Using smart technologies for climate change adaptation in Western Sydney: A CAPS Research Report

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Executive Summary

The Climate Adapted People Shelters (CAPS) project has initiated collaborative, design-led approaches to reimagining the place and function of bus shelters, specifically in response to conditions of increasing urban heat and extreme weather events in Western Sydney.

This Report contributes to the research outputs of the project, with a focus on the current and potential uses of smart infrastructure technologies within bus shelter designs. Looking ahead, research into potential areas for future investigation has also been undertaken, with a view to informing ideas and strategies for future investment in urban heat mitigation activities in Western Sydney.

What do we mean by smart technologies?

In this Report we are focused primarily on the following aspects of smart technologies:

- Sensors and wireless networks associated with the 'Internet of Things' (IoT), that enable the collation of real-time localised data, and facilitate the operation of more 'responsive' materials and infrastructures;
- Digital interfaces and information screens that can be embedded into physical infrastructure such as bus shelters, displaying real-time information to support travel planning and information during extreme events.
- New approaches to government service provision and communication that reflect the opportunities enabled by pervasive computing technologies.

Key questions

This research was commissioned to focus on the different uses of smart technologies within the field of 'smart bus shelters'. Cities around the world have been trialing the use of smart bus shelters to improve services to commuters. We have reviewed the potential applications of smart bus shelters to support the aims of the CAPS project in responding to conditions of increasing urban heat and extreme weather events in Western Sydney. With a view to addressing wider opportunities for the use and implementation of smart technologies to respond to conditions in Western Sydney, we have also broadened this scope somewhat to take in other potential infrastructures, services and approaches to using smart technologies.

The key questions are:

- Smart bus shelters: How are smart technologies used to improve the management and functionality of bus shelters?

- In what ways might the integration of smart technology within bus shelters be used to address key areas of climate vulnerabilities (rising heat; extreme weather events)?
- How can the wider application of Internet of Things (IoT) sensors and related data capture and information management tools be used to support the needs of citizens impacted by urban heat islands (UHI) and extreme weather events?

Key findings

Smart Bus Shelter Precedent Review

The integration of smart technologies into bus shelters has been an area of investment for a number of years now. Innovations have spanned relatively simple interventions, such as the inclusion of interactive screens to support trip planning, to more radical, ambitious attempts to rethink the positioning and function of ‘mobility shelters’ in an era of ride-sharing platforms.

The rise of smart, distributed technologies also means the bus shelter is expanding from single-use to multi-use infrastructure. The integration of smart sensing devices facilitates a variety of services to be managed through the bus shelter, including access to free or high quality WIFI, charging stations, and/or wider city information services. Likewise, smart sensors can be used to support the creation of more climate-controlled environments, such as the triggering of additional sun shelters or mist/water vapour on very hot days. A more responsive bus shelter design could also feature information displays relevant to context, including specific health warnings, travel advice, or emergency contact information.

Integration of environmental sensors such as temperature readings could provide a much more contextually-rich understanding of areas of vulnerability in Western Sydney. This data could be used to create a clearer understanding of the impacts of different kinds of materials and structures on micro-climates across Western Sydney (UHI). Micro-climate data could also be integrated with demographic data and/or Opal card data to help create a much richer map of vulnerability across Western Sydney to inform a number of areas of government policy.

Wider smart services opportunities

Many of the features available through smart bus shelters, including increased Wi-Fi connectivity, information displays and ambient data collection through integrated sensors, are also being trialed through a range of other smart infrastructure and services. In this sense, bus shelters are not the only piece of 'everyday urban infrastructure' that can be made 'smarter'.

While many smart infrastructure services, such as smart lights, remain in trial or prototype mode, central to their effectiveness over the coming years will be the need for an *integrated data strategy* that aligns data collection efforts around key priority service areas, and addresses issues around data privacy, data security. A focus on common standards for data collection, and opportunities to promote access and re-use of data by a range of user groups will be needed to maximize the benefits of these services over the coming years.

While existing infrastructures – including networks of bus shelters and lighting infrastructure provide potentially useful sites for the integration of smart services, there are also opportunities to establish more 'bespoke' internet of things (IoT) sensors that offer greater flexibility and access to underlying data. Initiatives such as the Array of Things platform, first developed in Chicago, underscore the importance not only of the specific technical functionalities afforded by emerging smart technologies, but also the wider partnerships, platforms and governance contexts that structure how data from connected devices is accessed and used.

Effective smart services require effective digital design and strategy aligned to priority service areas

Smart services increase the potentials for highly localized data capture creating more context aware information relating to micro-climates and services demands. In this respect, it is vital that the potentials for smart technologies be understood not only in terms of 'point solutions' within physical infrastructure (e.g. the physical usage and design of an individual bus shelter), but also, more widely, as part of a wider ecosystem of data-driven services that address the needs of citizens in Western Sydney.

A focus on developing a wider ecosystem of data services that utilize a mix of existing infrastructure and/or new services could target the following activities and domains:

- Urban heat island (UHI) monitoring: Improving awareness of different climatic conditions and 'hot spots' and providing more localized information to citizens in these environments; integrating smart or adaptive materials that can facilitate cooling and/or enhanced shelter;
- Extreme weather, including more severe and frequent storms: Targeting warnings and other hazard-preparedness information on a real-time basis to those exposed to extreme weather, at locations known to experience regular disruptions during extreme weather events;
- Development of a 'red button' tool that allows citizens to quickly access a range of emergency services on demand at a variety of locations (e.g. bus shelters).
- Establishment of an open data platform or data sharing portal that makes available selected mobility and environmental data. This platform could be accompanied by hackdays or discovery days focused around the needs of citizens and commuters in Western Sydney, with a view to accelerating innovation in service delivery.

Summary Findings

The Report canvasses opportunities to address climate change impacts in Western Sydney through the use of smart technologies. While the focus for the precedent review has been on the use of smart bus shelters as part of the CAPS project, wider opportunities are also detailed relating to areas such as smart lighting, IoT platforms and networks, and intelligent materials. Findings from the research can be summarised as follows.

- There are many opportunities to utilise sensor-based services to improve understanding of micro-climates and contributors to urban heat islands across Western Sydney.
- Focus should also be on the relative alignment of UHI with other determinants of vulnerability, including demographic factors (old age, young children, low income earners).
- Bus shelters are a useful ‘everyday infrastructure’ for trialing the implementation of new smart services, and are particularly useful for the delivery of context-aware information to commuters who may not otherwise access smartphone services. However, additional infrastructures such as smart lighting, or commissioning bespoke sensor platforms, are also useful platforms for data capture. Innovations in smart lighting in particular can facilitate more data capture than smart bus shelter designs, however data sharing provisions should be managed carefully.
- Future investments in smart technologies and services should be accompanied by clear strategies for data collection, data sharing and data privacy.
- Opportunities to trial IoT networks such as LoRaWAN in collaboration with The Things Network are worth investigating. This could include data capture trials accompanied by hackdays and challenge-style events.
- The Federal Government’s *Smart Cities and Suburbs* program will provide funding to local governments over 2017 to trial new smart technologies. This provides an opportunity to support local government technology trials or partnerships.

About the researchers

The Report has been commissioned by the Institute for Sustainable Futures at the University of Technology Sydney. Research has been led by Dr. Sarah Barns, Research Fellow at the Institute for Culture and Society at Western Sydney University, and a leading expert in the field of smart cities and digital transformation. Research assistance to support the Precedent Review has been provided by Andrea Pollio, Guilia de Maso and Rene Fernandez, all researchers at ICS. The research project reflects a collaboration between UTS, ISF and WSU in the delivery of the CAPS project during 2016.

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Introduction

Background & context

The Climate Adapted People Shelters (CAPS) project has initiated collaborative, design-led approaches to reimagining the place and function of bus shelters, specifically in response to conditions of increasing urban heat and extreme weather events in Western Sydney.

CAPS has been a collaboration between the University of Technology Sydney's (UTS) Institute for Sustainable Futures, U.lab and Centre for Management & Organisation Studies, the NSW Climate Adaptation Research Hub and the Institute for Culture and Society at Western Sydney University (WSU). The project is supported through the Building Resilience to Climate Change grants scheme, funded by the NSW Office of Environment and Heritage and the NSW Environmental Trust and administered by Local Government NSW.

There have been three distinct phases to the CAPS project:

- Stage 1 has involved the co-design of bus shelters in four local government areas (LGA) via an open design competition;
- Stage 2 has included the construction of winning designs; and
- Stage 3 comprises research activities in regards to three interdependent research agendas of resilience, digitization and co-creation.

This report forms a component of Stage 3. It reports on the outcome of research into the current and potential uses of smart infrastructure technologies, and specifically the integration of digital tools and sensing platforms, within bus shelter designs. Looking ahead, research into potential areas for future investigation has also been undertaken, with a view to informing ideas and strategies for future investment in urban heat mitigation activities in Western Sydney.

What do we mean by 'smart technology'?

This report has a focus on the use of distributed computing devices and platforms that can be integrated into the built environment.

In this Report smart technologies include the following:

- Sensors and wireless networks associated with the 'Internet of Things' (IoT), that enable the collation of real-time localised data, and facilitate the operation of more 'responsive' materials and infrastructures;
- Digital interfaces and information screens that can be embedded into physical infrastructure such as bus shelters, displaying real-time information to support travel planning and information during extreme events.

- New approaches to government service provision and communication that reflect the opportunities enabled by pervasive computing technologies.

Each of these domains relate to the ability of smart technologies to harvest localized information (data capture), deliver more contextual information (digital screens), and improve service delivery (responsive services).

In the discussion of smart technologies, it is not the intention to focus on specific proprietary systems, sensors or emerging standards, but instead to focus on relevant application areas that are likely to be beneficial to the management of urban heat and extreme weather events.

Key focus areas

- Smart bus shelters: How are smart technologies used to improve the management and functionality of bus shelters?
- In what ways might the integration of smart technology within bus shelters be used to address key areas of climate vulnerabilities (rising heat; extreme weather events)?
- How can the wider application of Internet of Things (IoT) sensors and related data capture and information management tools be used to support the needs of citizens living within urban heat islands?

1. Setting the scene: IoT, smart cities and connected systems

A world of connected devices, people and things

The past decade has seen the widespread integration of pervasive computing technologies across urban environments. Gartner Research (2015) has estimated that around 6.4 billion connected devices were in worldwide use at the end of 2016, up 30 per cent from the previous year. By 2020, it is estimated that some 20.8 billion connected devices will be in operation.[i] Widespread deployment of connected devices and objects are now becoming more commonplace across our cities, enabling the potentials of internet connectivity to extend to an emerging 'internet of things' (IoT).

In Australia, there are now more than 16.6 million GPS-equipped smartphones, delivering a range of location-based and social media services to citizens on the move.[1] New 4G LTE networks are now prolific across Western Sydney, supporting low cost machine to machine (M2M) wireless communications. More and more service providers recognise the mobile device as the primary platform for communication for an increasing majority of Australians.

Widespread consumer uptake of smartphones has now vastly increased the volume of location-specific data generated by citizens as they increasingly interact via digital means.[2] This has improved the ability of citizens to access real-time information, including emergency service information, along with travel, news and weather updates from a wide array of sources. However, a digital divide remains particularly among older demographics who are less likely to use apps and smartphone services particularly while commuting.

