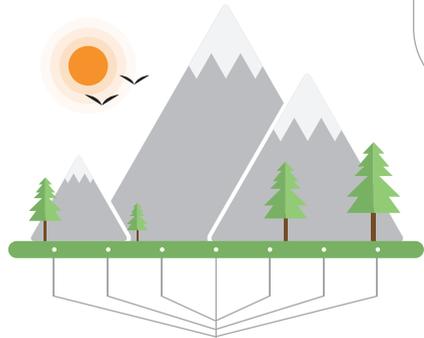
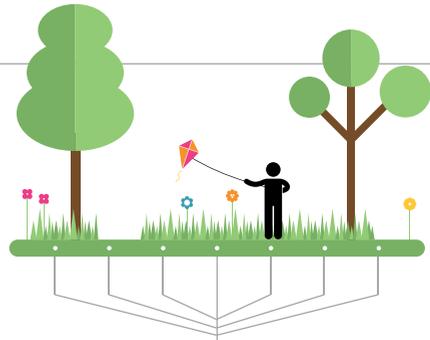
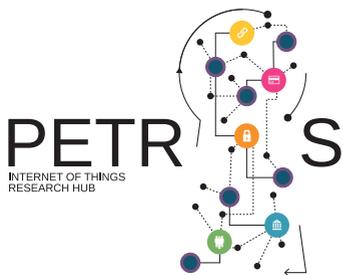


# The Little Book of CONNECTED ENVIRONMENTS and the Internet of Things



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Steven Gray



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# The Little Book of CONNECTED ENVIRONMENTS and the Internet of Things

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London.

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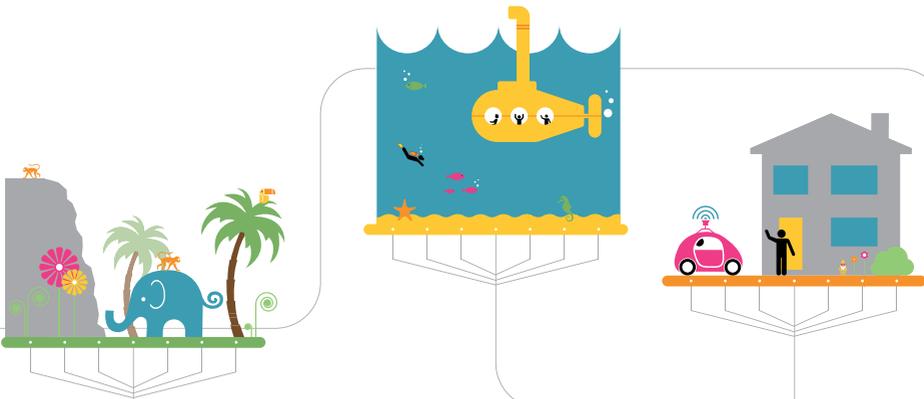
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# What this little book tells you

This Little Book is about opening up the potential of Internet of Things (IoT) devices to provide information about our environment. From city-wide systems and the idea of the Smart City through to building-level management systems and the connected home, data is being joined up - connected. Via a series of case studies this book explores the wide array of possibilities, from environmental data (Shazam for Bats) through to connecting everyday devices in public park settings (Tales of the Park) and onwards to adding IoT into the Curriculum via the Internet of Schools.

The context and impact is wider than these case studies. Connected environments have the potential to change everything we know about not only our urban environments but also our homes, healthcare, transport, security and beyond. This little book builds on work carried out by a team of computer scientists, social scientists, environmental scientists and artists over the last decade, providing a glimpse into the potential of connected environments. We hope to show that how, in many ways, we are at the start of a new digital revolution of connected devices which will transform how we view, manage and use our environments.

So, what does this Little Book tell you? We begin by clearly explaining what we mean by connected environments and the Internet of Things. After this, we go into a bit more depth, presenting a number of case studies which we believe illustrate the potential of these technologies to change our lives for the better.



# What are Connected Environments?

Put simply, a connected environment is any place – a home, a building, a street, a park, even a whole city – where sensors have been deployed. Collecting data through these sensors allows it to be analysed, checked for quality control, joined up with other data sets and used to enhance the area, be it for management, social, environmental or economic reasons. Advances in IoT technologies means that we are at the beginning of a revolution in device deployment, data collection and more importantly ease of use, understanding and access to these data sets.

