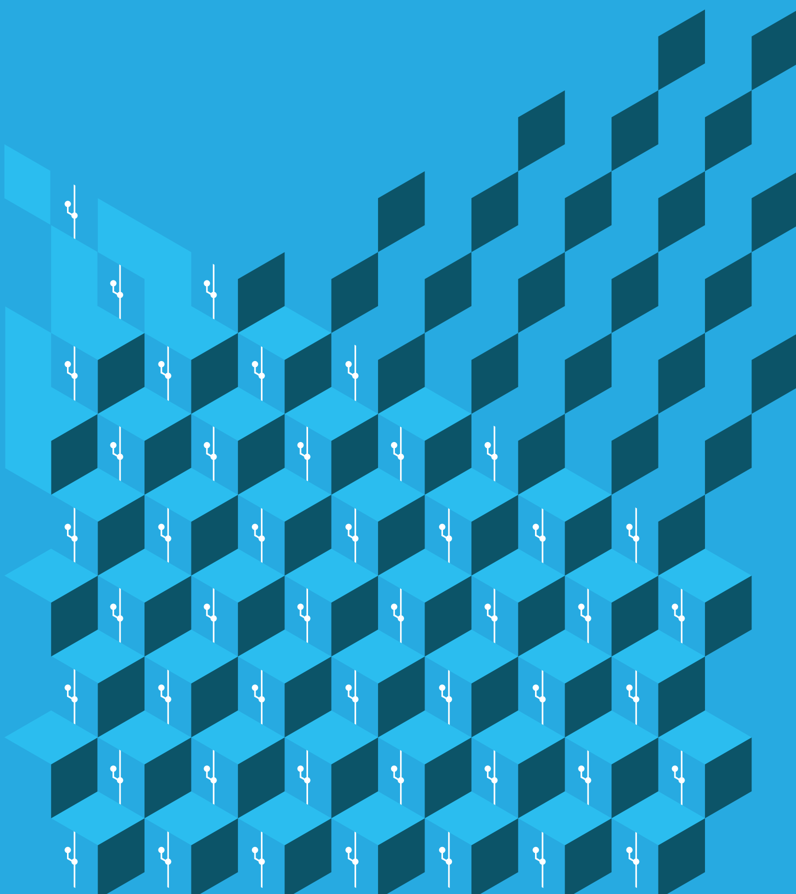
ICRI CAPSTONE

2016 2017



INTEL COLLABORATIVE RESEARCH INSTITUTE FOR SUSTAINABLE CONNECTED CITIES

2016 / 2017

Prepared November 2017

THIS REPORT

ICRI Urban IoT
An overview of the Intel Collaborative Research Institute contextualises our research focus and provides the background to the Intel ICRI / ISTC programme.

Research + Living Labs
Our work focused on the challenges of developing novel IoT technologies and testing them in situ, in the harsh environment of the city.

People + Publications
A summary of the people who have contributed to projects conducted in the ICRI and the many publications generated as a result of their research.

Reflections
Observations from the initial 3 year Discovery Phase of the ICRI and the final 2 year Capstone project.

C O N T E N T

FOREWORD

Charlie Sheridan
Managing Sponsor,
Intel Labs Europe

The world is experiencing 2 mega trends that shall have a profound effect on the shape of society and cities in the future:

1 .We are experiencing the largest demographic population shift in history, driven by the mass movement of people from rural to urban centres.

2. The rise of the Internet of Things (IoT) driven by the explosion in growth of connected things – projected to reach 30 billion+ devices by 2020.

Smart cities include services and capabilities across multiple areas, when these are connected, intelligent, and manageable, the outcomes can be significant—from lower power consumption to safer citizens. Intel-based ecosystem innovations are allowing smart cities to benefit from the Internet of Things, while helping to ensure solutions are manageable, scalable, secure, interoperable and sustainable. The ICRI team in London has played a significant role in identifying the future challenges in Smart Cities and delivering world class research projects which helped inform Intel's direction and strategy on Smart City projects.

Mark Abel
University Research and Collaboration,
Intel Labs

Intel has a long history of working with the academic research community and sponsors various science and technology centres at universities around the world in order to foster collaborations and development of communities among Intel and academia. These Intel funded and jointly led research communities focus on a specific technology area or discipline. Each ICRI brings together top researchers from across academia working with Intel to explore and uncover not only new answers, but new questions.

In 2012 an agreement was signed at 10 Downing Street to create the ICRI for Sustainable Connected Cities and the team began a journey to explore how technology could support and sustain the social and economic development of cities worldwide. The centre was deliberately a novel mix of engineers, technologists, architects and social scientists and the variety of projects delivered over the 5 years demonstrates that multidisciplinary approach.

A core goal of the ICRI model is to create an environment where the collaborative research in the partner organisations informs the development of a new research agenda internally within the company. In addition to the technology transfers this implies it is also measured on the thought leadership created and, pragmatically, the number of researchers that go on to join Intel as full time staff. This Capstone report demonstrates what can be achieved when a multidisciplinary group of researchers are brought together to explore the future use of technology.

“BUILDING UP MEANINGFUL LEARNING, EVIDENCE AND TRUST IS ESSENTIAL FOR INNOVATION”

Scott Cain
Future Cities Catapult

We exist to help grow the UK’s advanced urban services sector, and to do so we focus on overcoming barriers to innovation. Mostly through partnerships and collaborative projects, this means forging new ways of working and often doing a lot of the unseen but difficult first or hard-to-do things.

Building up meaningful learning, evidence and trust is essential for innovation but is rarely easy, especially when bringing together public institutions, the science and research base and businesses of differing scales and maturity. Working with ICRI and the wider Intel team - as well as the full range of partners - has been an example of how these things can grow; where things become possible through working together that are impossible otherwise.

From combining insights, service design, industrial design and data science through to the more applied and fundamental research and deployments in the city, so much has been gleaned. In using a human-centric, design-led approach, we have developed the kind of compelling innovation uses-cases that leading-edge technologists, researchers and businesses will be engaged with far beyond any formal partnerships. And for the early stage firms that won the right to deploy their solutions, many such as OpenPlay have used their proof-point from the project to go on to global successes.

And so reflecting back to 2012, when this collaboration began, together we have taken meaningful steps toward our mission: to grow the UK’s share of this $1 trillion advanced urban services market, and to overcome some of the most challenging barriers to innovation.

Jim Wood,
Director of IT and Information Services, London Legacy Development Corporation

London Legacy Development Corporation is using technology on Queen Elizabeth Olympic Park to help deliver the legacy of the 2012 Olympic and Paralympic Games. Given the wide range of stakeholders on the Park, including housing developers, employers, leisure and sport venue operators, we see innovative technology solutions as critical to delivering our citizen and visitor engagement and sustainability objectives. We have a range of technology organisations (commercial, not for profit, education, government) involved and the Capstone programme is an excellent example of different organisations working together to deliver against real world case studies.

The Capstone work complements the overall Smart Park programme and the EU funded Smart Sustainable Districts programme. The planned cultural and education quarters (V&A, Sadler’s Wells, UCL, UAL’s London College of Fashion) gives even more impetus for using technology and digital tools in operating the Park and in engaging visitors. ICRI came to the Park with tools that have been tested over the last few years and were therefore ready to meet live business challenges. Additionally, the cutting-edge technology research positions the Park as a true demonstrator space for smart solutions thereby contributing significantly to developing market ready products, supporting the local economy and in delivering the Greater London Authority’s Smart London Plan.

I C R I

U R B A N

I O T

The move toward urbanization provides great opportunity; cities are places where people, meet, exchange, work, live and interact. They bring people with different interests, experiences and knowledge close together. They are centres of culture, economic development and social change. On average, larger cities produce more wealth and innovation per capita than smaller ones. Those living in cities tend to produce substantially less CO_2 per capita compared to those living in rural or suburban areas. Cities offer unique options for efficient sharing of limited resources.

In a sense, cities can serve as an efficient means of living – culturally, interactively, and ecologically. However, as with most complex systems, understanding the city system is essential in facilitating their operation in a cost-effective way, making these capacity boundaries elastic. The rhetoric of the “Smart City” has increased awareness of the potential for connected devices to support urban systems, but as the Internet of Things hits the peak of the Gartner hype cycle we need to expand our thinking around how the use of these technologies will be sustained.

In 2012 it was the convergence of those themes around urbanisation and increasingly connected urban systems that motivated our research around sustainable connected cities. In 2015 as we reviewed the outcomes of our initial discovery phase research, we focused on two core themes - the challenges of delivering IoT at scale and delivering stakeholder engagement. As we graduated into the final two capstone years our vision remained close to our original goals:

ICRI Urban IoT delivers research activity to demonstrate the compute fabric needed to support an urban Internet of Things at city scale.

With our academic partners and fellow travellers from industry and government we delivered research in an urban environment with a variety of stakeholders that demonstrated the potential for intelligently deployed IoT. This report summaries those projects.

Duncan Wilson
Intel PI, ICRI Urban IoT, London

Two Inaugural lectures by ICRI PI's:

JULIE MCCANN: "TOWARDS THE DIAMOND AGE"

(https://www.youtube.com/watch?v=tQT3GgYeU-4)

LICIA CAPRA: "URBAN COMPUTING: FROM SMART CITIES TO ENGAGED CITIZENS"

(https://www.youtube.com/watch?v=FIkJ_-GZRCk)

Prior work on Hypercat at ICRI developed and published as

PAS 212:2016 AUTOMATIC RESOURCE DISCOVERY FOR THE INTERNET OF THINGS.

Specification available as free download at: http://shop.bsigroup.com/forms/PASs/PAS-212-2016-download/

hosted a **REVIEW OF THE ICRI WITH SIR MARK WOLPERT, UK CHIEF SCIENTIFIC ADVISOR** *at Imperial College.*

HOSTED MINISTERIAL VISIT TO ICRI AT FUTURE CITIES CATAPULT

for Matt Hancock, Minister of State for Digital and Culture

Leveraging the investment by Intel over the 5 years to

OVER $15M IN FUNDED RESEARCH ACTIVITY AT THE INSTITUTE

(funding bodies included: EU FP7, EU H2020, Innovate UK, EPSRC, EU EiT).

LIVING LABS + RESEARCH

In 2015 we had identified: three key technical research areas which required further investigation (batteryless edge devices, tools for designing / deploying / maintaining IoT and adaptive communications); observed the challenges of sustaining user engagement (user acceptance, understanding, participation, ownership); and witnessed the importance of creating sustainable eco-systems of services (interfaces, interoperability, commercial viability). Our research agenda for 2016/2017 was motivated by these observations and informed the following packages of work:

BILLION DEVICE CHALLENGE +

Power

Keeping nodes alive constantly for long operational periods.

Manageability

Orchestrating resource sharing on many devices for multiple stakeholders.

Communication

Managing radio communications in densely-populated networks of sensing devices.

CITIZEN ENGAGEMENT +

Sense making with citizens

How to explicitly bring citizens into the loop of Urban IoT and support them as data prosumers; both consuming available urban data for personal / community gain and providing valuable new data in the form of citizen experiences and feedback.

Soft sensing experiences

How to implicitly bring citizens into the loop of Urban IoT and take into account their socially shared thoughts and experiences in urban spaces.

CREATING SUSTAINABLE ECOSYSTEMS

Performance in use analysis

Can we create a framework for analysis of “performance in use” for IoT technologies that enables the market to make decisions on investing in technology infrastructure.

Circulatory Data

What are the socio-technical requirements to create federated data repositories in the park that support the use and reuse of data across all stakeholders in the QEOP living lab.

Throughout the five years of the ICRI, we have worked to three guiding principles: design for humans as part of the solution; build for the long term and the imperfections of the real world; deliver the triple bottom line - social, economic and environmental value. Those core concepts have driven our focus on conducting our research in a Living Lab - to conduct research on the impact of technology in the urban environment we need to be situated in that environment. We continued to build on our successful Living Lab model demonstrated in the discovery phase of the ICRI and focused our capstone efforts in London’s Queen Elizabeth Olympic Park (QEOP). The Living Lab at QEOP is located in East London at the intersection of four surrounding boroughs - Hackney, Newham, Tower Hamlets and Waltham Forest. This vast site was the main location for the London 2012 Olympic Games and is now managed by the London Legacy Development Corporation (LLDC) which is responsible for the long-term planning, development, management and maintenance of the Queen Elizabeth Olympic Park and its impact on the surrounding area. It is their task to transform and integrate one of the most challenged areas in the UK into sustainable and thriving neighbourhoods.

The following pages describe the individual projects conducted in the ICRI and are framed around their primary research question, an overview of the work and observations on what we learnt.

P R O J E C T S

How can we leverage latest advances in IoT and edge computing to design and develop smart sensors that monitor bat activity in real-time across a large diverse urban environment?

NATURE SMART CITIES

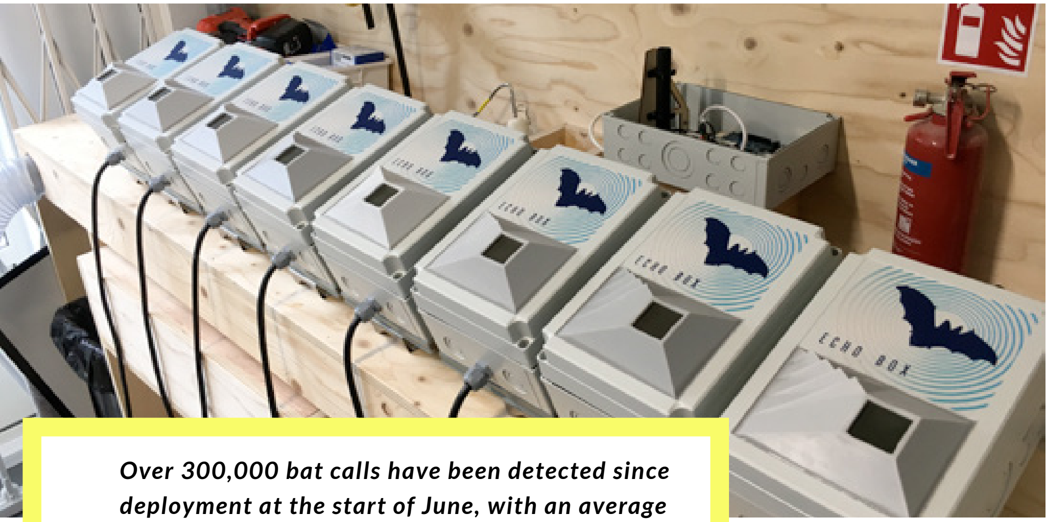
AI at the edge

UCL, BAT CONSERVATION TRUST, LONDON WILDLIFE TRUST AND ARUP

Nature Smart Cities brings together environmental researchers and technologists to develop the world's first end-to-end open source system for monitoring bats, to be deployed and tested in the Queen Elizabeth Olympic Park, east London.

