image: 2 – nCounter data from an amenity block at Speers Point. X-axis shows time (Hrs). Peak visitation hours for weekdays and weekends are clearly visible

Data actuated public art installations

Data actuation involves the use of live data to control the behaviour of an automated system. If a sensor is a deployed device that generates data, an actuator is a deployed device that uses data.

Actuation can be considered in two broad categories:

1) Actuation for utility
2) Actuation for data visualisation and engagement

Actuation for utility comprises a large number of automated systems associated with smart cities and is primarily concerned with operational efficiencies. Automated irrigation systems that respond to soil moisture and weather data, or building management systems that respond to temperature fluctuations are two common examples of utilitarian actuation.

Actuation for visualisation and engagement strays into a more creative arena as it is concerned with bringing data to life in the public realm. Smart city data can be dry, complex and impenetrable for the average person, even if it relates to topics that directly impact our wellbeing, such as urban liveability. Actuated public art takes uses live smart city data to create a dynamic experience for the viewer. Light, movement, sound and water may all be manipulated in real time to bring form to a data stream, with countless examples to be found in public spaces around the world. This sort of engaging public art helps to activate public spaces and can play an important role in urban renewal projects.

The project developed two pieces of actuated public art in Lake Macquarie and one mobile 'beacon' for community education purposes. These projects are detailed on the following pages.

TULIP actuation architecture

The data architecture used for managing the actuations in the project allowed devices to be controlled from the Urban Pulse dashboard (data visualisation and analytics) or from the Reekoh data ingestion layer. Third party data could also be connected, such as weather data and storm warnings from the BOM.

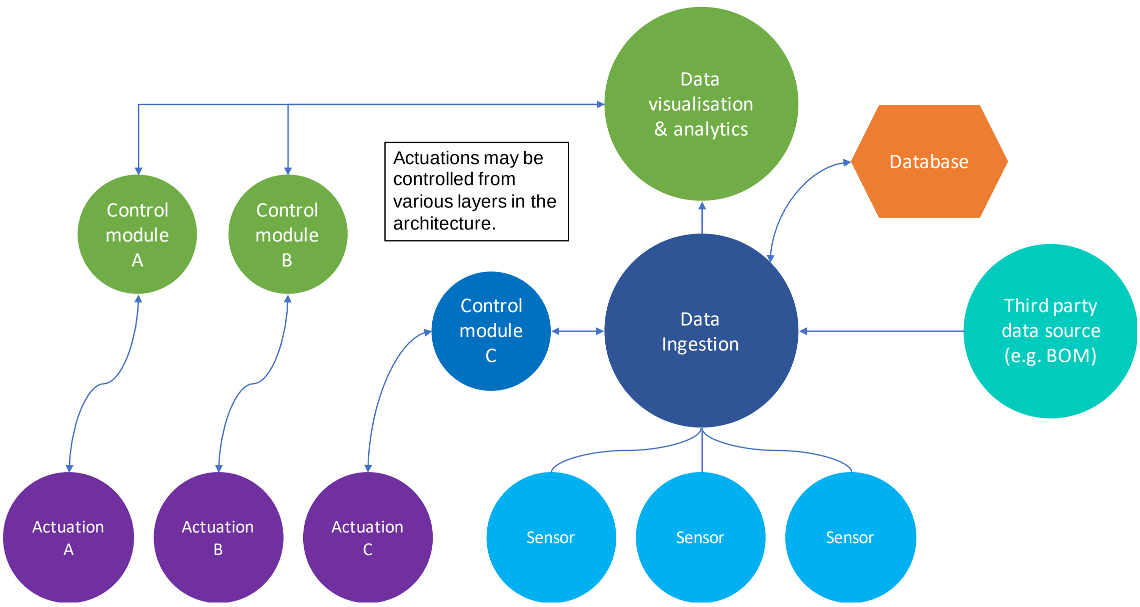


Image: 3 - TULIP actuation architecture

Examples of actuated data visualisation around the world

Image: 4 - Smart fountain in Andalucia

The Main Square in Andalucia, Palma del Rio, uses smart water jets that respond to the presence of people nearby. The result is an interactive experience that encourages play and breathes life into a well-loved space. *Image credit: Lumiartecnia Internacional.*

Image: 5 - High Water sculpture, Green Square, Sydney

High Water is a City of Sydney public art work outside the newly opened Green Square Library. Coloured lights respond to real time tide and weather data. *Image credit: City of Sydney*

Project actuation 1: Antenna, Charlestown Skatepark

Artist: David Cianci

Material: Corten steel, glass, LED lights

Lake Macquarie City Council (LMCC) installed a large piece of permanent public sculpture called *Antenna* in a new skate park facility in Charlestown. Antenna operates as a way-finder artwork; a 6m obelisk marking a symbolic centre to Charlestown where the youth play a pivotal role in enlivening the place. The sculpture is also intended to enhance night-time safety. The work is constructed from corten steel and glass, conducive to an active recreation precinct, and is lit from within by addressable 'smart' LED strips.

The production of Antenna was handled by the LMCC public art team and drew upon a budget external to the project. Project funding was used to augment the artwork with smart technology. Local technology start-up Newie Ventures was contracted to develop the Rosella actuation driver. Rosella connects to the TULIP platform and can be used to control custom LED light patterns. Antenna makes use of local rain and temperature data from sensors deployed as part of the project. It also draws upon a third party data source that provides alerts relating to hazardous weather conditions.

The lighting was designed as overlapping layers that work together in concert:

Layer 1

The first layer uses 22 temperature brackets that correspond to RGB colours. For any given temperature, all the lights of the sculpture fluctuate between the two colours assigned to that temperature band, causing a soft pulsing effect.

Layer 2

The second layer uses moving bands of white light that travel from the top to the bottom of the sculpture, falling past the base colour of layer 1. The density of bands and the speed at which they move corresponds to the real time intensity of rain in the vicinity. Light rain causes sparsely packed bands to move slowly downwards. Heavy rain results in densely packed bands that fall much faster.

Layer 3

The third layer responds to weather warnings and can be superimposed on top of layers 1 and 2. If a weather warning is issued, the alert reaches the TULIP platform and triggers Layer 3 for a set period. If Layer 3 is active then all lights in the sculpture pulse slowly on and off, while maintaining the layer 1 and 2 patterns when 'on'. Thus all three layers can be visible at the same time.

Temperature colour schema for Antenna

Lower value (C)	Upper value (C)	Colour #1	Colour #2
	44+	255,0,239	229,0,255
42	44	255,0,189	238,12,254
40	42	255,0,156	255,0,239
38	40	255,0,187	255,0,189
36	38	255,0,0	255,0,156
34	36	254,59,0	255,0,187
32	34	253,89,0	255,0,0
30	32	253,119,0	254,59,0
28	30	255,165,8	253,89,0
26	28	255,190,33	253,119,0
24	26	255,214,28	255,165,8
22	24	255,229,0	255,190,33
20	22	253,246,12	255,214,28
18	20	235,240,22	255,229,0
16	18	213,238,0	253,246,12
14	16	208,239,129	235,240,22
12	14	206,235,199	213,238,0
10	12	200,236,227	208,239,129
8	10	170,237,232	206,235,199
6	8	111,216,239	200,236,227
4	6	82,187,241	170,237,232
2	4	65,129,244	111,216,239
0	2	22,66,255	82,187,241

Image: 6 - Antenna sculpture, Charlestown Skatepark. Image credit: Lake Macquarie City Council

Project actuation 2: Chimera, Speers Point Park

Artists: Susan Milne and Greg Stonehouse

Material: Stainless Steel, LED lights

Lake Macquarie City Council (LMCC) and the University of Technology Sydney (UTS) activated a new public artwork called *Chimera*, located in Speers Point Park on the northern shore of Lake Macquarie. Using smart technology and live environmental data, the initiative was part of the larger Smart Liveable Neighbourhoods project. Chimera is part of a broader lakeside regeneration initiative by Council. The sculpture is a 13m stainless steel weathervane and includes forms reminiscent of boats, birds and fish. It is a celebration of the local natural environment and people's enjoyment of it.

The production of Chimera was handled by the LMCC public art team and drew upon a budget external to the project. Project funding was used to augment the artwork with smart technology. Local technology start-up Newie Ventures was contracted to develop the Rosella actuation driver. Rosella connects to the TULIP platform and can be used to control custom LED light patterns.

Chimera makes use of local wind data from a weather station deployed as part of the project. An additional interactive component was added in the form of a button, which when pressed, shifts the lighting display from Layer 1 (showing wind direction) to Layer 2 (showing wind speed).

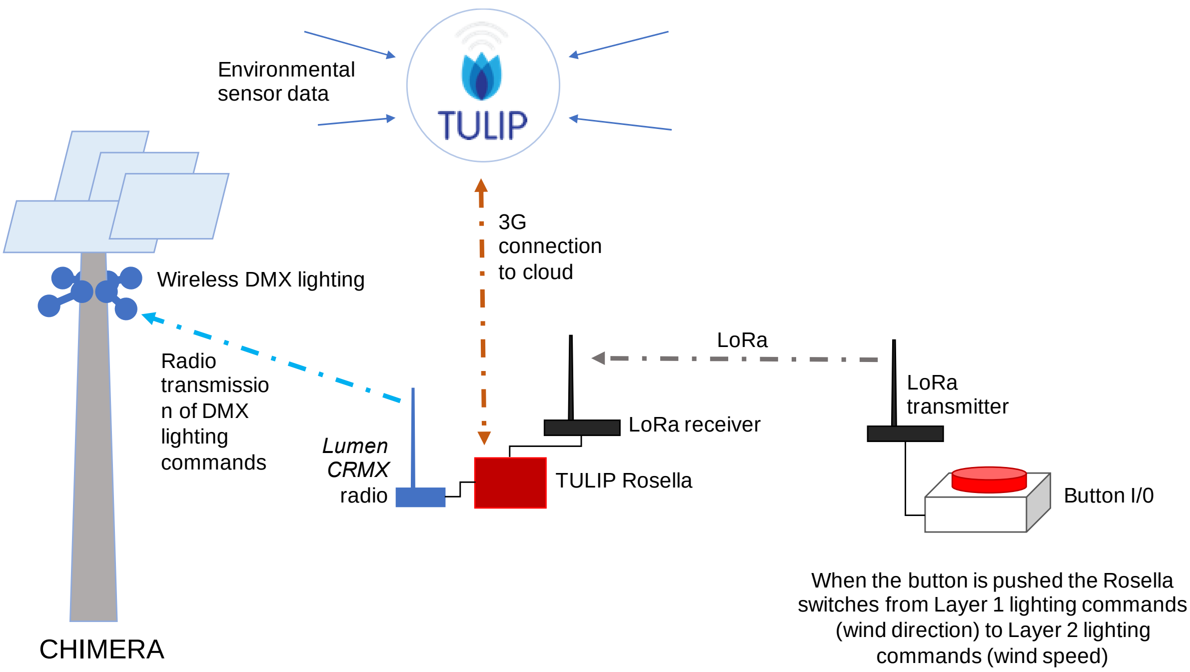


Image: 7 - Technical architecture of Chimera

Layer 1: Wind direction

Sixteen points of the compass were assigned a colour, with corresponding numerical values as 22.5 degree brackets. There is no standardised colour scheme for compass bearings, however the association of red with north has a colonial past. In attempt to avoid that association and embrace more local aspects of the environment, in line with the design aesthetic of the sculpture, an original lighting design was created.

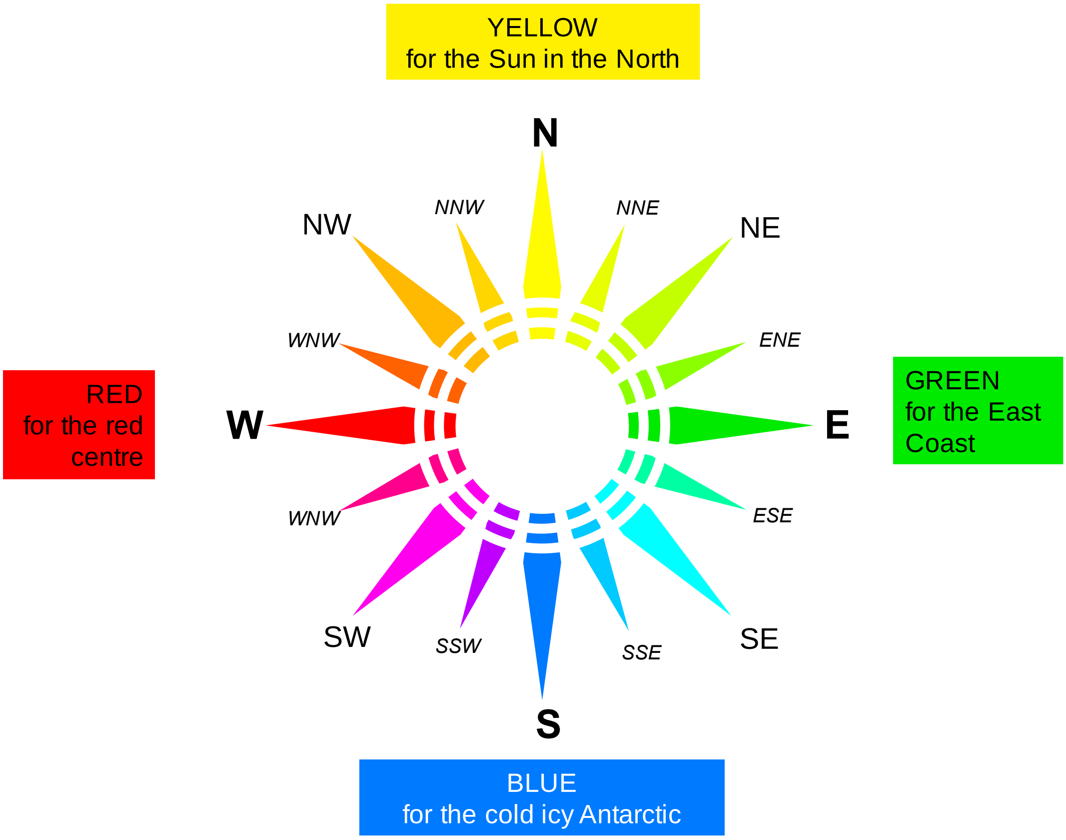


Image: 8 - Chimera wind compass and colour schema

Layer 2: Wind Speed

Wind speed in knots corresponds to the standardised Beaufort Scale of storm severity, which has an established colour schema associated with it. This schema was brightened to stronger hues and expanded (to give more intermediate colour tones).

Wind speed ref #	Min value (Kts)	Max value (Kts)	Colour #1	Colour #2
0	0	0	133,233,255	111,216,239
1	>0	5	111,216,239	145,241,170
2	5.1	10	145,241,170	208,239,129
3	10.1	15	208,239,129	235,240,022
4	15.1	20	235,240,022	255,229,000
5	20.1	25	255,229,000	255,190,033
6	25.1	30	255,190,033	253,119,000
7	30.1	35	253,119,000	254,590,000
8	35.1	40	254,590,000	255,000,187
9	40.1	45	255,000,187	255,000,189
10	45.1	50	255,000,189	229,000,255
11	50.1	55	229,000,255	201,000,255
12	55.1	60	201,000,255	149,000,255

Image: 9 - Chimera sculpture, Speers Point Park, Lake Macquarie. Image credit: Andrew Tovey

Project actuation 3: Mobile Beacon

The Mobile Beacon was a UTS-led data-actuation initiative as part of the Smart Liveable Neighbourhoods project. While other actuations delivered for the project were fixed public art pieces, the Mobile Beacon was designed as a small, portable public engagement and education tool. It was developed in partnership with Newcastle technology start-up Newie Ventures and makes use of the Rosella actuation driver that was developed for the Antenna and Chimera sculptures.

The Mobile beacon consists of a central hub, containing the Rosella and a battery. Ports allow mains power input and connection of five LED lights which can be spaced around the hub at a distance of up to two metres. The original concept included wireless communication from the hub to each beacon however this was dropped due to budget and time constraints.

The Mobile beacon has been designed to respond to PM2.5 particulate data, which is a primary indicator of air quality. Two data channels can be sent to the beacon, corresponding to data output from two different sensors. A button on the beacon hub allows a user to switch between the channels, causing the five LED lights to respond to the channel that has been selected.

Making air quality visible to the public is a vital part of building a wider conversation about something that is largely invisible and often overlooked. Poor air quality has been linked to a range of respiratory and cardiovascular health impacts in Australian cities and is a serious concern of the NSW Office of Environment and Heritage. In NSW cities there can be a strong variation in air quality between suburbs and even between specific locations in cities and suburbs. One may assume that air quality in our cities is reasonably good, and for the most part this is true. However, at some locations, at certain times of day, pollution can spike, and this has generally not been picked up by official monitoring stations, which are positioned well above street level and are sparsely located. Poor air can also result from dust storms or smoke from bush fires, temporarily dropping air quality to levels more usually associated with Delhi or Beijing. Poor air during extreme heat events can have a significant impact on health. The Mobile Beacon makes this highly localised and temporary pollution visible.