The devices through which we can sense and collect this data come in all shapes and forms. As IoT technologies become cheaper and smaller, we can add sensors to almost anything. They do not have to be inaccessible black boxes hidden away but could be a park bench, a rubbish bin or even a tree. With the onset of connected environments, everything and anything can be made to collect data, and almost anything that can be sensed can be measured, collected and shared via the Internet to help us understand, manage and enhance the environments in which we live.

From environmental data such as air pollution, temperature and wind speed through to the qualitative information from social media in a particular place, data produced by lighting and heating systems and even the humble lamppost - all can be connected via the Internet of Things. It is this connection and supply of data which is leading the revolution. Sensors can be attached to a myriad of things, data collected, checked for accuracy, linked to a wider collection of data and run through algorithms to provide analysis and insights into our environments.

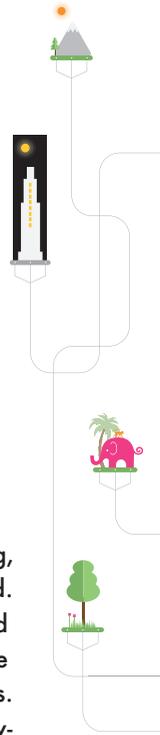




Figure 1. Sensor image

Yet, as much as this is about new ways of collecting and analysing data, key to the insights generated by connected environments is location. Knowing what, where, and when something happened at a hyper-local scale opens up the possibility of a 'Geography of Everything.'

# What is the Internet of Things?

The Internet of Things, often known as IoT, is simple: it's about Things, anything and potentially everything, being connected to the Internet. There are already an estimated 23 billion IoT devices in existence with a predicted 75 billion by 2025 (Figure 2).

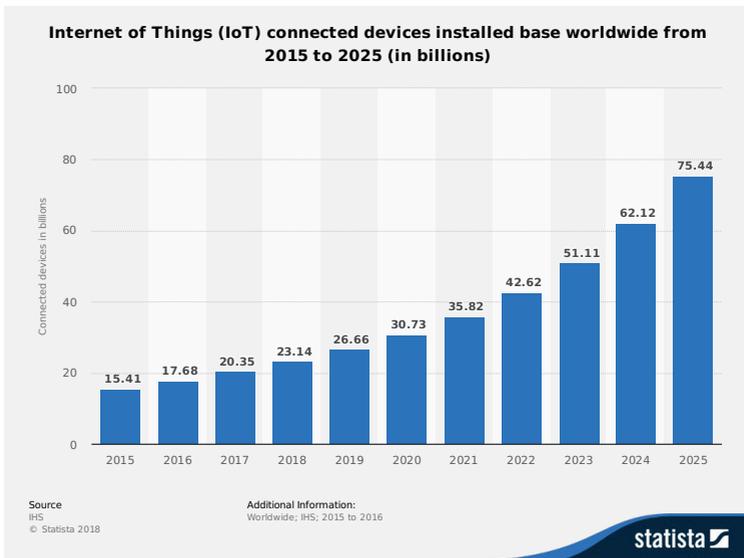


Figure 2. The number of IoT devices is predicted to exponentially increase according to Statista: <https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/>

Once an internet connection is in place (and there are many new ways to connect devices in addition to the familiar technologies of WiFi and Ethernet), data can be shared and written back to an object, allowing it to not only tell us about its environment but, in a sense, for the device itself to become aware of what's going on around it - how warm it is, if it is light or dark, is it noisy, is it full, and so on. Once data is shared and known, algorithms can be developed, neural networks trained, and with on-device data analysis and processing, or Computing on the Edge,<sup>1</sup> then the Things in a connected environment can potentially be making decisions about it without human intervention. Entering the world of Algorithms, Artificial Intelligence and Computing on the Edge can become overwhelming. Put simply though, data can be collected through devices - the 'things' of the Internet of Things - and then a series of rules can be developed via an 'If This Then That' logic - *if this happens then do that*. With this mindset, collecting data about our environment allows us to do things that manage, enhance and change our world. Small changes on the large scale that is the Internet of Things can make notable social, economic and environmental impacts.