Bats are considered to be a good indicator species, reflecting the general health of the natural environment – so a healthy bat population suggests a healthy biodiversity in the local area. In this project we are exploring bat activity in one of the most iconic and high profile of London's regeneration areas, the Queen Elizabeth Olympic Park. We have developed a network of 15 smart bat monitors and installed them across the park in different habitats. It is hoped that this exploratory network of devices will provide the most detailed picture yet of bat life throughout this large urban area.

Each smart bat monitor – Echo Box – works like



Over 300,000 bat calls have been detected since deployment at the start of June, with an average of 7000 bat calls per night and a maximum of 20000+ calls recorded in one evening.

"Shazam for bats". It captures the soundscape of its surroundings through an ultrasonic microphone, then processes this data, turning it into an image called a spectrogram. Deep learning algorithms then scan the spectrogram image, identifying possible bat calls. We are also working towards identifying the species most likely to have made each call.

Measuring bat activity in the Queen Elizabeth Olympic Park provides a very interesting real-world use case that involves large amounts of sensor data – in this case acoustic data. Rather than sending all of this data to the cloud for processing, each Echo Box device will process the data itself on its own chip, removing the cost of sending large amounts of data to the cloud. We call this "edge processing" since the processing is done on devices at the edge of the network.

Calculations show that for the network of 15 smart bat monitors, machine learning algorithms at the edge of the IoT network reduce data transfer to the cloud from 180GB per day to 2.1MB per day.

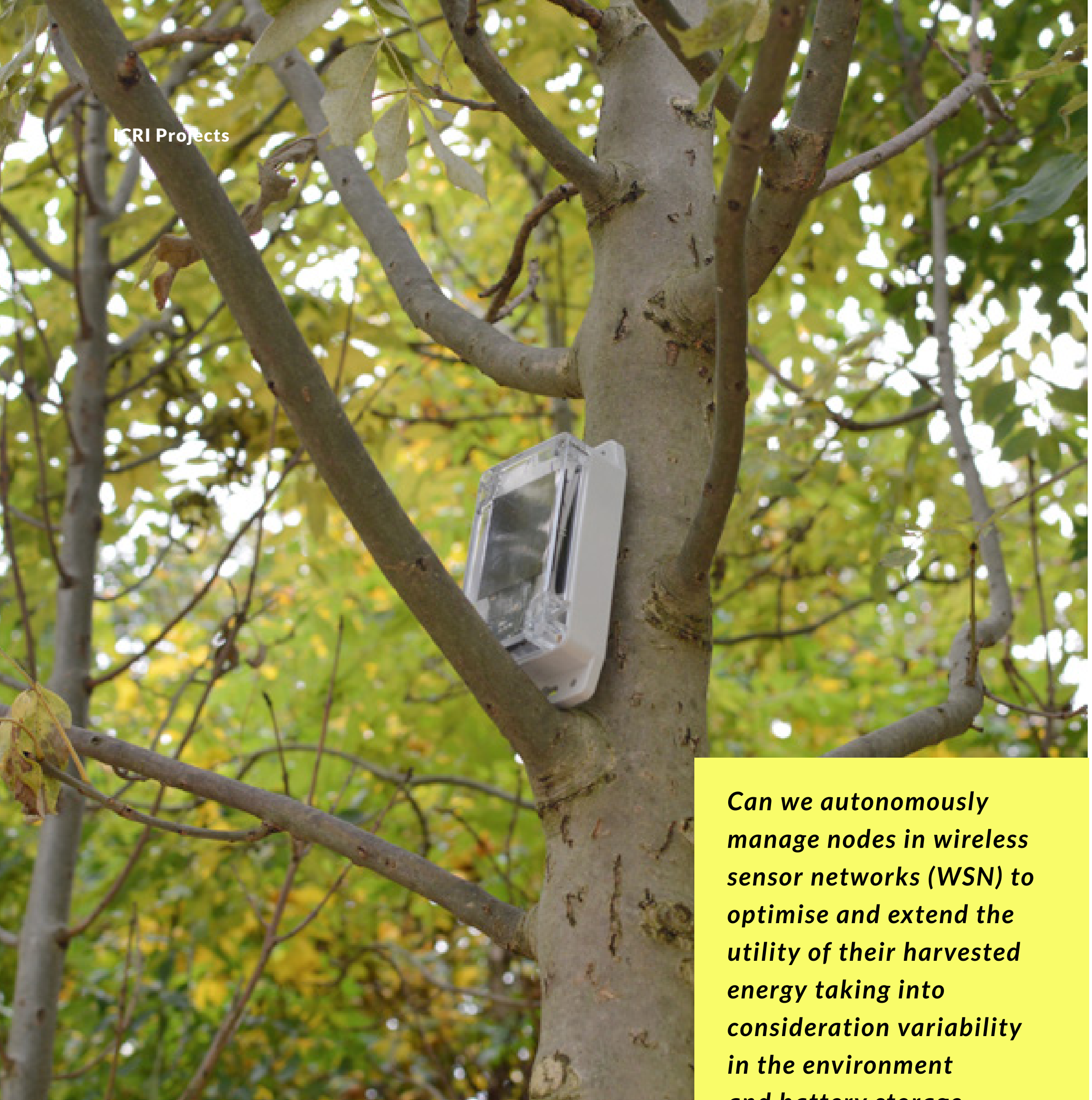
Inside each Echo Box is an Intel Edison with Arduino breakout, plus a Dodotronic Ultramic 192K microphone. To capture, process and identify bat calls each Echo Box performs the following 4 steps:
First – a microphone on each device, capable of handling ultrasonic frequencies, can capture all audio from the environment up to 96kHz. Most bats calls occur at frequencies above 20kHz

(the limit of human hearing) with some species going as high as 125kHz (although none of these species are found in the park).

There has been extensive press coverage including a national television live interview (BBC Breakfast), BBC online and radio coverage including BBC R4 Today program, BBC R4 Inside Science program, 5Live Breakfast show, BBC London news.

Second – every 6 seconds, a 3 second sample of audio is recorded and stored as a sound file. This means that audio from the environment is captured as 3 second snapshots at a consistent sample rate across all smart bat monitors.

Third – the recorded audio is then turned into a spectrogram image using a method called Fast Fourier Transform. The spectrogram image shows the amplitude of sounds across the different frequencies over time. Bat calls can clearly be seen on the spectrogram as bright patterns (indicating a loud noise) at high frequencies.
Finally – image processing techniques, called Convolutional Neural Networks (CNN), are applied to the spectrogram images to look for patterns that resemble bat calls. If any suspected bat calls are found in the image, then we are working towards applying the same CNN techniques again to each individual bat call to look at its shape in more detail and determine what species of bat it most likely is.



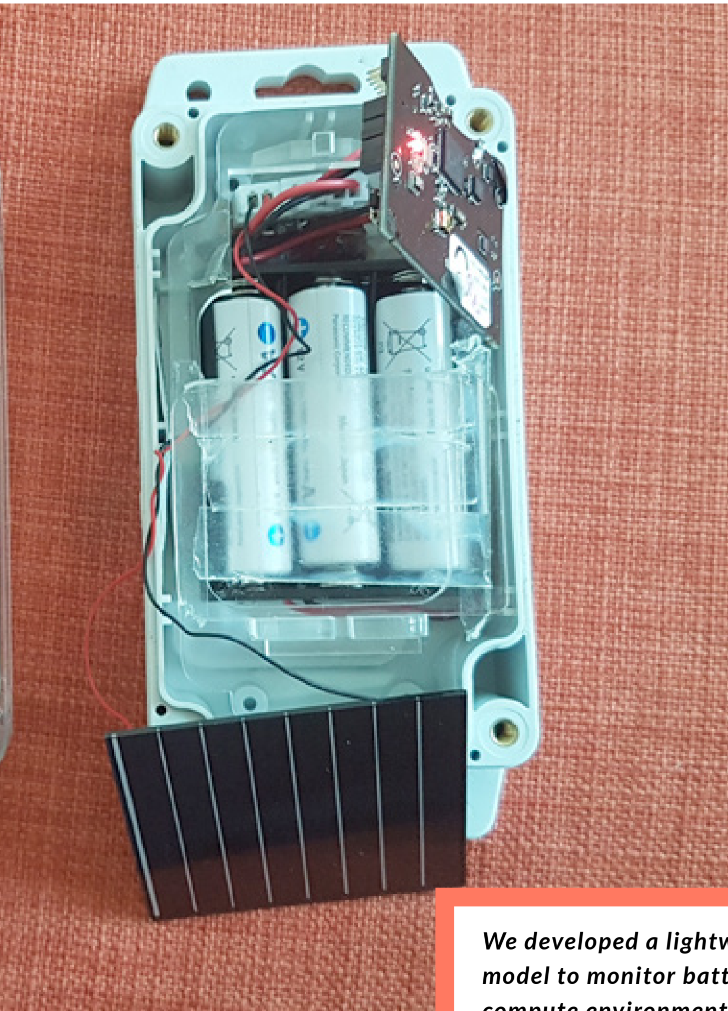
Can we autonomously manage nodes in wireless sensor networks (WSN) to optimise and extend the utility of their harvested energy taking into consideration variability in the environment and battery storage degradation?

E N E R G Y N E U T R A L O P E R A T I O N S

Battery degradation

IMPERIAL

The Internet of Things (IoT) has rapidly matured in recent years and is becoming a viable solution for real world deployments. The major barriers to the practical adoption of IoT systems have been the limited deployment opportunities if the devices run on mains power and limited operational lifetime if the devices run on batteries. Added costs include the need for human intervention when batteries eventually need to be replaced, the environmental concerns of disposal of batteries, and the introduction of errors when those batteries near end of life. Energy harvesting from sources, such as solar, wind, thermoelectric, and vibration have been put forth as potential solutions to this problem when paired with a rechargeable battery. The introduction of energy harvesting to IoT brings improvements for system performance, however, gains from energy harvesting come with additional complexities, i.e. management of the energy budget given dynamic demands on the network,



We designed and deployed a 20 node network of microclimate sensors in Queen Elizabeth Olympic Park and tested the proposed algorithm for two months.

potentially unpredictable energy generation and energy storage life-time management.

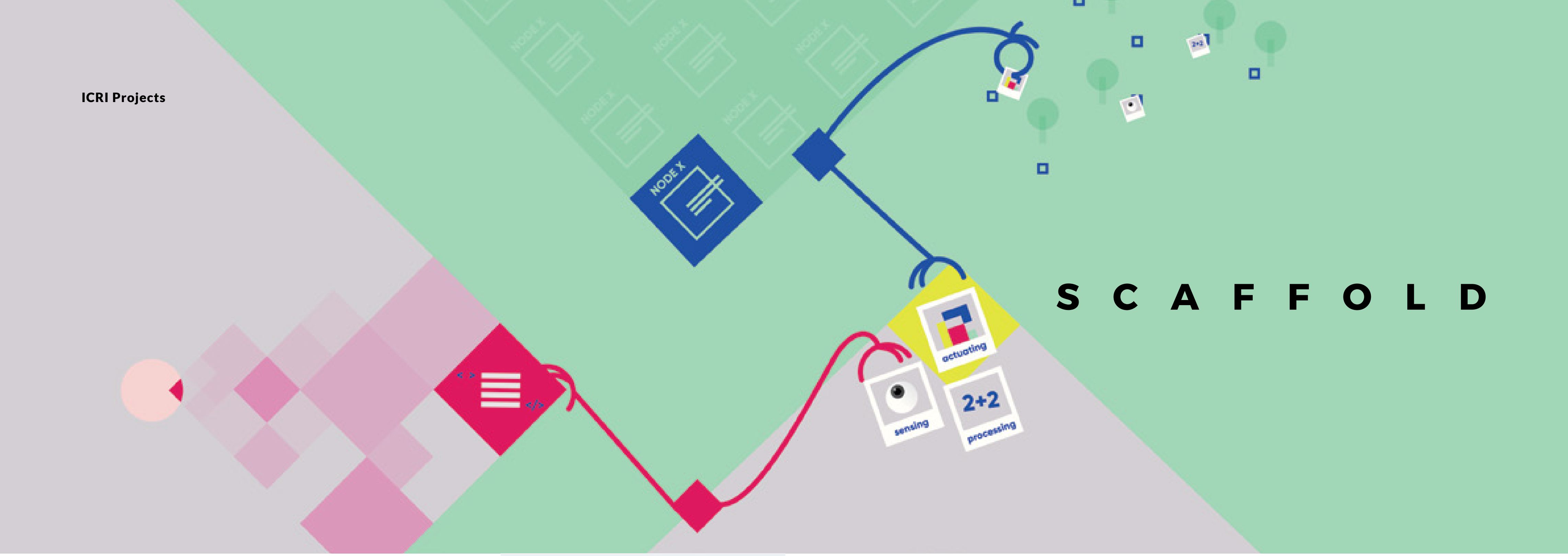
Energy Neutral Operation (ENO) is a mode of operation of an IoT object where the energy consumption is always less or equal to the energy harvested from the environment. However, existing ENO approaches do not take into account the degradation of the capacity of the battery. Specifically, the capacity of the battery is assumed to be fixed throughout the lifetime of the deployment. In fact, battery capacity degrades over time and can only undergo a limited number of charge/discharge cycles before it fails. Through our research, we aim to address the issue of how to incorporate awareness of this degradation into ENO optimisation algorithms so that both the battery capacity and duty cycle of each sensor node in an arbitrary IoT application are maximised. As a result, the deployment time of an application can be extended, which results in reducing the associated costs of replacement and in field maintenance.