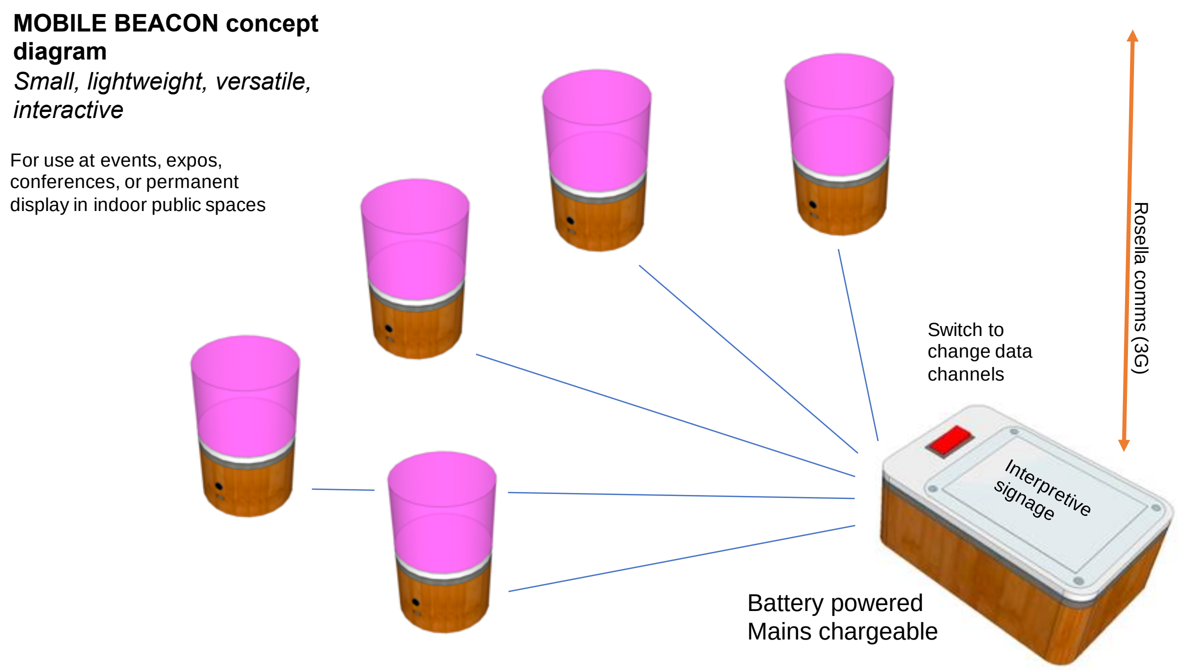


Image: 10 - Mobile Beacon concept diagram. Image credit: Andrew Tovey

An air quality colour schema for the Mobile Beacon

Air quality information is mostly presented to the public as AQI (Air Quality Index), which is calculated as a combination of particulate and noxious gas data. It also tends to be released as 24 hour rolling average. Live PM2.5 levels do tend to synchronise with AQI but it is important to understand that they are not the same thing. There is an existing colour schema associated with AQI that is used by the NSW DPIE and can be viewed here https://www.environment.nsw.gov.au/aqms/uhunteraqmap.htm.

Mobile Beacon references the standard colour schema to display PM2.5 data. The number of colour brackets was expanded to give more intermediate tones, particularly at lower levels. This increases the chance of the Beacon reacting to smaller low-level changes in air quality, making it more interesting to the public.

The colour scale is kept in line with the DPIE schema by working with interim shades. In reference to AQI colour charts, the two highest colour bands have been set as red, then purple, as opposed to purple, then red. This is easier to do in terms of making the colour gradients work (orange naturally blends to red, then purple). The colour hues have been shifted to be more vibrant in order to translate better into light. Note the inclusion of two colours for each telemetry bracket. The lights shift back and forth on a smooth fade in a 4 second cycle, adding dynamic intrigue to the work.

	Air quality bracket (µg/m3)			
PM 2.5 bracket	Lower value	Upper value	Colour #1	Colour #2
1	0	3	000,255,255	133,233,255
2	3.1	8.5	0,255,195	0,255,125
3	8.6	16.7	0,255,0	195,255,000
4	16.8	20	235,255,0	255,251,000
5	20.1	25	255,225,0	255,180,0
6	25.1	37.5	255,120,0	255,098,000
7	37.6	50	255,000,000	255,000,187
8	50.1	75	255,000,189	229,000,255
9	75.1	500	149,000,255	177,0,136

Image: 11- Inside the Mobile Beacon

Image: 12 - The Mobile Beacon. Image credit: Newie Ventures

7 Device development

- TULIP Environmental Monitoring System (EMS)
- TULIP Rosella

TULIP Environmental Monitoring System (EMS)

The TULIP Environmental Monitoring System (EMS) was designed as a reliable, compact, low-cost, IoT-enabled solution for distributed collection of environmental data in communities and cities across Australia. It was delivered through a partnership between UTS and The ARCS Group and is the focus of ongoing research and development.

Parameters measured:

- Temperature
- Humidity (RH)
- Particulates (PM1/2.5/10)
- Carbon Monoxide
- Nitrogen Dioxide
- Ozone
- Noise (dBA)

The TULIP EMS can also be extended to include a solid state weather station that measures:

- Barometric pressure
- Precipitation
- Wind
- UV
- Brightness.

Detailed information about the EMS can be found in the manual: *http://bit.ly/EMS_Manual*

Image: 13 - First EMS prototype, September 2018, courtesy of The ARCS Group

Characteristics of the TULIP EMS

Commercial scalability: Designed for rapid scaled commercial production.

Non-Proprietary: Open access to data, allowing integration with any suitable third party platform.

Tough: Rugged outdoor protection (IP65) and no moving parts. Designed and built in Australia, for Australian conditions.

Low-cost: Designed for high quality performance with a retail price significantly lower than any similar devices.

Self-contained: Solar and battery optimised (no mains power required) for fast and simple installation.

Benchmarked: UTS has tested sensor performance under controlled lab conditions

Rationale

Initial procurement of monitoring devices for use in the project only a few commercially available air quality and noise monitors that met the core requirements for devices stipulated in the project's device procurement guidelines. These requirements were:

a) Non-proprietary system with open access to the device and data, with no vendor lock-in
b) LoRaWAN communications compatible with The Things Network
c) Self-sufficient power and battery optimisation
d) Compact and aesthetically appropriate
e) Low cost (<$5000)

The two commercial devices that did meet these requirements were both around $5000 per unit. Upon procuring test units, one was dead on arrival and could not be made to function. The other presented significant technical difficulties associated with the design of the firmware and proved to be impractical for scaled deployment. As a result of these early investigations, UTS engaged The ARCS Group to develop the TULIP EMS in line with the critical requirements. In addition to the requirements listed above, the final retail price of each EMS unit was to be lower than any similar product on the market (it ended up being $2500, roughly half that of competitors). High sensor performance was also emphasised.

A scalable Australian-made product

Many universities have chosen to invest time and funds in the development of a low cost environmental monitor. These devices are generally developed and assembled 'in house'. The drawback of this approach is a lack of scalability. From the outset, UTS decided to work with a commercial hardware developer in order to develop a device that not only met our needs, but which was a commercially scalable product. This kind of research and development is a costly and often drawn-out process. UTS provided project funding to kickstart that process but recognises significant and ongoing input from The ARCS group. All rights to the EMS as a product are held by The ARCS Group and UTS holds no claim to any part of the IP. By outsourcing design and production, UTS forfeited control and ownership but gained a device that perfectly met our requirements, for a fraction of the cost that would have been involved with inhouse development. We believe that having access to the EMS, and a close ongoing working relationship with The ARCS Group, has produced the most powerful outcome possible from a minimal investment. We are excited to see the EMS grow in popularity as the only Australian-produced device of its kind. Given UTS' deep understanding of the EMS we look forward to working with many new partners as uptake rises.

The version of the EMS in production in mid 2019 was the result of iterative improvements on the initial prototype, with the project providing a context for fine tuning of the device. UTS has benchmarked the device under controlled conditions and shown that it performs well against reference monitors and that it is 'best in class' when compared to other commercially available devices.

As of late 2019, the Smart Liveable Neighbourhoods project has deployed 12 TULIP EMS units across Lake Macquarie and 9 units across the City of Sydney. Three of these are at primary schools. Another 14 units are being deployed in the City of Parramatta as part of a different TULIP project. UTS is also aware of a number of Councils around Australia who are now independently purchasing the EMS, including the City of Parramatta, the City of Melbourne and the City of Greater Geelong. The ARCS Group informs us that as of January 2020, an additional 100 EMS units are in production, to meet rising demand.

Image: 14 - TULIP EMS deployed in Charlestown, Lake Macquarie. Credit: Lake Macquarie City Council

TULIP Rosella

The TULIP Rosella as a data actuation device for DMX lighting control. It can communicate with the cloud via 3G and receive commands that relate to lighting patterns. The Rosella was commissioned by UTS as part of the Smart Liveable Communities project. It was designed and built by Newcastle technology start-up Newie Ventures. The Rosella was used for three actuations as part of the project. Two were permanent public art installations in Lake Macquarie (Nightlight and Chimera) and one was a portable public engagement tool (Mobile Beacon).

Image: 15 - The TULIP Rosella

All aspects of the Rosella design and firmware have been documented according to open source guidelines and are available for public access under a creative commons license via Github

8 Community engagements

- Community engagements: Events
- Community Engagements: Smart Liveable Neighbourhoods Challenge
- Community Engagements: Adopt-a-sensor
- Community Engagements: Open public API

Community engagements: Events

Image: 16 - The project stall at the Lake Mac Smart Living Festival. Credit: Lake Macquarie City Council

Lake Macquarie Living Smart Festival 2018

Around 30,000 people attended the 2018 Living Smart Festival, the Hunter region's largest sustainability festival hosted by Lake Macquarie City. The community were invited to view devices being installed as part of the project and discuss objectives and activities with the project team

Greater Hunter Makers Festival 2018

The Greater Hunter Makers Festival brings people and ideas together, showcasing the Hunter Region's world-class engineering and manufacturing capabilities. Over 70 displays of ideas and creativity, designed to inspire, inform, connect and entertain thousands of attendees in a family-friendly environment.

Attendees were invited to view devices being installed as part of the project and discuss objectives and activities with the project team.

Image: 17 - The project stall at the Greater Hunter Makers Festival

Key learnings from presenting the project at the festivals

I. The public were generally positive and enthusiastic about the new technologies

II. There was a gap in knowledge and digital literacy apparent with a majority of people engaged

III. Many people struggled the see direct value of the new technologies to them in their daily lives. Longer term strategic insights and improvements based on new data were often seen as too removed from people's lived reality. Direct sensor feedback (e.g. how busy is the dog park?) was understood more readily by people as being about them.

IV. Without live visualisations it was difficult to convey the new systems and user experience to people. With the TULIP platform now complete Council is in a better position to engage people with live demonstrations at future events, making engagements more interactive and relatable.

Community Engagements: Smart Liveable Neighbourhoods Challenge

The Smart Liveable Neighbourhoods Challenge combined investment in digital infrastructure with engagement of local innovators to improve city liveability.

We asked the community to develop an Internet-of-Things (IoT) concept that helps improve liveability, and to connect this device to the city's long range wide area network (LoRaWAN). Participants were invited using Council's media channels, with a reach of 200,000 people. Council staff also presented at the Newcastle IoT Pioneers group of approximately 400 members.

Participants were awarded free kit worth $150 and invited to a free workshop to help develop their device. At the close of the Challenge, five finalists were invited to pitch their creation at a breakfast with Lake Macquarie's Mayor and Councillors and selected Council staff.

Details of the five winning entries can be found in APPENDIX F

Image: 18 - A winning DIY entry. Credit: Lake Macquarie City Council

Key learnings from the Smart Liveable Neighbourhoods Challenge

V. Confirmation that there is an existing latent community of IoT enthusiasts in the LGA with interest and enthusiasm for the project and for making use of the open community LoRaWAN network

VI. Confirmation that some basic skills for working with LoRaWAN sensors already exist in the Lake Macquarie community

VII. Confirmation that people with a smaller amount of specific technical knowledge can, with support, quickly learn the necessary skills and produce working results within a short time frame.

VIII. Small local IoT equipment provider Core Electronics was very supportive of the initiative and provided invaluable support by hosting up-skilling workshops for the community. It was established that this was an appropriate and effective channel of engagement from Council to the community and that the situation was directly beneficial to Core Electronics. It is further understood that a growing grassroots/community innovation ecosystem around IoT depends a great deal on local vendors such as Core being positioned as focus points and community resource hubs.

IX. The resulting devices were varied and creative, demonstrating that community is readily capable of innovating when given access to this new technology.

X. Participants confirmed interest in helping co-design a local living lab or equivalent program to facilitate local innovation and development of new Internet-of-Things products and services. Participants recommended curating a program to share critical city challenges that local innovators can work with government to help solve. Such a concept is being explored as part of Council's update to its Smart City Strategy.

Community Engagements: Adopt-a-Sensor

The Adopt-a-Sensor program was a major delivery of the Smart Liveable Neighbourhoods project in Lake Macquarie. Local residents, community groups, sports facilities and schools were invited to take ownership of a sensor and host it at their location. 26 of the 81 devices deployed in the Lake Macquarie network came under the Adopt-a-Sensor initiative.

Adopt-a-Sensor is a powerful demonstration of what a smart city sensor network could look like if it had multiple device owners, all sharing data into a centrally accessible commons. Most low-cost sensor initiatives around the world are owned and managed by a single entity, most often a local government. Adopt-a-Sensor repositions Council as a data steward and facilitator of IoT in the community, rather than remaining the sole owner and manager of equipment and data. It is quite possible to imagine a future scenario where any group or individual can purchase their own sensor, connect it to a local network and start sharing data with their community. If this were to occur it is likely that Councils would play a critical role in bringing it about. Adopt-a-sensor is a heavily curated exploration of this space that could point the way to a more participatory future for low-cost environmental sensing.

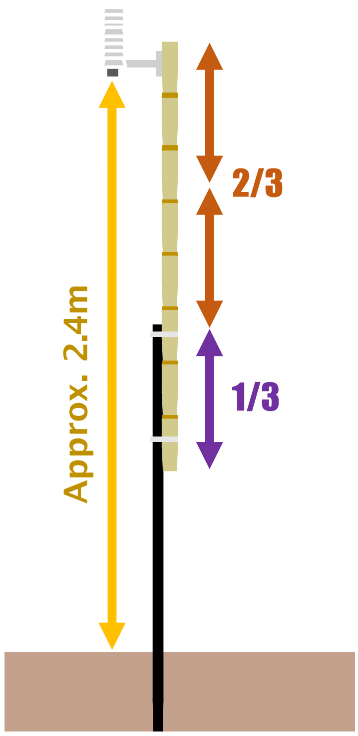
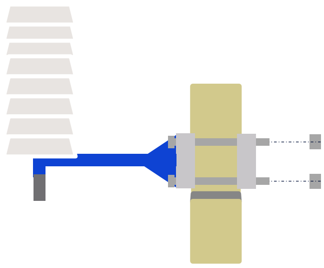


Image: 19 - Adopt-a-sensor illustrations. Credit: Andrew Tovey



Device types included in the Adopt-a-Sensor initiative:

1) Netvox R712 Temperature and Humidity Monitor
2) TULIP EMS (air quality, urban heat, noise)

Overview of participants:

6 schools; 15 residents; 2 sports facilities; 2 bowling clubs; 1 scout hall

The device in the illustration is the temperature and humidity node that was installed by residents using a star picket and a length of bamboo.

Managing correct installation

Correct installation of a device is vital for it to send data successfully and for the data to be usable. Critically, we needed to ensure that there was a viable LoRaWAN signal and that the device was positioned away from direct interference factors such as thermal radiation from a nearby wall. A comprehensive illustrated guide was created to take people through the process of choosing a deployment location and installing a device.

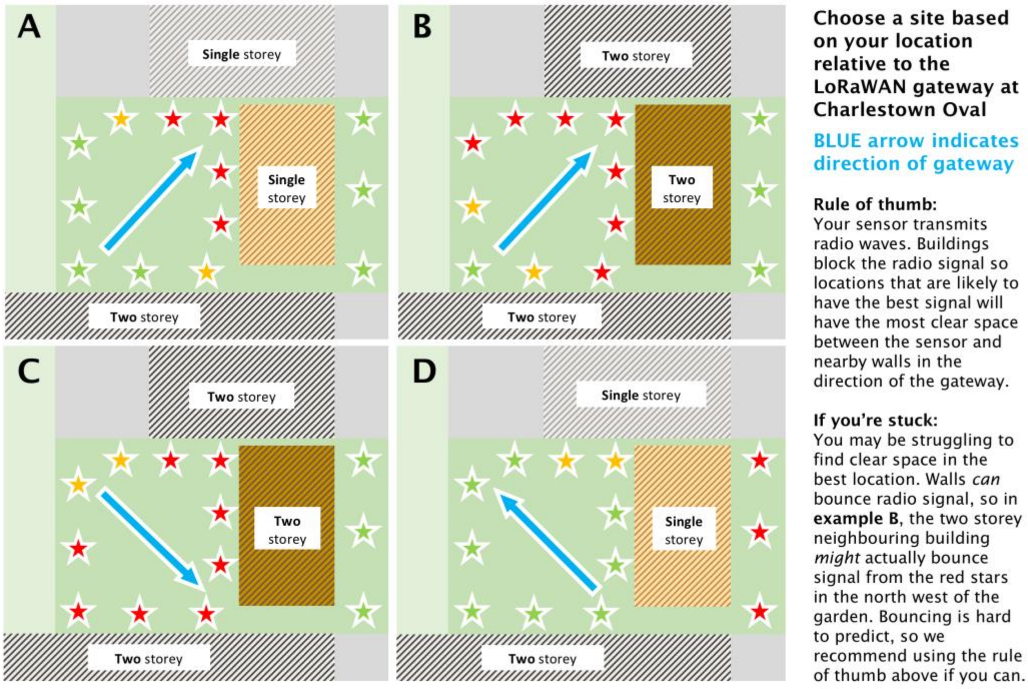


Image: 20 - Illustration provided to residents to help identify a location with suitable LoRaWAN signal strength

Participants signed a Participation Agreement created by Council's legal team. The Agreement clarifies that the device remains in Council ownership and that all data generated will be made publicly available. Devices will remain in place for a one year period, however this will be reviewed after the first year, with a view to continuation.

Dedicated ongoing engagement with participants was critical. Council assigned a project officer to manage the initiative, plus a dedicated schools liaison assistant. Council staff visited schools and delivered presentations to teachers to ensure buy-in.

All participants are able to access the data from their sensor, and others in the network, via the TULIP public dashboard, created for the project in collaboration with the Urban Institute. The dash board allows users to select one or more sensors, create graphs of the data, customise the time period viewed, and plot two data streams against each other on one graph.

Image: 21 - A teacher participating in the Adopt-a-Sensor initiative. Credit: Lake Macquarie City Council

For further information about the Adopt-a-Sensor initiative, please contact the Integrated Planning department at Lake Macquarie City Council.

Community Engagements: Open public API

What data is in the API?

The open public Application Programming Interface (API) was developed to provide a live stream of environmental data from devices deployed in Lake Macquarie. The telemetry included temperature, humidity, air quality and noise. The API was built and hosted by the Urban Institute, which also provided the data visualisation and data storage for the project.

Some <u>hypothetical</u> use case examples:

The API contains a broad amount of environmental data. Users are likely to filter out specific sub-sets of that data to meet specific needs. The project team developed some ideas about how different users might engage with the data. Here are some hypothetical examples:

Hackathon

Council is holding an urban heat hackathon in the summer of 2019/20. The challenge is to develop a community focused app that helps people to identify and navigate to the cool spots around Charlestown during a power outage in extreme heat. Participants have access to real time public transport data alongside heat and humidity data from the TULIP Lake Mac API.