<sup>1</sup> 'Edge' computing refers to the use of low-powered computer systems to process data out in the world - at the 'edge' of the network - rather than sending it all back to a central computer. The 'Shazam for Bats' project described below is an example of this design pattern in action.



case. In 1854 he made a map of an ongoing cholera outbreak in Soho. On it, he plotted where the people who died had lived and the location of the water pumps. Looking at his map, a very clear cluster of deaths can be seen around the pump on Broad Street. On his instructions, the pump handle was removed, and the number of new cases began to decline immediately.

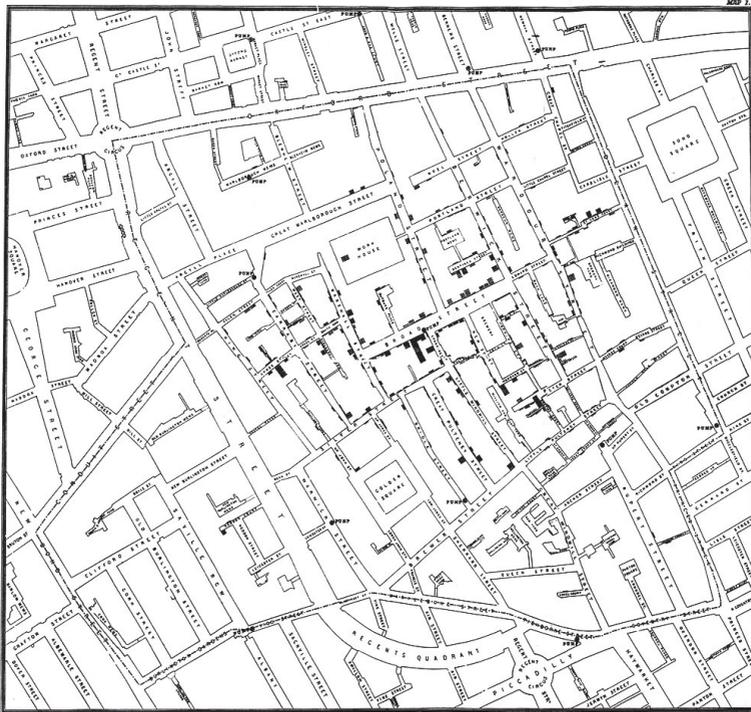


Figure 3. John Snow's Cholera map (1854).

By correlating the locations of the pumps and deaths from cholera, Snow was able to make a much more convincing case about how the disease spreads. Whilst his work was controversial at the time, it contributed to the advancements in water treatment and sanitation undertaken by engineers such as Joseph Bazalgette, which in turn led to vast improvements in public health towards the end of the century.

Snow's map demonstrates the analytic power of connecting events in

space and time. Yet Snow had to reconstruct his data from paper medical records, after the fact. Today, increasingly cheap computer processing power, sensors, and Artificial Intelligence, combined with improvements in power consumption, battery life, and the development of low-power wireless networking technologies means that the capacity exists to collect and analyse data of all kinds in real time: the connected environment. If Snow's map could unlock the cause of a deadly disease and halt its spread, then the promise that these technologies offer is new insights into how our towns and cities work, and how we might make them safer and more pleasant for the people who live in them.

Some of this promise has already been realised, with the use of 'tap in' technologies in public transport such as London's Oyster card system, the use of WiFi networks to track how people move through the city, and the deployment of networked sensors in buildings to improve their efficiency and comfort. Projecting from these uses, the dream of a fully automated city, where the connections between people, events, and places of the sort made by Snow happen routinely, and therefore allowing city authorities and companies to respond quickly to changing conditions on the ground, remains an alluring one.

Yet this potential is for the most part untapped. A number of IoT, environmental and Smart City-badged demonstrators and deployments have been run throughout the UK, but the wider revolution is still to come. Indeed, in terms of their position on the Gartner Hype Cycle (a trend analysis system looking at upcoming and current technological innovations), it would be fair to position these technologies somewhere between the 'Peak of Inflated Expectations' and the 'Trough of Disillusionment'.