We developed a lightweight battery degradation model to monitor battery health in a constrained compute environment.

We developed a novel lightweight sensor management scheme to extend the lifetime of the deployment of an arbitrary IoT application while guaranteeing energy neutral operation.

The results show that an increase of deployment lifetime of 307% can be achieved without a reduction in average system performance.

Beyond WSN, the optimisation of rechargeable battery health to promote longevity has applications in electric vehicles, home battery backup systems, healthcare, and consumer electronics such as wearables, smartphones, and beyond.



S C A F F O L D

How can we program at scale to ensure highly- decentralised, lightweight protocols and algorithms utilise the mix of heterogeneous computational devices dispersed throughout future cities?

IoT at Scale

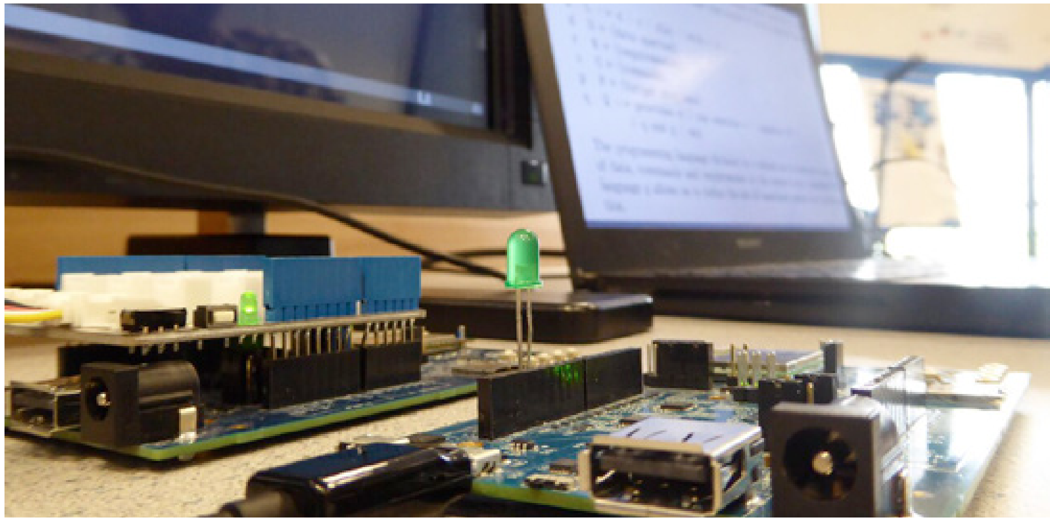
IMPERIAL

The Smart City vision is to have widespread sensing of city conditions to guide infrastructure, policies and services. However, we must be careful in how we instrument the city and not lose track of long-term consequences. When sensing truly becomes ubiquitous, bringing with it an explosion of devices communicating data, then existing network infrastructures will become saturated. This motivates IoT and sensor nodes running multiple applications that might belong to different stakeholders. This leads to a continuum where data is processed from source devices via edge devices to the cloud. The question is where do we carry out processing: with what nodes and how? Specifically, maximizing the use of these systems is important but also brings many challenges in terms of scheduling processes and programming systems without knowing where they run.

We view the city as a programmable device. The

Network-wide programming allows us to overcome the cognitive overload of programming a large heterogenous network of devices.

A significant reduction in the codebase that needs to be maintained.



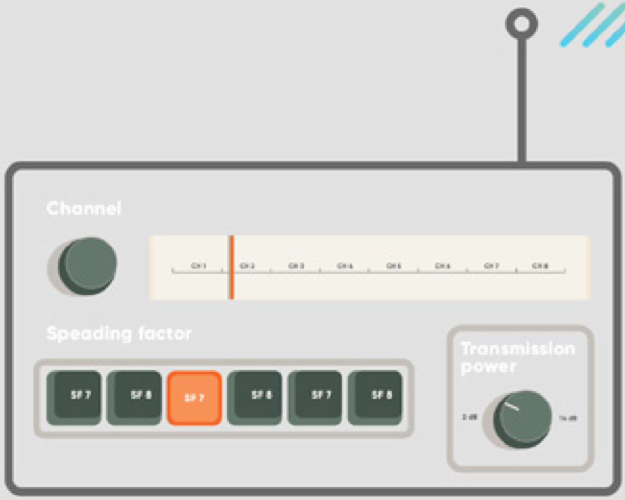
traditional approach to programming over many devices is to place a runtime on all nodes to abstract away the underlying hardware. We take a different approach. Given that code deployment can be initiated remotely and at any time, it makes sense to instead adapt compiler based approaches where optimisation is done when the application is compiled/ initially deployed. We believe that in order to cope with the large heterogeneity present in our target networks we should aim to have controlled variation, rather than arbitrary homogeneity. This ensures that hard to foresee complex interactions involving the placement of computation and communications can be ironed out in advance.

To this end we have developed a framework for developing smart city applications, which we name Scaffold. The main component of this framework consists of a compiler, which takes a program annotated with source data, commands and requirements in our Scale language and automatically determines the minimal set of actual programs that will need to be running in the nodes that compose the network, cloud to edge. Depending on the requirements this compiler can also inject the programs with runtimes, allowing for dynamic behaviour, whilst retaining as much intelligibility as possible.

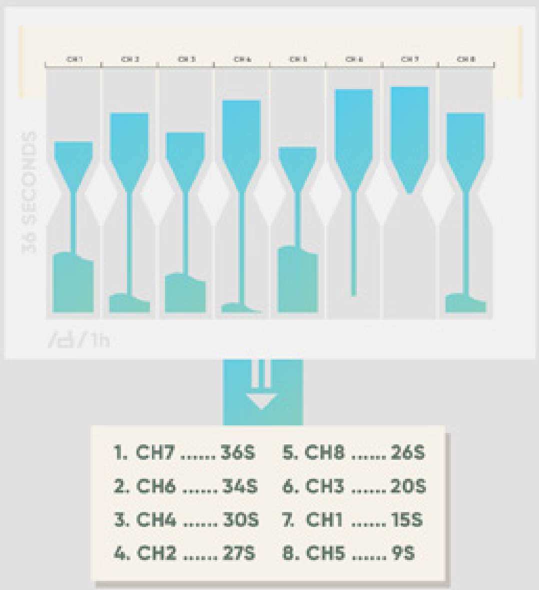
We have also developed Scanner, a registry and automatic deployment system for sensors, actuators and processor nodes in smart city scenarios. This system allows us to take the output of the Scale compiler and query the current state of the network in order to determine appropriate target nodes in which to install the various images produced by the Scale compiler. In order to have optimal communications and satisfy application requirements, we need to be able to distribute the application layout in the network in the best way. That could range from in-network processing to cloud computing. Optimising the layout of the application in the heterogeneous network thus implies that the nodes inside the network might be doing processing and relaying for applications that are not the ones produced by their owners. This implies a notion of multi-tenancy, quotas and process isolation.

A runtime that automatically registers devices with minimal overhead.

A proof framework shows that no semantics are lost through network-wide programming as compared to programming devices individually.



ADAPTIVE LOW POWERED WIDE AREA COMMUNICATIONS



Can we make Low Powered Wide Area (LPWA) communications systems adaptive to ensure delivery of data according to application demands in dense city environments?

Optimising LoRa

IMPERIAL

In wireless networks that support LPWA communications (e.g. LoRa, Zigbee 868, SigFox etc), an important question that arises is how should a node select the best radio parameters taking into consideration current dynamical environmental conditions and varying application demands?

Our adaptive communications research has focused on the LoRa communications protocol, in order to optimize the way in which sensors communicate to a base station, therefore allowing for more nodes to transmit data reliably at the same time. This can be achieved by improving the process of selection of three parameters: the channel, spreading factor and transmission power.

Low-Power Wide-Area (LoRa) is a type of wireless network that enables long range communication at a low bit rate between sensor nodes and a base station. LoRa uses the 868 MHz band

In the theoretical study we are the first to derive an optimal value of active LoRa nodes per each cluster that maximizes the area spectrum efficiency and energy efficiency network wide and which takes interference from other LoRa and LPWA networks into account.

and comes with a protocol called LoRa WAN, which is a set of algorithms that defines three key aspects of the communication process: which channel the sensor node will send data on, at what spreading factor and finally, the amount of transmission power to be used for the communication. The main constraint of LoRa is that it operates at a maximum of 1% duty cycle.

We initially analysed the theoretical performance of LoRa to give us insight into how it should behave with other coexisting radio communications systems operating in the same environment; a situation important in dense city areas. More specifically, we considered a node topology of a cluster-based city-wide hierarchy and built two models of network behaviour: one with a fixed number of active LoRa nodes and the other with a random number of active LoRa nodes. Within each model, two cases are explored: the first is LoRa node is selected either randomly or by the order of distance to the typical receiver. Using stochastic geometry, we were able to determine theoretically the performance of these networks in terms of coverage probability, area spectrum efficiency, and energy efficiency. Our models have been verified by simulation and show that these models allow us to better place nodes in a cluster to maximise performance.

Using this knowledge we developed a new resource management protocol for LoRa with adaptive configurations, named LoRADAP, in order to avoid the spreading factor conflict as well as optimize transmit power.

LoRaDAP attempts to optimize the transmission by creating a preference list of channels for each node. This preference list is based on the counter each node has that keeps track of the time already spent in each channel. The LoRaDAP protocol transmits the available time per channel in the preferred order. This means that if a node has not transmitted a lot on one channel, this channel is more preferable because it has more available time to transmit data. Subsequently, the server will check if there is a spreading factor conflict within each channel based on the proposals from nodes and reconfigure the conflicted nodes to avoid retransmission as much as possible. The server will then optimize the transmit power of nodes assigned into the same channel with the purpose of maximizing the achievable minimal signal to noise ratio; that is, maximising the achievable reliability of the communication. Finally, the server will send the updated configurations to each node for the upcoming transmission and thus the network's performance is maximised dynamically.

The LoRADAP simulation results have shown that the channel assignment design can achieve more than 80% performance improvements compared to a baseline method, but with the added advantage of much lower complexity, which extends the battery lifetime of the sensor devices.

How can we implement dynamic, fair and verifiable scheduling of resources for programming of multi-tenancy edge IoT devices?

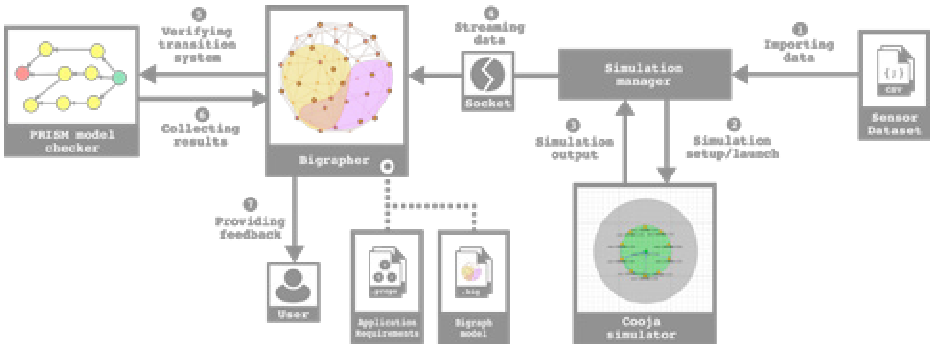
MULTI-TENANCY

Verifying and reasoning in WSN

IMPERIAL

The adoption of wireless sensor network (WSN) technology is becoming increasingly prevalent in cities where sensor nodes are deployed over large geographical areas for the purpose of providing high-value services to citizens. Traditionally, WSNs have been designed following a model that allocates all the sensor network resources to a single application. For modern city-scale WSNs, this model has been shown to incur high costs in terms of deployment and maintenance and to yield a limited return on investment to the owner of the sensor-network infrastructure.

To address these problems, research efforts in the WSN domain are increasingly focusing on enabling network resources to be shared among multiple applications also referred to as shared sensor networks. That is, much like computers run several applications in parallel, sharing the resources of the computer, a city wide sensing infrastructure can

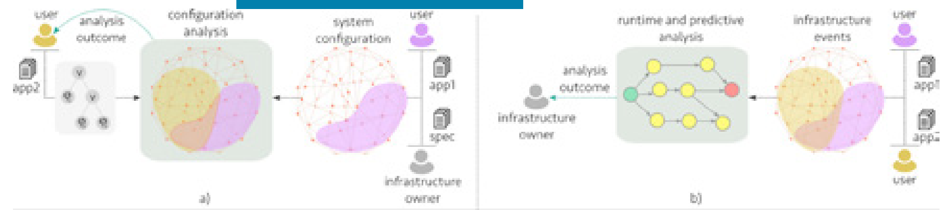


Research article presenting modelling of WSNs and requirements verification by means of BRS and model checking.

be used by multiple tenants sharing the resources while achieving their individual goals. This has the potential to significantly reduce deployment and maintenance costs for large-scale sensing applications that are geographically co-located and therefore can be supported by the same infrastructure. We refer to this approach as multi-tenancy.

However, this concept brings about a number of issues that need to be addressed to make multi-tenancy functional. For example, a city-wide sensor network infrastructure can be established by the mayor or the city council for the purpose of environmental monitoring including air pollution, water quality, structural health, etc. To allow applications from other tenants to be deployed, it is crucial to determine whether requirements of resource competing applications can be ensured by the infrastructure not just at deployment time, but over the network's lifetime. This process has to verify the availability of required sensors, processing power, delivery models (e.g., periodic, query-driven, event-driven), node density per area of interest, etc. and determine whether the infrastructure has enough resources to sustain application requirements in a long run. In addition, the infrastructure owner has requirements that need to be considered to avoid the depletion of battery power, network congestion or high maintenance costs.

Tool-based support for the evaluation of the multi-tenancy approach based on the Cooja network simulator and BigraphER.



To address the many concerns arising with multi-tenancy operation, we provide a novel systematic approach dedicated to enabling multi-tenancy in shared sensor networks, that supports:

1) application requirements specification at design time;
2) configuration analysis to determine if requirements can be met before deployment;
3) runtime verification and predictive analysis to ensure requirements are met in the face of failures and changing conditions of the infrastructure;
4) abstraction for contextual reasoning based on a straightforward graphical representation that facilitates reasoning about the system.
5) A set of programming language constructs (see Scaffold) that ease the programming of such systems at these vast scales and also provide guarantees of preservation of network wide semantics, allowing us to overcome the cognitive overload that comes with programming networks of heterogenous systems.