Start-ups and third party app developers

A local start-up creates an app that allows prospective home buyers/renters to input an address and see the 'liveability' scores for that address. They use the TULIP API to access real-time data and build up their own longitudinal profiles for locations across Charlestown, applying their own innovative spatial interpolation algorithms to the data. Charlestown is one of the first places with a dense sensor network and openly available data for them to test and develop their idea. They hope to take it international as smart city sensor networks become more widespread.

Professional researchers

Professional researchers of urban microclimate gain access to the Lake Macquarie data for research purposes. This means that the data can be used to inform research anywhere in the world. It gets picked up by the NSW Office of Environment and Heritage and used in their emerging work into microclimate air quality issues. The Climate Council also pick up on the open data and use it to inform their climate change adaptation research, positioning Charlestown as a notable case study in a wider national conversation.

Community members

A parent with children who regularly use the Charlestown Netball Courts responds to the challenge of extreme heat out on the courts during summer. He uses the TULIP API to set up a service whereby a referee gets a tweet to their phone if the sensor near the courts registers a temperature over a particular threshold. This tells the ref to call off the match/practice.

A member of the Speers Point Sailing Club creates an automated twitter account that posts updates on wind speed and direction, taken from the Speers Point Lufft weather station and accessed from the TULIP app. This information is used by sailors across the lake.

A community member who suffers from asthma creates an app that tells you the current air quality at various bus stops in Charlestown. You can enter which bus you plan to catch (the app draws on NSW transport data) and the app will calculate how long you need to wait at the bus stop and (using the TULIP API) what your exposure might be to poor air quality during that time. It will either tell you that air quality is fine at that bus stop, or if not, it will suggest waiting elsewhere and arriving right before you need to get on board. The app proves popular with everyone, not just asthma sufferers.

Council

Council decides to develop a widget that appears on the web pages for Speers Point and Charlestown Swim Centres. The widget tells you the temperature, windiness and UV level at each pool. Council also trials a new twitter account called @mylakemacpool that posts twice a day about the conditions at each pool. Community followers rise, leading to discussions at Council about expanding sensor coverage to include other swim centres in the LGA.

Defining the API

There were two broad considerations for the generation of the API. Each was considered in light of Council data policy and the implications of open data.

1) Telemetry to be included

DEVICE	Included	Excluded
DecentLab	Temperature, Humidity	Battery, Lat:Lon
EMS	Temperature, Humidity, Particulates, CO, NO2, O3, Noise	Battery, Lat:Lon
Lufft WS10	Temperature, Humidity, Air Pressure, Wind direction, Wind speed, Rain intensity, Daily rain, Precipitation type, UV, Brightness	Battery, Lat:Lon
Netvox R712	Temperature, Humidity	Battery, Lat:Lon
Microclimate.One	Temperature, Humidity, Air Pressure	Battery, Lat:Lon

Table 1 - Telemetry included in the open public API

2) Metadata to be included

Field	Example
Device Manufacturer	ARCS Group
Device Model	EMS (Environmental Monitoring System)
Device Name	ARCS001_EMS_LMCC
Device Nickname	EMS_Speers Point Pool
Deployment Date	01/01/19
Device Status	Active
Device Owner	LMCC
Height above ground (m)	3.0 (*Relevant for environmental data science)*
Orientation	SE (*Relevant for environmental data science)*
Type of mount	Street pole – wood WIDE
Longitude	-33.884153
Latitude	151.1987782
Location type	Open public space
Suburb	Charlestown

Table 2 - Metadata to be included in the open public API

Format

The API was made available in JSON format

9 Research initiatives

- Research brief for urban heat monitoring and data analysis
- Research brief for air quality monitoring and data analysis
- Research brief for noise monitoring and data analysis
- Distributed urban heat monitoring: comparative analysis of old and new technologies for City of Sydney
- Smart Sensing for Climate Responsive Neighbourhoods

Research brief for urban heat monitoring and data analysis

Aims of the work

The aim of the work was to explore the data collected from the approximately 80 low-cost temperature and humidity monitoring devices deployed in Lake Macquarie. There were two core areas of interest:

Part 1: Understanding the available data from the project

- **Interpolate** project data **temporally**, allowing direct comparison between sensor locations
- Understand **spatial trends** between sampling locations - where are the hot and cold spots?
- Understand short term **temporal trends** across all sampling locations. Explore how comparison of temporal variations at specific sensor locations can help to flatten out the effects of variable turbulent and radiative transmission of heat from the surrounding area, providing a more representative reading for that location.
- **Compare** spatial and temporal distributions **to existing Infrared** (IR) aerial images or GIS data and comment on the extent to which the new sensor data conforms with known distributions.
- Understand how locations and time periods with high urban heat interact with where people live, work and play (i.e. what can we say about the **human impact** of the trends we identify?)
- Comment on the **feasibility of spatial interpolation of microclimate temperature and humidity data in the Urban Canopy Layer (UCL)**, between sensor locations, informed by GIS data on topography, land use, built environment and tree cover.

Part 2: Validating and assessing data quality and critically evaluating the data capture methodology

- Position the methodology of low-cost distributed longitudinal urban heat and humidity data collection against more established urban heat data collection methodologies.
- Understand the validity and usefulness of the project data
  - Review papers describing similar projects and consider applying variations on the data analysis techniques used.
  - Validate the project data against other available certified sources for the area and identify correlation (e.g. BOM, OEH, aerial IR images)
  - Analyse the project data for potential anomalies via such techniques as comparison of data between different nearby locations.
  - Review data from the four types of device in the deployment and determine if there is detectable variation in output from each, accounting for spatial distributions.
  - What can we confidently say based upon the data and what can we not say? What is data like this reliably useful for?
- Critical evaluation of the methodology
  - Review the experimental design choices in light of data analytics outcomes (e.g. choice of locations, height above ground, spatial distribution and density), including reference to design restrictions and considerations.
  - Comment on the limitations of the experimental method used for the project
  - Suggest useful future analytics exercises, once the data set grows
  - Suggest recommendations for expanding a distributed urban heat sensor network based on early insights from this analysis.

Study results will be published in 2020. Contact UTS for details

Research brief for air quality monitoring and data analysis

Aims of the work

The aim of the work was to explore the data collected from the 12 low-cost air quality monitoring devices deployed in Lake Macquarie. There were two core areas of interest:

Part 1: Understanding the available data from the project

- Understand **spatial trends** between sampling locations - where is the cleanest air and the most polluted air, based on the data we have?
- Understand short term **temporal trends** across all sampling locations – how does air quality vary throughout the day and the week?
- Use an understanding of spatial and temporal trends to identify **probable sources** of poor air in the areas monitored
- Understand how locations and time periods with poor air quality interact with where people live, work and play (i.e. what can we say about the **human impact** of the trends that we identify?)
- **Interpolate** TULIP data **temporally**, allowing direct comparison between sensor locations.
- Explore the **feasibility of spatial interpolation** between sensor locations, informed by GIS data on topography, land use, built environment and tree cover.

Part 2: Validating and assessing data quality and critically evaluating the data capture methodology

- Position the methodology of low-cost distributed longitudinal data collection against more established air quality data collection methodologies.
- Understand the validity and usefulness of the TULIP data
  - Analyse the TULIP data against other available certified sources for the area and identify correlation (e.g. BOM, OEH)
  - Analyse the TULIP data for potential anomalies
  - Refer to device benchmarking work conducted by Dr Nic Surawski (UTS FEIT) as part of the TULIP Lake Macquarie project
  - Given the lower quality of data, what can we confidently say based upon it and what can we not say? What is data like this reliably useful for?
- Comment on:
  - The appropriateness of experimental design choices (e.g. choice of locations, height above ground, spatial distribution and density)
  - The limitations of the current method
  - Useful future analytics exercises, once the data set grows
  - Recommendations for expanding a distributed sensor network based on early insights from this analysis.

Study results will be published in 2020. Contact UTS for details

Research brief for noise monitoring and data analysis

Aims of the work

The aim of the work was to explore the data collected from the 12 low-cost noise monitoring devices deployed in Lake Macquarie. There were two core areas of interest:

Part 1: Understanding the available data from the project

- Understand **spatial trends** between sampling locations - where are the loud and quiet spots?
- Understand short term **temporal trends** across all sampling locations – how does noise vary throughout the day and the week in key locations?
- Understand how locations and time periods with high recorded noise interact with where people live, work and play (i.e. what can we say about the **human impact** of the trends that we identify?)
- Comment on the **feasibility of spatial interpolation of noise data in the Urban Canopy Layer (UCL)**, between sensor locations, informed by GIS data on topography, land use, built environment and tree cover.[1]

Part 2: Validating and assessing data quality and critically evaluating the data capture methodology

- Position the methodology of low-cost distributed urban noise data collection against more established urban noise data collection methodologies.
  - Comment on the current knowledge gaps in the field of urban noise monitoring and the limitations of established data capture methods.
  - Position the TULIP methodology against other similar initiatives
  - Comment at a high level on new insights that might emerge from the new methodology and smart technologies.
- Determine the validity and usefulness of the project data
  - Review papers describing similar projects and consider applying variations on the data analysis techniques used.
  - Analyse the project data for potential anomalies (e.g. via such techniques as comparison of data between different nearby locations)
  - What can we confidently say based upon the data and what can we not say? What is data like this reliably useful for?
- Critical evaluation of the methodology
  - Review the experimental design choices in light of the data analytics outcomes (e.g. choice of locations, height above ground, spatial distribution and density), including reference to design restrictions and considerations.
  - Comment on the limitations of the experimental method used for the project
  - Suggest useful future analytics exercises, once the data set grows
  - Suggest recommendations for expanding a distributed urban noise sensor network based on early insights from this analysis

Study results will be published in 2020. Contact UTS for details

[1] We recognise that spatial interpolation is likely to be a significant undertaking and major focus for new data science research in this area. Given the initial constraints of this proposed piece of work we suggest that high-level comments on feasibility and approach would be appropriate at this stage. GIS may be obtained from Council upon request.

Device benchmarking study

Research lead:

Dr Nic Surawski, School of Civil and Environmental Engineering, Faculty of Engineering and IT (FEIT)

Research assistants:

Jimmy Guo Jing Tang; Peter Irga; Tom Pettit; Jen Brown; Nicholas James

Additional contributors:

Andrew Tovey; Frank Zeichner; Jeremy Brun; Fraser Torpy

Background

All three of the device types deployed at scale for the project were assessed at UTS by a team from the Faculty of Engineering and IT, in collaboration with the Faculty of Science. An additional three air quality monitors that were not deployed for the project were also benchmarked to provide insight into comparative performance of the EMS. Using a custom-designed chamber to control environmental variables, the quality of data from each device was directly compared to data from a high-performance reference monitor. Device performance was also compared between devices allowing them to be ranked.

Three devices deployed at scale for the project (TULIP EMS; Netvox R712; DecentLab Temperature Sensor) were found to perform to a satisfactory or high standard across all parameters. This independent assessment supports their use in the project as devices that produce reliable and trusted data. The EMS performed best in its class for particulates and NO2, when compared to three other air quality monitors. It could not be compared to a CO or O_3 monitor.

Image: 22 - The EMS mounted inside the test chamber. The perforated sheet separates the visible test section of the chamber from the mixing section behind. Image credit: UTS

Test chamber design

A test chamber was constructed using the design for a Continuous Mass Flow Reactor (CMFR) to enable introduction and thorough mixing of pollutants before emissions sampling, ensuring that reference monitors and IoT devices sampled precisely the same concentrations. The chamber had an interior volume of 308 litres and was lined with stainless steel to minimise chemical interference from chamber walls.

Device benchmarking research aims and method

1) Confirm that devices deployed for the project are fit for purpose
2) Determine how project devices perform against common commercially available competitors

Project devices benchmarked

Manufacturer	Model	Measures	Measurement range	Measurement technique
The ARCS Group	Custom-designed Environmental Monitoring System (EMS)	$PM_{2.5}$ O_3 NO_2 CO Temperature and Relative humidity **Noise** **Location**	0-500 µg/m^3 ($PM_{2.5}$) 0-1000 ppm (CO) 0-5 ppm (O_3) 0-5 ppm (NO_2) -40-80 °C (temperature) 0-100% (relative humidity)	Laser light scattering ($PM_{2.5}$; Plantower PMS7003 sensor) Electrochemical sensors (O_3 – SPEC 3SP_O3_5 sensor; NO_2 – SPEC 3SP_NO2_5F sensor; CO – 3SP_CO_1000 sensor) Electret microphone (noise) Capacitative type sensor (MaxDetect RHT03 sensor) Global Positioning System (location)
Decentlab	DL-SHT35-002	Temperature and Relative humidity	-40-125 ° C 0-100%	Band-gap temperature sensor Capactive type humidity sensor
Netvox	R712	Temperature and Relative humidity	-10-50 ° C 10-90%	Capactive type humidity sensor

Table 3 - Project devices included in the device benchmarking study

Comparison devices benchmarked

Manufacturer	Model	Measures	Measurement range	Measurement technique
Libelium	Smart Cities Pro	PM_1, $PM_{2.5}$, PM10 NO_2 **NO** **CO** Temperature, Relative humidity and pressure	10,000 particles/litre in 16 size bins (PM_1/$PM_{2.5}$/PM_{10}) 0-20 ppm (NO_2) 0-18 ppm (NO) 0-500 ppm (CO) -40-85 °C (temperature) 0-100% (relative humidity) 30-110 kPa (pressure)	Optical particle counter (Alphasense OPC N2) Electrochemical gas sensors Integrated environmental sensor (Bosch BME280)
GlobalSat	LS-113P	$PM_{2.5}$ Temperature and relative humidity	0-500 µg/m^3 ($PM_{2.5}$) -40-125 °C (temperature)	Laser light scattering Complementary metal-oxide semiconductor

			0-95% (relative humidity)	
Aeroqual	AQY-1	$PM_{2.5}$ **O_3** **NO_2** Temperature and relative humidity **Dew point**	0-1000 µg/m^3 0-200 ppb 0-500 pbb -40-125 ° C 0-100% -30-50 ° C	Laser light scattering ($PM_{2.5}$) Gas sensitive semiconductor (O_3) Electrochemical sensor (NO_2)

Table 4 - Commercially available devices used for benchmarking comparison

Reference monitors

Manufacturer	Model	Measures	Measurement range	Measurement resolution
TSI	8533 DustTrak	$PM_{2.5}$	0.001-150 mg/m^3	±0.1% of reading or 0.001 mg/m^3 whichever is great
Ecotech	EC9841AS	NO, NO_2	0-1000 ppm	2 ppb or 0.1% of reading whichever is greater
Ecotech	EC9830	CO	0-200 ppm	0.025 ppm or 0.1% of reading whichever is greater
Ecotech	Serinus 10	O_3	0-20 ppm	0.5 ppb or 0.2% of reading whichever is greater
TSI	VelociCalc Model 9565	Temperature, relative humidity and pressure	-10 – 60 °C 5-95 % 517.15-930.87 mm Hg	± 0.3 °C (temperature) ± 3% (relative humidity) ± 2% of reading (pressure)

Table 5 - Reference monitors used for the device benchmarking study

Summary of findings from the device benchmarking study

Device	Aim	Parameter	Outcome
TULIP EMS	Confirm device performs to a minimum standard and is fit for purpose	Particulates	Confirmed
		NO2	Confirmed
		CO	Confirmed
		O3	Inconclusive (technical challenges with test equipment)
		Noise	Not part of scope
		Temperature	Confirmed
		Humidity	Confirmed
	Establish how the device performs relative to other commercially available products in its class	Particulates	Best performer out of four devices assessed
		NO2	Best performer out of two devices assessed (EMS and Libelium)
		CO	Only device with CO sensor so could not be compared
		O3	Only device with O3 sensor. Could not be tested.
		Noise	Not part of scope
		Temperature	Best performer out of four devices assessed
		Humidity	Worst performer out of four devices assessed. Indicates potential design alteration required for EMS
DecentLab Temperature and Humidity monitor	Confirm device performs to a minimum standard and is fit for purpose	Temperature	Confirmed
		Humidity	Confirmed
	Establish how the device performs relative to other commercially available products in its class	Temperature	Ranked last out of 4
		Humidity	Ranked 3 out of 4
Netvox R712 Temperature and Humidity monitor	Confirm device performs to a minimum standard and is fit for purpose	Temperature	Confirmed
		Humidity	Confirmed
	Establish how the device performs relative to other commercially available products in its class	Temperature	Ranked 2 out of 4
		Humidity	Ranked 2 out of 4

Table 6 - Summary of findings from device benchmarking study

Discussion points and caveats

- Electrochemical cell technology is widely used in low cost gas sensing applications, and is known to cause issues such as batch-to-batch variability in sensor response (e.g. good results with one batch of sensors does not imply good performance with a new batch of sensors). An expanded study could compare the performance of a number of devices of each type.
- With PM sensors there are known problems with detecting higher concentrations related to the issue of coincidence corrections. At higher concentrations multiple particles can be present in the optical sensing chamber at a particular time and without the appropriate correction algorithm, improving the non-linear response of a sensor is not possible.
- Further work is required to investigate the sort of calibrations that could be applied in cases where sensor response is linear although with a systematic bias towards either over or underestimated concentrations.
- Further work is required to remove the likelihood of a low cost sensor reporting a negative concentration. This issue could be related to the zero calibration applied at the point of manufacturing.

The full study report can be accessed at: http://bit.ly/EMS_Benchmarking_Report

Distributed urban heat monitoring: comparative analysis of old and new technologies for City of Sydney

Research undertaken by UTS Institute for Sustainable Futures

Project development/Management:	Andrew Tovey
Technical writing additions:	Andrew Tovey
Writing, data analytics, report production:	Emily Prentice
Expert consultant:	Brent Jacobs

Background

From 2017 to 2018 The Technology for Urban Liveability Project (TULIP) trialled low-cost LoRaWAN temperature and humidity sensors for City of Sydney (CoS) in street locations in Chippendale and Redfern (Sydney) in order to assess urban heat on a microclimate scale. These devices were trialled with a view to replacing three existing temperature sensors owned by CoS. The old models (supplied by a provider called Ajenti) are costly to maintain and bulky, making any upscaling to a larger sensor network impractical. TULIP provisioned sensors that cost roughly $400 per device (all costs, including configuration and installation), roughly one-tenth of the cost of the existing sensors. The first three of these were deployed in Chippendale and Redfern on the same poles as the old Ajenti sensors (literally half a metre distant). The idea was to test the performance of the new sensors against the old. The new low-cost sensors have very low annual maintenance costs and have the potential to form the basis of an expanding urban heat monitoring network across the LGA. They upload data packets every 15 minutes. Nik Midlam (Carbon Strategy Manager, CoS), who oversees the Ajenti sensors and who has worked with TULIP since the start of the trial, was keen to shift entirely to TULIP and cease operations with Ajenti. In order to justify the full shift to TULIP, away from Ajenti, Nik commissioned ISF to produce a short report that compared the performance of the new sensors with the old.