This is for a number of reasons. Firstly, deploying this technology, whilst getting easier, is still hard; but perhaps more importantly, much of the rhetoric around these technologies has focused on the idea of the Smart City. This top-down notion of how and why we might use IoT technologies in our cities has been criticised by people such as Adam Greenfield for its utopianism and its technocratic, centralising and anti-democratic assumptions.<sup>4</sup> Moreover, there is an increasing awareness of the power that

<sup>4</sup> Adam Greenfield, *Against the Smart City*, (London: Verso, 2013).

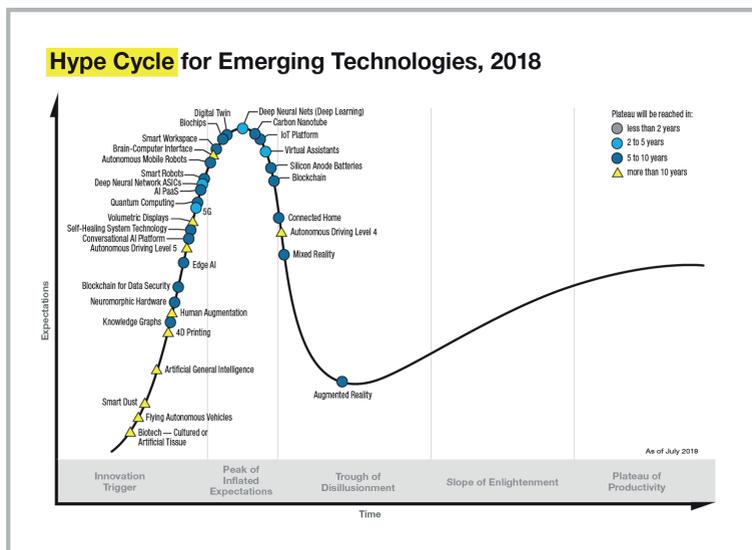


Figure 4. Gartner Hype Cycle (2018).

large-scale data analytics platforms offer to those who own and run them. The Cambridge Analytica scandal, where highly-targeted political ads were shown to swing voters on Facebook, is only the most prominent example of how large-scale data collection can bring with it unanticipated effects. As numerous technologists, academics, and researchers have pointed out, for all the benefits that networked technologies have brought, they have also seen corresponding increases in racism,<sup>5</sup> loneliness,<sup>6</sup> and threats to privacy. Finally, as events such as the 2016 DDoS attacks launched from unsecured IoT cameras illustrate,<sup>7</sup> a more connected world is inherently one which is more vulnerable to hacking, espionage, and other security threats.

<sup>5</sup> Safiya Noble, *Algorithms of Oppression: How Search Engines Reinforce Racism* (New York: NYU Press, 2018).

<sup>6</sup> Sherry Turkle, *Alone Together: Why We Expect More from Technology and Less from Each Other* (New York: Basic Books, 2011).

<sup>7</sup> Brian Solomon, 'Hacked Cameras Were Behind Friday's Massive Web Outage', *Forbes*, October 2016, <https://www.forbes.com/sites/briansolomon/2016/10/21/hacked-cameras-cyber-attack-hacking-ddos-dyn-twitter-netflix/#79467a8b4fb7>, accessed November 2018.

There is, therefore, a need to articulate an alternative vision for these technologies. If their first wave and the uses that we've imagined for them have tended towards top-down solutions, then the term 'connected environment' begins instead with Snow's simple insight that observing where and when something happens is as important as observing what happens. A connected environment isn't one that just sucks up data about the people moving through it so city authorities, landowners, and technology companies can manage and extract value from it. It starts, instead, not with 'things' but with 'us' - the people in the environment. How do we live in it, what do we want from it, and how could technology help us to make it better? It means thinking not only about hardware—connecting sensors and computers—but using that hardware to connect people more meaningfully with each other and the places in which they live and work.

# Case studies

## Tales from the Park

As more devices become connected, how they work and the ways in which they can interact with one another becomes more complex. For the people who end up buying and living with these devices, and even for the companies that make them, this can bring unintended consequences. Recent high-profile incidents have included people across America accidentally ordering products with their Amazon Echo because the 'Alexa' activation keyword was said on television; televisions continually recording what their owners were saying; or most spectacularly, 'Cayla', the 'smart' doll whose camera, microphone, and unsecured Bluetooth connection led to it being banned in Germany as an espionage device.<sup>8</sup>

Cases like this show how we tend to assume that if something can be bought in a shop that it's 'safe', yet this isn't necessarily the case. Moreover, even if the devices we buy are secure, when people discover how they actually work, they're often struck by how 'creepy' or 'leaky' they are.<sup>9</sup> People need to understand what it is that they are buying, regulators need to understand what is being sold, and there's obviously much more technology companies and designers can be doing to help people understand how the devices they sell work.