The proliferation of connected devices means that huge amounts of ‘big data’ about our environments are now being generated every day. This is significantly enhancing the

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[1] 7.3 million Australian smartphone users agree with the statement "I can't live without my mobile phone", up 55% over the past 5 years. Source: Roy Morgan Research, as reported in the *Sydney Morning Herald*, June 2016 at http://www.smh.com.au/business/consumer-affairs/as-smartphone-ownership-grows-more-australians-cant-live-without-mobile-phones-20160623-gpq77n.html

2 Shin’ichi, K. and Roussos, G. (2016) Enriching Urban Spaces with Ambient Computing, the Internet of Things, and Smart City Design. IGI Global, p50.

potential for the localized and real-time monitoring of a range of environmental and social conditions.

The ‘data exhaust’ generated by mobile-equipped urban populations and connected 'things' has given rise to new fields of information science or ‘informatics’ including ‘urban informatics’ that utilise computational techniques and big data analytics to analyse the dynamic relationships between spaces, objects, infrastructures and users.

Ambient intelligence, personalisation and responsive services

This range of developments has prompted growing interest across industry, government and academic environments in using smart technologies to address current environmental and urban challenges (Kitchin 2010; McCullough 2013; Greenfield 2006).

This rise of ‘urban ambient analytics’, reflects advances in the volume of data available, the distribution of sensing platforms and improvements in analytical tools and software used to understand and model complex urban interactions, including the interactions between human and natural ecosystems.

As real-time information systems, apps, wireless networks, satellite services, connected devices and digital displays become more embedded and pervasively used across the built environment, it’s becoming clearer that smart technologies offer two primary domains of potential.

The first domain relates to *improving intelligence* through the increased quantities of highly localized data about urban context, captured through distributed sensors, GPS-enabled smart phones, RFID cards, remote sensing or others. This volume of ‘big data’ combined with advanced analytics can be used to deliver more personalized services to citizens, understand local complexities and improve wider planning processes. For example, real-time transportation data can be used to better understand traffic bottlenecks, model alternate scenarios and devise solutions to address them. Urban heat islands are now recognized through remote sensing technology.

But while data-driven analytics are now widespread, an important emerging domain for smart technologies relates to the ability for machine to machine (M2M) communications, enabling infrastructural services and materials to become more responsive to ambient, environmental conditions. This represents a shift from data-driven *intelligence* to more *responsive, data-driven infrastructure services*.

We are now familiar with a range of services driven by ambient, distributed technologies and sensors. The Opal smart card, like RFID transport cards used around the world, enables users to travel across public transport systems using dynamic pricing models for fares that reflect variants such as length of trip (number of zones), type of transport and time of day. However, data generated by the widespread use of Opal cards is now used by a range of agencies to support new, more 'peronalised' approaches to transport planning. For example, Transport for NSW (TfNSW) aims to use traffic activity tracked by Opal to warn commuters of disruptions to regular services they are known to catch.[3] The Opal data is also being made available via an open data platform to enable external developers to make apps that citizens can choose from to plan their transport across multiple transport types. In this way, the introduction of a sensor-enabled device, such as a smart card, can catalyse the delivery of a range of additional services by government and business.

The idea of 'responsiveness' also goes beyond personalisation and customisation. The idea of smart, responsive infrastructures is also being explored as a means for built infrastructure and services – whether traffic signaling, network charging, shelter design, or lighting systems – to operate in response to changing uses, demands and environmental conditions. Well known examples of these 'responsive' services include the use of smart street lights, which respond to human activity, or 'smart bins' that will send a message to waste providers when they are full. Looking ahead, there is also the potential for different *systems of services* to connect and be made more responsive to each other in the future. This is often described as a kind of 'closed loop environment', in which an incident or hazard will generate its own data to inform not only people but also other systems or decision-making infrastructures of necessary adaptive responses.

As Stephen Goldsmith and Susan Crawford have written in their book *The Responsive City,* the ability to collect, analyse and share vast amounts of data today is changing the role of data analytics in day to day decision making. The authors have argued that today's data analytics can allow governments to move from what they call a 'compliance model' – using data to monitor achievements across particular targets or goals – to a problem solving approach.[4] For example, if a particular locale is a known hot spot or hazardous environment during storms, what measures can be put in place to protect citizens, and/or improve the resilience of available infrastructure?

Mind the gap: from technology-led solutions to co-ordinated governance and integrated service design

Increasingly there is growing interest not only in instrumenting discrete services or 'point solutions' with connected devices, but in adopting more holistic approaches to managing a connected environment as a 'system of systems'. While at a relatively immature stage of development, the focus of increasing investment is now on the underlying digital architectures and governance approaches needed to support 'connected systems'

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[3] https://www.itnews.com.au/news/tfnsw-looks-to-opal-data-to-personalise-commute-418178

[4] Goldsmith, S. and Crawford, S. 2014. *The Responsive City: Engaging Communities through data-smart governance*. Wiley, San Francisco.

environments, specifically to enable the application of data-driven solutions across multiple infrastructure systems in a given locale. As more and more connected devices are brought into operation, the platforms and services that connect different data streams and enable devices to be made more interoperable are being recognized as vital to the wider 'ecosystem' of connected environments.

The area of smart cities has in recent years addressed the digital infrastructures and ecosystems needed to manage effectively these 'systems of services' in cities. Smart cities research addresses the role that distributed technologies and devices, big data analytics and cloud platforms can play in improving the management of urban environments (Robinson 2016; Townsend 2014). Smart city technologies can be seen to involve four key interconnected elements:

- Use of distributed sensors to monitor traffic, pollution, people movement, temperature change, and so on;
- The massive amounts of data that flow in real-time from those connected devices;
- Systems and software platforms that are capable of making sense of data; and
- Responsive actions to infrastructure, services and decision-making.

Where smart cities target the application of advanced technologies in the urban domain, other concepts such as the 'industrial internet' or 'industrial internet of things' address specific domains such as water, transportation, energy and waste management. Many of these domains have begun to establish common conventions and standards designed to support the effective integration of connected devices and advanced analytics to improve the management of key infrastructures.

For example, the Industrial Internet Consortium (IIC), promotes the accelerated growth of the Industrial Internet of Things by "coordinating ecosystem initiatives to securely connect, control and integrate assets and systems of assets with people, processes and data using common architectures, interoperability and open standards."[5] Likewise, investments in smart cities are focusing on the need to establish common and interoperable frameworks for data sharing across domains traditionally managed as separate 'verticals' such as transportation, energy, water and waste, towards a much more integrated 'connected systems' approach (Adler 2015; Batty 2012).

An understanding of the role of common standards and interoperability in managing connected environments (and data streams) has heightened emphasis on the role of collaborative public private partnerships in coordinating investments, and also ensuring open standards are in place. In the smart cities domain, this has been described as a progression from 'Smart Cities 1.0' which focused on discrete technology platforms or domains, such as smart parking trials, smart lighting, or smart bins, towards a 'Smart Cities

[5] See 'About Us' section at: http://www.iiconsortium.org/

2.0' approach that emphasizes the need for a common and secure data architecture to allow data streams to be made available for wider deployment by third party service providers.

Many of the initial technology trials involving smart city services have also been criticised as adopting a 'technology-push' model that has failed to address citizen needs and deliver substantive improvements for local governments. Recent focus areas in the field of smart cities can therefore be summarized as applying to the following domains:

- Service innovation: The creation of interoperable and secure data architecture to enable third party providers to access and re-use data in the delivery of new services, including data-driven responsive services.
- Connected systems approach: Appropriate data architecture is in place to ensure a connected environment can be managed as a set of interconnected systems, rather than discrete 'verticals' with no relationships between them.
- Collaborative partnerships across university, public sector, industry and community organisations to trial IoT applications for city services.

Addressing climate adaption in Western Sydney: The role of smart technologies

The Towards a Resilient Sydney (TaRS) project (Jacobs, Boronyak, Dunford, Kuruppu, Lewis and Lee 2014) undertook an assessment of the vulnerability and adaptive capacity of government service delivery under projected climate change. In addition to increases in average temperature, climate projections show that Sydney can expect higher incidence of extreme climate events such as heat waves, bush fires, intense low pressure weather systems leading to riverine flooding, and coastal inundation from sea level rise. Climate adaptation strategies address the interventions that are needed to mitigate the impacts of these changes on populations, ranging from improved planning and infrastructure changes for at risk areas to emergency warning systems and disaster management strategies (OEH 2014: 11-12).

The lack of a shared understanding of the Sydney context of vulnerability was identified by the TaRS project as a critical challenge for climate adaptation strategies. This in part has reflected the lack of a city-wide body for coordinating the response to climate change (Miranda et al. 2011), exacerbated by having 41 local councils within the metro area all at different stages of understanding and implementing climate change mitigation and adaptation. The recent establishment of the Greater Sydney Commission to support metropolitan wide planning represents an opportunity for improvement in the co-ordination of adaption plans.

This Report addresses the role of smart technologies in supporting improved government service delivery aligned to climate adaptation strategies. Clearly, distributed sensors have an important role to play in improving awareness and knowledge of highly localised environmental conditions, including UHI and roadside conditions experienced by some of our most vulnerable members of society who catch public transport. Likewise, tools that enhance the ability of citizens to access time critical information are also likely to play an important role in improving services available to citizens during extreme weather events.

The integration of smart technologies into bus shelter designs represents one of the very tangible ways in which smart services can be used to create more personalised and time- or context-aware, responsive services to citizens. This could include more visible travel alerts into information screens, or even by enabling particular weather events to activate additional shelters through embedded sensors.

However, given the potentials for data capture and more context aware information, it is vital that the potentials for smart technologies for the CAPS project be understood not only in terms of the physical usage and design of an individual bus shelter, but also, more widely, as part of a wider ecosystem of data-driven services that address the needs of citizens in Western Sydney.

This wider ecosystem of data services could include initiatives directed towards the following activities and domains:

- Urban heat island (UHI) monitoring: Improving awareness of different climatic conditions and 'hot spots' and providing more localized information to citizens in these environments; integrating smart or adaptive materials that can facilitate cooling and/or enhanced shelter;
- Extreme weather, including more severe and frequent storms: Targeting warnings and other hazard-preparedness information on a real-time basis to those exposed to extreme weather;
- Development of a 'red button' tool that allows citizens to quickly access a range of emergency services on demand.

2. Smart Bus Shelter Precedent Review

Introduction

Recent years have seen widespread innovation in the integration of digital platform services as part of the design and management of bus shelters.

Reflecting the potential for digital sensors and information displays to support the aims and objectives of the Climate Adapted People Shelter Project (CAPS), this research report has investigated how cities around the world have designed and implemented smart bus shelters and their range of uses. A summary of ‘smart bus shelter’ initiatives and trials is contained in Appendix A of this report.

Summary findings

The integration of smart technologies into bus shelters has been an area of investment for a number of years now. Innovations have spanned relatively simple interventions, such as the inclusion of interactive screens to support trip planning, to more radical, ambitious attempts to rethink the positioning and function of ‘mobility shelters’ in an era of ride-sharing platforms.

In this report we examine the extent to which smart technologies are provoking new ideas and approaches towards the role and design of bus shelters. This is aligned with the wider focus of the CAPS project, which has aimed to do more than simply ‘upgrade’ bus shelters but to more expansively reimagine the role of bus shelters as ‘people shelters’ in the context of *both* rising temperatures and smart city innovations as they relate to transport and information and communications technologies (ICTs).