Objectives

There were two major objectives associated with this work:

1. Outline cost effectiveness of installing the new sensors for ongoing monitoring of urban heat
2. Provide a case for developing a more significant urban heat monitoring strategy in the City of Sydney LGA

Project Tasks

PART A

i. Analyse the longitudinal data from past operation of the three Ajenti sensors in Chippendale and Redfern and present 'insights to date'. At the time of the study, no formal analysis of this data had been undertaken.

PART B

ii. Analyse new data from the TULIP sensors and compare it to the continuing data from the Ajenti sensors. Carry out appropriate analyses to assess whether there is a statistically significant difference between the old and new sensor options and that the TULIP sensors are fit for purpose.

iii. Develop some high-level recommendations to the City regarding future work on urban heat, with particular focus on the opportunities enabled by expanding the TULIP sensor network and implementing our data platform. Draw upon limitations evident from data monitoring to date in order to recommend areas for development.

The report included

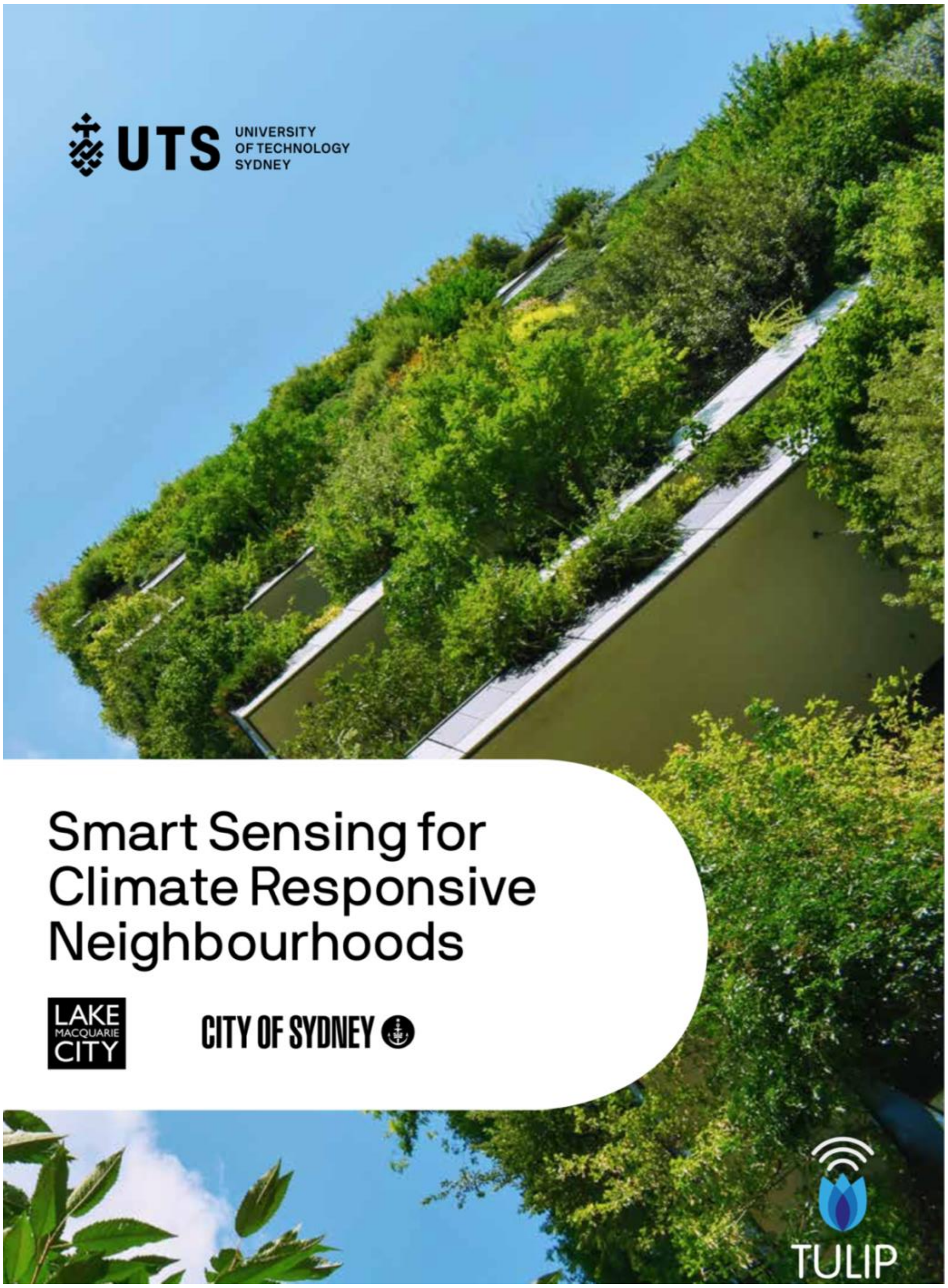
- A foreword by Dr Brent Jacobs, Expert Advisor in Urban Heat Mitigation Strategy
- Technical descriptions of sensor capabilities
- Results and interpretations of data analysis (including graphical representations of findings)
- Recommendations for future work/next steps

Conclusions

- The study demonstrated the value of longitudinal monitoring to assess urban heat and the factors influencing temperature extremes in the urban environment. Time series data like the data logs acquired from the Ajenti and TULIP sensors provides opportunities to assess trends over space and time, generating powerful insights into the impact of urban microclimates in mitigating extreme heat events.
- While macro trends show little discernible variation between locations under most conditions, extreme heat events have been shown to produce highly localised variation (up to 5°C) that is assumed to correspond to tree canopy cover. A full investigation of this factor was outside the scope of the study, but it would appear that canopy cover (and possibly other environmental factors) reduced air temperatures in one location by several degrees in January 2018.
- Low cost may have an important role to play in investigating the role of canopy cover and ground cover in urban heat considerations for the Sydney CBD.
- Comparisons carried out in this study to test the reliability of the TULIP sensors alongside their Ajenti counterparts does suggest that these sensors are comparable in their performance, provided that the TULIP data packets are transmitted and acquired in full (some data gaps were apparent). The obvious advantage with further deployment of TULIP sensors rather than Ajenti sensors is that a greater number of sensors can be deployed in different locations, increasing data acquisition and providing broader options for spatio- temporal analysis.
- Further roll-outs of TULIP sensors in locations carefully chosen to assess differences in urban microclimate is recommended. Future studies could examine the impact of factors such as water bodies, building surfaces and glazing, groundcover (type/colour), and vegetation cover and type upon urban heat.
- The addition of air pollution monitoring alongside relative humidity and air temperature would allow for further analyses of the interaction between urban heat and air quality parameters. These factors can be analysed through modelling, statistics, GIS, remote sensing or a combination of these approaches.
- There is potential to create automated (online portals) and/or interactive (dashboard) analyses of this data with a view to involving the community in citizen science and encouraging education in urban ecology and the health impacts of urban heat.

View the complete report here: http://bit.ly/CoS_Urban_Heat_study

Smart Sensing for Climate Responsive Neighbourhoods



UTS produced a 20-page illustrated booklet about distributed urban microclimate monitoring, aimed primarily at Local Government. There is a rapidly emerging paradigm of low-cost sensing and many Councils are starting to actively experiment. Using examples from project activities in Lake Macquarie and the City of Sydney, as well as from around the world, this booklet explores some of the what, why and how of this new space.

The booklet is available as an electronic download

10 TULIP platform development

- Overview of the TULIP platform as an integrated open modular architecture
- Overview of the UrbanPulse Council Dashboard
- Overview of the UrbanPulse Public Dashboard
- Data Modelling for TULIP

Overview of the TULIP platform as an integrated open modular architecture

From the outset, UTS has developed the TULIP platform as a multi-vendor modular ecosystem. A majority of smart city platforms are single-vendor proprietary products that offer top to bottom IoT solutions yet are inflexible and difficult to integrate with wider Council systems. A handful of larger service providers are starting to deliver more open platforms that are capable of integrating multiple data sources, however these still represent something of a technical monoculture, with restricted commercial flexibility.

TULIP breaks down the standard smart city platform into distinct functional layers and then populates each of those layers with a service provider that meets the specific functional need.

TULIP platform partners

The TULIP data platform consists of service contracts with the following organisations:

Meshed

LoRaWAN network provider and official Australian facilitator of The Things Network (TTN). Meshed install and maintain open-access community LoRaWAN gateways.

The Things Network

The Things Network is an open access free-to-use community LoRaWAN service that allows anyone to connect a LoRaWAN device (through a TTN server) and retrieve data. TTN use does not involve a service contract and is not considered a project partner, however it does form a significant layer in the TULIP platform so has been included here.

Nokia

Nokia was a project partner and provides the Impact platform as an in-kind contribution, with technical support and development as a direct labour (cash) contribution. Use of Impact was not a direct cost to the project. Impact is a device management and onboarding layer for TULIP.

Reekoh

Reekoh provide a data ingestion layer for TULIP. This layer is able to ingest data from any type of network, any type of sensor, and any third party data source, making it incredibly versatile. Reekoh forms the core of the TULIP platform, into which most other layers connect.

[u!] Urban Institute

Urban Institute [UI!] provide an upper layer of dashboards and analytics and were judged to provide a unique product that was well suited to the needs of the project. A key consideration was the way in which the Urban Pulse platform operates as a city-wide data aggregation platform and is structured to allow and encourage direct integration with third party modules and software. Urban Pulse was used to create the Public Dashboard and Council Dashboard and incorporated a range of other functions such as data threshold alerts, the public API, and hosting of actuation command modules.

The development of TULIP as an integrated open modular data architecture solution has involved close collaboration between development teams at multiple organisations (notably UTS, Nokia, Reekoh and Urban Institute). Senior staff and development staff are included in the project Technical Team and attended weekly teleconference ‘Work In Progress’ meetings as well as corresponding closely between meetings. All partners saw mutual benefit in project involvement and worked with an understanding that the task at hand was inherently open and experimental. Learnings and capacities developed through collaboration helped to build the capacity of TULIP, prove the open modular architecture model, and provide direct value to partners as a demonstration of how their product works in the context of a larger ecosystem.

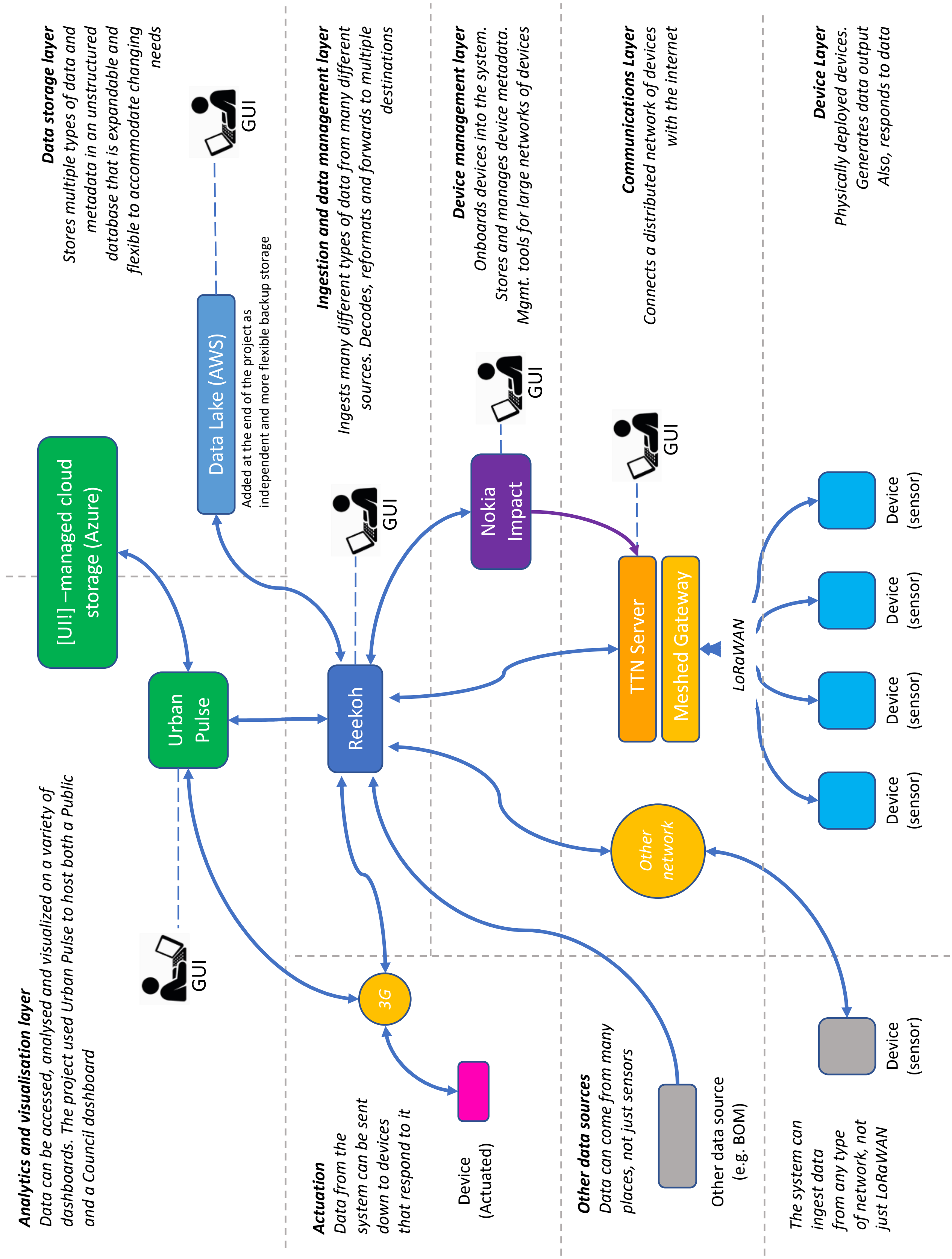


Image: 23 - TULIP data architecture

Overview of the UrbanPulse Council Dashboard

The UrbanPulse is a tool that takes data from sensor data streams such as environmental sensors as well as from existing systems such as Enterprise Resource Planning, open public transport data or billing systems. It can then store, analyse and visualise that data so that city officers can better understand what's happening in their city and provide more cost-effective and innovative services. UrbanPulse is powered by the KX platform. For TULIP, the UrbanPulse is being used to process environmental data from a number of environmental sensors installed in Lake Macquarie and Sydney. Urban Pulse can be used to build customised dashboards tailored to specific use cases. For this project, two dashboards were built: a Council dashboard; and a Public Dashboard.

The Council Dashboard provides a visual display of information pushed to it from TULIP environmental sensors deployed in Lake Macquarie and Sydney and is designed to be used by Council administration staff. It is accessible via a custom URL and personal login.

Core features of the [ui!] Council Dashboard

- **Sensors visible on a Google Map** - All sensing devices visible as pins on an embedded Google map, with tooltip metadata information visible when hovering the mouse over a sensor.
- **Advanced search and filter** - Ability to search and filter the list of available sensing devices (by multiple metadata and telemetry fields) to view a smaller sub-set on the map and in a selectable list.
- **Multi-telemetry graphing** - Ability to plot multiple telemetry streams of the same type on one graph, allowing comparison of data between two or more locations.
- **Graph zoom function** – Zoom in on a shorter time period on the graph to view finer temporal detail.
- **Custom downloads** - User-defined telemetry and metadata downloads (CSV).

Features unique to the Council dashboard
(not available on Public Dashboard)

- **Metadata management** - Ability to view and edit all metadata associated with deployed devices.
- **User-adjustable display** - Ability to for the user to adjust the size and position of the different viewing panes in the dashboard (e.g. expand the map or graph box in order to show greater detail).
- **Offline sensors** – Offline sensors are listed, with a user-adjustable reporting threshold (e.g. list as 'offline' if not heard from for >1hr).
- **Telemetry threshold breaches** – user-adjustable telemetry thresholds can be set, with alerts issued when breached (e.g. generate alert in dashboard when temperature sensor X sends a reading >40°C).

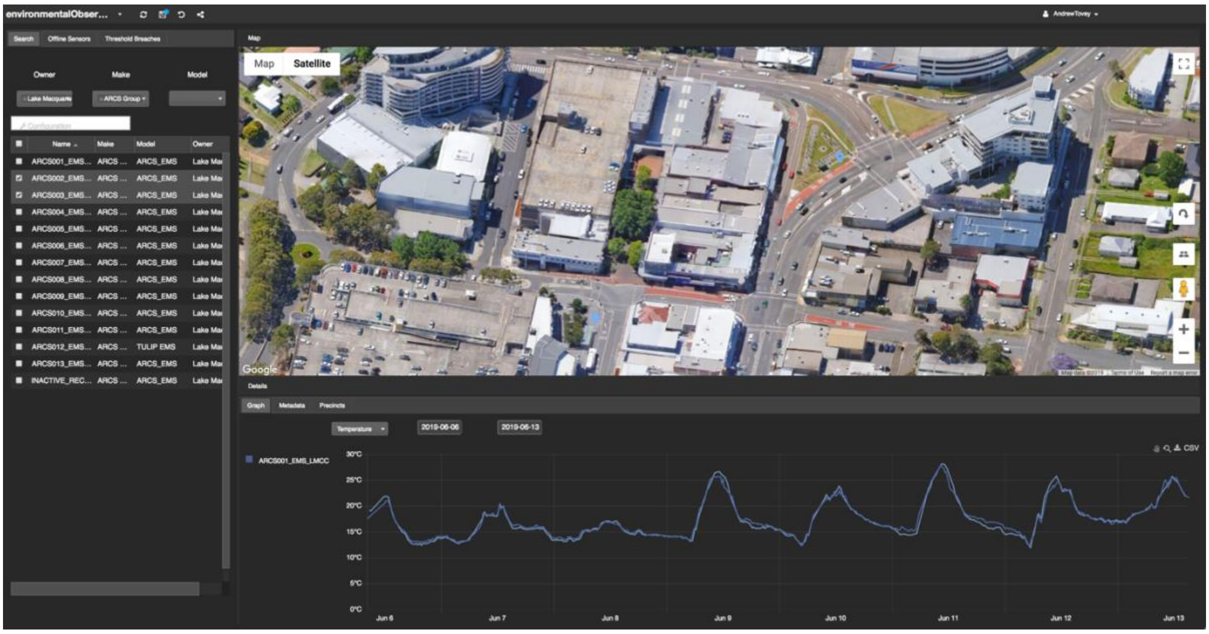


Image: 24 - Overview page of the council dashboard

Overview of the UrbanPulse Public Dashboard

The UrbanPulse is a tool that takes data from sensor data streams such as environmental sensors as well as from existing systems such as Enterprise Resource Planning, open public transport data or billing systems. It can then store, analyse and visualise that data so that city officers can better understand what's happening in their city and provide more cost-effective and innovative services. UrbanPulse is powered by the KX platform. For TULIP, the UrbanPulse is being used to process environmental data from a number of environmental sensors installed in Lake Macquarie and Sydney. Urban Pulse can be used to build customised dashboards tailored to specific use cases. For this project, two dashboards were built: a Council dashboard; and a Public Dashboard.