Tales of the Park was what the games designer and philosopher Iain Bogost calls a 'serious game', designed to help people explore some of these

<sup>8</sup> 'German parents told to destroy Cayla dolls over hacking fears', BBC News, February 2017. <https://www.bbc.co.uk/news/world-europe-39002142>, accessed November 2018. Though Cayla was banned under counter-espionage laws, the aim of the ban was to protect the privacy of the dolls' owners.

<sup>9</sup> Irina Shklovski et al., 'Leakiness and Creepiness in App Space: Perceptions of Privacy and Mobile App Use', Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (2014), pp. 2347-2356. This excellent study of several smartphone apps explores how people can find the apps they use 'creepy' when they discover how much data these apps can 'leak' to the companies that made them.



issues. Produced in collaboration with Queen Elizabeth Olympic Park in East London, it consisted of 15 IoT 'creatures' placed throughout the public places in the Park. Each creature contained a Low-Energy Bluetooth Beacon: a simple IoT device which can be used to broadcast web links to people's smartphones. We used these devices to give each of the creatures a 'personality' by linking them to a chatbot: a simple program, similar to that used in an Amazon Echo, which allows people to interact with computers using everyday language. When people went near to the creatures, if they were signed up for Google's 'Physical Web' platform, they would be sent a link through which they could 'talk' with the creature. A core part of this is understanding how it is that devices in connected environments are not only able to send data but, via advances in Artificial Intelligence, they can also 'talk' to us. This is both exciting and concerning at the same time - exciting as it opens up human-like conversation with devices in our environment (imagine talking to a park bench), but concerning as 'rogue' devices could be deployed to gather information from the unsuspecting public at large.



Figure 5. Creature in situ

The creatures were each loaded with information about the place they 'lived'. For example, Rosi the Bee (the creatures were all named and painted by children living near the Park) was placed at the bottom of the ArcelorMittal Orbit, and knew all sorts of facts about it, like how tall it is, who designed it, where it was made, and so on. However, the creatures wouldn't just tell you what they knew: they wanted to exchange information with you so they learned more. If you gave them a memory or a fact about the place the creature lived, they would then tell you something they knew about it, or something someone else had told them.



Figure 6. Chatbot interface

The creatures were very up-front about what they were doing: people were told that the creatures were learning things from them, and that anything they told them would be shared with someone else. In this way, storytelling and secret-sharing were used as a way to help people to understand how networked devices might work in ways that you might not always expect. In a world where environments are becoming connected, the devices that populate them won't be like the devices we see today. They will have personalities, and will talk and converse with us. As an extension of the work done on Tales of the Park, the authors of this Little Book are about to launch a series of Talking Trees on Hampstead Heath, London. The Internet of Trees will converse about their history and the park, the environment they're in, and remember what people say to them. Our connected environments are about to change, considerably.

# The Internet of School Things

Building a foundation for the future and an understanding of all the aspects of building, living in and using connected environments needs to start at an early age. The Internet of School Things project (funded by Innovate UK) offered every school in the UK the ability to measure and share data in a way that helped deliver the curriculum in a fun and accessible way, helped inform the design of the next generation of schools, and better prepared children to work within the digital economy. The project team worked with school children to co-design artefacts and objects in their schools that could then be used as blueprints for deployment in schools across the country.

Scientific measuring equipment in schools is not a novelty. From litmus paper to electric circuits, there are many forms of equipment used to teach the building blocks of science. The goal was to move such technology beyond the confines of the science lab into the broader school environment and to investigate the potential for whole school experimentation as a learning process. The internet of things design pattern provided a key enabling technology to facilitate that process.

The co-creation workshops with children to develop use cases for school prototypes surfaced many interesting avenues to explore, such as connecting drinking water supplies in the staff room to the boys toilets (via a sensor enabled reed bed for natural filtration) to interactive interfaces to capture the “mood” of the school throughout the year. Whilst connection to the curriculum was essential to support any deployment, the additional benefit of the data being created and shared highlighted the greater opportunity.