Extension of the BigraphER tool to support the modeling of WSNs and predicate checking.

Ongoing evaluation of the multi-tenancy approach, which will reveal how our approach performs for WSNs at different scale and various topologies

Looking beyond these specific contributions, we have also established a general approach to modelling and analysing shared sensor networks based on Bigraphical Reactive Systems (BRS) and formal verification of logical predicates.

ADAPTIVE COMPRESSIVE SENSING

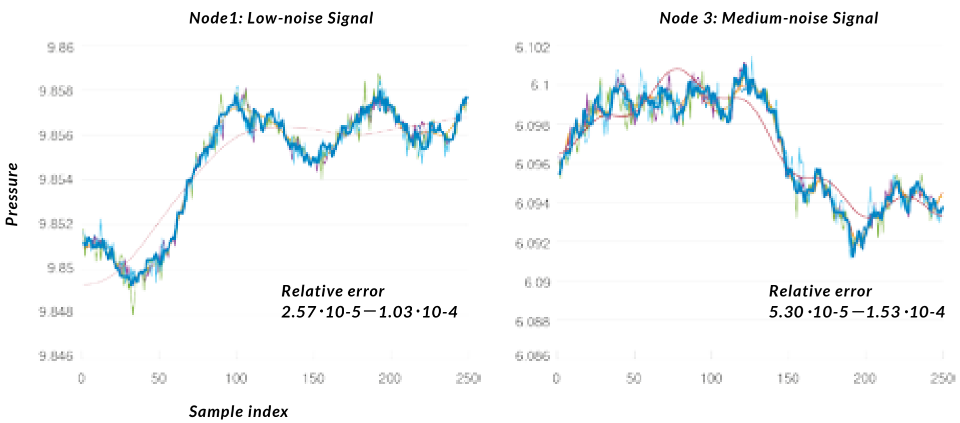
QoS at the edge

IMPERIAL

Can we exploit distributed compressive sensing to adaptively select sample rates in a sensor network whilst guaranteeing the quality of data?

For decades, the sampling process has been largely dominated by the classical Nyquist-Shannon theories. However, several studies have shown that many natural signals are amenable to highly sparse representations in appropriate transform domains (e.g., wavelets and sinusoids). Compressive Sensing (CS) provides a powerful framework for simultaneous sensing and compression, enabling a significant reduction in the sampling and computation costs on a sensor node with limited memory and power resources. CS has been used widely in multiple domains including image and video processing, communication and networking, and biological applications.

In spite the benefits of CS, data correlation among different data sources has not been considered. In order to exploit data correlation and to improve the reconstruction performance, Distributed Compressive Sensing (DCS) has been introduced. DCS provides two main benefits



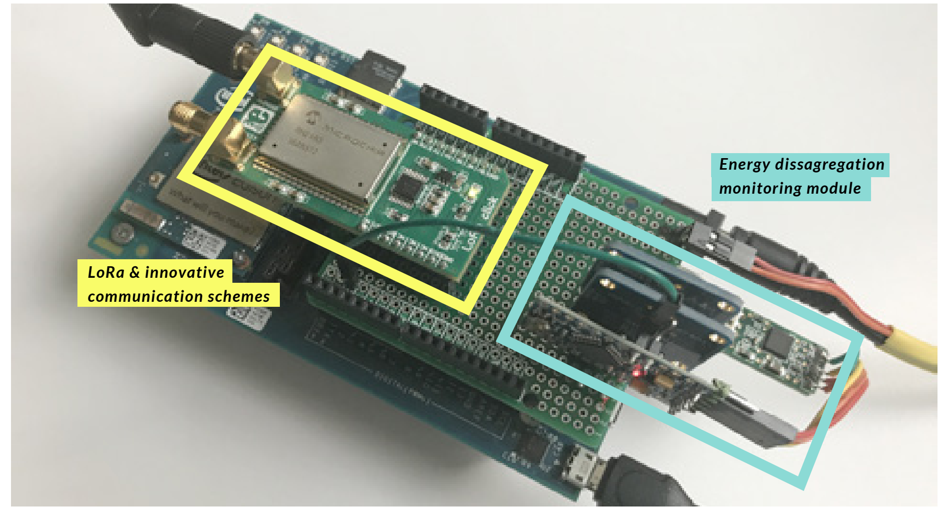
As proof of concept, a small-scale testbed consisting of four Intel Edison boards, an isolated wifi network, a synchronization server, and a Matlab server was developed.

A high-frequency low-power energy monitoring hardware module was developed to measure and disaggregate energy consumption due to communication and other operations (i.e. sensing and idle state) in real time. Experimental results reveal that our hardware improves the knowledge of energy consumption by ~20% compared to the estimation techniques.

compared to classic CS: it decreases dramatically the number of required measurements, achieving low reconstruction error by exploiting data correlation from different nodes and transferring the complexity from edge to the base station, which is critical in resource constrained wireless sensor networks.

In both CS and DCS approaches, the state of the art research solutions use a static selection of the sample rate based on only the application data properties, such as the sparsity level, ensuring an upper bound of reconstruction error. However, this data-driven fixed selection of sample rates leads to: (a) underutilization of edge node resources, especially when a limited and dynamic harvested energy is supported, and (b) inability to adapt to changes in sparsity.

In this project, we overcome these problems by proposing



a distributed system that adaptively selects the sample rates in a sensor network considering the existing resources. To compute the optimal sample rate policy, a lightweight algorithm was designed and developed that minimizes the DCS reconstruction error (i.e. Quality of Service - QoS), while ensuring the sustainable operation of the sensor network under dynamic conditions given variable energy harvested in the sensor node.

LoRa communication modules and new MAC layers were integrated to the testbed to enable the incorporation of "Adaptive Low Powered Wide Area communications" project.

Seven CS and DCS algorithms evaluated in terms of reconstruction error and execution time. With data transmission reduced by 80%, the reconstruction error varies between 10-4 and 10-5 depending on the noise level.

An algorithm that guarantees sustainability and ensures data reliability (QoS) based on application requirements has been developed for the in-vitro testbed. In addition, data from the ENO deployment in QEOP is used during the evaluation process.

R O A M . I O

Sensing with context

UCLIC, MADEIRA INTERACTIVE TECHNOLOGIES INSTITUTE (M-ITI)

How can we enrich sensor-based data with human input?

Newly emerging urban IoT infrastructures are enabling novel ways of sensing how urban spaces are being used by people. However, the data produced by these systems is largely context-agnostic, making it difficult to discern the meaning of patterns and anomalies in the data.

To address this challenge, we developed a hybrid approach that combines quantitative data collection through an urban IoT sensing infrastructure with qualitative data collection from people answering relevant questions in situ. For this purpose, we developed a new way to survey the public through a robot-like, physical installation called Roam.io.

Roam.io is designed to encourage the general public to engage with urban IoT data through data visualisations of sensor-derived data and relevant questions. It allows them to voice their opinions, comments, and perspectives on the data displayed. A hybrid dataset is created from the combination of the

The hybrid dataset generated by Roam.io was able to provide a richer picture of activity in public spaces - in this case, the flow of tourists on an island - and provide new information for the tourist board.

quantitative sensor data with people's qualitative in situ responses and contextual observations. This dataset uniquely helps to build a better understanding of what is happening in this urban space and allows for new insights from the gathered IoT data.

The goals of Roam.io were to:

- entice passers-by to walk up and interact with a public physical installation
- engage the public in data exploration through visualisations and interactive questions
- see whether the public can help explain anomalies and changes in the data
- explore whether the public is willing to complement data logs with subjective interpretations, opinions, and in situ observations

Roam.io was deployed in the city centre of Madeira, Portugal as part of a week-long study. Madeira is a popular tourist destination, seeing as many as 1.2 million visitors each year. With a population of only 270,000 people, local authorities have become increasingly concerned about the economic, ecological, and social impact of tourism on the island. To track where tourists visit and how many go where, an infrastructure has been set up throughout the island that provides time- and place-sensitive people count data (or 'people flows') using passive Wi-Fi hotspot analysis.

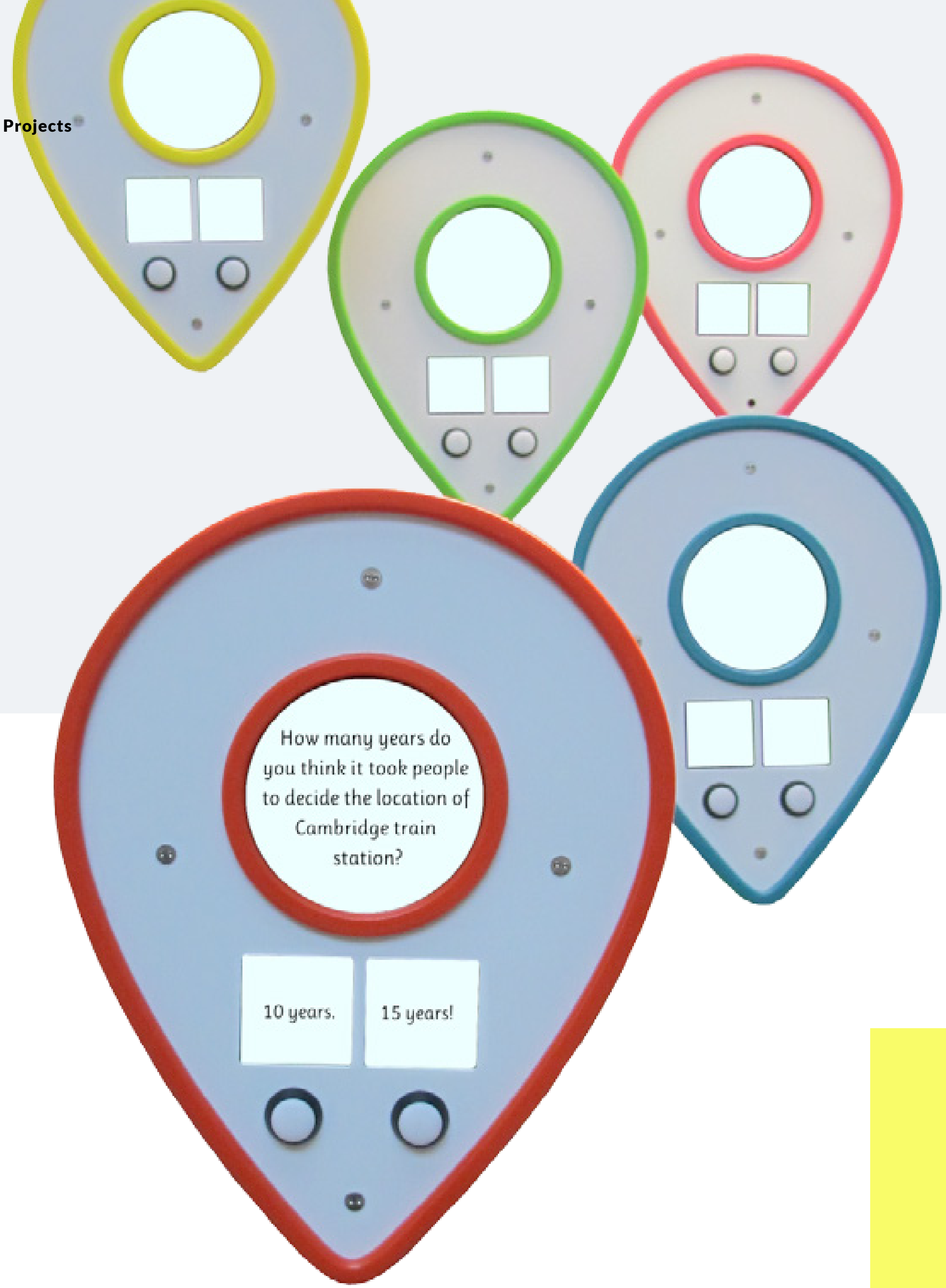
We designed the Roam.io installation with a subtle anthropomorphised robot look to create a friendly and open interface for people to approach in a public setting.

Our 'in the wild' study demonstrated how Roam.io successfully engaged the public to answer a range of questions and interpret data visualisations.

Roam.io asked a broad set of 34 questions. These included 5 demographic questions about nationality or language, 8 contextual questions asking the user to describe the environment, 10 data questions in which users were asked to comment on a data infographic, and 11 factual questions about Madeira Island.

Opening data by enabling the public to comment on and respond to sensed IoT data (in our case, WiFi activity data) has great potential to enable the public to perceive and understand data about themselves and the environment while also providing new insights that can inform the management of public services.

The visualisations depicted historical tracking data across days, weeks, and even months. Each question asked users to 'vote' for the best matching interpretation or contribute their own interpretation of the dataset via the installation's keyboard. The visualisations were designed as simplified graphs that could be easily read, showing peaks and valleys in people flows at different locations and times on the island. We were interested in finding out whether people could infer what these represented; for example, whether a peak on a Saturday afternoon indicated an influx of people on a tour visiting a tourist site in the city centre or locals attending a festival. This hybrid data was then shared with the tourist board and other communities to help them develop a better understanding of the impact of the people flows on specific areas.



P I N S I G H T

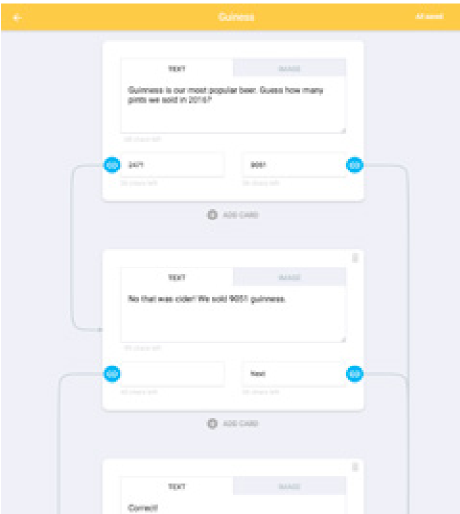
In situ community knowledge sharing

UCL, LLDC

How can we design IoT toolkits to enable new ways of knowledge sharing within communities?