The Public Dashboard provides a visual display of information pushed to it from a selected sub-set of TULIP environmental sensors deployed in Lake Macquarie and Sydney. The visible metadata is also a slected sub-set of the total fields available. The Public Dashboard is designed for general use by the public and can be accessed via a URL with no personal login required. It has been the primary means by which participants in the Adopt-a-Sensor initiative have viewed and accessed their data.

Core features of the [ui!] Public Dashboard:

- **Sensors visible on a Google Map** - All sensing devices visible as pins on an embedded Google map.
- **Simple search and filter** - Ability to search and filter the list of available sensing devices (by telemetry type and date range) to view a smaller sub-set on the map and in a selectable list.
- **Advanced view page** – More complex graphing tools
- **Graph zoom function** – Zoom in on a shorter time period on the graph to view finer temporal detail.
- **Custom downloads** - User-defined telemetry and metadata downloads (CSV)

Features unique to the Public dashboard *(not available on Council Dashboard)*

- **Selectable map icons** – Icons on the map can be selected and the corresponding sensor will be selected in the search list. This is a feature introduced based upon user feedback from use of the Council Dashboard.
- **Double Y-axis telemetry graphing** - Ability to plot two telemetry streams of different types on one graph, using two different y-axes. Cannot plot more than two telemetry streams of the same type on one graph (which is possible in the Council Dashboard)

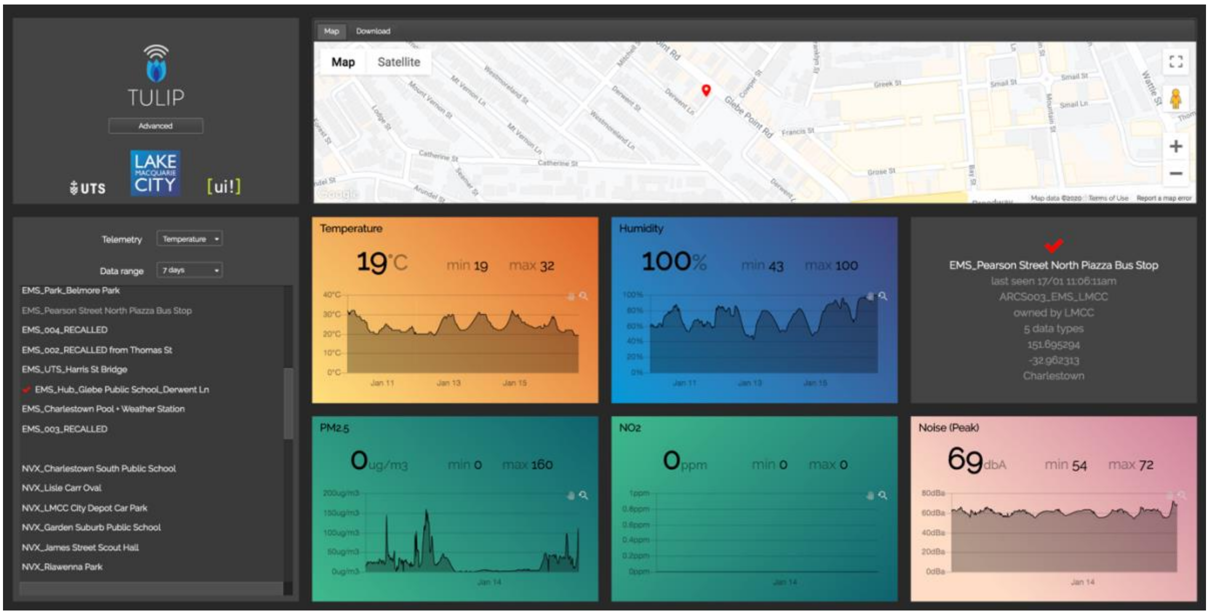


Image: 25 - Overview page of the Public Dashboard

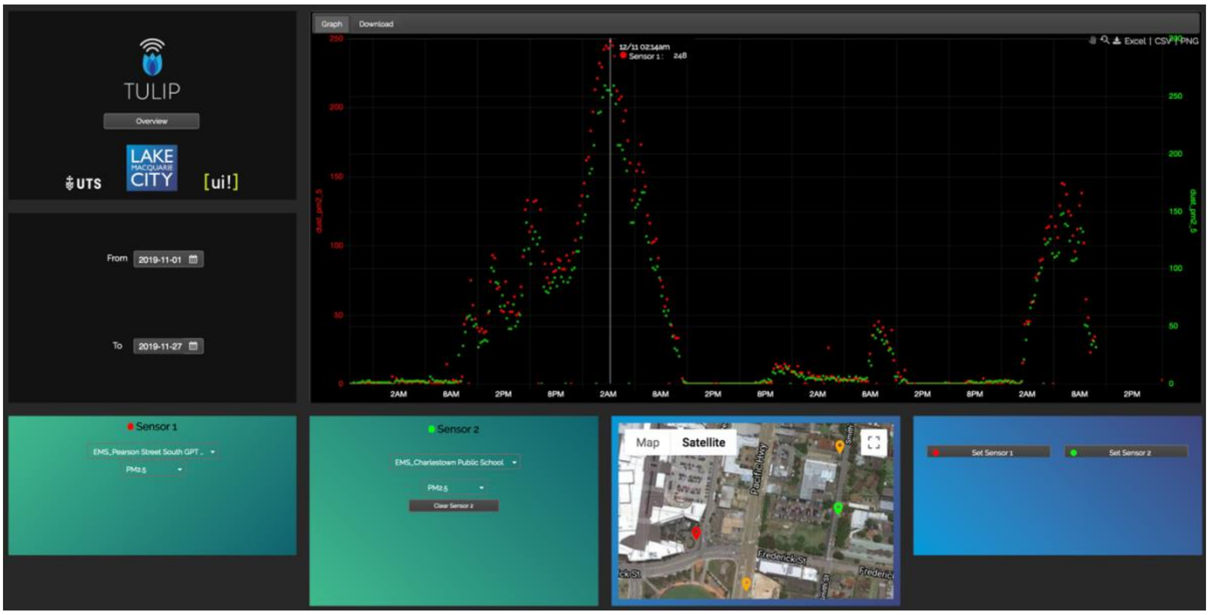


Image: 26 - Advanced graphing page of the Public Dashboard

Advanced graphing

Here we see two EMS sensors selected in Charlestown, Lake Macquarie, in locations that are only a few hundred metres apart. The elevated PM2.5 levels correspond with a major bushfire smoke event on the 12th of November 2019. The ability to graph multiple telemetry streams together allows the user to see variation between the two locations.

Data Modelling for TULIP

Within the context of the project, the ‘data model’ was conceived as a framework for labelling and managing data across the multiple layers of the platform.

What data a system needs to hold, where in that system the data should reside and what relationships there are between the data are all immensely important considerations.

Summary of key project learnings regarding data modelling

- Within the time and budget constraints of an 18 month grant-funded project, practical solutions that expedite the project’s critical path will tend to dictate simplified approaches that do not necessarily align with best practice. This was the case with the TULIP data model for this project.
- We do not know of an appropriate existing standard of metadata labelling urban microclimate modelling, or for broader smart city sensor use cases. In the absence of a standardised experimental methodology for distributed urban micro-climate monitoring (and given that it may not even be possible to standardise such a methodology), agreement on a standard ontology for device deployment metadata becomes critical. In other words, if we cannot guarantee that all devices will deployed in the same way then we must seek to record information about how they have been deployed in a standardised fashion so that they can be compared.
- A data model cannot be conceived as a single framework that spans all components of a multi-layered architecture, as originally conceived during the early stages of the project. Data models must relate to the relationship between two entities and no more. A modular architecture like TULIP should therefore have multiple data models that are only loosely coupled.

Step 1: An idealised data model concept

An idealised early concept for a 'TULIP data model'

During the initial phases of the project, as the first devices were procured and required provisioning into the TULIP platform, all the partners collaborated to explore a common understanding of both the data model requirements and implementation of these requirements.

The initial consideration of a TULIP data model included the ability to model various distinct objects or entities:

Device type, and specific devices

A generic device type with various common attributes may be modelled as separate to a specific unique device, which has both device type and unique identifiers as its attributes.

Sensor type, and specific sensors

A device houses multiple sensors. Some sensor types (e.g. gases) have a lifetime shorter than a device and may be swapped out for a replacement. Each specific sensor may also have unique attributes relating to its calibration, of relevance to the decoding of its data output. Therefore in an ideal world each sensor within a device should exist as a separate object. This in turn requires the model to accommodate a generic sensor type (manufacturer, model, etc.), and a specific sensor (serial number, etc.).

Users as digital entities with defined permissions

Multiple users of the platform may be granted different access privileges. A user may also be connected to device ownership, data access and ownership, or specific activities such as device onboarding or device management. Creating a list of users and user metadata thus becomes a critical component of the idealised model.

Locations as distinct entities with which data and devices may be associated

Locations should ideally be modelled as separate entities to devices and users. A single location may host two or more devices. Or it may host one device for a period, then host a replacement device, with a continuous data record associated with that location that is not tied to one device.

Commonly agreed telemetry lists

A telemetry list needs to be agreed between the part of the platform that decodes sensor data and the part of the platform that visualises it. The list defines labels and units.

A first draft of an idealised data model was produced:

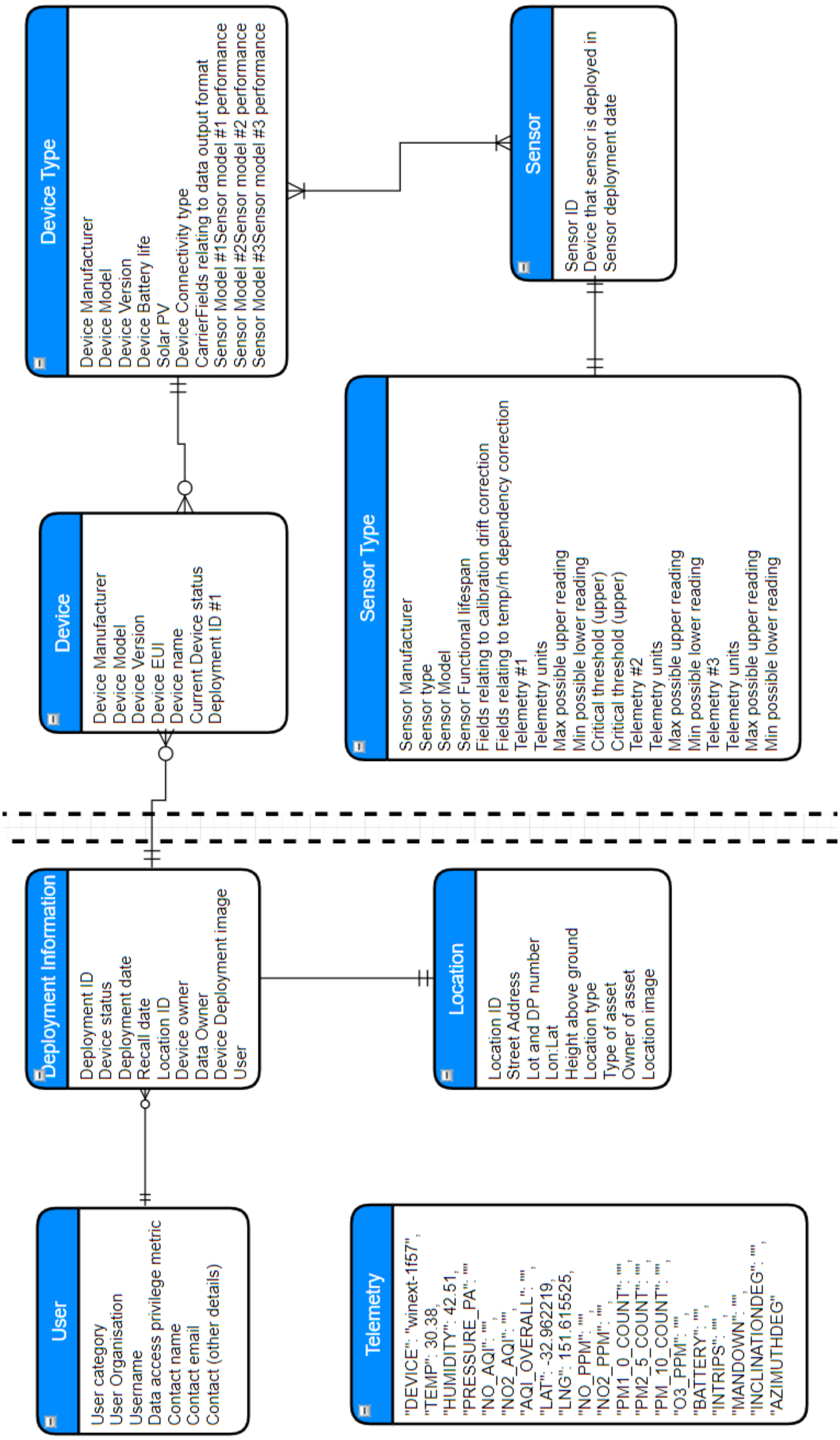


Image: 27 - the first idealised TULIP data model

Step 2: A simplified 'working data model'

The initial concept for an 'idealised' data model proved to be too complex to implement within the bounds of the project. With devices in need of provisioning and limits to what platform partners could reasonably explore within project constraints, it became necessary to agree upon a simplified working data model for immediate practical use. This became two fixed lists for telemetry and metadata fields.

In practice, these lists were updated throughout the project, leading to multiple versions. This created a number of practical challenges discussed below in part B.

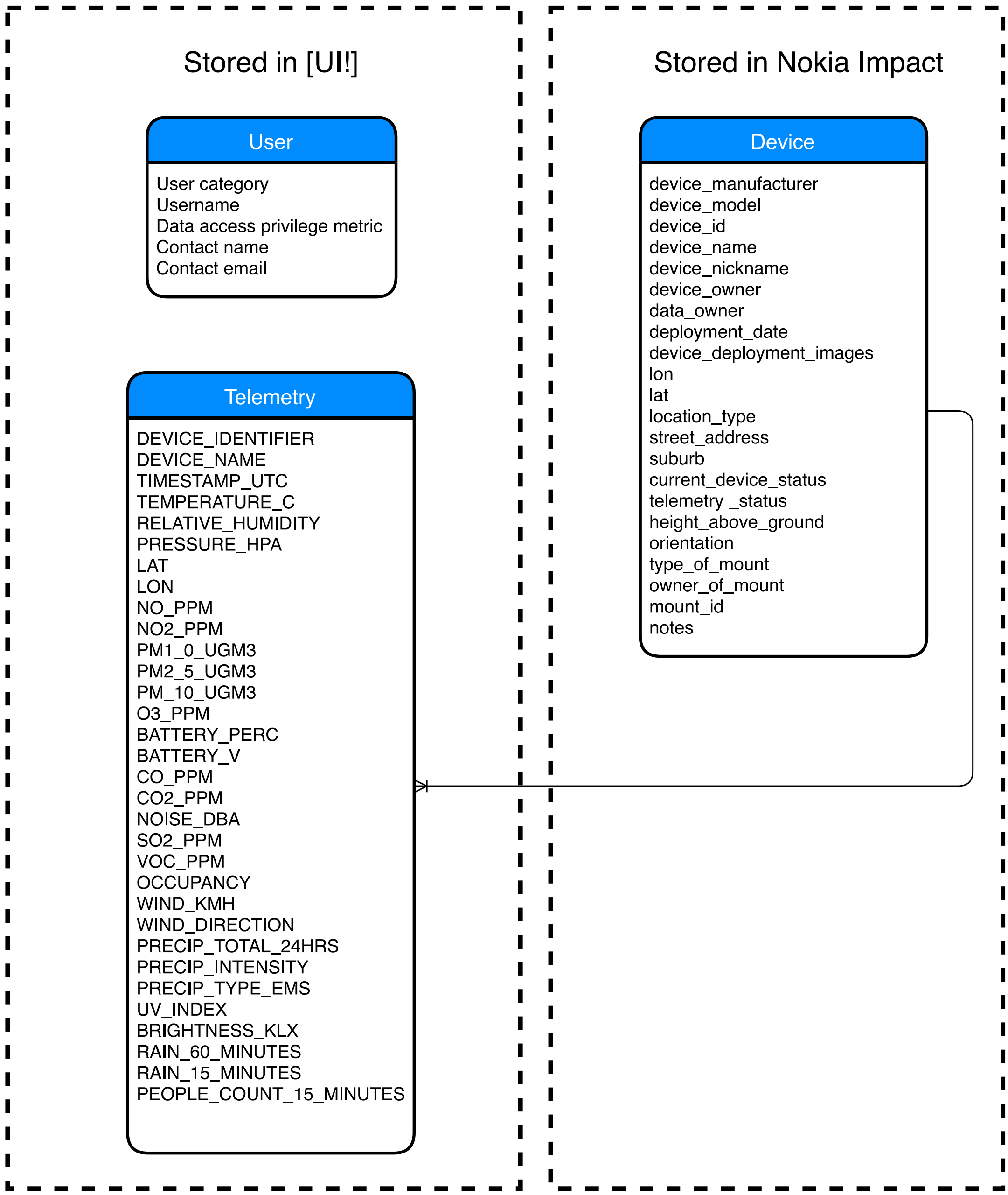


Image: 28 - Revised and simplified working data model that was actually implemented for the project

Discussion

A lack of standardised data ontology

A data ontology in this context refers to the language or knowledge system associated with data. It is critical for interpreting data and shifting it from a loose unstructured state to an organised structured state that can support meaningful outcomes. At a basic level, the data ontology is the collection of commonly agreed terms that we use to label telemetry and metadata. With telemetry, this relates to units used (e.g. degrees Celsius), as well as to the specific form of notation (e.g. we might agree to write 'Temperature_C' as short-hand for a telemetry type). For metadata, it covers the descriptor (e.g. height above ground) and units (e.g. m).