All schools teach about weather, and many will have a weather station in the school grounds or will make their own weather monitoring equipment. But when these devices are connected to the internet so that they can share their current measurements, the focus shifts from reporting the current conditions to exploring data from additional school stations across the country to support weather forecasting. This in turn led to an exploration of the variety of ways in which our climate can be monitored, such as the creation of a sensor that recorded when the cherry tree at the school entrance blossomed so that it could be compared with results across the country. In one school, children used live readings from a weather station in Rwanda

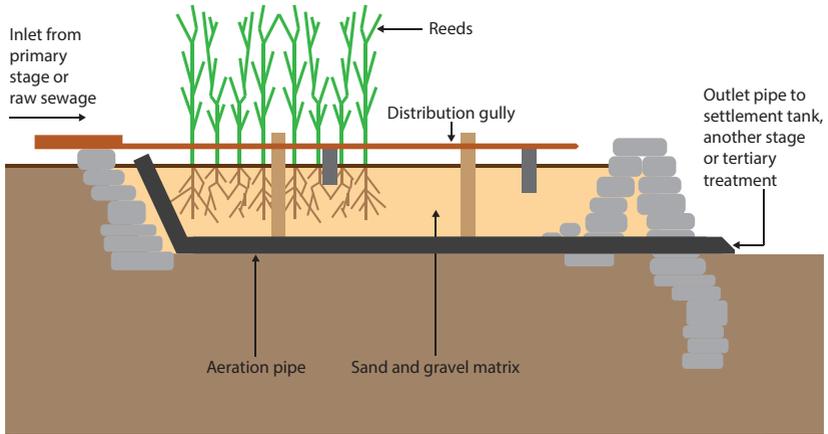


Figure 7. Reed bed

to grow orchids native to that country in the school greenhouse. Rather than relying on a theoretical model of the average climate in Rwanda, they could use live, real-time data to more accurately replicate the ideal growing conditions for their plants.

This notion of slow data - in the case of the cherry tree, one reading per year - provided an alternative view to the high velocity, high volume 'big data' championed by those commercialising IoT. For example, in another school project the children designed a '60 year clock' to reflect annual multi-generational activity across the school. The 60 year wheel was used to host an archive of objects by each year group from each school year. So, the object might be the most popular product of the year, or the favourite class song. The children were intrigued to know what their parents and grandparents would have submitted.

In one school the digital infrastructure was used to develop a programme of activity based on Air Quality readings at the school gate to nudge parents into considering alternative travel methods to the school, and potentially increase walking and cycling. In addition to the educational benefits, the initial installations also highlighted how the connected devices created new ways to engage with the broader school and local community.



Figure 8. Growing orchids in the greenhouse with data from Rwanda.