It is worth noting that many existing precedents reflect relatively modest goals of improving general amenity and enhancing the accessibility of relevant transport information. These projects are examples of what Bulkeley and Broto (2013: 366) describe as being quite 'passive' in their experimentation, insofar as the urban context functions as the background for primarily technology-focused interventions, with little consideration to wider system wide changes required or provoked by new technologies.

For example, smart bus shelters often integrate real-time trip planning data that supports users in reducing their wait times. However, the ability to access real-time data about shared transport services may ultimately reduce reliance on the need for bus shelters, as users begin to access other shared transport services such as UberPOOL[6]. While Uber is a commercial mobility provider, the same technology could be used for public services. In

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[6] See https://www.uber.com/en-AU/ride/uberpool/

Canberra, ACT, technology research organisation NICTA trialed the use of taxis to replace bus services in outlying areas through use of a smartphone app customers could use to indicate their travel plans.[7] This points to the potential for wider disruptions in the design and use of bus shelters in an era of real-time data and location-based services. Likewise, the impacts of extreme weather events on commuter behaviour is also an important area for further research.[8]

While some trends point to a reduced need for bus shelters in the future, other advocates point to an expansion in the role and function of these shelters to accommodate other uses. This reflects the expansion of new business models for service provision, developed by technology operators such as Ericcson and Nokia who are now active in the smart bus shelter marketplace.

Nokia (2016) described the opportunities for smart bus shelters in a recent 'Innovation 2020' report:

> *Traditional bus shelters are quickly becoming obsolete. Outside of aesthetics, bus shelters have remained the same for ages. This is changing. New technologies and applications are now being used that enable bus shelters to be much more. Within the context of a smart community, bus shelters equipped with ultra-broadband connections can come alive, improve user experiences, and enable new business opportunities.*

From single-use bus stops to multi-functional people shelters

The Precedent Review of existing smart bus shelters addressed the uses of smart technologies within the design of the bus shelter itself. It found that the rise of smart, distributed technologies means the bus shelter is expanding from single-use to multi-use infrastructure. The integration of smart sensing devices facilitates a variety of services to be managed through the bus shelter, including access to free or high quality WIFI, charging stations, and/or wider city information services.

Expanding the remit of service provision

A major emerging trend in the design of bus shelters is the integration of other services that may not be immediately related to public transport functions and that are not necessarily connected to smart or digital technologies. Case studies in Paris (2) London (10) show how bus shelters with sufficient space available can incorporate bike sharing stations and/or recharge stations for electric bikes/cars. The Millennial Bus Stop prototyped in Saint Paul,

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[7] See https://www.itnews.com.au/news/nicta-trial-replaces-some-canberra-buses-with-taxis-391064

[8] See for example, Tsapakis, I., Cheng, T., and Bolbol, A. 'Impact of Weather Conditions on Macroscopic urban travel times'. In Journal of Transport Geography, 28 (2013) 204-11.

Minneapolis (13), and the Project Bus Stop in Singapore (16), instead, feature bike racks as an integral part of the shelter design.

Retail functions can also be a collateral component of the bus shelter structure. Although vending machines have long been placed in close proximity to various waiting areas, including bus stops, an emerging trend in the design of bus shelters sees them as part of the architecture itself, with display shelving embedded in the structure of the shelter. The integration of retail services provides a rather traditional business model to public transport providers, who can rent the bus stop space to vendors in order to create an additional source of income. This approach moves in a different direction to the trend of offsetting bus stop ownership to advertising companies – which has been quite common thus far (Nokia, 2016).

Private retail functions can be accompanied by services of public utility, like book sharing or even an e-book borrowing dashboard provided by the local public library (case study 16). The example of Sean Godsell's bus shelter house (case study 5) explores another opportunity for enhancing the public functions of a bus stop: a fully-functional bus shelter during the day, his provocative prototype becomes a sleeping pod for homeless people during the night.

The 'communicating bus shelter'

In the field of digital innovation, various smart technologies have been experimented, especially with the aim of creating further business models and revenue opportunities for public transport providers concerned with the high maintenance cost of bus stops. The case studies analyzed in this report show the integration of several typologies of smart services, from connective technologies to interactive touchscreens. Whilst almost all the cases incorporate or are designed to incorporate Wi-Fi hotspots, more experimental approaches feature the integration of satellite cells in the structure of the shelter: in this way the bus stop becomes an 'antenna', a cell site that can be rented to mobile phone providers to extend the coverage of their broadband services, particularly in busy areas where high aerials are less effective.

Other connective technologies may offer additional services, especially near-field protocols, like Bluetooth or NFC, which allow the bus stop to communicate with devices like smartphones and tablets, and provide relevant information. These protocols can be used to provide targeted advertising or public information. In this sense, Google's example of outdoor screens shows machine-learning opportunities for street furniture advertising (case study 11). Other research shows the applicability of these technologies in making the bus stop responsive to the queries of its users (see Kasim et al, 2016), and also capable of readdressing these queries to operating buses: for example, communicating the presence of wheelchairs or bikes in order to trigger a response from the coming bus driver (see David et al, 2013).

City information services

Smart screens can be used also to run applications developed by urban governments to make tourist-friendly cities. Several examples (cases 1,2,6,7,9) show how existing urban data can be employed to create interest for tourists or visitors, showcasing landmarks, biking routes, restaurant guides, etc. These datasets can be accessed through specific apps, but also in more engaging ways. For example, the real-time data about the geolocation of buses, which provides estimated arrival times, can be integrated into the lighting of the bus stop, which can glow at different level of intensity (case study 1), or with different colours (13), or include a musical tune (2) to communicate the arrival of a bus. Arrival times have been part of the interactive features of bus stops for quite some years (see Weiss, 2009). However, the use of smart touch screens can also be a vehicle to enhance multimodal transport: as the case study in Paris (6) shows, bus stops can provide information of the geolocation of bike sharing and car sharing stations, as well as train and metro timetables that can be cross-matched with buses' ETAs. In this sense, the bus shelter becomes a 'communicating bus stop' (David et al. 2011) which has been defined as an example of IoT that incorporates a range of different datasets and makes them available to passengers.

Enhancing safety

Another important area of digital enhancement for bus shelters is represented by safety technologies. These devices range from traditional CCTV cameras embedded in the shelter's structure, as in New Zealand (case 13), to more interactive solutions like help buttons (case 20). Further possibilities include the inclusion of defibrillators (6) or audible wayfinding through near-field communication protocols. Cameras can be also used for video-recognition, in order to gather data about occupancy and use, as well as for emergency response.

Enhancing ambient urban intelligence

Like other examples of smart street furniture, bus stops can incorporate sensing devices that capture localised data, from passenger traffic to temperatures and air pollutants. Although the case studies analyzed for this report are mostly prototypes or concepts when it comes to urban sensors, it is an area of great possibilities of innovation.

Bus stops can become urban sensors providing real time information to local governments – or even be rented out to private companies seeking to capture and/or monetise urban data. Some researchers have described the potential for the bus stop to become "context-aware middleware for ambient intelligence" (Xu, 2011), through integration of sensor and video-recognition-enabled cameras. Smart sensing is indeed a field where diverse business models can be experimented as further revenue opportunities for the operations and maintenance of bus stops, whereby ambient intelligence and machine learning are deployed to deliver targeted content (case study 12).

Recent developments in the use of obsolete phone booths point to potential applications for smart bus shelters. In New York, the consortium CityBridge, consisting of public and private partners including the City of New York and telecommunications providers, has developed LinkNYC as a new communications network that utilises the infrastructure remaining from the 7,500 pay phones across New York that are no longer maintained. Each pay phone now functions as a 'Link' that provides superfast, free public Wi-Fi, phone calls, device charging, access to emergency services and public service announcements, and a tablet for access to city services, maps and directions. The network is funded through an advertising model that in turn provides brands with a "rich, context-aware platform to reach New Yorkers and visitors".[9] Information collected by LinkNYC includes data collected by environmental sensors, cameras, and user login information.

Addressing the benefits of smart bus shelters for climate change adaptation

Adaptation and mitigation strategies for urban heat islands (UHI) are primarily focused around urban greening (planting trees in open spaces or along streets); blanketing rooftops with vegetation (living roofs/green roofs); and, increasing the reflectivity of built surfaces.[10] However, innovative bus shelter designs also have a role to play. Firstly, they can protect passengers during extreme weather events by providing a more protective environment for waiting passengers. This is an area where both the physical design of the architecture and the use of climate-control devices is crucial. Secondly, smart bus shelters could also be used to collect more micro-scale temperature data to improve understandings of the nature of urban heat islands, and the relative impacts of different mitigation strategies and interventions.

The Precedent Review available in Appendix A of this report shows how heat mitigation and/or climate control can be achieved across three areas: 1) parametric design aided by BIM or other parametric software; 2) integration of energy production (ie solar panels, smart paving); 3) mitigating strategies for extreme weather conditions and emergencies.

As far as parametric design is concerned, bus shelters can be mathematically designed to maximize or minimize sun exposure in relation to a series of other parameters and to the

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[9] See https://www.link.nyc/

[10] See Corburn, J. 2009. "*Cities, Climate Change and Urban Heat Island Mitigation: Localising Global Environmental Science*". *Urban Studies,* 46 (2) 413-427; Available from: https://www.researchgate.net/publication/258199028_Cities_Climate_Change_and_Urban_Heat_Island_Mitigation_Localising_Global_Environmental_Science [accessed Mar 10, 2017].

eventual need. Parametric design is also functional to computer-aided-fabrication (CAM), like laser-cutting or 3d-printing, which offers the possibility of having adaptable solutions without entirely losing the economy-of-scale of standardized industrial production. With CAM each bus stop can be fabricated with locally-specific climate-control features.

Whilst the inclusion of solar photovoltaic panels is not new in the design of shelters, other possibilities can be explored with new battery accumulators that can take shelters off grid in remote areas. Energy produced by the bus shelter can consequently be used for warming or cooling systems that target the environmental conditions underneath the shelter. In case of extreme heat, bus stops can be conceived as indoor, air-conditioned structures (case study 8) or equipped with green roofs (cases 7, 16) that abate the heat-island effect in built-up areas. In Manchester the heating strips installed on the bus stop are controlled by the users with a near-field communication protocol (case study 17). Air filters and misting systems can also be used to manipulate extreme heat and pollution in crowded cities (case study 18).

While not all smart bus shelter precedents incorporate specific designs or services for extreme weather events or emergencies, the inclusion of real-time information displays clearly has a role to play in helping to deal with risks during such events as heatwaves, floods and storms. Particularly for those who may not have access to a smartphone, travel advisory warnings, emergency alerts and hazard reduction plans could be incorporated into bus shelter information services particularly during summer periods.

The use of health and/or travel warnings could be enhanced through the integration of smart sensors capable of detecting localised temperatures or other conditions. For example, once certain temperature thresholds are met, these sensors could trigger a display that provides advice on how to protect yourself during heatwaves, and contacts for emergency services. This would offer a highly localised, yet automated service designed to accommodate different kinds of extreme conditions experienced by commuters in Western Sydney.