Integrating digital information about places into the physical world allows users to experience it in the moment and in its real-world context. Drawing on physical computing and IoT technologies, Pinsight is a novel platform that enables local communities to create and share digital content about places through tangible interactive devices that can be placed in and moved around physical spaces, such as streets, urban districts, parks, public buildings. This enables the people connected to those places to tell stories, share ideas, and collect opinions relevant to spatial and social contexts.

Pinsight is comprised of a series of eye-catching interactive tangible devices, 'Pins', and a web interface for authoring their content. The Pins resemble the shape of digital location markers to indicate their situatedness. They present a question or statement and two response options that can be selected using one of two buttons. Upon selecting a response, the next item is displayed, allowing



Enticed content creators to share information differently from conventional media through the constrained format of content and metaphor-based design.

for a conversational-style presentation of content.

The authoring interface presents a map of the area in which the (physical) Pins are placed. Clicking on the digital version of the Pin brings up a menu that allows the content creator to Edit or Preview the Pin's content. In the Edit screen, new content can be created or existing content can be added from the cloud. A conversational format can be constructed by linking response options to next items.

Engaged visitors of places by making invisible stories visible

Allowed communities to share local information via eye-catching IoT devices placed in the environment

We conducted three case studies with a set of four Pins. The aim was to explore how Pinsight can be used to share digital content in-situ by different user groups, and how the socio-spatial setup affects content creation and consumption through this platform.

The first study occurred at the Great Get Together festival in the Queen Elizabeth Olympic Park (QEOP). It was used to engage visitors to explore activities at the event and key places within the park. The event organisers and stakeholders decided to give each Pin a different role with respective content about the festival, the park, future events, and visitor feedback. Throughout the afternoon, the Pins attracted ~ 350 individual / group interactions with a variety of demographics. The visitors personified the Pins as they "talked" to them. The curious ones hunted multiple Pins for fun.

The second study took place at a historic street district in Cambridge. Seven volunteers from the local history society participated in a content creation workshop. They created stories for four locations (The Six Bell Pub, Bath House, St Phillip's Church cafe and Romsey Mill) and uploaded them into different Pins, which were then deployed for two days at the corresponding places. Pinsight engaged local community members to curate history in interesting ways that differ from conventional media. The reaction of passers-by differed across locations, reflecting the effect of context on their engagement.

Effectively engaged public audiences through the physical design and conversational-style interaction

The third study took place at a street party in Cambridge and explored ad-hoc content creation in the local neighborhood. The party attendees created short and humorous questions and answers about the local life and people. Passers-by were intrigued by the content and the ability to add on to it on-the-fly. In the end, a community dialogue was co-constructed and shared across the Pins, allowing Pinsight to mediate a collective experience.

Foursquare venues
Points coloured by category and sized by number of users (scaled)

- Food & drink
- Shops & services
- Arts & entertainment
- Nightlife
- Residential
- Work & leisure
- Education
- Parks & outdoors
- Travel

Can combined real time data streams digitally reveal life in a large scale urban area?

S O C I A L S T R E A M S

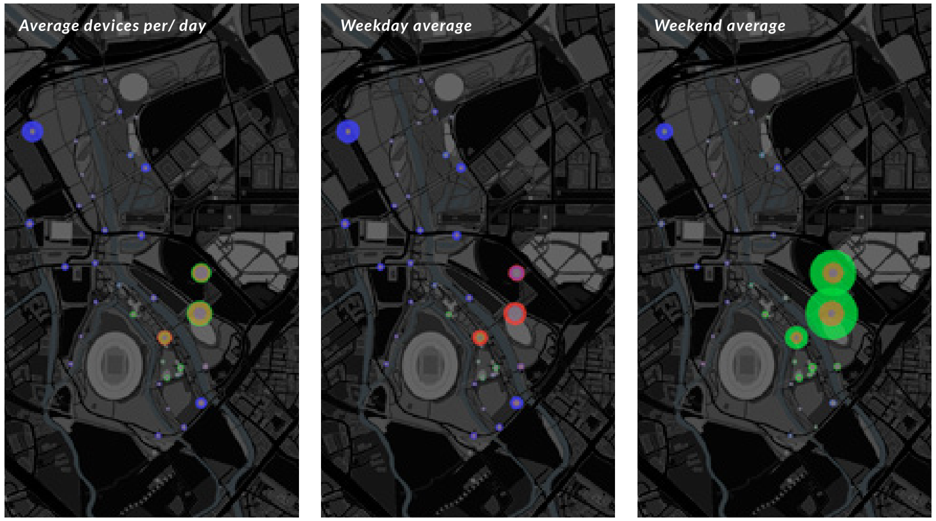
behaviour mapping and situation analysis

UCL

In the past decade, the growing volume of data captured and shared from mobile and embedded devices during daily urban interactions has created a new approach to situation analysis: the use of real-time data to monitor and predict events as they unfold.

However, data about real-world scenarios contains uncertainty. Sensors contain different levels of accuracy and precision, that can disrupt or distort readings. Digital devices require power and access to a communications network to record and transmit observations. A loss of either can result in missing data. An objective for this research is to evaluate the usefulness and reliability of real-time data sources for revealing everyday human behaviours within a large-scale urban open space.

The spatial scope for this analysis is the Queen Elizabeth Olympic Park (QEOP) in Stratford, East London. It is one of the



Devices making first connection to wifi network

- *Regulars* — *May 2016 Stats - Regular vs Tourist vs Solo visits*
- *Tourists* — *Hypothesis: people with different levels of spatial familiarity may have route*
- *Solo visits* — *preferences (high familiarity) or rely on direction/ signage (low familiarity)*

Our research findings show that analysing trends across multiple data sources reveal more behavioural information than focusing on a single data source (e.g. webcams showed number of people in the park, but Wi-Fi event logs showed how long people spend at different locations).

Combining temporal and spatial analysis made it possible to test assumptions (e.g. March data showed an unexpected rise in volumes that coincided with an event at the velodrome, but the spatial analysis showed it was unlikely to be related since it was in a different area of the park).

largest urban parks in Europe and combines parkland with play areas, and a number of event venues. It is bordered by residential, retail, commercial, and educational structures. This research will explore the potential for analysis of real-time data to better understand life in the park.

Our research combines behaviour mapping and situation analysis, using open

Spatial concentration of geo-tagged tweets for 28th August 2016

It was not anticipated that the Foursquare data would prove useful due to its small volume and the majority of readings occurring for venues located within the Westfield shopping centre. However, temporal variation in 'HereNow' check-in volumes under different conditions closely mimicked the webcam data.

Our research findings show that there is a basic signature that could be used to establish thresholds for expected versus unexpected behaviour under different conditions to create an alerting mechanism.

and accessible methods. Two types of data were collected and analysed: sensor readings from devices embedded within the park and unprompted social media shared publicly whilst visiting the park. The sources were webcam footage (webcams), the park's wireless network logs (Wi-Fi), Twitter messages and Foursquare venue check-ins.

Data collection took place over 2 periods: 4th to 31st March 2016 and 1st May to 31st August, during which the park hosted a multitude of events, ranging from the World Track Cycling Championships and a Sports Relief charity event to an AC/DC music concert and the West Ham football team officially moving to the London Stadium. This period was also particularly active due to the Easter bank holidays and summer school holidays.

For each analysis, four questions were considered: Are there variations in behaviour for different situations occurring in the park? Can real-time data reveal contextual differences that may affect behaviour? Are the changes detected consistent across data sources? Do different data sources provide complementary information?

Do interactive urban data visualisation tools help our shared understanding of how cities are used?

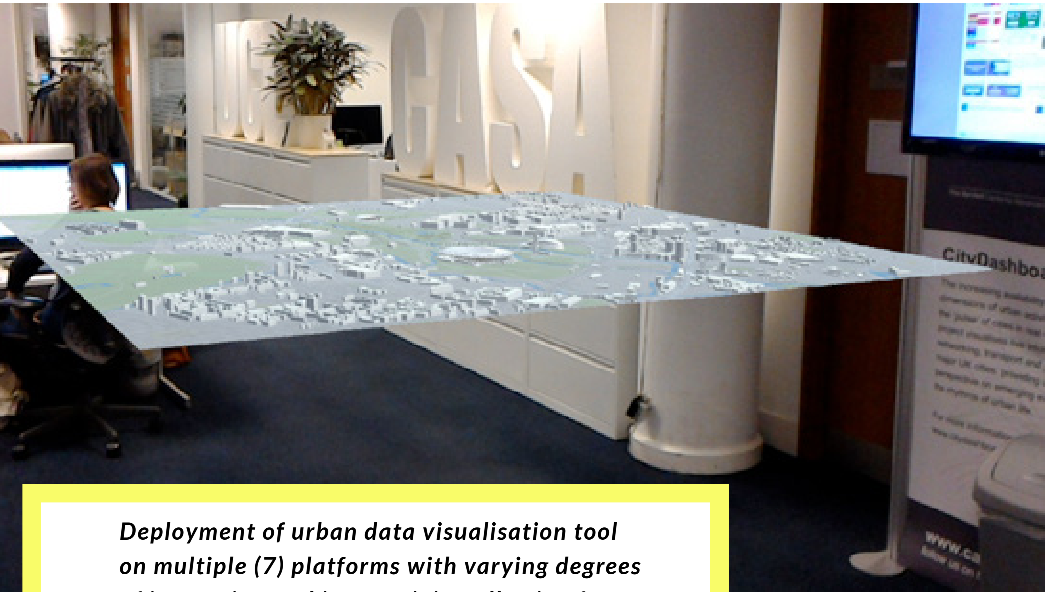
SMART PARK DATA TABLE

Urban IoT AR / VR

UCL

The Smart Park project aims to help people understand how cities are used, through a combination of state-of-the-art interactive visualisation methods and urban data sets. This project examines the potential of Augmented and Virtual Reality tools as platforms for urban visualisations that communicate Real-Time Data generated via Internet of Things devices, aimed at opening urban data to the wider public. The project focuses primarily on Queen Elizabeth Olympic Park (QEOP) as a case study, collecting and visualising real-time data sets relating to the park.

Multiple data sets are brought together to create a virtual view of the park as captured through urban data. Sources include open and publicly available datasets, such as transport data (using Transport for London's web API), weather conditions (Wunderground web API), and social media, data generated by sensors deployed in the

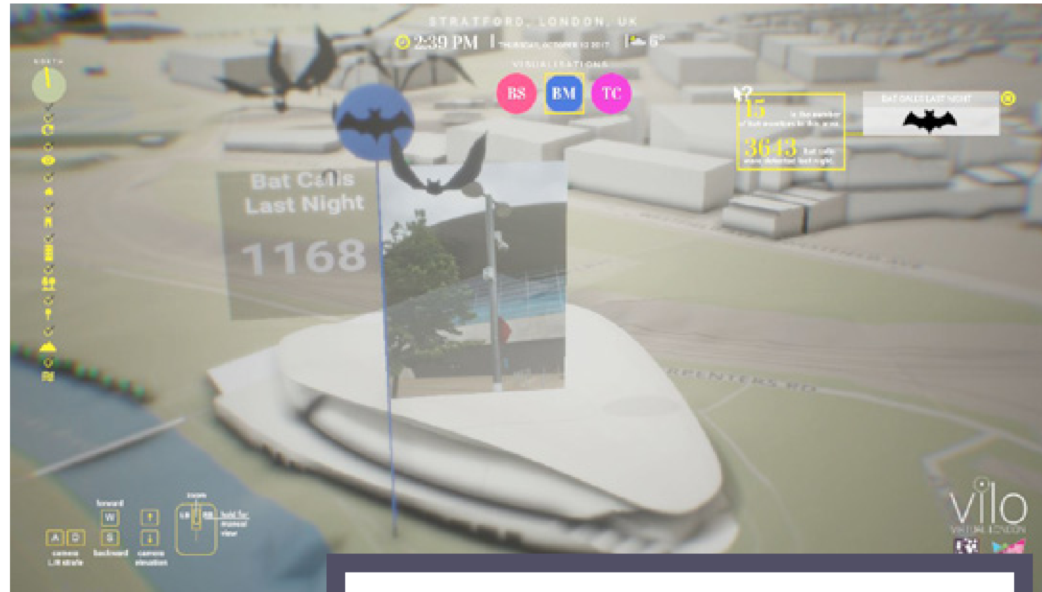


Deployment of urban data visualisation tool on multiple (7) platforms with varying degrees of immersion and interactivity, allowing for comparison between the different tools and their applicability on visualising urban data.

park (smart bat monitors), as well as simulated data. These datasets are overlaid over a highly detailed 3D map of QEOP using the Virtual London (Vilo) platform, an interactive 3D urban data visualisation platform developed at CASA. Using this setup, information is visualised within its environment, providing meaningful context for observers, thus helping them better understand urban data.