Different parts of the platform need to have a shared data ontology, or otherwise we need to be able to translate from one set of terms to another. It makes good sense for the whole system to utilise a data ontology that is established more broadly. For example, meteorology in Australia tends to used degrees Celsius, as opposed to Fahrenheit. Convention uses 'Temperature' as opposed to a shortened 'Temp'. The use of an underscore, brackets or other separator between a word and unit is not so clearly standardised and this is also part of the consideration. Loose convention in IoT provides a guide but a specific notation convention is not universally accepted.

Metadata ontology is often more complex still. For example, if TULIP uses height above ground, we are measuring the height in metres, to two decimal places, from the ground immediately beneath the pole or wall that a device is attached to. However, another project may choose to work with the Australian Height Datum (AHD), which is an official and widely used geoscience standard for height above sea level. AHD can be simply derived from Longitude, Latitude and 'height above ground', thus third party users of TULIP data can determine it for all our sensors. The critical point is that such users must have clear information about what they are actually looking at. Consider a device deployed at a beach, which might be 3m above the ground, with a 4.5 metre AHD value (i.e. the two values are relatively close and can be easily confused). If the metadata states 'deployed height of device (m)' then it is impossible to know for certain what its true deployment height is. TULIP devices have 25 metadata fields and for each of these, thought has gone into precisely what we are recording and how we are recording it.

Two types of metadata

Metadata falls into two broad categories:

1. *Metadata about a device*
2. *Metadata about telemetry*

Metadata about a device includes administrative details (e.g. EUID, date of deployment, etc.) and deployment details. Deployment details are critical as they capture the context in which telemetry is captured and across multiple devices they stand as a record of methodology employed. As a rule, metadata about a devices tends to stay fixed and is used for device management and for more advanced data analytics (e.g. understanding patterns and trends in environmental data).

Metadata about telemetry tells the data platform how to decode and manage that telemetry. For example, certain types of sensor experience calibration drift and this can be corrected using a correction factor that is unique to a specific sensor. The unique correction factor for a sensor may be derived from analysis of past telemetry. This sort of metadata tends not to be fixed and is often derived by the system. Its inclusion is therefore necessarily more complex than metadata about a device. The working data model implemented for this project only covered metadata about the devices. Inclusion of more sophisticated analytics functionality and its accompanying derived metadata is on the TULIP roadmap for future exploration.

Choosing a schema for deployment metadata

We are not aware of any comprehensive or widely acknowledged data labelling standards for the capture of deployment metadata in the context of distributed urban microclimate monitoring. The decision about what information to capture about the deployment context of a device was dictated predominantly by practical considerations but included consideration of existing administration systems and some limited reference to established methodologies, where applicable.

Practical considerations require a primary description of location, including longitude, latitude and height above ground, enabling a device deployment to be identified as a precise location in three dimensions. Additional metadata fields capture finer details, such as the orientation of a device on a pole, as well as the type of pole or fixed asset that the device is mounted on. These details are known to have a potential impact on sensor readings. For example, the thermal mass of a street pole, or its shadow, may interfere with a temperature reading and a record of such details may be valuable for future data interpretation. Countless other specifics of a location are also likely to impact measurements from sensors. For example, the distance of a wall or building. However, the complexity involved with meaningful capture of such details rapidly increases as we move outwards from a device. If we wish to record the distance of a nearby building then we also need to record what material the wall is made from, what direction it is in, what colour it is, how much direct sun it receives, what its radiative profile is throughout the day, and so on. Otherwise the distance measurement on its own is not meaningful. There is similar complexity if we consider the ground beneath a device, nearby tree canopy, and the fluctuations of sun, shadow and wind throughout the day. To capture even a modest amount of detail about the area immediately surrounding a deployed device, it becomes clear that we need to start working with advanced 3D environmental modelling such as we see emerging in City Information Modelling (CIM). As of 2019, following the success of the Smart Liveable Neighbourhoods Project, UTS has begun to work with global GIS-provider ESRI to explore this space. It seems likely that future integrations of distributed microclimate data, GIS and CIM will allow metadata capture and management to expand greatly in sophistication and this in turn may support significantly more complex data analysis, modelling and insights.

For further discussion of the practicalities of device deployment, please refer to section 6 and APPENDIX E of this report.

Lessons learned: TULIP data modelling

Our rigid approach to metadata and telemetry is now understood as a critical pain point

The approach taken to fixed metadata and telemetry lists between Reekoh and UI was born of necessity, in that it was the simplest and shortest path to project delivery. However, combined with associated limitations of the architecture (notably the position and management of data storage), our fixed lists removed a great deal of freedom and flexibility in the system, reduced UTS' direct control, and created significant delays in device onboarding. The project was inherently experimental and this lack of flexibility and control constricted our options and our productivity.

In real terms, adding a new device type involved the addition of new telemetry types and new metadata fields to our lists. Use cases evolved iteratively through the project, as did our understanding of appropriate deployment methodology. This meant that we were generating updated telemetry and metadata lists on an almost monthly basis. Those updates took the form of requests to Reekoh and UI and the nature of those platforms and our positioning of them meant that carrying out those requests was somewhat complex and involved a significant amount of development time. Regular requests for changes therefore created a tension and a strong pressure on UTS from partners to settle on final fixed lists. Working with the evolving demands of the project meant that this was challenging and ensured that the requests (and tensions) continued through to the end of the project. Final fixed lists were of course set, and they fit the needs of TULIP as things currently stand. However there is now a realisation that the fixed list approach is the real source of the problem, and will continue to be unless a new more flexible and expandable approach is adopted.

The need for loose coupling

In systems with multiple components, the relationship between any two components should, as far as possible, be decoupled from the wider system. The reason for this is that if an issue arises between two components, or if a change is required, it is best to isolate that issue or change rather than letting it create knock-on effects through the system that lead to a much greater overall impact. The TULIP architecture for the Smart Liveable Neighbourhoods project had a fixed relationship between three critical components: Reekoh, UI and UI's database of record (an AWS cloud service). What this meant was that when a new device type was added, its data could not be stored until UI and Reekoh updated their shared TULIP data model to accommodate the new telemetry and metadata fields required. In this scenario, UTS lacked direct access and control over data storage, our workflow became dependent upon the actions of third parties, and early data from the new device was lost.

In a loosely coupled approach, primary storage (the database of record) would not lie with UI, but would be an independent node in the architecture, with direct access possible for UTS. A data model would be created between that storage and Reekoh and this would be *separate* to the data model between Reekoh and UI. In this scenario, data from a newly added device type could be stored immediately in an unstructured format, ensuring that no data is lost. This storage could occur independently to any updates required to the Reekoh-UI data model. The purpose of the Reekoh-UI data model would be reduced to support UI's function as an analytics and visualisation platform at the top of the TULIP stack and it would cease to be a bottle neck that Impacts the whole system. The loose coupling approach should extend to all APIs in the TULIP architecture, whether they are internal (i.e. between layers of the TULIP architecture), or external (i.e. between TULIP and a third party). Each API needs its own flexible and independent data model that is designed to meet the needs of that specific relationship and end user.

A note regarding existing frameworks

The project team is aware of certain existing data frameworks that have gained some attention in smart city circles and we will acknowledge them here:

a) Fiware

Fiware is ‘a curated collection of opensource platform components’ that are in widespread use in over 100 cities, by a large and growing community of tech startups. It is most prevalent in Europe. Fiware includes guidelines for smart city data model development and standardised APIs, and an opensource code library is available for developers. UTS is aware of at least one Australian city council that has explored Fiware in some depth and built their city IoT platform using adapted Fiware elements. The TULIP team believes that Fiware may be worth investigation in future.

b) HyperCat

HyperCat is a UK-based IoT labelling standard backed by a consortium of 40 companies. It is essentially an online library of metadata labels that an IoT platform can query. The aim is to standardise data labelling for the purpose of facilitating greater interoperability and data sharing. Following its launch in 2014, HyperCat enjoyed a great deal of attention in the smart city community as it promised to solve a number of widely recognised problems relating to the lack of shared data standards. In the last couple of years, attention has waned and for whatever reason, HyperCat has not enjoyed the widespread uptake that many first hoped to see.

The original project pitch for the Smart Liveable Neighbourhoods project (made in 2017) actually identified HyperCat as a labelling standard that we would seek to implement. Once we began to work with partners to deliver solutions for the project, it became clear that HyperCat was not suited to our needs, despite the fact that Reekoh actually had a previously built Hypercat module operational. We were working multiple platform partners and not all of them used HyperCat so it didn’t work for us. We. Therefore dropped HyperCat integration from our delivery plans.

11 Appendices

- APPENDIX A - Governance Arrangements
- APPENDIX B – LMCC staff co-design workshop (11th April 2018)
- APPENDIX C: Phase 1 devices (not deployed at scale)
- APPENDIX D – TTN gateway deployments
- APPENDIX E – Device pre-provisioning and provisioning process
- APPENDIX F - Smart Liveable Neighbourhoods Challenge: Five Winning Entries
- APPENDIX G - TULIP device telemetry schema
- APPENDIX H – TULIP device metadata schema

APPENDIX A: Governance Arrangements

Smart Cities & Suburbs Round 1 Project: Liveable Neighbourhoods in Lake Macquarie and Sydney

Project Delivery Team

Name	Title	Department and organisation	Role and responsibilities
Andrew Tovey	Senior Research Consultant; TULIP Program Manager	Institute for Sustainable Futures / Knowledge Economy Institute, UTS	Project Manager Project strategy and management; partner and stakeholder engagement; work stream integration; project and use case co-design; tech procurement; study design; device deployment planning and production; communication and activation co-design; research and reporting co-author Grant management and milestone reporting
Ed Tyson	TULIP Technical Manager	Knowledge Economy Institute, UTS	Device onboarding and management; platform and integration development
Tom Boyle	Strategic Planner	Integrated Planning – Development and Planning, LMCC	LMCC Project Manager Liaison; Project lead and strategy at LMCC; project and use case co-design; tech deployment; communication and activation co-design *Left role prior to completion of project*
Catherine Pepper	Senior Sustainable Living Officer	Environmental Systems - Built and Natural Assets	Task support and advice – IoT integrations and environmental systems *Left role prior to completion of project*
Samantha Hardie	Strategic Planner	Integrated Planning - Development and Planning	LMCC project delivery assistance; people counting data interpretation; urban acoustics and development policy; smart mural integration liaison

			Joined project delivery team following departure of Tom Boyle
Kent Plasto	Strategic Planner	Integrated Planning - Development and Planning	LMCC project delivery assistance; adopt-a-sensor lead *Joined project delivery team following departure of Tom Boyle*
Ben Maddox	Sustainability Analyst	Environmental Systems – Built and Natural Assets	Task support and advice – IoT integrations and environmental systems; Waste receptacle integration; AusGrid Liaison (for device mounting) *Joined project delivery team following departure of Catherine Pepper*
Nik Midlam	Manager Carbon Strategy	City of Sydney	

Project Control Group

This group met monthly throughout the project and provided technical and strategic oversight, with a focus on Lake Macquarie. Relationships:

- Liaises with strategic & technical advisors
- Liaises with Pearson St Mall upgrade PCG
- Facilitates ChIP and Speers Point sprint teams

Name	Title	Department and organisation	Role and responsibilities
Andrew Tovey	Senior Research Consultant; TULIP Program Manager	Institute for Sustainable Futures / Knowledge Economy Institute, UTS	Project Manager Project strategy and management; partner and stakeholder engagement; work stream integration; project and use case co-design; tech procurement; study design; device deployment planning and production; communication and activation co-design; research and reporting co-author Grant management and milestone reporting
Frank Zeichner	Director, Knowledge Economy Institute	Faculty of Engineering and IT, UTS	Expert direction and oversight; TULIP architecture development; high-level design for data modelling; high-level design for international standards benchmarking; partner engagement and work stream integration
Tony Farrell	Deputy CEO, Planning for the Future	LMCC	Executive Oversight, LMCC
Wesley Hain	Manager Integrated Planning	Development and Planning, LMCC	Project direction advice
Tom Boyle	Strategic Planner	Integrated Planning – Development and Planning, LMCC	LMCC Project Manager Liaison; Project lead and strategy at LMCC; project and use case co-design; tech deployment; communication and activation co-design *Left role prior to completion of project*

Catherine Pepper	Senior Sustainable Living Officer	Environmental Systems - Built and Natural Assets	Task support and advice – IoT integrations and environmental systems *Left role prior to completion of project*
Samantha Hardie	Strategic Planner	Integrated Planning - Development and Planning	LMCC project delivery assistance; people counting data interpretation; urban acoustics and development policy; smart mural integration liaison *Joined project delivery team following departure of Tom Boyle*
Kent Plasto	Strategic Planner	Integrated Planning - Development and Planning	LMCC project delivery assistance; adopt-a-sensor lead *Joined project delivery team following departure of Tom Boyle*
Ben Maddox	Sustainability Analyst	Environmental Systems – Built and Natural Assets	Task support and advice – IoT integrations and environmental systems; Waste receptacle integration; AusGrid Liaison (for device mounting) *Joined project delivery team following departure of Catherine Pepper*

Task Support

Core support, UTS

Name	Title	Department and organisation	Role and responsibilities
George Pang	Accountant, Research, Faculty Finance	Faculty of Engineering and IT, UTS	Assistance with UTS project accounting
Xavier Mayes	External Communication Officer	Institute for Sustainable Futures, UTS	Media and communications support
Jane Easton	Technical Officer	Institute for Sustainable Futures, UTS	Media and communications support

Core support, LMCC

Name	Title	Department and organisation	Role and responsibilities
Thomasen Knight	Sustainability Engagement Officer	LMCC	Adopt-a-sensor schools liaison
Neil Keene	Communications and Engagement Officer	Communications – Organisational Services, LMCC	Media and communications support
Ben Maddox	Sustainability Analyst	Environmental Systems – Built and Natural Assets	Waste receptacle integration; AusGrid Liaison (for device mounting)
Bryn Hernandez	Sustainable Living Officer	Environmental Systems – Built and Natural Assets	Speers Point Swim Centre Optimisation Liaison
Joshua White	Urban and Public Art Project Leader	Cultural Services – Service Delivery	Chimera sculpture environmental data integration
Neale Farmer	Sustainability Officer Climate Change Adaptation	Environmental Systems – Built and Natural Assets	Urban heat resilience policy integration
Daniel Woods	Snr Sustainability Officer Environmental Health	Environmental Systems – Built and Natural Assets	Air quality policy integration

Tani Mitchison	Cadet Sustainable Living Officer	Environmental Systems – Built and Natural Assets	Data analysis and interpretation

Core support, City of Sydney

Name	Title	Department and organisation	Role and responsibilities
Frank Morosin	Principal Engineer Electrical & Furniture Assets	City of Sydney	Sensor deployment planning and approvals
Joel Johnson	Manager, City Greening & Leisure	City of Sydney	Sensor deployment planning and approvals

UTS research

Name	Title	Department and organisation	Role and responsibilities
Nic Surawski	Lecturer, School of Civil and Environmental Engineering	Faculty of Engineering and IT, UTS	Sensor benchmarking and reporting lead
Didar Zowghi	Professor of Software Engineering, School of Software	Faculty of Engineering and IT, UTS	A benchmarking framework for smart city platforms and architecture – co-author
Murray Hall	Research Principal	Institute for Sustainable Futures, UTS	Emerging technologies for climate responsive neighbourhoods research and report; Urban heat data analysis and reporting
Quang Ha	Associate Professor, School of Electrical and Data Engineering	Faculty of Engineering and IT, UTS	Air quality data analysis and reporting lead
Xiaojun Qui	Professor in Audio, Acoustics and Vibration, School of Mechanical and Mechatronic Engineering	Faculty of Engineering and IT, UTS	Noise data analysis and reporting lead
Mahdi Fahmidehgholami	Research administrator, School of Software	Faculty of Engineering and IT, UTS	A benchmarking framework for smart city platforms and architecture – co-author
Santanu Metia	Casual Academic	Faculty of Engineering and IT, UTS	Air quality data analysis and reporting – research assistant
Tran Hiep Dinh	Administrative Assistant, International Recruitment	Faculty of Engineering and IT, UTS	Air quality data analysis and reporting – research, design and publication assistant
Jiaxin Zhong	PhD student, School of Mechanical and Mechatronic Engineering	Faculty of Engineering and IT, UTS	Noise data analysis and reporting – research assistant
Xiao Tong	PhD student, School of Mechanical and Mechatronic Engineering	Faculty of Engineering and IT, UTS	Noise data analysis and reporting – research assistant
Ben Madden	Senior Research Consultant	Institute for Sustainable Futures, UTS	Urban heat data analysis and reporting
Emily Prentice	Research Consultant	Institute for Sustainable Futures, UTS	Urban Heat Monitoring Trial (Report to City of Sydney, 2018) – lead author

Brent Jacobs	Associate Professor and Research Director	Institute for Sustainable Futures, UTS	Urban Heat Monitoring Trial (Report to City of Sydney, 2018) – Research supervision

Technology for Urban Liveability Program (TULIP), Technical Delivery Team

Name	Title	Department and organisation	Role and responsibilities
Andrew Tovey	Senior research consultant; TULIP Program Manager	Institute for Sustainable Futures, University of Technology Sydney	Project strategy and management; partner and stakeholder engagement; work stream integration; project and use case co-design; tech procurement; study design; device deployment planning and production
Frank Zeichner	Director, Knowledge Economy Institute (KEI)	Knowledge Economy Institute (KEI), University of Technology Sydney	TULIP architecture development; high-level design for data modelling; high-level design for international standards benchmarking; partner engagement and work stream integration
Ed Tyson	TULIP Technical Manager	Knowledge Economy Institute, UTS	Device onboarding and management; platform and integration development
Simon Kaplan	CEO, [ui!] APAC	[ui!] the urban institute	Data platform development and integration
Liz Armstrong		[ui!] the urban institute	Data platform development and integration
Tynan McKay	Design & Systems Engineer	[ui!] the urban institute	Data platform development and integration
Helen Airiyan	Sales Director	Reekoh	Data platform development and integration
Andrei Hawke	Technical Solutions Manager	Reekoh	Data platform development and integration
Jamie Chard	*Contracted engineer at Nokia*	Nokia	Device management and onboarding; data platform development and integration
Catherine Caruana-McManus	Director, Sales and Strategy	Meshed	LoRaWAN network; device procurement and configuration
Andrew Maggio	Founder and Director of Operations & Technology	Meshed	LoRaWAN network; device procurement and configuration
Phil Lock	Director	ARCS Group	Custom sensor development (TULIP EMS)
Isaac Correia	Developer	ARCS Group	Custom sensor development (TULIP EMS)
Satish Hrit	Engineering IoT Solutions	Bosch Australia	Sensors and support

Heath Rafferty	Founder and Director	Newie Ventures	Custom actuation device (TULIP Rosella)
Mitch Bright	Developer	Newie Ventures	Custom actuation device (TULIP Rosella)

Advisors

Name	Title	Department and Organisation	Role and responsibilities
David Middleton	Special Projects Officer	Community Assets - Built and Natural Assets, LMCC	Pearson St Mall upgrade liaison; Nightlight sculpture integration liaison
Kate Davies	External Stakeholder Relations	Customer Service and Communications, LMCC	Media advice *Time pressures. Removed version 3.*
Emily Ownly	Business Systems Coordinator	Business Systems – Organisational Services, LMCC	Corporate systems advice
Emma Waterhouse	Business Transformation Lead	Business Transformation – Organisational Services, LMCC	Advice on amenities block usage monitoring BI project and workshop facilitation and BI program integration
Caitlin Botha	Business Transformation Lead	Business Transformation – Organisational Services, LMCC	Advice on BI program integration
Brooke Humphries	Chief Information Officer (former)	Corporate Information, LMCC	Present for first phase of project. Developed LMCC data policy in collaboration with project delivery team. *No longer at LMCC*
Kate Deacon	Executive Manager - Strategy & Urban Analytics	City of Sydney	Smart city strategy integration

APPENDIX B: LMCC staff co-design workshop (11th April 2018)

This workshop was held to engage key members of staff from across Lake Macquarie City Council. The aim was to explain the TULIP/ChIP project and the technology behind it, explore how their particular areas of interest and operations overlapped and ultimately to build a sense of ownership and enthusiasm for the project.