The use of smart sensors within bus shelters to capture localised temperature data is clearly an area worth further investigation. Embedded sensors could be used to model the relative impacts of different urban heat island mitigation strategies, such as street trees, green roofs and/or altered surface properties. These could be used to complement existing approaches used by the NSW Office of Environment and Heritage (OEH) and ISF including aerial imagery and Landsat data.[11] Additional data including daily volumes of bus shelter usage could in turn be used to identify areas of greatest vulnerability - highest UHI combined with bus shelter activity levels. When this data is also correlated with passenger demographic data

[11] This could extend vulnerability mapping work undertaken by ISF and OEH reported in *Adapting to urban heat island events: by mapping vulnerability hot spots.* NSW Office of Environment and Heritage (OEH), LGNSW. Available at: http://www.lgnsw.org.au/files/imce-uploads/122/Penrith_urban_heat_case_study.pdf

via Opal card data there is the potential for a more granular understanding of areas of vulnerability.

Conclusion: Understanding connected bus shelters as part of a connected digital ecosystem

This report has provided a review of a range of existing smart bus shelter precedents, identifying how digital technologies are changing the role and functionalities of bus shelters, with consideration to the ways in which in smarter bus shelters could be used to mitigate risks associated with extreme weather events and UHI effects. This research has identified a number of ways in which digital technologies are expanding the range of services available through bus shelters, in particular the delivery of enhanced network communications infrastructure (such as Wi-Fi) and access to city information services.

The potential for bus shelters to improve location-specific urban data or 'ambient intelligence', through integration of environmental sensors such as temperature readings, could provide a much more contextually-rich understanding of areas of vulnerability in Western Sydney, comprising demographic data from Opal cards, location-based activity reporting and micro-climate temperature data. This data could help create a much richer map of vulnerability across Western Sydney to inform a number of areas of government policy. At a very localised level, for the commuter, a more responsive bus shelter design could also in turn trigger information displays featuring specific health warnings, travel advice, or emergency contact information.

These opportunities are worth more detailed consideration by relevant government agencies.

3. Smart services and multi-functional infrastructures

Smart bus shelters have the potential to augment the functions of bus stops, improve their responsiveness to climatic events, and create more contextual data about conditions of vulnerability across Western Sydney. However, it is worth noting that many of the features available through smart bus shelters, including increased Wi-Fi connectivity, information displays and ambient data collection through integrated sensors, are also being trialed through a range of other smart infrastructure and services. In this sense, bus shelters are not the only piece of 'everyday urban infrastructure' that can be made 'smarter'.

The rise of the 'Internet of Things' (IoT) points to an explosion in connected devices with the potential to easily deploy wide area networks of connected sensors and infrastructures. It is expected that by 2020, there will be 212 billion "things" in the world, which is predicted to enable more efficient and better adapted climatic mitigation components which respond more rapidly to citizens' needs (Santamouris 2015). Some emerging areas for smart services, advanced materials and IoT approaches are discussed below.

Smart lighting

"One piece of city infrastructure that is seen as having great potential to harness the internet of things is the lamppost." [12]

The potentials of smart lighting technologies are currently garnering significant attention. 'Smart street lighting' includes street lighting infrastructure that performs the role of traditional street lighting but with additional features designed to increase efficiencies, productivity and services. Smart street lighting infrastructure consists of (at least) LED luminaires (able to be dimmed if needed), data collection sensors and communication technology. Other features could include digital signage, CCTV, speakers, 'push to talk' emergency system and electric vehicle charging. As noted by the Lighting Council of Australia in its 2016 Discussion Paper on smart lighting[13]: "The combination of the pole, data collection, data sharing, analytics and application development has the capacity to significantly increase services".

[12] See 'Lamppost shines a light on smart cities', *Financial Times*, Jan 28 2015. See https://www.ft.com/content/53b285c8-851d-11e4-ab4e-00144feabdc0

[13] http://lightingcouncil.com.au/files/Smart%20street%20lighting%20in%20Australia%20-Discussion%20Paper.pdf

Examples of the additional functionality available across a range of smart lighting solutions are detailed below.

- Variable lighting levels:
  - to increase light levels around event precinct areas and create night economies; and
  - to decrease light levels (light pollution) and save energy when vehicles and pedestrians are not on the streets.
- Increased control, centralised monitoring, outage detection, fault prediction, maintenance planning and asset management improvements.
- Image sensing (CCTV, photography, traffic and pedestrian movements).
- Parking vacancy sensing to support smarter parking and payment applications.
- Digital signage for way-finding, alerts, announcements, entertainment and revenue generation.
- Speakers for music, alerts and announcements.
- Façade lighting (colour changing) for entertainment and ambience.
- Use as a distributed energy source
- Use as electric vehicle charging stations.

As is clear from the above examples of smart lighting functionality, the introduction of smart street lighting and smart poles point to the integration of areas and services that have not previously co-existed. This includes more demand responsive street lighting, dimming, communications, and metering, along with the increased ability to monitor environments including traffic circulation, parking spots, air quality, weather emergencies through the integration of sensors and computer vision technologies. Smart lighting systems can also integrate photovoltaic systems, connection sockets, EV charging and potentially other components. [14]

While there are a range of benefits associated with smart lighting technologies relating to energy reductions, reduced maintenance costs and improved lifetimes, it is the additional environmental and data monitoring functionalities we are primarily concerned with here. Many trials and examples of smart lighting systems have integrated functionalities with traffic sensors and smart parking services, along with environmental monitoring capabilities to capture localised ambient data relating to temperature, rain, flooding and air quality. Smart lighting systems can also have considerable benefits in managing surge protection during electrical storms.

In Australia, smart lighting systems are still in their infancy. This compares to the United Kingdom, where it is reported that approximately 1.5 million out of a total of 6 million road lighting luminaires are using some increased 'smart' functionality. Despite the widespread

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[14] Recent smart lighting technology trials include Current CityIQ sensors. See https://www.engadget.com/2017/02/27/atandts-smart-streetlights-can-smooth-traffic-detect-gunshots/

upgrading of street lights with LED lights across by many Australian councils, few have begun to integrate more advanced smart functionality.[15] however this can be expected to change over the coming months, particularly with the release of the Federal Government's *Smart Cities and Suburbs* initiative highlights smart lighting as a potential area for investment in local government areas.

Existing trials to date in Australia include the City of Adelaide and the City of Parramatta. In 2015 the City of Adelaide partnered with tech giant Cisco and lighting specialist Sensity to modify more than 60 lights along Pirie Street and Hindmarsh Square in the heart of the CBD. [16] The project ran for a total of 5 weeks in 2016, with data collected from the Smart LED Pilot Project designed to inform 'future street light replacements'.[17] The City of Geelong has also introduced a new ‘integrated smart lighting system’ that connects LED public lighting to Wi-Fi and smart phone applications.[18]

The City of Sunshine Coast has also endorsed an Urban Lighting Masterplan in September 2016 that includes deployment of advanced smart city solutions.[19] Smart lights can be used to deploy not only Wi-Fi but also a 'mesh network' and/or associated IoT platform as the basis for a range of services to developed. These include LORAWan/LPWAN or low power wide area networks, which enable the deployment of low cost sensors such as environmental sensors.

As reported by the Lighting Council of Australia, some of the current challenges and obstacles preventing the wider adoption of smart lighting services include regulatory reform; a lack of evidence relating to benefits needed to support business cases for increased upfront expenditure; and lack of common standards and specifications.

Community and environmentally focused IoT platforms

Smart lighting technologies are a very tangible way in which a range of environmental sensors can be deployed in urban settings, using commonplace infrastructure to integrate a range of new services. Some cities are also trialing bespoke or custom made sensing

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[15] See Lighting Council of Australia Smart Lighting Discussion Paper, 2016, p 12. Ironbark Sustainability reports that there have been over 368,000 street lights replaced with LED lights in Australia, representing around 16% of all lights and 23% of all residential (or local) roads. However LED lights are only one feature of 'smart lights' being considered here.
[16] http://investadelaide.com.au/why-adelaide/adelaide-smart-city/smart-lighting-trial-project
[17] See http://investadelaide.com.au/why-adelaide/adelaide-smart-city/smart-lighting-trial-project
[18] http://www.govnews.com.au/greater-geelongs-big-smart-lighting-switch/
[19] See Sunshine Coast Council Urban Lighting Masterplan at https://www.sunshinecoast.qld.gov.au/Council/Planning-and-Projects/Council-Plans/Urban-Public-Lighting-Master-Plan

platforms through collaborative partnerships between universities, city governments and local product manufacturers.

In Chicago, the Argonne National Laboratory has partnered with the City of Chicago and the University of Chicago to create the 'Array of Things', a network of open source sensors to be installed across the city. The project has created an open, modular network, which can accept sensors from a range of organisations. The researchers are also publishing open–source specifications for all of the software and hardware the project develops.

Using this collaborative approach to network design, locations for the nodes and relevant data applications were also determined through a series of consultations with community organizations and research groups. These helped to determine the major priority issues for community groups and the areas where data gaps were largest (e.g. where the sensors could have the biggest or most useful impact). Examples include sensors placed close to schools for tracking air quality and its relationship with asthma and other diseases, and studies of pedestrian and vehicle flow in relation to traffic safety in local neighborhoods. Scientists at UChicago and Argonne also chose locations that could allow for optimal measurements of features related to urban weather and climate change.[20] As the Director of the program has outlined, the project is "about creating new streams of data that help us understand and address the most critical urban challenges. Where we see an intersection of resident concerns, science interests and policymaker interest, that's where we see opportunity for Array of Things deployment in Chicago."

Data collected by Array of Things nodes is open, free, and available to the public, researchers, and developers. Data is published through the city of Chicago Data Portal, and open data platform Plenar.io, and via application programming interfaces (APIs). As specified by the Array of Things privacy and governance policies, no personally identifiable information is stored or released by sensor nodes.

The Array of Things platform demonstrates the importance of understanding not only the specific technical functionalities afforded by emerging smart technologies, but also the wider partnerships and governance contexts that structure how data is accessed and used. In particular, it highlights opportunities to design sensing platforms in partnership with external collaborators, researchers and the community to not only help ensure data captured through these technologies is made more widely available and accessible, but also to ensure new services reflect local knowledge and expertise.

Smart rain gardens

[20] https://news.uchicago.edu/article/2016/08/29/chicago-becomes-first-city-launch-array-things

Bio-climactic design is clearly critical to the management of UHI and extreme weather events in Western Sydney. A recent 2016 trial of IoT technologies included the development of a 'smart rain garden' that generates real-time environmental data to support new methodologies to more effectively manage water services, particularly during extreme events (flooding).

The Smart Rain Garden trial in New York is described as follows:

> *Through the use of monitoring nodes, we have access to real-time empirical data. By making datasets available (here is an example of an open data portal) to the general public, stakeholders may conduct analyses of water flow, and subsequently develop, recommend, and implement methodologies to effectively manage municipal runoff. Utilizing connected devices/IoT to monitor rain gardens, citizen-scientists can assist local government to help quantify rain-garden capacity and provide a compelling, empirical argument for inclusion into future civic planning, or even into future building code requirements.*

Hardware is designed to support monitoring of temperatures and moisture levels in the soil, the temperature of water leaving the drain spout and entering the garden, and environmental conditions like light level, air temperature, and humidity. Sensors included:

- Ambient Light Sensor (TSL2561)
- Soil Temperature and Moisture Sensor (SHT10)
- Water Temperature Sensor (DS18B20)
- Air Temperature and Humidity Sensor (DHT22)

More detailed project specification details can be found at the Project website. [21]

High performance architecture (HPA) and intelligent materials

High Performance Architecture (HPA) also offers many smart solutions to climate change impacts in Western Sydney. Advanced materials for outdoor spaces and buildings are being developed allow alteration of the thermal balance of cities, decrease the energy consumption and improve indoor and outdoor environmental quality in the built environment.