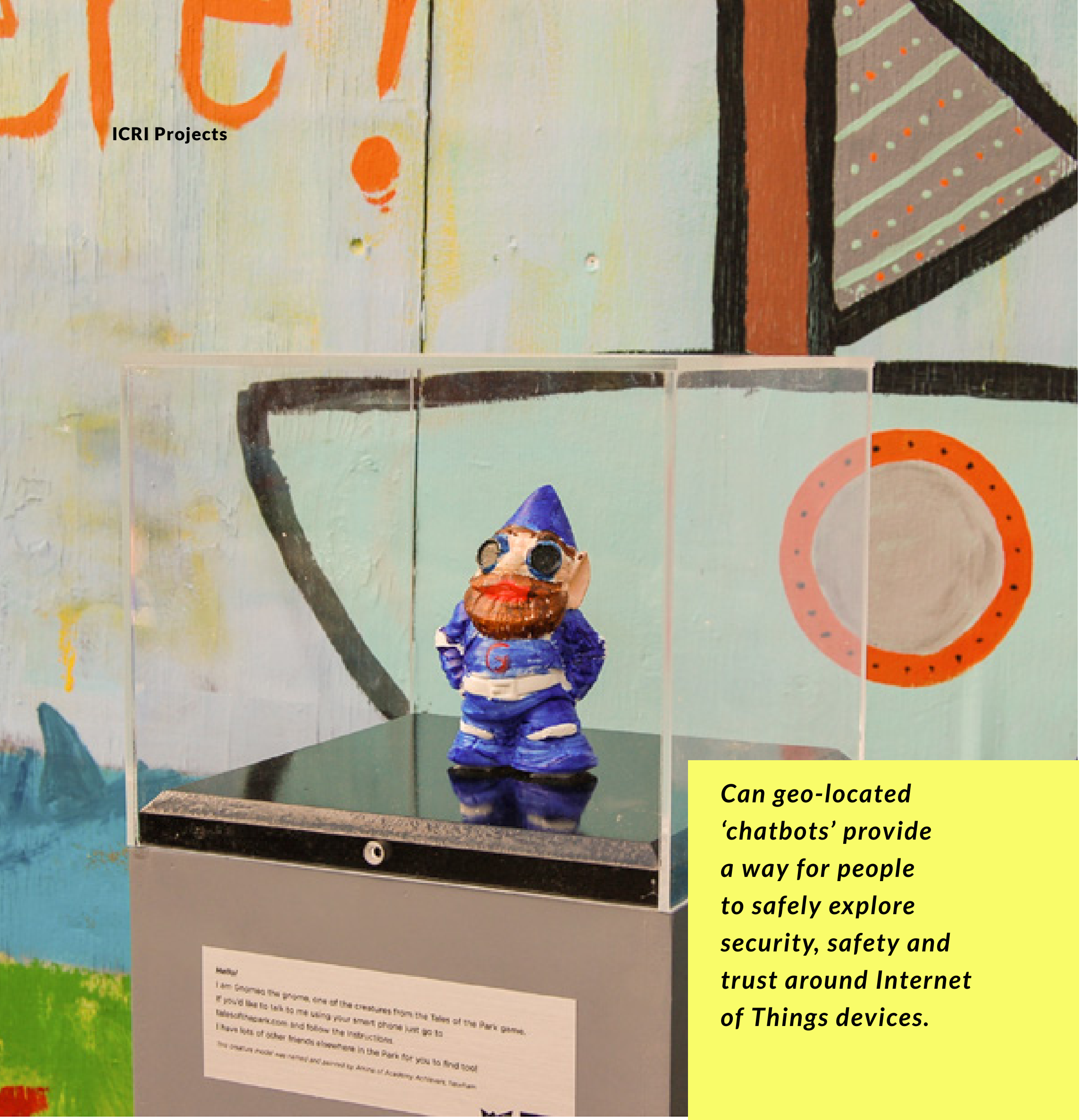
Multiple visualisations were developed exploring a wide range of approaches, with varying degrees of interactivity and immersion, from passive data monitoring to interactive data manipulation. The QEOP Data Table, developed at CASA, uses an overhead projector to project data onto a table cut in the shape of the park, cycling through layers highlighting current conditions at the park, providing ample context with minimal interaction. Augmented Reality (AR) tools

Augmented Reality technologies proved to be more easily deployable, requiring a single mobile device, and non-specialist members of the public found them to be more immersive, easier to use, and to offer more intuitive navigation of 3D space.



were used to add interactivity and immersion to the visualisation, by allowing users to overlay digital data on surfaces using different AR technologies (Apple's ARKit, Google Tango, Microsoft's HoloLens). The AR versions were implemented using handheld or head-mounted devices, and allowed users to view 3D geometry overlaid over the device's camera feed, and toggle data layers on and off. Finally, two fully immersive Virtual Reality (VR) versions were developed using HTC Vive and the Google DayDream, which allowed users to navigate within virtual 3D space and explore QEOP from multiple perspectives. Current work-in-progress focuses on combining benefits from both AR and VR approaches into a single application (VR Binoculars), allowing for the virtual representation of data overlaid over large areas of the park viewed from a distance, thus giving the viewer an overview of information on the park while they are looking at the actual park.

Virtual Reality approaches required special equipment to deploy (headset and/or controllers), thus reducing the user's familiarity with the controls, but were found by non-specialist members of the public to be better overall for understanding urban datasets.



Can geo-located 'chatbots' provide a way for people to safely explore security, safety and trust around Internet of Things devices.

TALES OF THE PARK

Chatbots and trust

UCL, QUEEN ELIZABETH OLYMPIC PARK

Tales of the Park is part of a research project being conducted to explore security, safety and trust around Internet of Things devices. The research takes the form of an installation of 15 creatures that visitors to Queen Elizabeth Olympic Park can chat to on their smartphones.

The project builds on the success of the 'Tales of Things' platform, a website and app which allows people to attach memories to physical objects using QR codes. The creatures in the Park are fitted with Bluetooth Beacons, and are designed to allow researchers to ask questions such as: how are users able to understand the layers of code which augment our world? Do users understand the often transactional nature of data provision? And how does this affect their willingness to adopt such services?

Chatbots have a long history in computing, the first being ELIZA, developed by Joseph Weizenbaum in

15 Tales of the Park creatures were installed in Queen Elizabeth Olympic Park between September and December 2017

1966 at MIT; however, it's only recent advances in computing power that have made them reliable enough for general purpose use, especially when combined with speech processing.

At present, technology companies are competing to develop speech and text-based interfaces for use both in the home and on the street. However, there are fundamental differences between a natural language interface and using a keyboard or touchscreen. With speech interfaces, the boundary between 'using' and 'not using' the device is blurred: for a device like Amazon Echo to function, for example, it needs to listen out for its activation keyword all the time - in other words, it's always listening. Similarly, when engaging with chatbots on social media, it's not always clear whether you are interacting with a computer or a human, and there's lots of potential for people

Each creature was named and painted by young people from the Olympic Boroughs

to inadvertently expose sensitive information to people who might not have their best interests at heart.

To date, the Creatures have had conversations with more than 200 people, with more than 140 unique memories being submitted by Park visitors.

Tales of the Park is a playful, safe way to explore some of these issues. As you interact with the Creatures using your smartphone, they ask you for your memories of the park, and in return they'll share what they know or what other people have said to them. They also remember you, and they talk about you with each other behind your back! We're interested in what people will say to the creatures, whether they trust them, and what sort of things they will share with them.

How can citizen engagement inform the design of food waste recycling services?

LONDONERS' LAB

Nudging waste recycling

UCL, FCC, FERROVIAL SERVICES, BOROUGH OF EALING, CITY OF LONDON, RESOURCE LONDON, GREATER LONDON AUTHORITY

Recyclable waste that ends up in landfills is a costly problem both financially and environmentally in Greater London. The Mayor of London has set a goal to drastically improve recycling performance in the London boroughs by 2020. To tackle this challenge and encourage more people to recycle, a joint programme, Londoners' Lab, has been set up to improve the state of waste services using a citizen-centric approach.

As research leads in Londoner's Lab, we carried out a three-phased study to engage with multiple project stakeholders and the residents of a housing estate in the London borough of Ealing. A literature review of recycling behaviours and interventions, a set of interviews, a co-creative workshop, and observations of the estate's recycling bins were conducted to scope the problem, engage with citizens, and gather

We took a novel approach to defining recycling interventions through citizen engagement, in the wild approach, and persuasive technologies.

requirements for the recycling intervention. Multiple engagement methods were employed to ensure a holistic approach: participation in estate events; doorstepping; and engagement with the residential board; background research and sourcing of third party resources.

Our key findings were twofold: engaging residents in a diverse estate was challenging, and interest in food waste recycling was low. However, three design directions for an intervention that could encourage participation in food waste recycling were revealed: residents could be persuaded to change their behaviour through more pleasant, awareness-raising, and convenient design solutions. New guidelines for conducting collaborative, multi-stakeholder citizen engagement were also discovered: the need for multiple methods and a multi-phase structure combined with flexibility and creativity in data collection, to counterbalance the unexpected events that arise when researching in the wild.

Physical intervention designed and implemented for testing during Winter 2017.

We tested multiple methods to engage with residents towards identifying gatekeepers to the community and building trust between the researchers and residents.

How can we improve health and wellbeing in Queen Elizabeth Olympic Park?

HEALTH AND WELLBEING INSIGHTS

SME projects

FCC, LLDC, OPENPLAY, LIVING MAP, BETTERPOINTS, THE ECOLOGICAL SEQUESTRATION TRUST

The Olympic Park in East London is an area of rapid change and development and an ideal place to test new, community-focused technology interventions. It's a fast-growing space with residential, commercial and cultural developments growing side-by-side.

This project questioned what makes a park a park, and how green spaces and urban development should work together to ensure communities are getting the most out of the areas they live in.

In order to more richly understand how technology may be used to improve health and wellbeing in communities we started with an insight sprint. Our Insight Sprints are rapid research efforts with a holistic approach. They bring together user-led qualitative research alongside case studies and data analysis, and included literature reviews, 13 diary studies, nine expert interviews with people working in the health and wellbeing field, vox pop interviews with local residents, and urban observation over a number of days in the park itself observing how people use the space and what activities currently take place there.

From the research, we uncovered a set of challenges:

Accessibility & Exploration

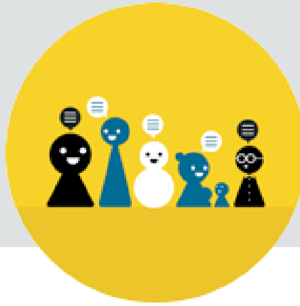
Queen Elizabeth Olympic Park is a dynamic place of constant change and development. This change can be confusing for visitors but also means there's always something new to discover.

How might we use connected technologies to maintain good access to the park, keep people informed of changes to the park, and help visitors find great ways to exercise, relax and be healthy?

Safety & Security

It's essential to a healthy lifestyle that people feel safe and secure in their city. Could innovations help people feel safer in the park, take care of each other, as well as enjoy Queen Elizabeth Olympic Park by day or night?

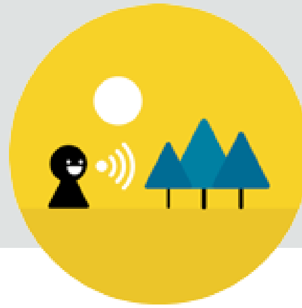
The park has been built both for people and for wildlife, with some areas deliberately dark and quiet. How can we help the public understand which areas are safest and most suitable for exploration and different activities?



There's no one size fits all

People have a diverse set of motivations when it comes to health and wellbeing – there is no 'one size fits all' solution.

How can the park better help different people with diverse needs take the first steps on the journey towards a healthier lifestyle and make this more attainable? How can we connect people to the buzz of exercise, and inspire them to play and have fun within the growing community of Queen Elizabeth Olympic Park?



Connecting with nature

Simply being in nature is good for our health and city dwellers living in built up areas aren't getting enough of it. Queen Elizabeth Olympic Park has become a haven for nature and wildlife.

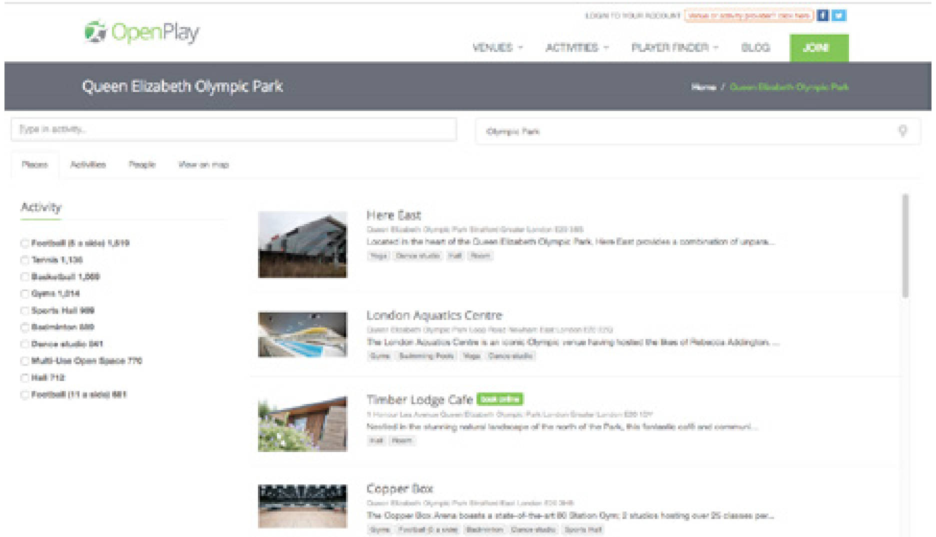
How can we help people discover, explore and understand the wonder of this East London habitat? How can we give Londoners the full benefits of this urban escape? Could the weather, the smells and the sounds of nature be the key to unlocking healthier lifestyles in the park?

When life gets in the way

No matter who we are, our busy urban lives often prevent us getting adequate exercise or relaxation, and sometimes we don't recognise the little changes that could make a difference. How could Queen Elizabeth Olympic Park become part of everyday health for Londoners? How could we help kick start daily healthy habits that can become part of people's lives?

Social health habits

Social isolation is a growing problem for people living in cities. At the same time, social activities come with a commitment to each other and a common goal. Connecting with others is a vital part of health and wellbeing, so how can we foster healthy social activity, peer to peer encouragement and help connect new and existing communities around Queen Elizabeth Olympic Park?



Open call

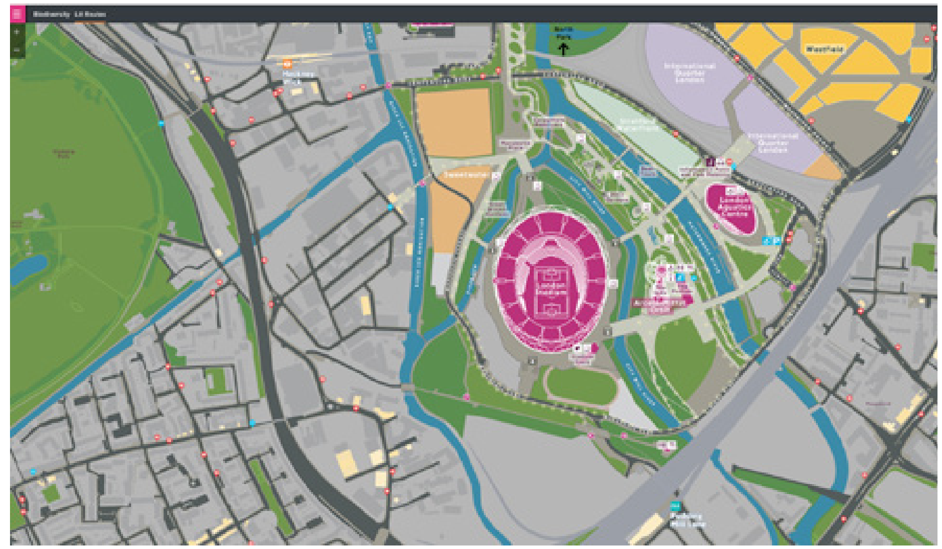
The next step was to prototype and demonstrate how these challenges might be solved, through implementing technology and interventions in the park. Four UK SMEs took part in an Open Call.