Attendance: 35 persons including Council staff, project partners and Hunter Water Corporation

- Strategic Planner Economic Focus
- Land Development Officer
- Corporate Information Coordinator
- Sustainability Analyst
- Manager Leisure Services
- Business Transformation Leads
- Senior Sustainability Officer
- Workforce Analyst
- Pearson St Mall Upgrade Project Manager
- Business Systems Coordinator
- Strategic Planner GIS Technician
- Manager Asset Management
- Compliance Coordinator
- Manager Cultural Services
- Infrastructure Assets Section Manager
- Waste Officer
- External Stakeholder Relations Officer
- Business Coordinator Waste and Environmental Services
- Senior Sustainability Officer – Climate Change Adaptation
- Environmental Security Project Officer
- Executive Officer
- Development Contributions Project Delivery Officer
- Landscape Architect – Pearson St Mall Upgrade
- Strategic Planner & Digital Economy Officer
- Chief Information Officer – Hunter Water

- Deputy CEO

An overview of workshop activities

Activities 1 and 2 focused not on technology, but on challenges faced by council staff in their work. We wanted to start with these challenges, identifying and positioning them as the basis for smart city use cases.

Activity 1: Share your aspirations or challenges

In groups of 3-5:

1. Share your role or operational area within Council.
2. Share a challenge you face with a particular project you're working on or service you deliver. This can be a longer term Council aspiration or target, or a day to day challenge.
3. Write down your aspiration or challenge - one per sticky note, use big writing. See template questions on your desk.

Example challenge:

Our customers tell us public toilets aren't cleaned regularly enough, but we can only clean on a semi-regular basis, and we don't have a good picture of when might be the best time to clean different areas.

Example aspiration:

We want to improve the customer experience of using public toilets.

Activity 2: Clustering aspirations and challenges

A representative from each group:

1. Stick your aspirations or challenges to the wall. Read them out to the room as you go.
2. Try to cluster things into groups

What do we notice?

Are there any emerging themes?

Image: 29 - Clustered challenges from Activity 2

Activity 3: Unpacking and responding to aspirations and challenges

Activity 3 was about building links between identified challenges and data gaps, pointing the way towards data-driven solutions. An aim was for people to discover how data can be integral to a broad range of challenges, including the ones that they face.

- *Form a new group.*
- *Select on aspiration or challenge from the wall - what feels most pressing?*
- *Run through the template print out on your desk.*

Step 1: Vision Words (desired future state)

Write down some vision words that describe a world where your aspiration has been achieved or your challenge overcome.

<u>Example</u>

Challenge: Main roads and adjacent areas have poor liveability and are not places that people want to be in.

Vision: We have beautifully designed, comfortable, safe, clean, cool, inviting, interesting, quiet, etc. streets for people to enjoy.

Step 2: Strategies, actions and information

Thinking about your vision words, how do we get to that desired state?

1. What are some strategies or actions we could take (or are taking) to address this aspiration or challenge?
2. Could these strategies or actions benefit from more information?

Some thought starters

- *What do we need to know to help us carry out our actions?*
- *What data can empower us?*
- *Long-term strategic responses?*
- *Real-time operational/maintenance responses?*
- *Education and behaviour change?*

APPENDIX C: Phase 1 devices (not deployed at scale)

Phase 1 included all phase 2 devices. Devices listed below are phase 1 devices that were procured and tested, but did not make the cut for phase 2 scaled procurement. Exploration of this broader range of options led to critical project learnings about the nature of the device market.

For details of Phase 2 devices, please refer to the main body of this report.

Image: 30 - Winext temperature and humidity sensor

Winext Temperature and humidity sensor

Manufacturer	Winext
Device name	Temperature and humidity sensor
Telemetry	- Temperature; Humidity
Quantity procured	2
Use case	Urban heat monitoring
Notes	- Speers Point Pool, Lake Macquarie - LMCC Admin Building, Lake Macquarie Continual issues with devices dropping from network and requiring manual re-join. No automatic link check function. Additional concerns about lack of solar shield and weatherproofing.
Verdict	Two devices remain deployed. Decision made to not use these for scaled deployment. Seek alternative option. **Device dropped after phase 1**

Image: 31 - AirSpot City

Spot Sensors AirSpot City

Manufacturer	Spot Sensors
Device name	AirSpot City
Telemetry	- Temp - Humidity - Pressure (bar) - PM10/2.5/1 - NO2 - SO2 - CO - O3 - VOC - Noise - Battery voltage
Quantity procured	2
Use case	Heat, air and noise monitoring Benchmarking
Notes	- Prolonged issue with delayed delivery. Items received many months late. Items received with loose parts. No documentation supplied. Prolonged issue obtaining documentation. When documentation was obtained it did not adequately support device activation and onboarding. After many months perseverance and no small amount of wasted time and effort, devices were sent back to manufacturer and a full refund was received.
Verdict	Not functional (DOA). Devices returned to manufacturer. **Device dropped after phase 1**

Image: 32 - Libelium Smart City Pro

Libelium Smart City Pro

Manufacturer	Libelium
Device name	Smart City Pro
Telemetry	- Temp - Humidity - PM2.5 - NO2 - CO
Quantity procured	1
Use case	Heat and air monitoring Benchmarking
Notes	Device was benchmarked at UTS with telemetry gathered via direct USB connection. Subsequent difficulties activating and onboarding the device to TULIP via 3G connection. A signal was received into Reekoh, however we were unable to correctly configure the device itself.
Verdict	Very complicated device to configure, with poor supporting documentation. When benchmarked it performed relatively badly compared to the TULIP EMS. **Device dropped after phase 1**

Image: 33 - Elsys ERS PIR sensor

Elsys ERS Proximity Infrared

Manufacturer	Elsys
Device name	ERS Proximity Infra Red
Telemetry	- Count (proximity triggers per 15 minutes) - Temperature - Humidity
Quantity procured	2
Use case	Asset monitoring - public amenities
Notes	Two devices deployed in the public amenities block, Speers Point Park, Lake Macquarie. Initial difficulties interpreting data but eventual success.
Verdict	Devices performed satisfactorily. Treated as a trial. People counting not a focus for scaled deployment but Council may consider procuring more after the project. **Device dropped after phase 1** *Note: Since the end of the project, the two devices are in continued use and LMCC operations staff have subsequently made use of occupancy data to improve the cleaning roster for the amenities block*

Image: 34 - Netvox R72623B

Netvox R72623B

Manufacturer	Netvox
Device name	Netvox outdoor particulate monitor (R72623B)
Telemetry	- Temp - Humidity - PM2.5
Quantity procured	1
Use case	Heat and air quality monitoring Benchmarking
Notes	Very large and aesthetically unsuitable for deployment in civic spaces. Discovered that there was no simple way to benchmark the device in the lab because it could not be directly ported into. Some difficulty setting up.
Verdict	Not able to benchmark and unsuitable for scaled deployment. To be deployed on UTS campus as one-off. **Device dropped after phase 1**

Image: 35 - Bosch connected sensor node: Smart Agriculture

Bosch connected sensor node: Smart Agriculture

Manufacturer	Bosch
Device name	Bosch connected sensor node: Smart Agriculture
Telemetry	- Temp - Humidity - Pressure - Wind speed/direction - Rain - Solar radiation/reflectance - GPS - + additional specialist functions
Quantity procured	1
Use case	Smart parks
Notes	Device was supplied by project partner Bosch as part of the value of their direct project contribution. The device operated using its own low-powered proprietary local area network, with a 3G uplink to the Bosch cloud. Attempts were made to integrate the Bosch cloud with Reekoh and the wider TULIP network. While some progress was made, this ultimately proved to be too problematic. By the end of the project the device was still not successfully integrated. Furthermore, LMCC were quoted a recurring annual fee for access to the device data, following conclusion of the project. This fee was considered to be too high to justify.
Verdict	The device works as a standalone proprietary system and proved to be unsuitable for integration into a larger hybrid Council system, despite best efforts to do so. Recurring fees for data access were a significant barrier to adoption. **Device decommissioned at conclusion of project**

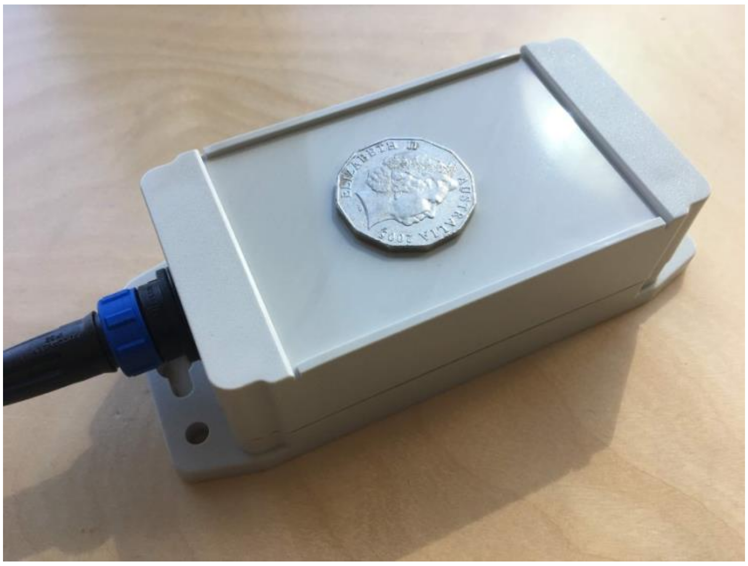


Image: 36 - Meshed nCounter

Meshed nCounter

Manufacturer	Meshed
Device name	nCounter
Telemetry	Radial proximity detection (silent wifi): - Count in (15 mins) - Count out (15 mins) - Total occupants (15 mins) - Dwell time (15 mins)
Quantity procured	LMCC: 3 UTS campus/test device: 1
Use case	Liveable streets (linking environmental data with use of public space)
Notes	Initial trial in Speers Point Park, Lake Macquarie (during the Living Smart Festival). Subsequent deployment in Pearson Street Mall, Charlestown. Difficulty integrating the devices into TULIP due to their reliance upon a standalone Meshed system for data interpretation.
Verdict	A successful trial that produced meaningful data. Council will continue to explore their use and revisit the possibility of integration to TULIP after the project. **Device dropped from core project focus after phase 1**

Image: 37 - Digital Matter Oyster

Digital Matter Oyster

Manufacturer	Digital Matter
Device name	Oyster
Telemetry	- GPS
Quantity procured	4 (2 for LMCC; 2 for Sydney)
Use case	LoRaWAN signal mapping for deployment planning The Oyster can be programmed to populate the open-access 'TTNmapper.org' website. Each time the device sends an update, a point appears on the map with information about the strength of the signal. A heat map can be built up around a LoRaWAN gateway. This is extremely useful for understanding actual signal coverage from a newly installed gateway.
Notes	In Lake Macquarie, Oysters were placed in municipal waste collection trucks, which drove along most residential streets. Over the course of a few weeks, a detailed heat map of signal coverage was built up, visible through TTNmapper. A similar approach was taken in the City of Sydney, though it involved a UTS staff member with an Oyster travelling through areas of interest on a bicycle.
Verdict	The Oyster is a truly 'set and forget' device that works extremely well for the described use case.

Image: 38 - Digital Matter Guppy

Digital Matter Guppy

Manufacturer	Digital Matter
Device name	Guppy
Telemetry	- Asset monitoring - gates, doors and amenities
Quantity procured	2
Use case	Asset monitoring - gates, doors and amenities
Notes	Obtained to trial as counters on gates to dog park at Speers Point, Lake Macquarie. Difficulties with configuration of accelerometer function to detect horizontal motion of gate.
Verdict	Trial unsuccessful. Devices reallocated for future use by LMCC **Device dropped after phase 1**

APPENDIX D – TTN gateway deployments

Newcastle outdoor community gateway support

Of additional note is that a community IoT Things Network configured LoRaWAN gateway in Newcastle was moved from being indoors to being placed on a rooftop. The reason for this is that an existing TTN IoT community exists in Newcastle. It was decided that the best way to activate a similar community in Lake Macquarie was to reach out and build a relationship, drawing neighbouring expertise up the hill to Charlestown. By boosting the Newcastle TTN gateway, at very little cost to the project, we made a move towards continuous coverage across the LGA border and made a significant gesture of support to the Newcastle IoT community, which was seen as a direct investment for establishing similar community activity in Lake Macquarie.

Gateway 1: Speers Point LMCC Administration Building rooftop

Images: 39 - Original and updated installations of Gateway 1, Speers Point

Location	Model	Serial No.	LoRaWAN EUI	Location
Speers Point	MTCDTIP-LEU1-266A	19618476	00800000A00026BE	Roof of Council Admin Building, Speers Point

Initial installation of the gateway can be seen in the image on the left. This installation was done incorrectly and resulted in signal loss due to obstruction by the mounting pole, and the relatively low height above the rooftop.

The image on the right shows the reinstallation of the gateway on the top of a three metre mast. This correction enabled 360 degree coverage and the extra height assisted with range as well as nearby coverage.

Gateway 2: Charlestown Oval

Image: 40 - Gateway 2, Charlestown Oval

Location	Model	Serial No.	LoRaWAN EUI	Location
Charlestown Oval	MTCDTIP-LEU1-266A	19618477	00800000A00026BB	Light pole at Charlestown Oval, Charlestown

The gateway is connected to an extension of the power supply for the light pole. The height affords excellent range. Some signal coverage is lost due to obstruction by the pole (contractor error). Due to only minimal signal loss resulting, the installation has not been adjusted, however it could be moved to the top of the pole in future so that the antenna projects above it, with 360 degree exposure.

Gateway 3: Lisle Carr Oval

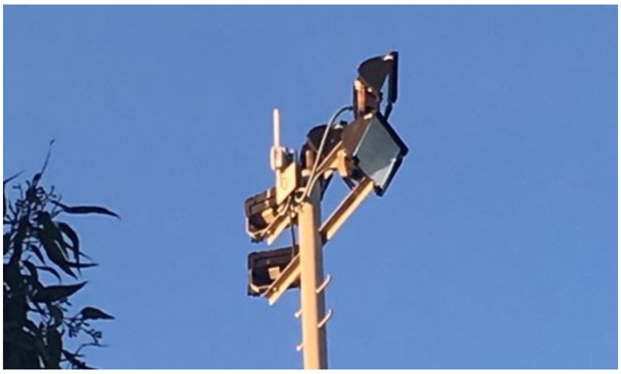


Image: 41 - Gateway 3, Lisle Carr Oval

Location	Model	Serial No.	LoRaWAN EUI	Location
Lisle Carr Oval	MTCDTIP-LEU1-266A	19618478	00800000A00026BA	Lisle Carr Oval, Whitebridge

APPENDIX E – Device pre-provisioning and provisioning process

The deployment procedure refers to the process by which a device is received from a manufacturer, configured, onboarded, lab-test, assembled with mounting equipment, labelled, administrated, redistributed to installation contractors, installed, field-tested, and ultimately commissioned.

This process can be split broadly into two parts:

1 – Pre-provisioning = configuration, onboarding and lab testing of a device

2 – Provisioning = assembly, physical installation, metadata capture and supporting administration

UTS had to develop processes, materials and administrative systems to manage all aspects of device deployment for the project. This was necessary for managing around 100 devices deployed as part of the project. It was also emphasised as an exploration of scaled deployment operations that may serve as a useful reference to others.