Initiatives currently in development within HPA at UNSW include:

- Deployment of an Energy Bus or 'mobile experimental lab'. The Bus creates an advanced monitoring system able to perform large scale measurements at high spatial resolution in the urban environment, using a 20m antenna accommodating

[21] *Smart Rain Gardens for Smarter Cities.* See https://blog.scriptr.io/smart-rain-gardens-for-greener-cities/

any kind of sensor, an aerial monitoring system (drone) as well as remote sensing equipment. This is designed to monitor the characteristics of the urban microclimate and urban heat island and to assess the thermal performance of applied mitigation technologies.[22]

- Cool paving: Photo voltaic assisted materials such as PV-pavements, which are shown to reduce surface temperatures compared to conventional concrete pavements.

Santamouris reports on the procedures undertaken by the HPA group to support research outcomes into the impacts of smart materials, which are worth detailing here (Santamouris n.d):

A. BEFORE: Detailed monitoring of all environmental parameters was organised before interventions to understand the local boundary conditions
B. DURING: Detailed simulations are carried out to design and optimise all environmental and energy parameters
C. AFTER: Detailed monitoring was carried out after the end of the rehabilitation to assess the real performance of the intervention.

[22] See https://www.be.unsw.edu.au/research-clusters/high-performance-architecture/research-projects#sthash.PSBQqYpi.dpuf. See also Santamouris (2016;2015)

4. Building an effective data ecosystem for smart climate-adapted services

Smart technologies enhance the ability to collect context-rich data on urban environments, helping to monitor conditions and provide more granular insights into local urban interactions across a range of environmental, social and mobility factors. The data generated through these smart services can in turn help deliver more responsive, context aware urban services, such as information alerts and/or demand-responsive mobility services. In relation to the challenges of climate change adaptation, these services can deliver more situational awareness of environmental conditions and micro-climates, improve understanding of how factors such as UHI impact on certain citizen demographics, while also improving services to citizens when in need. As Santamouris (2015) has argued: "Complete and accurate knowledge of the magnitude and the characteristics of heat island is a prerequisite for a proper and complete planning of urban mitigation and adaptation technologies"

As this Report has demonstrated, integrating smart technologies into infrastructures such as bus shelters means the inclusion of new functions not ordinarily associated with existing infrastructure. For example, a smart bus stop might become a charging station, or a hydration stop - it's no longer just a place to catch a bus. Likewise, a smart light might act as an environmental sensor, not only lighting the way or maintaining the safety of darkened streets.

However, achieving any real-world benefits will ultimately depend not only on the functionality of the sensors and the data capture devices. To be used effectively, data generated by these devices needs to be able to be used and made accessible across a range of contexts. This represents a balancing act between maintaining privacy and security on the one hand, and promoting access and use of data on the other.

To reach the full potential of smart services and IoT, these services and 'things' need to be findable, accessible and linked to other 'things' and services. To enable this interaction, a higher degree of interoperability is necessary, moving beyond simple protocol interoperability as provided by the Internet (Blackstock & Lea 2014). In particular, the deployment of IoT platforms and services has highlighted the importance of appropriate data storage, integration and access protocols and infrastructure that facilitate access and re-use of data by third party service providers.

This approach requires a shift away from one-off smart services or trials (vertical silos), towards a more 'ecosystem-wide' approach to trialing smart services. Where first generation smart city infrastructures created new data silos by attaching one type of data to each sensor type or smart service, the rise of more and more IoT based services has made it more important for data to be made accessible and usable to many different organisations and users. From a city services perspective, this interoperability and data portability is necessary to enabling insights into relationships *across* urban domains and infrastructures, whether transport, heat, air quality, soil quality, lighting.

Today many IoT platforms and smart services remain in trial or prototype mode. However, central to their effectiveness over the coming years will be the need for an *integrated data strategy* that addresses issues around data privacy, data security, common standards for data collection and opportunities to promote conditions that allow for appropriate access and re-use of data by a range of user groups.

Making sense of urban big data, and developing more granular insights about localised micro-climates and their population impacts, will in this sense require not only one off technology investments but also the creation of an *effective data strategy* that aligns data curation and sensing initiatives with specific areas for either sustained policy focus or intervention.

There are now a number of initiatives designed to foster an ecosystem-wide approach to smart services using IoT and machine to machine (M2M) communications. The Hypercat Alliance[23] is an industry alliance originally developed in the UK, now with representation in Australia, that promotes specifications for IoT interoperability. It functions as an open, lightweight hypermedia catalogue format for exposing collections of uniform resource identifiers (URLs) for surfacing information about IoT assets over the web. For example,this initiative allows for the ability of streetlights to, theoretically, automatically communicate with parking sensors in addition to other streetlights[24].

Another initiative is the LORA Alliance[25], which uses LoRA WAN (a Low Power Wide Area Network (LPWAN) specification) to allow for interoperability among smart Things and an open architecture for many partners. The network uses unlicensed radio spectrum in the Industrial, Scientific and Medical (ISM) bands rather than cellular connectivity to enable low power, wide area communication between remote sensors and gateways connected to the network. Cisco is delivering services using LoRaWAN, while a crowdfunded organisation called The Things Network, in partnership with the University of Technology Sydney and IoT company Meshed Network, have also launched a public access IoT network in Sydney[26]. In New York, The Things Network was used to support the recent smart rain garden trial.

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[23] See http://www.hypercat.io/
[24] See TechRadar: http://www.techradar.com/news/internet/web/what-is-hypercat-exploring-the-latest-internet-of-things-standard-1255230
[25] LORA is a trademark of Semtech Corporation.
[26] See The Things Network Sydney at https://www.thethingsnetwork.org/community/sydney/. See also

Open data platforms for community collaboration

A central component of many IoT trials and smart services currently being deployed is the creation of an open data platform to encourage third party developers, researchers and other citizens to make use of environmental data for new services. While for many years smart city services were implemented through proprietary gateways and platforms, today there is growing evidence that greater benefits can be delivered through open platforms that allow a variety of third party collaborators, including citizens, to co-create smart solutions for their communities. This represents the expected embrace of 'data marketplaces' established by local governments that allow citizens and corporations to trade access to a variety of local data, including personal data and real-time data. According to Gartner, by 2020 20 per cent of local government organisations will generate revenue from value-added open data through data marketplaces.[27] A current example is the Copenhagen Data Exchange, which builds beyond the current approach to open data portals by combining data discoverability with data consumption and data publishing functions.

The wider significance of these data marketplaces, driven by open data solutions, is the capacity for citizens, communities and businesses to develop ideas and experiments of their own volition. This approach departs from the more traditional technology procurement pathways familiar to local governments, and enables different kinds of services and solutions to emerge from a wider cohort of stakeholders. To accelerate this approach to open innovation using micro-climate data, local governments could also run hackdays or challenge events targeting urban heat mitigation ideas. The 'smart rain garden' project is an example of a project developed through a hackday run by the Things Network in 2016.

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https://www.iotaustralia.org.au/2016/07/20/iotnewanz/meshed-offers-free-access-lorawan-network-sydney/

[27] http://www.thinkdigitalpartners.com/news/2016/12/15/half-smart-city-dwellers-will-sharing-data-2019-gartner/

6. Findings and recommendations

This Report has canvassed opportunities to address climate change impacts in Western Sydney through the use of smart technologies. While the focus for the precedent review has been on the use of smart bus shelters as part of the CAPS project, wider opportunities have also been detailed relating to areas such as smart lighting, IoT platforms and networks, and intelligent materials.

Findings from the research can be summarised as follows.

- There are many opportunities to utilise sensor-based services to improve understanding of micro-climates and contributors to urban heat islands across Western Sydney.
- Focus should also be on the relative alignment of UHI with other determinants of vulnerability, including demographic factors (old age, young children, low income earners).
- Bus shelters are a useful 'everyday infrastructure' for trialing the implementation of new smart services, and are particularly useful for the delivery of context-aware information to commuters who may not otherwise access smartphone services. However, additional infrastructures such as smart lighting, or commissioning bespoke sensor platforms, are also useful mechanisms for data capture. Innovations in smart lighting in particular can facilitate more data capture than smart bus shelter designs, however data sharing provisions should be managed carefully.
- Future investments in smart technologies and services should be accompanied by clear strategies for data collection, data sharing and data privacy.
- Opportunities to trial IoT networks such as LoRaWAN in collaboration with The Things Network are worth investigating. This could include data capture trials accompanied by hackdays and challenge-style events.
- The Federal Government's *Smart Cities and Suburbs* program will provide funding to local governments over 2017 to trial new smart technologies. This provides an opportunity to support local government technology trials or partnerships.

Some possible scenarios for future exploration in this area are introduced below.

Scenario 1: Developing a vulnerability map of Western Sydney using composite data (environmental, demographic and mobility).

Environmental sensors are integrated across a series of bus shelters (or smart lights), to generate a more detailed reading of the impacts of different urban typologies on UHI. This data could be augmented through access to Opal card data showing the volume of use at a given bus stop at given times of the day, and aggregate trip destinations, if available. This composite data could then be used to highlight the most vulnerable bus stops from a UHI perspective, and those that attract the highest number of daily passengers. These could be used as trial locations to prototype enhanced government services to these commuters, including more responsive information displays and more climate controlled infrastructure.

Scenario 2: Establish an UHI challenge event (hackday) leveraging the LoRaWAN network

Implementation of an UHI data mining trial with The Things Network in Sydney could include the deployment of an LoRaWAN gateway in a designated location in Western Sydney. This could be accompanied by the deployment of a range of sensors to maximise environmental data about micro-climates. A hackday in Western Sydney could make this data available for a select period of time, integrated with wider open data sets available via the NSW open data portal. Developers and other representatives of the community could be invited to create applications using this data that specifically target urban heat mitigation opportunities and/or responses to extreme weather events such as flooding. Winning applications could then be trialed and evaluated with participating councils. This program could also be established with support from the Federal Government *Smart Cities and Suburbs* program funding.

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Appendix A.

Smart Bus Shelter Precedent Review

1. Introduction

This appendix contains a case-study review of precedent examples of people shelters (or related infrastructures) which have been conceived or implemented with the aim of integrating other services and/or climate adaptation strategies in their design. Some relevant trends are highlighted as emerging directions in the physical and digital layout of people shelters. The 21 case studies presented below have been selected according to four areas of innovation:

- Integration of services not related to public transport
- Integration of climate control/adaptation design and technologies
- Use of smart technologies
- Bus stops as urban sensors

While some of the precedents show inventive design only in one of the four fields, most examples are, in fact, innovative across more than one area. Hence, it could be said that a general trend appears to be a holistic design approach to innovating people shelters. Many of the cases, for example, show how the integration of data infrastructures goes hand-in-hand with augmenting the basic functions of a bus stop, or climate-adaptive design features with embedded smart technologies.

Integration of other services into bus shelter designs

A major emerging trend in the design of bus shelters is the integration of other services that may not be immediately related to public transport functions. In particular, the case studies show that at least three types of other services could be integrated into the physical infrastructure of the stops:

- Integration of other transport infrastructure (eg. bike sharing)
- Integration of retail functions
- Integration of other public services (library, book sharing, etc).

Case studies in Paris (2) and London (10) show how bus shelters with sufficient public space available can incorporate bike sharing stations and/or recharge stations for electric bikes. The Millennial Bus Stop prototyped in Saint Paul, Minneapolis (13), and the Project Bus Stop in Singapore (16), instead, feature bike racks as an integral part of the shelter design. The Singaporean case, in particular, offers smart bike racks with locks controlled digitally.