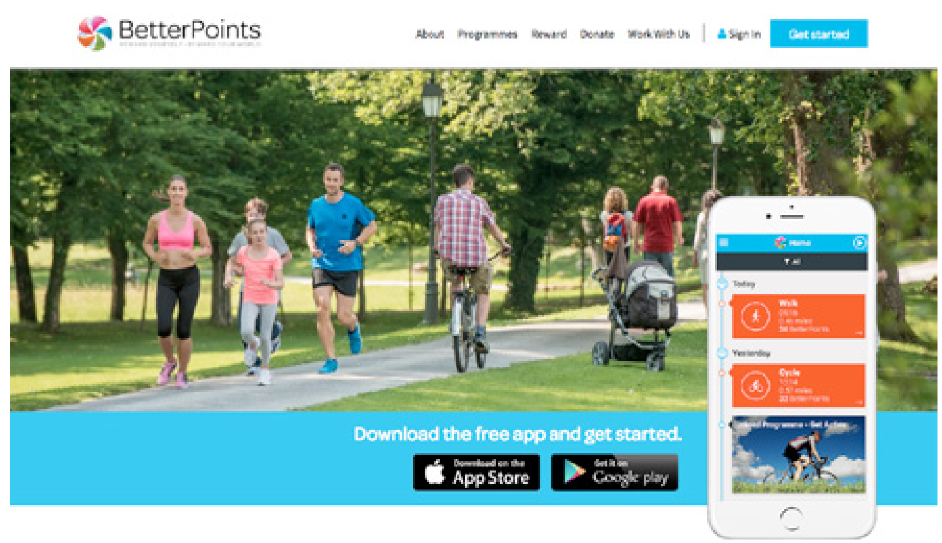
In order to encourage people to get active in Queen Elizabeth Olympic Park, OPENPLAY developed a landing page specifically focused on the park and the surrounding leisure activities, making it easier for people to find and book local facilities.

Betterpoints is an application that enables users to earn points as they exercise, which is recorded in the app. In order to incentivise people to walk, run or cycle in Queen Elizabeth Olympic Park, BetterPoints offered extra points per minute of activity performed in the park, which could be exchanged for a high street retail voucher or donated to a charity or local community group.

Living Map designed a detailed, layered map of Queen Elizabeth Olympic Park. This map makes it easier for users to navigate the park and encourages people to get out and explore; it features bio-diversity routes and lit routes for people wanting to travel through the park after sunset.

The Ecological Sequestration Trust worked alongside Groundwork London to design a tailored, holistic intervention. They convened a series of workshops using participants who had been identified as being at risk of social isolation (and were over fifty years old). Based on their findings, they developed an SMS service that encouraged participants to visit the park. Each weekly text provided a weather forecast, suggested travel routes (including disruptions), activities and the telephone number of QEOP information line.





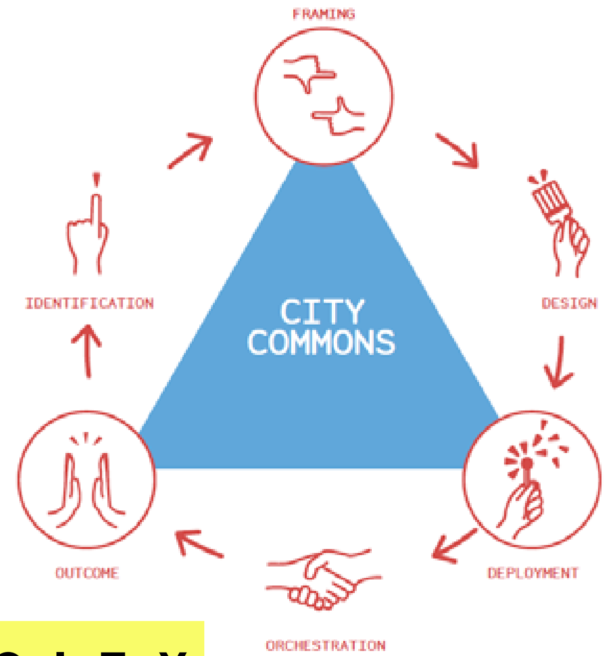
PHD PROJECTS

URBAN VISUALISATIONS

Lisa Koeman

Advances in computing have enabled the deployment of technology in public settings such as high streets, squares, and parks. The role such community technology can play in engaging and connecting people in the urban environment has become of increasing interest in recent years, amid widespread concerns that cities are becoming less socially connected. Until now, however, many of the studies have focused on displaying games, photos, and other entertainment content on public screens, with the aim of bringing people together through play. Less is known about the use of publicly situated installations as a tool for encouraging people to view the perspectives of others and to share their personal perceptions.

This thesis explored the use of situated public input technology and visualisations, collectively coined urban visualisation interventions, as a means of fostering community engagement. People's responses to and interactions with different topics, input devices, and visualisations were studied in a series of in-the-wild deployments in residential neighbourhoods and at events. In addition to the presentation of the design and evaluation of these deployments, the thesis presented an urban visualisation framework that outlined the key design and contextual factors that affect engagement, such as: the impact of the visualisation's update frequency on sustaining the community's interest, the influence of the input mechanism on the contribution quality, and the importance of positioning to ensure participation by a diversity of people.

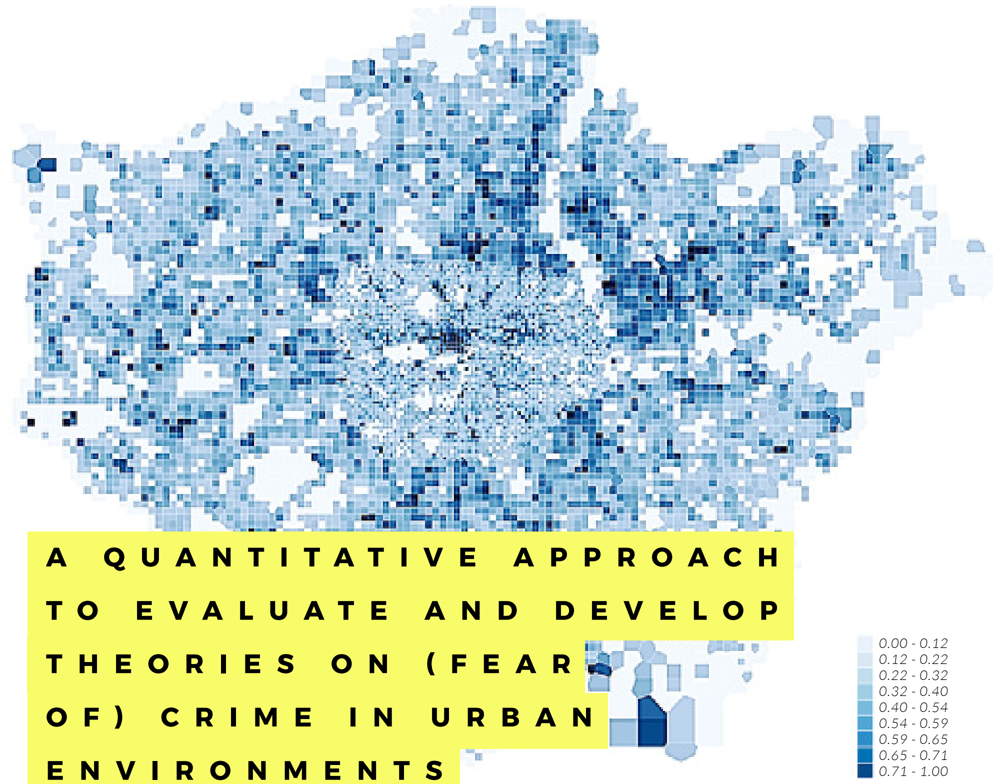


A CITY IN COMMON

Mara Balestrini

The goal of the PhD was to identify the factors that can guide the design and deployment of engaging, sustainable and impactful civic technology interventions, from the perspective of the communities that they intend to benefit. Three case studies were presented: an ethnographic study of an existing civic technology, and two design and evaluation studies of novel interventions. A set of themes was derived from the studies that highlight factors that are positively associated to engagement, sustainability and impact. Based on these themes and on experience from deploying interventions, a framework was developed and validated. It comprises six key phases: identification of matters of concern, framing, co-design of community technologies, deployment, orchestration, and evaluation.

In line with a new wave of civically engaged HCI and participatory methods, the framework puts people at the heart of socio-technical innovation and technology in the service of the common good by fostering the development of a commons: a pool of community managed resources. Using this approach, the thesis explores how researchers, entrepreneurs, artists, city councils and communities can collaborate to address community issues using digital technologies. It further suggests how citizens can be supported to develop skills that will allow them to appropriate and sustain the interventions.



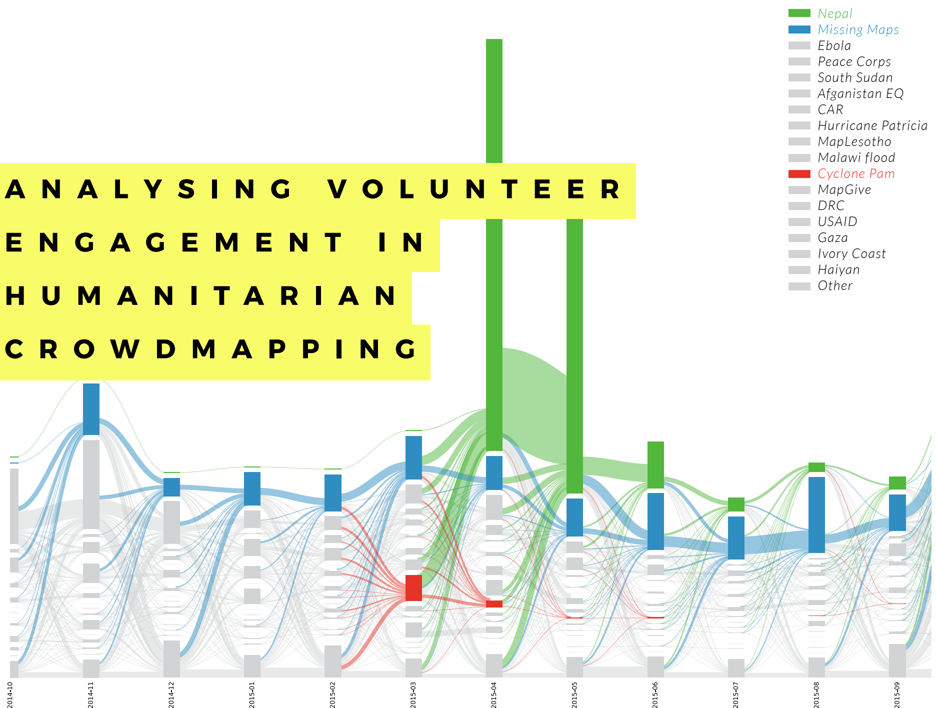
A QUANTITATIVE APPROACH TO EVALUATE AND DEVELOP THEORIES ON (FEAR OF) CRIME IN URBAN ENVIRONMENTS

Martin Traunmueller

This research explored the role of people dynamics in relation to (fear of) crime in cities. Besides the physicality of architecture, urban environments are being defined by social life that happens in between built space, and hence show different (fear of) crime patterns that change dynamically. Based on qualitatively conducted and well established urban crime studies from architectural theories, this work focus on different demographical properties, such as age, gender or ethnicity of urban population, and discusses their relation to crime activity and fear of crime perception in a city on a quantitative level. The project developed a set of methodologies that support urban researchers to validate and expand urban (fear of) crime theories at scale, by following a data mining and a crowdsourcing approach.

All three studies have been published in academic venues of both, computer science and urban studies, and have lead to significant debates within the research communities. Martins PhD work lead to the award of a McArthur Foundation fellowship at the Center for Urban Science and Progress (CUSP) at NYU/New York University, where he continues his research on urban crime with the New York Police Department (NYPD) and other interesting urban data related projects for the city.

ANALYSING VOLUNTEER ENGAGEMENT IN HUMANITARIAN CROWDMAPPING



Martin Dittus

Martin produced four empirical studies for the Humanitarian OpenStreetMap Team (HOT), a novel crowdsourcing setting where thousands of volunteers produce maps to support humanitarian aid. How can volunteer capacity be built proactively, so that trained volunteers are available when needed? How important are opportunities for social encounter, either online or in person? HOT's diversity of settings provided opportunities to observe the effects of different coordination practices. His evaluations of novel practices were informed by existing community concerns, and revisited existing theories in social and behavioural science in the context of HOT. He used statistical methods to analyse participation records across the full HOT contribution history.

The work has already achieved significant impact: all four studies have been published in major academic venues, and one study has been awarded Honorable Mention at a top-tier conference. In addition, over time the work has lead to significant debate and reflection within the HOT community, and on more than one occasion it has already informed specific changes in organiser practice. The research demonstrated that coordination practices can have a marked impact on volunteer activity and retention. Complex task designs can be a deterrent, while social contribution settings and peer feedback are associated with a significant increase in newcomer retention, and event-centric campaigns can be significant recruiting events.

BLOCKCHAIN AND SUPPLY CHAIN TRANSPARENCY

Jessi Baker

This research focused on Human Computer Interaction in a specific ecosystem - product supply chains and retail environments. It asked the question of whether new technologies can enable more transparency between the producers of products and the consumers. She conducted interviews with makers and small scale producers as well as shoppers to gauge interest in increased transparency and assess assumptions. Her research lead to a series of prototypes for collecting, securing and presenting data to "nudge" shoppers into more conscious decisions. Her experiments including using the bitcoin blockchain to store authenticated data about a product and carry it along the supply chain with the product to communicate it in a trustworthy way. This lead to large scale prototypes using blockchains in product supply chains to enable transparency and trust in the data. This research is ongoing.