1: Pre-provisioning

The following is the working pre-provisioning procedure developed and used during the project

Step	Action	Owner	Comment
1	Internal UTS Procurement	UTS	
2	Issue PO to vendor with Device/LoRaWAN Band/Quantity	UTS	UTS to create Monday.com pulse and raise JIRA case with Meshed. ARCS Group to confirm process (Monday.com update preferred)
3	Notify UTS of date to start pre-provisioning	Vendor	Vendor may need to build devices or order from 3rd party. Meshed to update JIRA case. ARCS Group to confirm process (Monday.com update preferred)
4	Program device with the TULIP's AppEUI and AppKey	Vendor	May need to be done by vendor or 3rd Party
5	Ensure devices are powered on and ready for pre-provision	Vendor	Devices should be able to join network (TTN or NNNCo). Meshed to update JIRA case. ARCS Group to confirm process (Monday.com update preferred)
6	Request pre-provision via Monday.com	UTS	Monday.com pulse for each device should be populated with all available data, such as device_name.
7	Pre-provision devices into TULIP	Nokia	Allow 24 hours for response - update Monday.com with status on completion.
8	Verify devices have succesfully joined TTN (OTAA and uplinks)	UTS	Check via TTN or NNNCo console that devices are present and frames have been received.
9	Inform Reekoh that data is available	UTS	Via Monday.com
10	Reekoh confirm data being passed to UI	Reekoh	Update into Monday.com
11	UI Confirm data received	[ui!]	Update into Monday.com
12	UTS sign off that device is fully pre-provisioned.	UTS	Update into Monday.com
13	Ship devices to address on purchase order	Vendor	

Table 7 - Pre-provisioning procedure

2: Provisioning

Tools and resources referenced in the table below:

Google Sheet: 'Liveable Neighbourhoods Device Deployment Planning'

This was the primary shared document used to track the planned deployment of all devices in the project. Devices and their metadata are entered into the sheet and assigned to locations. All details of locations are also held in the sheet. Until the point when a device is commissioned and all of its metadata has been correctly input into the TULIP platform, this Google Sheet served as the main reference.

Monday.com

A commercially online task and project management service that was used to coordinate taskflow between project partners

Batch deployment guide

Devices were deployed in batches. Each batch had a guide consisting of

- A page per device/location with annotated photograph indicating how to mount the device
- All relevant mounting schematics

Legal waiver

In certain cases (e.g. 26 Adopt-a-Sensor locations), a legal waiver was required to specify device an data ownership, site access, etc. This was produced by the Council's legal team.

Mounting equipment check form

Each mounting solution required a particular number and assortment of fixings. With many different mounting solutions, a series of mounting equipment check forms were created. These were printed prior to undertaking batch assembly and used as a guide to ensure all components were present.

Device Deployment Checklist

A per-device checklist that contains all vital information about a device and where to deploy it, plus a step-by-step deployment guide for use by a contractor. Contains space and prompts to add metadata updates (e.g. height above ground) and general notes. One sheet per device, for every device. All completed sheets handed back to Council/UTS following installation.

Digital label maker

A large number of customised labels were needed for each device. A digital label maker was purchased and used with a weather and UV-resistant tape.

Provisioning procedure

ID	Task	Responsibility	Description	CONFIRMATION
1	**Device posted to owner**	Supplier (ARCS, Meshed, etc.)	Must only occur *after* device is showing in Urban Pulse as 'Pre-provisioned - ACTIVE'	Device supplier to email owner and UTS to inform that device is posted. **[Owner confirms email has been received]**
2	**Owner receives device and tests connection to local gateway**	• Device owner (LMCC) • UTS (ET)	**Owner (Council)** 1. Activate device (e.g. add batteries) 2. Place device in a secure location with guaranteed strong signal to local gateway **UTS** 3. Check for data in TTN, Impact, Reekoh and UI	Device owner (Council) to email UTS and supplier to acknowledge receipt. **[Owner to confirm that a receipt of goods email has been sent]** Devices activated in test location **[Owner confirms]** Data is visible throughout the TULIP platform **[UTS confirms]** [Monday.com to have columns designated for tracking data flow to each level of the platform]

3	**Location planning**	Owner (LMCC)
		UTS (AT)
			1. Location verified for appropriate signal strength
			2. Mounting solution confirmed in the Batch Deployment Guide (annotated photograph of deployment + designated mounting solution)
			3. Approvals (e.g. Ausgrid, school, etc.)
			  1. Agreement of mounting solution
			  2. Legal approval signed off
				1. LPWAN Assessment column should show 'good' or Moderate' **[UTS <u>or</u> Owner can confirm]**
				
				2. Batch Deployment Guide entry confirmed **[UTS confirms]**
				
				3. Email from mounting asset owner (e.g. Ausgrid, school, etc,) to UTS and/or owner (Council) confirming approval (and details) **[UTS <u>or</u> Owner can confirm]**
				
				4. Legal waiver signed and archived **[Owner to confirm]**

4	**All device metadata confirmed in ‘Liveable Neighbourhoods Device Locations List’.**	Owner (LMCC) UTS (AT)	See columns in Google Sheet for deployment status (UTS/Council).	UTS and Council must both show ‘All metadata confirmed’ before proceeding. **[Both to complete ‘Liveable Neighbourhoods Device Deployment Planning’ sheet]** **[UTS to complete this check]**
5	**Manually update device metadata in Urban Pulse using the metadata editing function in the GUI**	UTS (ET)	1. Log in to Urban Pulse Council Dashboard using UTS admin access 2. Access device and edit metadata, using ‘Liveable Neighbourhoods Device Deployment Planning’ sheet as source of truth.	Device(s) have all pre-deployment metadata entered into Urban Pulse **[UTS to confirm]**
6	**Prepare mounting solutions**	UTS (AT)	1. Using the ‘Liveable Neighbourhoods Device Deployment Planning’ sheet, identify, procure and assemble a mounting solution for all devices in the batch. [Use a mounting equipment check form for each device]	Print and check off the appropriate ‘Mounting Equipment Checklist’ for each device.
7	**Assemble mounting kit(s) and attach sensors**	Owner (LMCC) UTS (AT)	This is to be done in-house. Book a large workspace for one or two full days if handling a large batch.	Mounting kits placed with their specific devices, as part of a deployment package
8	**Label devices**	UTS (AT)	○ [Device name] ○ [Device nickname] ○ Serial no. (if present) ○ Property of […] ○ Deployed [month/year] ○ Contact	Device(s) has all labels attached
9	**Prepare physical deployment packages**	Owner (LMCC) UTS (AT)	[Label hardware package with a Batch ID] A. Device B. Mounting kit (all parts collected in one distinct package) [**Or** fully assembled device+mount solution] C. Paperwork (to print) 1. Device Deployment Checklist 2. Batch Deployment Guide and check against UI GUI 3. Mounting Guide (section per device/per pole type)	Batch Deployment Guide has been physically ticked off by UTS person, confirming that it matches details in TULIP All deployment packages ready for collection by contractor
10	**Contractor collects deployment packages for batch(s)**	Contractor Device owner (LMCC)	All paperwork and equipment handed to contractor	Form is counter-signed by contractor and device owner to acknowledge receipt of all equipment and also that full instructions have been received and understood.

11b	**Deployment of device(s)**	Contractor	Contractor installs device at agreed location, as per paperwork. Specific meta-data is collected/confirmed: • Date of deployment • Height above ground (to nearest cm) • Orientation • Notes (optional) Three photographs are taken: 1. Close-up of device label prior to installing on pole (showing the EUID) + page from batch deployment guide. This is a cross-check to ensure that we know which device was actually installed at the location. 2. Device installed (close up, showing detail of device on pole) 3. Recreate the image from the Batch Deployment Guide, with the device now deployed and visible on the pole, in the context of the streetscape.	1. Device is ticked off on the deployment checklist. 2. All metadata updates are captured on the form. 3. Photos are taken in order. 4. All photos and completed forms from the batch deployment to be shared with Council and UTS within 48 hours of completed work. *Forms and photos to be emailed to:* *[enter email addresses]*
12	**Verification**	UTS	Review paperwork returned from contractor to ensure that it is complete and accurate. Review photos to verify that installations have been correctly undertaken.	
13	**Testing period**	UTS (ET) + UI + Reekoh + Nokia	A one week period for testing and verification: • All telemetry is present • Consistent receipt of data packets	After one week, if everything is working correctly, the device status is manually updated to “ACTIVE” by UTS, via the Urban Pulse GUI

Table 8 - Provisioning procedure

APPENDIX F - Smart Liveable Neighbourhoods Challenge: Five Winning Entries

Table 9 - Smart Liveable Neighbourhoods Challenge: Soundscape

Device name:	**Soundscape**
Description:	Soundscape is a IoT system, which measures the decibels of an area & makes that data available to be used on web systems.
Where and how your device will be used?	Anywhere from urban areas to rainforests, the device can be deployed to any area with The Things Network (TTN) / LoRaWAN coverage. The device will primarily sense the decibels of a certain area at regular iterations. The decibel recordings are then sent across TTN to our data storage system, which then makes the data available to display on web pages.
Who benefits from your device and how?	Communities & researchers can better quantify and understand a local soundscape. Overtime the detection of anomalous sound levels could be correlated with anything from bat migrations, CBD or house parties noise violations, industrial noise pollution (from transport trains near urban areas, jet aircraft over urban areas); which could in turn effect house designs & or property prices.
What would you do to improve your device?	Improvements could be made to improve the overall security of the stack, network transmission optimisations (room to save 1 byte per transmission), more accurate decibel calibration, improve battery life time & power consumption optimisation, additional sensors such light sensor & capacity to correlate decibel levels with organic light level reductions (is summer louder than winter?); reiterating this thought for each type of sensor (does temperature effect sound, by how much/little?)

Table 10 - Smart Liveable Neighbourhoods Challenge: Gate open counter

Device name:	**Gate open counter**
Description:	Counts each time a gate opens
Where and how your device will be used?	It will be strapped to the gate at Speers Point Park to indicate how busy it is at any point in time. Trends will be recorded and the current value can be compared to the long term trend to determine if it's busier than normal.
Who benefits from your device and how?	Parents like myself who frequent playgrounds and would like to know how busy they are before leaving home.
What would you do to improve your device?	Make it smaller in a more robust case.

Table 11 - Smart Liveable Neighbourhoods Challenge: Amenities usage monitor

Device name:	**Amenities usage monitor**
Description:	A LoRaWAN node that can work with multiple counters
Where and how your device will be used?	Monitor such things as how often toilets are flushed, enabling better scheduling of cleaning. Also if some are not used this could indicate faults or other problems (e.g. missing toilet paper) requiring investigation.
Who benefits from your device and how?	Better service to the public, and more efficient use of council resources.
What would you do to improve your device?	Add monitoring of water and electricity usage, how long toilets are occupied, switching off lights when not in use.

Table 12 - Smart Liveable Neighbourhoods Challenge: LoRaWAN counter

Device name:	**LoRaWAN counter**
Description:	My device is a Pycom Lopy4 with an ultrasonic rangefinder and a slide switch to change between modes.
Where and how your device will be used?	Could be used in a few ways. The first way is as a people counter. In Mode 1 the device will be fastened to a pole pointing either across a sidewalk or gate to count people walking past or pointing toward the street to count vehicles driving by. Every time something passes in front of the device its stored as a count. The count total is uploaded to an Adafruit.io dashboard every hour where it is available for viewing in both a graph and a spreadsheet. Including times that the recordings were made. In Mode 2 the device will be mounted in the underside of garbage bin covers, the sensor will point down into the bin. The distance will be measured into the bottom of the bin and a gauge online will show how full the bin is. Measurements will be taken at intervals, and when a change is detected it will be verified over the course of 20 minutes. After 20 minutes if the bin is indeed detected fuller, a message will be sent that will change the gauge on the dashboard. The device can also be made to send an email, tweet, or text whenever a bin is overfilled.
Who benefits from your device and how?	The council could use this device to monitor foot traffic or vehicle traffic easily, or they can detect if bins are filled in public spaces to better manage bin emptying schedules. All the data will be plotted and viewable on Adafruit.io for better interpretation.
What would you do to improve your device?	I would create a better waterproof housing.

Table 13 - Smart Liveable Neighbourhoods Challenge: Smart Sports Field Brain and Controller

Device name:	**Smart Sports Field Brain & Controller**
Description:	LoRaWAN sensor and actuation node
Where and how your device will be used?	At sports fields to control systems like lights, sprinklers, toilet locks, and more. Also to monitor things like power consumption, water usage, and field conditions (like soil moisture).
Who benefits from your device and how?	User: Community. Benefit: Convenience from immediate control of lighting systems in the event lights were not enabled. User: Council. Benefit: Accurate monitoring of power consumption and power optimisation, less resources devoted to ensuring lights are active for night time events, less angry citizens unable to use sports field due to inactive lights.
What would you do to improve your device?	1st (easy and quick): Add extra hardware features such as soil moisture monitoring, toilet door locks, and power monitoring. 2nd (easy but time costly): Add a public, online, field booking system where clubs can book fields for training and games, allowing for automatic control of lights, and accountability of clubs if they misuse public grounds and equipment. 3rd (difficult and time costly): Develop proof of concept (including improvements mentioned above) into a minimum viable product which can be manufactured and integrated into existing sports field infrastructure.

APPENDIX G - TULIP device telemetry schema

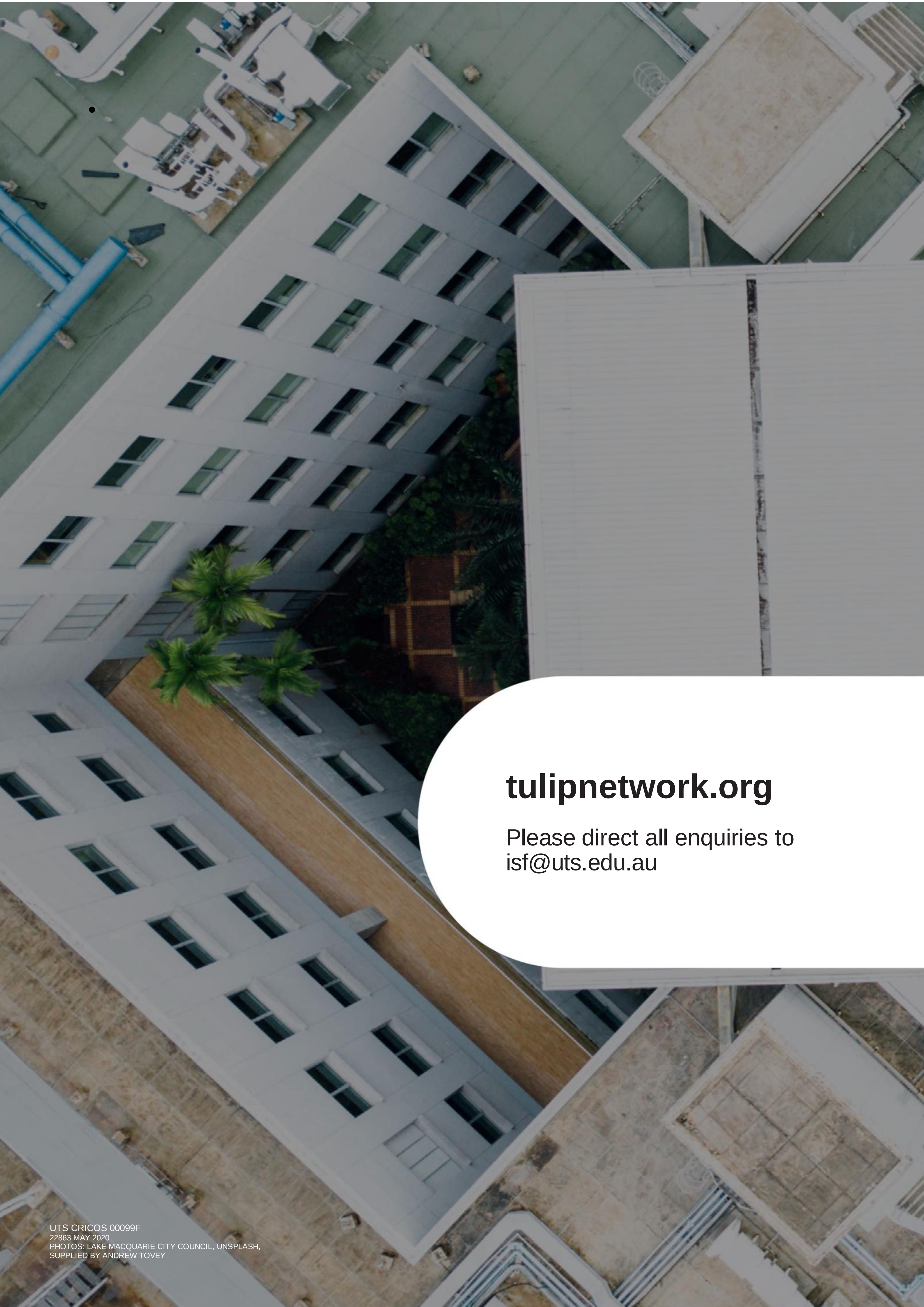
JSON Field name	Json Example	Meaning	Unit
DEVICE_IDENTIFIER	ffffff10000017a5	Device ID	ASCII String
DEVICE_NAME	WXT001_AN103_LMCC	Device Name	ASCII String
TIMESTAMP_UTC		Time in Universal Standard Time	
TEMPERATURE_C	23.5	Temperature Degrees Centigrade	°C
RELATIVE_HUMIDITY	56.6	Relative Humidity %	RH%
NO2_PPM	40	Nitrogen Dioxide PPM	ppm
O3_PPM	100	Ozone	ppm
CO_PPM	70	Carbon Monoxide ppm	ppm
PM1_0_UGM3	25	Particulate matter (1 micron)	
PM2_5_UGM3	25	Particulate matter (2.5 microns)	
PM_10_UGM3	50	Particulate matter (10 microns)	
NOISE_DBA	40	Sound level in Decibels	dBa
BATTERY_PERC	23.5	Battery percentage	%
BATTERY_V	3.34	Battery level	v
LAT	-32.96274	Latitude	
LON	151.697273	Longitude	
OCCUPANCY	1		BOOLEAN (0/1)

Table 14 - TULIP device telemetry schema

APPENDIX H - TULIP device metadata schema

Field Name	JSON Field name	Json Example
Device Manufacturer (code)	device_manufacturer	ARCS Group
Device Model (code)	device_model	Environmental Monitoring System
Device ID (EUI or equivalent)	device_id	0004A30B001BBB42
Device Name (derived)	device_name	NVX001_R712_LMCC
Description	device_nickname	EMS_Speers point pool
Device owner	device_owner	UTS
Data Owner	data_owner	UTS
Deployment date	deployment_date	43101
Device Deployment Image	device_deployment_images	
Longitude	lon	-33.884153
Latitude	lat	151.1987782
Location type	location_type	Open Public space
Street Address	street_address	Pacific highway
Suburb	suburb	Charlestown
Device status	current_device_status	Deployed - ACTIVE
Telemetry status	telemetry _status	Active
Height above ground	height_above_ground	3
Orientation	orientation	SE
Type of mount	type_of_mount	Street Pole – wood (>300mm Dia)
Owner of mount	owner_of_mount	Ausgrid
Mount ID	mount_id	1001154495
Notes	notes	Anything you want!

Table 15 - TULIP device metadata schema



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