Retail functions can also be an ancillary component of the bus shelter structure. Although vending machines have long been placed in close proximity of various waiting areas, including bus stops, an emerging trend in the design of people shelters see them as part of the architecture itself. This is particularly evident in the Dubai-produced Smart Bus Shelter (case 8), which houses retail and display shelving systems, with food, basic hygiene products, as well as small appliances, like USB cables and earphones. The integration of retail services offers a traditional business model to public transport providers who can rent the bus stop space to vendors in order to create an additional source of income.

Private retail functions can be accompanied by services of public utility. This is exemplified in various instances by the integration of small libraries for book sharing, or, on a larger scale, an e-book borrowing dashboard provided by the local public library (case study 16). Sean Godsell's bus shelter house (case study 5) explores another opportunity for augmenting the public functions of a bus stop: the prototype, realized in Melbourne in 2014, becomes a fully-equipped sleeping pod for homeless people during night hours.

Integration of climate control and other adaptation strategies

As outdoor architectures, innovative bus shelters are designed to mitigate extreme weather conditions and provide a pleasant environment to passengers waiting. Climate control, however, is not only achieved through the physical design of the bus stop, but also with the integration of other technologies of energy generation and/or temperature control. Relevant emerging trends seen in the case studies are:

- Parametric design (ie. automated design that adapts to changing external conditions)
- Integration of energy production (ie solar panels, smart paving)
- Mitigating strategies for climate control (ie green roofs, air-conditioning systems,).

Parametric design is a common direction in the conception of architectures that adapt to changing sun exposure. Specific algorithms can help maximize sun shading during summer and/or maximize sun exposure in colder months. Furthermore, parametric design can help in contexts where bus shelters need to adapt to diverse geographic and historic urban conformations, as in the case of Florence (case study 1). Parametric design is also functional to 3d-printing or laser-cut fabrication, as in the case of the Interchanging bus shelter (21).

Whilst the inclusion of solar photovoltaic panels is not new in the design of shelters, other opportunities can be explored, as in the concept for a bus stop in Noort-Brabant, in the Netherlands, where the photovoltaic shelter also recharges electric buses. Energy produced by the cells can be used to take the bus stop off-grid, as in Saint Paul, Minnesota, where a battery stores the electricity (case study 13) and powers the LED lighting system. The Barcelona case (15) also explores other means of electric energy production, such as smart tiles that absorb the kinetic energy of cars and pedestrians.

As far as climate mitigation is concerned, innovative projects also feature warming or cooling systems that target the environmental conditions underneath the shelter. While the extreme heat of the Arabian Peninsula translates into an indoor air-conditioned bus stop (case study 8), in Manchester the heating strips installed on the bus stop are controlled by the users (case study 17). Extreme pollution is also another meteorological condition that can be manipulated with specific solutions, as the Hong Kong's bus shelter prototype shows (case study 18).

Integration of smart technologies and use of digital data

Another area of innovation in the conception of people shelters is the integration of various smart technologies that allow passengers to engage interactively with the bus stop and with its various additional services. This is a particularly important area of experimentation because it may provide further business models and revenue opportunities for public transport providers. The case studies analyzed in this report show the integration of several typologies of smart services:

- Connective technologies (WiFi, 4G)
- Touchscreens and projections
- Lighting
- NFC and other technologies of near-field communication
- Smart Security

Almost all the cases incorporate or are designed to incorporate technologies of connection to the Internet. This is usually achieved through Wi-Fi hotspots, that can be easily added in the design of new bus shelter or used to retrofit existing ones, as has happened in Los Angeles (case study 20). However, more experimental approaches can be pursued, as with Ericsson's bus stop, which integrates a satellite cell, making the shelter itself a connective hotspot (19).

Other connective technologies may offer additional services, especially near-field protocols, like Bluetooth or NFC, which allow the bus stop to communicate with devices like smartphones and tablets, and provide relevant information. The nature of these communication protocols facilitates implementation of various business models , for example providing targeted advertising or public information. In this sense, Google's example of smart screens shows an avenue in the field of machine-learning opportunities for street furniture (case study 11).

Another prominent area of experimentation is that of smart screens or responsive projections which become an integral part of the bus shelter and provide opportunities for various forms of engagement for citizens and tourists. Smart screens can be enabled with touch-sensitive controls, and feature navigation apps that help users with journey planners and other public transport information. Various cities across the world have developed their own native apps in collaboration with other public or private agencies. These apps can be made available on smart screens at bus stops. Furthermore, advertising opportunities can provide additional sources of income for local governments or public transport providers, without necessarily installing advertising screens, but simply creating ad hoc applications for publicity and classified ads. In this sense, bus shelters can include platforms for civic engagement as well as community participation.

Given the flexibility of these screens, some of the experiments featured below (cases 1,2,6,7,9) use existing urban data to showcase information that can be of interest to tourist or visitors, like local landmarks, biking routes, restaurant guides, etc. These datasets can be accessed through specific apps, but also in more engaging ways. For example, the real-time data about the geolocation of buses, which provides estimated arrival times, can be integrated into the lighting of the bus stop, which can glow at different level of intensity (case study 1), or with different colours (13), or include a musical tune (2) to communicate the arrival of a bus.

In terms of the engagement potential of "augmented" bus shelters, the case studies show three emerging trends that can be summarized as:

- A move beyond ETA (estimated arrival time) to more readable or engaging ways of communicating arrival times;
- Integration of search functions to find routes and shortest transport combinations in the shelters' touchscreens;
- Integration of third-party mobility and other applications;

Finally, another area of inclusion of smart devices is represented by safety technologies. These devices range from traditional CCTV cameras embedded in the shelter's structure, as in New Zealand (case 13), to more interactive solutions like help buttons (case 20). Some case studies also show additional possibilities, like the inclusion of a remotely controlled defibrillator (6) or audible wayfinding through 'ibeacon' technologies. Cameras can be also used for machine-recognition, to gather data about occupancy and use, as well as to explore safety mechanisms such as broadcasting the real-time recordings to other bus stops, as in the Interchanging bus shelter (21).

Bus stops as urban sensors

Like other examples of smart street furniture, bus stops can incorporate sensing devices that monitor a number of different urban quantities, from passenger traffic to the presence of air pollutants. Although the case studies analyzed for this report are mostly prototypes or concepts when it comes to urban sensors, some emerging trends can be identified, such as:

- Inclusion of sensing technologies for monitoring the external environment (EMS);
- Inclusion of near-field communication protocols monitoring the presence of phones and devices;
- Possibility to incorporate machine-learning video recognition in CCTV camera recording for safety monitoring as well as gathering occupancy and use statistics.

This is certainly an area of extreme possibilities of innovation, with the potential for bus stops to become urban sensor providing real time data to local governments. In a pilot project not reported here (Taherzadeh, 2015), Ericsson partnered with two Serbian cities to install EMS on buses, in order to measure air pollutants and other environmental statistics. As EMS are GPS-enabled, the environmental monitoring could also provide real-time time data to the bus stops – which shows that sensing technologies do not necessarily have to be embedded in the shelters, but use other vehicles to gather data.

Smart sensing is also a field where various business models can be experimented, with third-party providers installing their own sensors, producing and selling their data, and, in doing so, creating a further revenue stream for public transport agencies. In this sense, the market trial conducted by Nokia and Downer (case study 12) showed revenue possibilities beyond the traditional outsourcing of ownership to advertising agencies. Two business models were experimented – one featuring 4G cells, whereby phone operators "hire" the bus stop to cover an area with high speed broadband, and one featuring targeted advertising, based on data gathered by the bus shelter as a smart sensor (see Nokia, 2016).

Case study 1

Name: eyestop
Location: Florence (Italy)
Year: 2012 (prototype)
Partners: MIT Senseable city Lab - ATAF (local public transport authority)

This prototype bus stop is a modular system that includes an information totem and a power-generating structure. A parametric computer program generates a unique design for each bus stop, providing both optimal sheltering for users and maximum sunlight exposure for power generation. In order to adapt to the existing city, in particular to the historic centre of Florence, the bus stop is designed so as to have a module that becomes a simple totem for the parts of the city where it is impossible to have larger shelters.
The totem glows at different levels of intensity to signal the approaching of a bus from afar. Riders can plan a bus trip on an interactive map, surf the Web, monitor their real-time exposure to

pollutants and use their mobile devices as an interface with the bus shelter.
Users can also post ads and community announcements to an electronic bulletin board. The EyeStop is partially covered with touch-sensitive e-INK screens, and features sensing technologies and a variety of interactive services. The journey planner helps to check the shortest route to the destination, as well as the exact location of the desired bus. The software also features a send-SMS function which messages the estimated arrival time to people waiting.
The bus stop also works as a sensing station – with environmental monitoring devices incorporated in the structure.

References:
http://senseable.mit.edu/eyestop/press.pdf
http://www.tuvie.com/eyestops-futuristic-bus-stops-from-senseable-city-lab-of-mit/

Case study 2

Name: Station Diderot
Location: Paris (France)
Year: 2012 (one built)
Partners: Paris trasport authority (RATP) and Marc Aurel Urban designer - Quantum Glass, C.R.A.F.T., Philips, Metalco

This bus shelter is located in one of Paris's transport hubs (Gare de Lyon) and it integrates four different forms of transport: pedestrian, bike sharing, private bikes, and buses, as well as being in close proximity to the train station.
Covering an area of 80 m2, it was designed as a multi-purpose public space. Variable light adjusts for day and night conditions. Some of the more innovative features include a free library; a central section that is heated slightly in colder weather to ensure a mild sensation of warmth; and sound ambiances that are not broadcast through speakers, but through the glass of the vertical sections. Within this idea of integration, the bus shelter also features a cafe-retail area, where coffee can be bought from a vending machine.
A series of touchscreens for different services showcase information about public transport and about the neighbourhood. A coloured-lights installation presents a sculptural map of the area. A soft musical tune, composed by Michel Redolfi, is also broadcasted when the stop senses that a bus is approaching.

References:
http://www.treehugger.com/public-transportation/paris-tests-out-snazzy-new-bus-stop-future.html
http://www.citylab.com/commute/2012/06/building-better-bus-stop/2325/
http://humantransit.org/2012/05/paris-the-bus-stop-of-the-future.html

Case study 3

Name: the blue spots
Location: Santa Monica (California)
Year: 2014 (built)
Partners: Big Blue Buses - Lorcan O'Herlihy Architects - City of Santa Monica

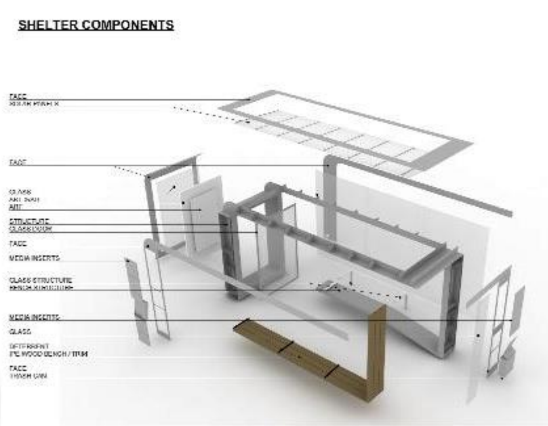
Blue spots bus stops were designed to enhance the city's coastal look. They feature a design which incorporates real-time information, solar LED lighting, updated maps. The bus stop structures utilize a modular system to adapt to variously sized locations and rider volumes. The three stop configurations are designed to accommodate passenger riderships from "low", to "medium" and "high volume". The bus stops also feature canopies providing shade during peak travel times, as well as WiFi services and USB recharge spots.
Each blue spot is endowed with a map or the lines as well as an ID number that gives real time arrival schedules via mobile phone.