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PEOPLE

INTERDISCIPLINARY

We are a mix of scientists, engineers, anthropologists and architects. The core team are hosted at Intel Labs Europe, University College London, Imperial College and the Future Cities Catapult. In the Capstone phase for 2016/2017 we partnered with the London Legacy Development Corporation to focus our Living Lab in the Queen Elizabeth Olympic Park.

OUR APPROACH

Working from several locations across London, the ICRI is led by a management team of Principal Investigators (PI's) from each organisation plus a managing sponsor and project director at Intel. The PI's are supported by a mix of postdoctoral researchers / research associates and PhD students. The former focus on project specific research, the latter focus on individual PhD activity informed by the vision of the institute. In addition to the core team we are continually welcoming visiting researchers and interns into the ICRI and aim to have 20% of staff flowing through the ICRI in that capacity.

LEADERSHIP

The management team report to a Board of Directors chaired by the VP of Intel Labs Europe and is supported by a Board of Advisors from government, industry and academia.

FELLOW TRAVELLERS

Since its inception, the Institute has established a number of working relationships with local councils, the London Mayor's Office, Innovate UK and companies large and small. We sit on the Connected Digital Economy Catapults advisory network, the Mayor of London's Smart London Board, the BIS Smart London Forum and engage in several academic communities through EPSRC programmes, conferences, workshops and summer schools. It is through innovative collaborations that we are able to create truly original and future shaping research. Cities are wide and diverse environs that provide a myriad of opportunities and ICRI Cities are proud of the strength of its collaborative working relationships across the UK.

INTEL

PI

Duncan Wilson (2012-2018)

Research Staff

Sarah Gallacher (2015-2018)
Sokratis Kartakis (2017-2018)
Simona Ciocoiu (2015-2018)

Alumni

David Prendergast (2012-2015)
Co-PI ICRI currently Intel Labs Europe
Mo Haghighi (2015-2017) currently at IBM
Alex Gluhak (2013-2015) currently IoT Manager at Digital Catapult in London
Greg Jackson (2013-2015) currently studying for a PhD at Imperial College London
Han Pham (2013-2015)
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Davide Carboni (2015-2017) currently at Center for Advanced Studies, Research and Development in Sardinia
Usman Adeel (2015-2017) currently Senior Lecturer at Teesside University
Jason Wright (2014) completed the Rotation Engineer Program at Intel
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Shane McLoughlin (2017) currently at Maynooth University
Rajiv Mongia (2012-2013) currently working in New Technology Group at Intel
Ian Lloyd (2013) currently working in HPC at Intel
Ye Lin (2014)
Jennifer Heier (2014)
Tania Calcada (2014)
Tessa Hammatt (2014)
Jelly Dent (2014)
Aksel Ness (2014)
Struan Noble (2013-2014)
Barry O’Brien (2013-2014)
Pedro Monteiro (2013-2014)

IMPERIAL COLLEGE LONDON

PI

Julie McCann
Director of Smart Connected Futures, Adaptive Emergent Systems Engineering, Imperial College London (2012-2018)

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Dr Pedro Martins - Researcher (2013-2018)
Dr Milan Kabac - Researcher (2016-2018)

Support

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Alumni

Vittorio Illiano (PhD) (2013-2016) Novartis Pharma AG, Digital Development
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Dr Reza Akhavan - (2014 - 2016), currently, Data Science Research Coordinator at Future Cities Catapult, London, UK
Dr Zhijin Qin - (2013-1017) now Lecturer (Assistant Professor) in Lancaster University, UK
Dr Marija Milojevic - research assistant (2015-2016)
Prof Shusen Yang - (2013-2014), now professor at Xi’an Jiaotong University, China
Dr Eskindir Asmare - (2015-2016)
Di Wu – (2014-2015) Currently Associate Professor, Vice Director of Key Laboratory for Embedded and Network Computing of Hunan Province, Department of Computer Engineering, Hunan University, China
Lambros Lambrinos (2015-2016)
Fengrui Shi (2014-2016)
Igor Talzi (2014)
Gerard Sandje (2015)
Gokul Balakrishnan (2013-2014)
Shailesh Ghimire (2014)
Cong Zhao (2014)

UNIVERSITY COLLEGE LONDON INTERACTION CENTRE

PI

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Licia Capra,
Director of Research, Computer Science Dept, UCL (2012-2018)

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Can Lui – Researcher (2016-2018)
Katie Seaborn – Researcher (2017-2018)
Danilo Di Cuia – Researcher (2017-2018)
Johanna Mähönen – Researcher (2017-2018)
Giovanna Vilaza – Researcher (2017-2018)

Alumni

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Sarah Gallacher – Researcher (2012-2015)
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Lorna Wall – Researcher (2012-2014) User Research Lead at Government Digital Service, London
Rose Johnson – Researcher (2015-2016) Freelance writer, volunteer and researcher
Steven Houben – Researcher (2014-2015) Now: Lecturer, Lancaster University
Sharon Betts - Project Manager (2012-2015) Now Project Manager Astrophysics Dept., UCL
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Paul Marshall – PhD supervisor (2012-2016), Now Senior lecturer, Bristol University
Duncan Brumby – PhD supervisor (2012-2016), Now Reader, UCLIC, UCL
Sami Andberg, Visiting RA in 2014 Now IT Specialist at University of Helsinki
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Martin Traunmüller (PhD) (2012-2016) Scientist & Business Developer, AIT Vienna
Martin Dittus (PhD) (2013-2017) data scientist at the Oxford Internet Institute
Tomas Diez (2012-2013) Instigator, Fab City Research Laboratory, Barcelona
Jessi Baker (2012-2018) Founder of Provenance, London
Chris Smith-Clarke (2011-2012) Data Scientist at decisionLab
Saskia Bakker (2015) assistant professor at the Industrial Design department, TU/e.
Emily Collins (2015) research associate at UCL & University of Birmingham.
Giovanni Quattrone (2015) currently Lecturer at Middlesex University

UNIVERSITY COLLEGE LONDON CENTRE FOR ADVANCED SPATIAL ANALYSIS

PI

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Research Staff

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Duncan Hay – Researcher (2016-2018)
Richard Milton – Researcher (2016-2018)
Flora Roumpani – Researcher (2016-2018)
Sharon Richardson – Researcher (2016-2018)
Valerio Signorelli – Researcher (2016-2018)
Ioannis Tounpalidis – Researcher (2017-2018)
Boyana Buyuklieva – Researcher (2016)

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Lucy Barrett
Scott Cain
Dan Hill
John Lynch
Lavinia Cox
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Teresa Gonzalez Rico

LONDON LEGACY DEVELOPMENT CORPORATION

Jim Wood
Ben Edmonds
Jennifer Daothong
Jack Connor

B A C K G R O U N D

What is an ICRI?

Intel developed the Intel Science and Technology Centers (ISTCs in USA) and Intel Collaborative Research Institutes (ICRIs in rest of world) as collaborative research initiatives among Intel (the founding sponsor), other sponsors (including either companies or governments), and leading universities in specific countries or regions worldwide.

Each Institute focuses on a specific technology area or discipline, bringing together a community of top researchers from across academia. The Institutes are funded by Intel and other sponsors for up to five years. With a significant investment going directly to the participating universities, the Institute's academic participants play a leading role in setting and driving institute research agendas.

Why did Intel develop and adopt the Collaborative Research Institute Model?

Intel derived the ICRI model to engage a broad set of universities and leading academics in a way that would be responsive both to new sponsor imperatives and to research advances realised within academia. Further, Intel wanted to significantly expand and strengthen collaboration between leading academics, companies, governments, and Intel's internal research community. The features of the ICRI model are designed with these goals in mind.

Maximizing the breadth and depth of intellectual exchange requires that sponsor researchers spend significant time at the ICRI's participating universities and, in turn, that academic researchers, including postdocs and interns, spend significant time at Intel. Although each sponsor may use a different internal approach, at Intel, to ensure direct communication and intellectual engagement, the ICRI will report into the Intel Labs research division that is best aligned with the research objectives of the institute.

Why London

London is one of the largest cities in the world; it has the largest GDP in Europe and with over 300 languages and 200 ethnic communities, its diversity offers an exciting test bed to create and define sustainable cities. The institute engages with local communities to understand how they want to live in their cities and involves them in co-designing technological innovations. The motivation for locating in London has been driven by 3 key factors:

The position of London as a diverse, cosmopolitan and complex city provides the perfect environment for exploring many of the issues facing western cities.

The external investments being made in developing London as a centre for research on "future cities" (e.g. UK government's InnovateUK)

The presence of two world class academic institutions (UCL and Imperial) and the established creative, design and financial sectors.

The investment in the Sustainable Connected Cities Institute reflects an increasing market desire to deliver systems at a city scale. This trend is enabled through our increased ability to sense and understand our environment. Technology is enabling the use of data as a new material to support connectivity and the shaping of our urban environment.

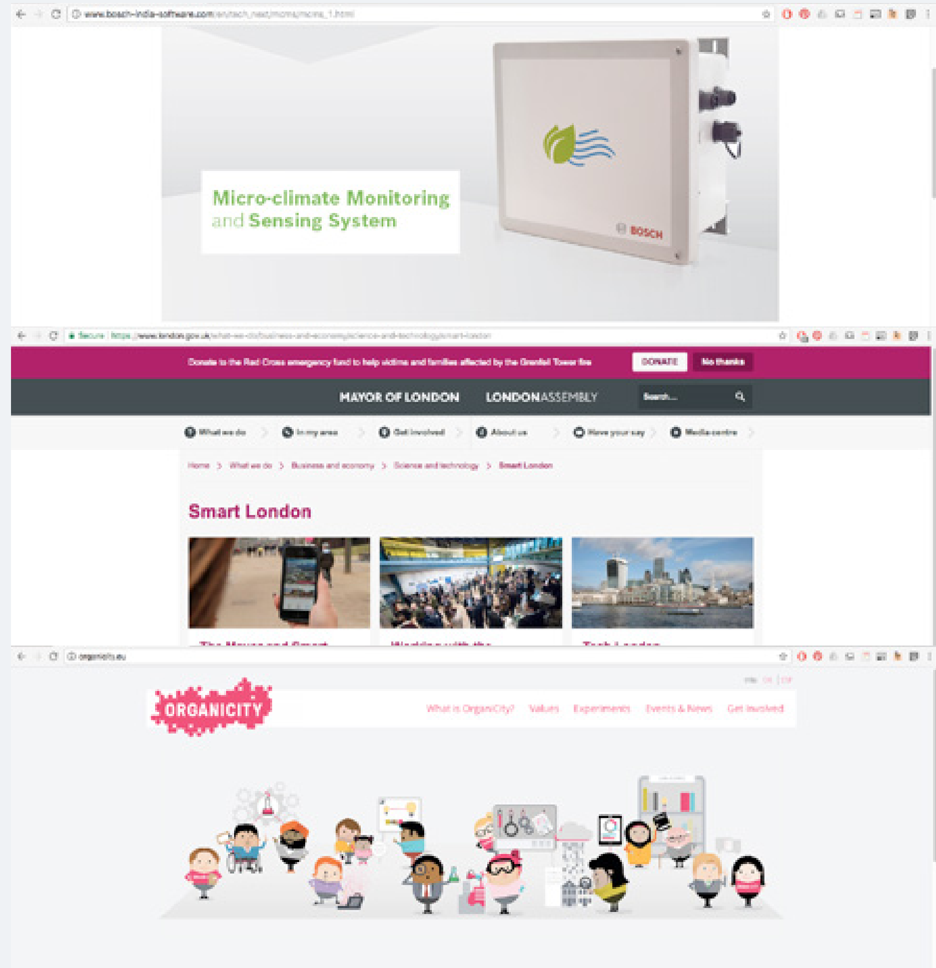
R E F L E C T I O N S

The goal of the ICRI Urban IoT was to deliver outstanding research recognized by industry and academia. We brought together researchers from industry and academia in an Open IP environment to research, collaborate and build systems for deployment in the field. We enhanced the visibility of Intel within future cities research, provided creative approaches to the use of technology in an urban context and continued to innovate the IoT technologies required to deliver sustainable connected cities.

Technology insights and innovations learned from “living lab” deployments influenced the early stage development and delivery of Intel’s first end to end IoT reference platform in 2014. This in turn led to an IoT Gateway design for Plug n Play sensors developed by Intel Labs Europe and Intel Internet of Things Group which was brought to market by Bosch in 2017. The requirement to deploy technology outside the lab and in the city created a number of challenges that also informed our research. For example, data validation and field testing of 131 Galileo (Gen 1) IoT gateways at scale provided technology insights for future product enhancements to Internet of Things Group and New Devices Group.

Our living lab approach gave us insights into the socio economic and political challenges of Smart City infrastructure. Our stakeholder engagement research and use cases featured in Intel Labs UX cross lab working groups, Intel Developer Forum demos and Intel Corporate Strategy Office E2E Vision project (“Smart Cities” vertical). The ICRI helped drive Intel’s position as thought leader in Smart Cities activity through continued engagement as advisors to Mayor of London (Smart London Board) and through industry recognition such as the 2014 Frost & Sullivan Global Smart City Infrastructure Emerging Market Innovation Award.

Our activity led to Intel being identified as a key partner to deliver IoT test beds as part of the EU H2020 Organicity project. The “Experimentation as a Service” platform initially tested in London, Santander and Aarhus is currently being deployed in a several European cities and is



supported by the Open & Agile Smart Cities initiative.

As the ICRI moves into its final phase we are concluding the Urban IoT research projects described in this report and looking towards their evolution. The “shazam for bats” project has garnered much attention in the press and is a great case study of how to deploy an in the wild experiment. It also points to the technology trends we need to develop for the next phase of Urban IoT - developing systems that can ingest large amounts of complex sensor data, process it in real time to make decisions using techniques from the domain of Artificial Intelligence and share that information with a network of systems so that it can be acted upon in a timely manner.

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Revision 1

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