References:
http://www.bigbluebus.com/Newsroom/Press/Big-Blue-Bus-Announces-Plans-to-Modify-New-Bus-Stop-Design.aspx?t=Press
http://www.smgov.net/Departments/PublicWorks/ContentArchitecture.aspx?id=26104
http://www.lawrenceanderson.net/santa-monicas-blue-spots/

Case study 4

Name: Lexington Bus Stop
Location: Lexington (Kentucky)
Year: 2014 (concept)
Partners: Mike McKay – City of Lexington

This modular concept features an adaptable bus stop system, which can be augmented with a range of smart technologies according to the needs of a particular location. An adaptable “media cabinet” can be fitted with devices like a touch screens with transport information or curated content LCD screens. The structure is designed to include a solar generation system.



References:
http://www.w3sh.com/2012/02/26/labribus-du-futur/
http://www.mikemckay.net/mckaybusshelter.html

Case study 5

Name: Bus Shelter House
Location: Melbourne (Australia)
Year: 2014 (concept)
Partners: Sean Godsell

The Bus Shelter House argues for compassionate infrastructure – it’s a bus shelter (when public transport is running) which converts into emergency overnight accommodation. The regular advertising hoarding is modified to act as a dispenser of blankets, food and water. As well the hoarding acts as a small gallery space. The shelter has the potential to be solar powered and it is proposed that its glass roof and back double as a giant digital projection screens.

References:

http://www.seangodsell.com/bus-shelter-house

http://www.theage.com.au/articles/2004/09/27/1096137166187.html

Case study 6

Name: Concept Bus Shelter
Location: ` (France)
Year: 2012 (prototype)
Partners: Patrick Jouin with JCDecaux

The Concept-Bus Shelter offers an array of multi-service innovations and is located on the corner of Boulevard Henry IV and Place de la Bastille. It combines improved levels of comfort (a wider bench and roof, improved access and a glazed roof that provides lighting at night and filters the sun's rays during the day) with features such as a free Wi-Fi connection, and mobile phone charging hotspot. The bus shelter allows the public to find out more about Paris and the local area via a 72-inch screen displaying high-quality historic photos. The screen is located in proximity to the bus timetables and displays news about Paris, France and the rest of the world.

The screen features a jcdecaux-designed platform with different apps (services that help people move around the city and discover what Paris has to offer are provided by the 'Décodeur Urbain', a common element shared by the different Intelligent Street Furniture items). This "City Box" offers users a range of applications on a 42-inch screen (or a 22-inch screen accessible to people in wheelchairs) – such as local classified ads, tourist and other urban information.
The bus shelter also includes a defibrillator monitored by a GPRS network. A second screen at a lower height is designed for wheelchair users.

References:
http://www.jcdecaux.com/en/Innovation-Design/JCDecaux-s-Intelligent-Street-Furniture
http://www.dailydooh.com/archives/65986

Case study 7

Name: Digital Harbour
Location: Paris (France)
Year: 2012 (built)
Partners: Matheiu Lehanneur with JcDecaux

Though not a bus shelter, this piece of public furniture shares with Concept bus shelter (case study 6) a screen with a jcdecaux designed platform with different apps. All these services that help people move around the city and discover what Paris has to offer are provided by the 'Décodeur Urbain', a common element shared by the different Intelligent Street Furniture items.

JCDecaux's in-house teams developed several mapping applications: a map of the Vélib' docking stations including dynamic bicycle availability data, a map of taxi ranks, a neighbourhood map covering the 4 districts where the "Décodeur Urbain" is located, highlighting places of interest: JCDecaux automatic public toilets, restaurants, cafés, theatres, etc. Other information shown on the City Box includes content developed by various partners, from food guides to transport authorities to bike sharing and marketing companies

References:
http://www.dailydooh.com/archives/66000

Name: Smart Bus Shelter
Location: Dubai (UAE)
Year: 2015 (built)
Partners: Al Shamil Foodstuff Trading - Dubai Roads & Transport Authority (RTA) - Right Angle Media

Case study 8

This smart bus shelter structure is conceived as an indoor air-conditioned space for the extreme weather conditions of the Arabic peninsula. The structure offers WiFi connection, NoI and telcom recharge, as well as services like bill payments, flight ticket purchase, charity donations, remittance services and mini-market shopping.
The smart shelter can become a retail store/mini mart with ad-hoc fit-outs where people can wait for the bus and shop at the same time.
Shelters are insulated from exterior conditions but have an Environment Monitoring System (EMS) to track climate and pollution-related data, which will be used by the government to monitor the city's environment.

References:
http://www.smartshelter.ae/services

Case study 9

Name: Intelligent Bus Stop
Location: Berlin (Germany)
Year: 2014 (product)
Partners: Wall – GK Sekkei design

This bus stop is part of a series of street furniture called "The Intelligent Series", which comprises smart public toilets, advertising totems and people shelters. Designed by Japanese firm GK Sekkei, the bus stop features a "bluespot terminal", which is the in-house totem with a built-in app that offers various services to tourists and citizens in Berlin. An LED display broadcasts updates about public transport. WiFi services are also available. The bus stop can be further integrated with a toilet of the same series, and Wall advertising boards. Translucent solar panels of the roof allow the production of solar energy.

References:
http://www.wall.de/en/innovations/innovative_street_furniture

Case study 10

Name: Smart Bus Shelter
Location: London (UK)
Year: 2014 (prototype - product)
Partners: Transport for London (TfL) and Clear Channel UK

The first prototype of the new London's smart bus shelters was installed at Piccadilly Circus in 2014, for a full-city roll-out in 2016. It incorporates a smart screen for London's data feed of live departure information to allow passengers to track their bus in real time. In addition, the interactive panel offers wider transport network updates from the London Underground and real-time availability of nearby Barclays Cycle Hire bikes and docking points. The digital out-of-home screens also offers local area information including maps and walking routes to nearby attraction.

References:
http://now-here-this.timeout.com/2014/03/27/interactive-bus-shelter-set-for-two-month-regent-street-trial/
http://screenmediadaily.com/interactive-real-time-travel-information-trials-uk-bus-shelters/

Case study 11

Name: Google Outside
Location: London (UK)
Year: 2014 (experimental project)
Partners: Google, R/GA London and DOOH (Clear Channel)

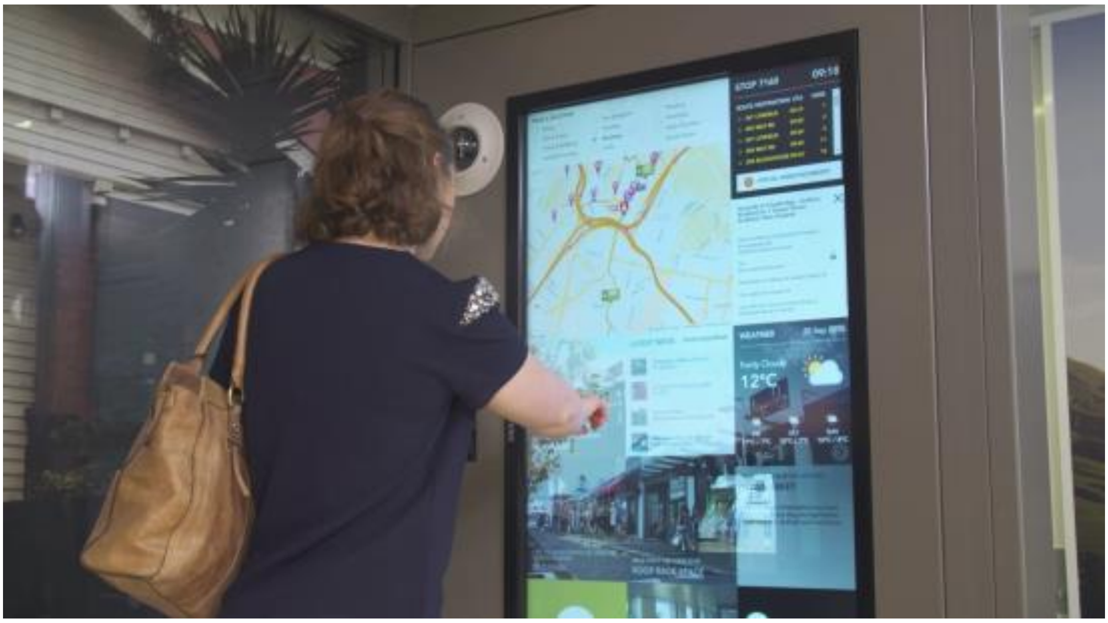
Not exclusively a people shelter, this project features an interesting use of smart street furniture that combines augmented reality and urban data. The pilot lasted for one month in 2014 and included 175 Digital Out of Home displays (DOOH)- marketing screens dotted across the city- to showcase Google Search app for iOS and voice control by delivering hyperlocal mini-guides to the area of the city they were located in. The screens are integrated into bus shelters and in Tube stations. The rationale of the project was to use advertising boards to show the potential of augmented smart street furniture. During the one-month pilot project, the selected digital screens were set up to anticipate the public's needs based on factors such as the time of day, geographical location and weather conditions, and then react to those needs in specific ways. Over 3000 unique stories were developed to give Londoners and tourists a different experience at every location, at any time of the day, concerning information about landmarks, tourist attractions and events, as well as real-time, relevant information about the area. Behind the screens, a team of data and advertising experts at R/GA London and Google developed an interface where they could manage the narrative sequences shown at each location. Through the interface platform they could also flag up unexpected or timely events, manually rewriting the story cards, with a new "story" that would be automatically interwoven into the algorithmic narratives.

References:
https://www.rga.com/work/case-studies/google-outside/
http://www.wired.co.uk/article/google-outside
http://www.dalziel-pow.com/google-outside/

Case study 12

Name: Smart Shelter Downer
Location: Auckland (NZ)
Year: 2016 (experimental project – market trial)
Partners: Downer in collaboration with Alcatel-Lucent, Solta, Designbrand, Samsung, Schneider Electric, Chorus and Nokia

This prototype bus shelter was developed and tested in Auckland as a result of a technology consortium led by Downer and featuring a series of other partners. The modular design includes a touch screen with a user interface specifically developed for the project, as well as a smart CCTV camera.
The user interface offers a journey planner, local news and weather, places of interest, ticketing, directed advertising and even a game. Advertising and local news can be broadcasted on the screen as well – with location-specific targeting.
Thanks to the partnership, the bus shelter featured a number of different sensor and a number of potential business models, including the option to charge a monthly fee to permit third parties to mount and connect their sensors, for the owner to connect sensors, collect data and sell access to the data, as well as for a city authority to install their own sensors and use them to monitor traffic, security, and environment statistics. During the trial project, the consortium deployed a low-cost, single board computer running a Wi-Fi device sensing application to count the number of mobile devices present and their associated dwell time, as an example of the data analytics that can be gleaned by adding sensors to the bus shelter.



References:
https://www.youtube.com/watch?v=bU0fOs-56bw&feature=youtu.be
http://www.downergroup.com/Investors-and-media/Downer-news/Case-studies/2016/The-Smart-Shelter.aspx
http://ngconnect.org/wp-content/uploads/2016/03/PR1512017052EN_Innovation-2020-Connected_Bus_Shelter_Report.pdf

Case study 13

Name: Millennial Bus Stop
Location: Saint Paul (Minnesota)
Year: 2015 (concept – 1 prototype built)
Partners: Metro Transit - University of Minnesota College of Design and School of Architecture - Rosco.

The design of this experimental bus stop was conceived during an architecture atelier at the University of Minnesota. The brief was to create a standard-sized bus shelter in locations where space is insufficient. Metro Transit, the local transport authority, was also interested in experimenting with solar energy production, which could be used to power the bus stop's lights, screens as well as a heating system for waiting passengers. The final design – made of modular blocks – includes a solar panel that provide a power-source for the illumination of the shelter, which is off-grid and accumulated the electricity into a battery. LED lights are used as a way to indicate to users the arrival of the next bus, with different colours signaling the distance. A bike rack module can be added to the bus stop in order to augment its intermodal transport function.

References:
http://www.4rmula.com/?portfolio=millenial-bus-stop
http://www.rosco.com/spectrum/index.php/2015/10/litepad-illuminates-the-bus-stop-of-the-future/

Case study 14

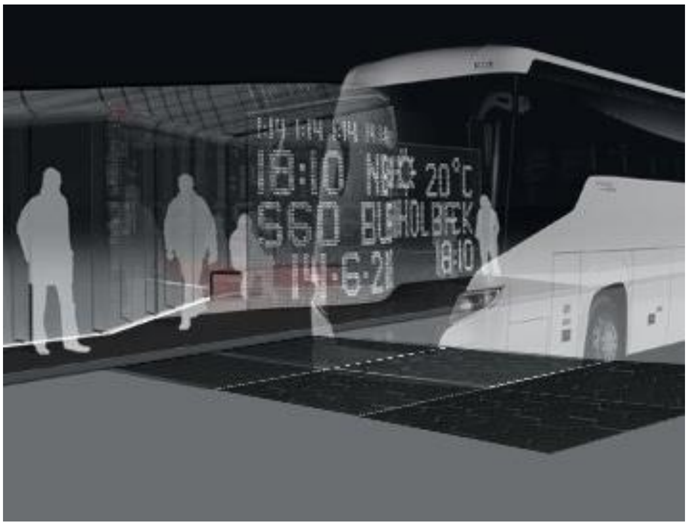
Name: Solar Curve Bus Shelter
Location: Noord-Brabant (Netherlands)
Year: 2015 (concept)
Partners: Studio Mango

Designed for integration with existing bus stops in the Dutch city of Noord-Brabant, the Solar Curve would place inductive charging technology into bus stops that would allow electric buses to recharge their batteries every time they stop to pick up passengers. A system called "inductive charging" uses an electromagnetic field to transfer energy between the shelter and the bus. Approximately 15.5 square meters of solar panels are to be installed on top of the structure's roof, converting sunlight into electricity throughout the day. The roof would be curved in a way that both shelters waiting passengers and allows the energy to be transferred to the bus wirelessly anytime the vehicle pulls up underneath the overhang. The bus stop can also feature a multimodal bike sharing station.

References:
http://earthtechling.com/2012/02/wireless-solar-bus-charger-ahead-of-the-curve/
http://www.treehugger.com/clean-technology/wireless-solar-charger-electric-buses-keeps-computers-rolling.html

Case study 15

Name: Solar Curve Bus Shelter
Location: Spain
Year: 2015 (concept)
Partners: Materfad - ELISAVA Barcelona - LEITAT - Borgos Pieper - Cricursa



This energy-autonomous bus shelter features a transparent structure that integrates photovoltaic cells, LED lighting and multimedia displays with interactive information. It works in connection with an energy-generating smart pavement system, which produces energy from the transit of cars and pedestrians.

References:
http://www.autonomousbusshelter.com

Name: Project Bus Stop
Location: Singapore
Year: 2016 (one built)
Partners: Infocomm Development Authority of Singapore, Land Transport Authority, National Parks Board and Urban Redevelopment Authority and DP Architects

Case study 16

This bus shelter was developed as a prototype for new stops in the city of Singapore.
The large structure features both a green roof and solar panels to mitigate the environmental impact of the stop. A swing and a book corner are also part of the stop, providing leisurely waiting times. The book corner is linked to the local National Library portal, through which passengers can download ebooks to their devices. A charging and Wi-Fi dock station is also one of the modules of the station. Intermodal transport is achieved through smart bike racks where users can leave their bikes.
Three digital boards proved transport data, an interactive journey planner as well as local information. The back of the stop showcases the drawings of local artists, as a public art gallery.

References:
http://www.channelnewsasia.com/news/singapore/smart-bus-stop-prototype/3053708.html

Case study 17

Name: Tweet-to-heat
Location: Manchester (UK)
Year: 2013 (experiment)
Partners: CHI&Partners and British Gas

This pop-up bus shelter experiment was developed in Manchester's Piccadilly Station. The shelter was part of a Manchester takeover campaign created by CHI&Partners for Hive Active Heating, a brand of British Gas promoting remote control for heating systems. As part of the campaign, the pop-up shelter used technologies from Visual Voice to process and respond to localized tweets under #TweetToHeat hashtag. Waiting passengers who tweeted anything under the hashtag were able to see a response from the Hive Twitter account, as the shelter would heat up for them.

References:
https://lbbonline.com/news/tweettoheat-this-bus-shelter-with-chipartners-british-gas-campaign/
http://www.squareone.uk.com/tweettoheat.htm

Case study 18

Name: Air Purifying Bus Shelter
Location: Hong Kong
Year: 2015 (product)
Partners: Sino Group - ARUP

Sino Group teamed up with Arup to develop a road-side air-purifying system incorporated into a bus shelter to provide clean filtered air to waiting passengers. The prototype was placed on the busy Queen's Road East in Hong Kong's crowded Wanchai district. The structure of the bus shelter absorbs air near ground level and removes not only PM 10 but also finer PM 2.5 particulates, pumping out fresh air through louvers at the top. The fresh air forms an air curtain, so anyone standing inside is largely sealed off from particulates. Preliminary data show a 30% to 70% reduction in particulate matter. A new version of the system will also feature further climate adaptation enhancements, like solar panels and mist-cooling systems.

References:
http://www.arup.com/news/2015_07_july/02_july_outdoor_air_purification_system_debuts_in_beijing
https://www.techinasia.com/outdoor-air-purifier-wait-bus-40-smoggy

Case study 19

Name: Connected Bus Stop
Location: presented at UITP World Congress in Milan
Year: 2015 (product)
Partners: Ericsson

Ericsson has developed a connected bus stop concept that incorporates 3G, LTE or Wi-Fi small cell technology. The connected bus stop's small cell infrastructure -a patent owned by Ericsson- can be leased to telecom mobile operators as a means of densifying their networks, or to local municipalities to deliver public WiFi. The small cell is an opportunity for public transport providers to create an additional source of revenue. It is particularly indicated for crowded area, where high-speed connection may be slowed down by high numbers of users. The bus stop design incorporates screens that display real-time information about bus movements and touch-screens that provide access to interactive maps, local news, tourist information and advertising. In addition, a closed-circuit television (CCTV) camera, panic button and push-to-talk functionality could be incorporated to increase security and make it easy for commuters to contact emergency services or the police.

References:
https://www.ericsson.com/news/1926277

Case study 20

Name: Connected Bus Stop
Location: Los Angeles
Year: 2015 (pilot)
Partners: JCDecaux – Outfront Media – City of LA

In this pilot project, two bus shelters located near LA city hall were retrofitted with WiFi hotspots, a USB port for charging devices, and displays of transit information. More importantly, ibeacons were incorporated into the shelters, allowing mobile phones to talk to the bus stop and viceversa. iBeacon technology allows a mobile software to understand its position on a micro-local scale, and deliver hyper-contextual content to users. The underlying communication technology is called Bluetooth Low Energy, and it has potential for advertising use, as users can accept to receive notifications from local shops as well as public transport information.

References:

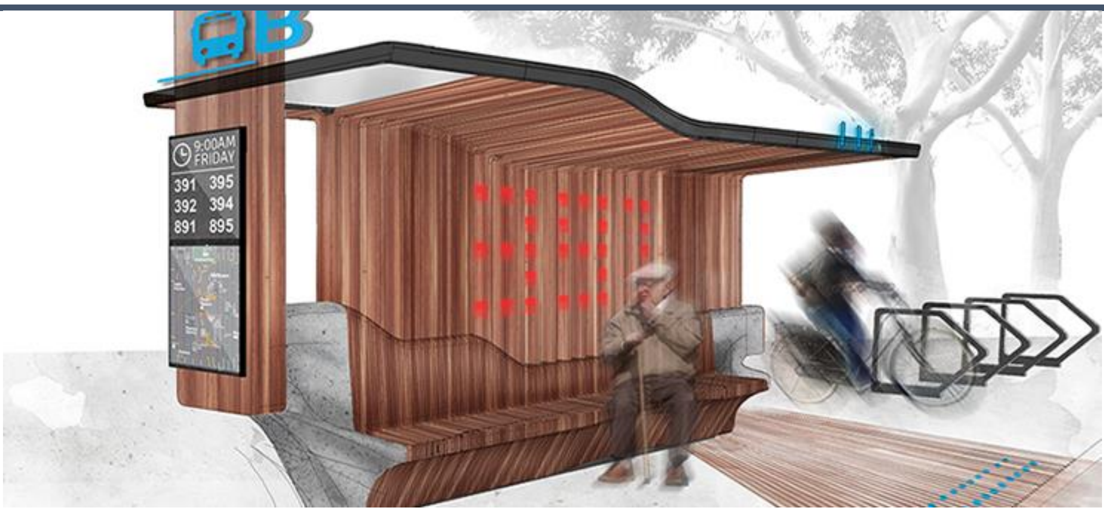
http://www.ibeacon.com/what-is-ibeacon-a-guide-to-beacons/
https://backchannel.com/these-two-la-bus-stops-might-change-the-future-of-cities-13268840f46e#.g3xk2cfi1

Case study 21

Name: Interchanging
Location: Sydney (Australia)
Year: 2014 (concept – 1 prototype built)
Partners: University of New South Wales – ARUP – Transport for NSW – City of Sydney – University of Technology Sydney – University of Sydney – Grimshaw - Encircle

This bus shelter was developed as a prototype for an exhibition of Sydney Design Week in 2014 - Interchanging. A parametric model was used to define the form of the wooden panels that compose the architecture – making it adaptable to different configurations.

The bus stop features three main screens. One is an LED display, which uses an array of diodes that can be controlled to light up and communicate bus numbers, arrival times and other real-time information. The second display, on the inside of the bus shelter, is a touch screen that functions as a community notice board – with possibility to upload photos, classified ads and other locally-relevant bulletins. A third screen, an LCD display, is also incorporated on the inside walls of the shelter, and broadcasts what is happening at another bus stop – as all of them feature high-definition cameras. This functions both as a safety measure and as an engagement tool, as well as allowing the public transport provider to monitor with machine-recognition technologies various statistics of use.
The bus shelter could ultimately incorporate other functions such as online shopping, or additional layers of information, such as multimodal travel.



References:
http://fieldsofactivity.com/bus-stop-future/