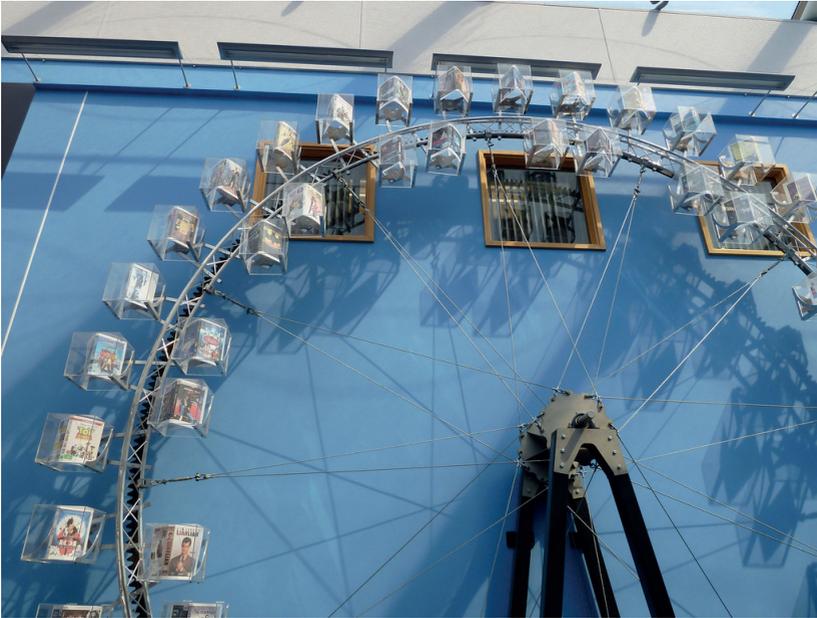


Figure 9. The 60 year clock project

# Shazam for Bats

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 the “Shazam for Bats” project we explored bat activity as part of a Smart Sustainable District program, again in the Queen Elizabeth Olympic Park in London. Through a stakeholder engagement program we developed a network of 15 smart bat monitors and installed them across the park in different habitats, creating a connected environment for monitoring wildlife.



Figure 10. Queen Elizabeth Olympic Park

Each smart bat monitor – or Echo Box – works like a “Shazam” for bats. (Shazam is one of the world’s most popular apps, used by hundreds of millions of people each month to instantly identify music). Each monitor 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 and identifying the species most likely to have made each one.



Figure 11. Bat Box

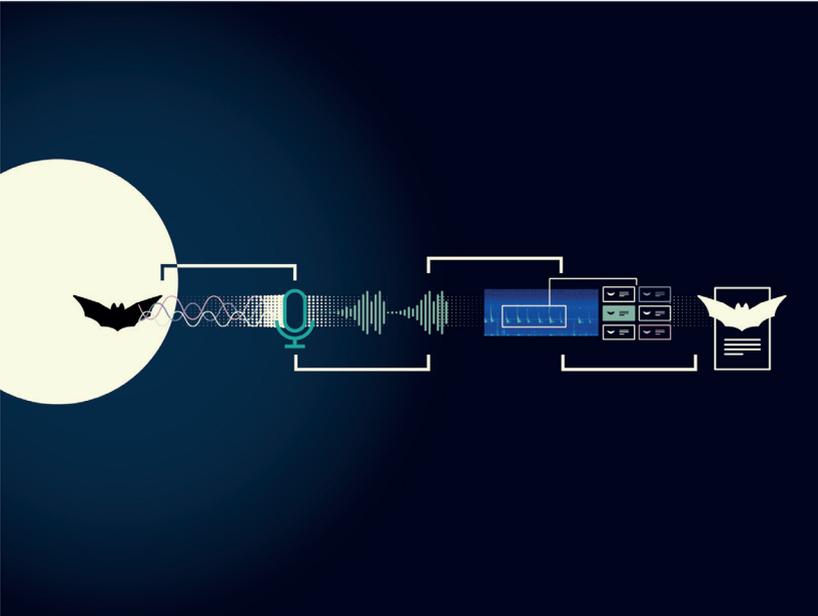


Figure 12. Data flow

Rather than sending all of this data to the cloud for processing, each device processed the data itself, removing the cost of sending large amounts of data over the wireless network. This 'Edge' processing has the benefit of being more efficient in the energy required to run the sensing device, and significantly reduces the data that needs to be handled by the researchers by processing it at source. During the one-year trial we observed a data reduction from 180Gb per day down to 2.2Mb per day: a factor of 8000.

Using IoT for this type of continuous longitudinal monitoring presented a different kind of data to the researchers, and was complementary to their normal expert surveys. Rather than having to spend time either in the field doing manual classifications or analyzing large volumes of audio data in the lab, the continuous processing approach has allowed them to identify seasonal shifts in activity and variations due to weather. The network of devices also supported the park ecologists in testing the impact of different operational scenarios on the park, such as impact of street lighting strategies, and communication of this activity to locals and park visitors.



Figure 13. People on night survey

Measuring bat activity in the Queen Elizabeth Olympic Park provided a very interesting real-world use case that involved large amounts of sensor data. There are still many challenges to delivering artificial intelligence at

the edge of an IoT network, including computing with energy and resource constraints. The challenge of maintaining infrastructure and operational devices is still in an emergent phase, but the benefit of longitudinal data in creating new ways of observing our environment during periods that are hard for researchers to study points to new opportunities for environmental monitoring.

## Mirror Worlds and Digital Twins

At its heart the concept of Connected Environments is based around a Digital Twin - a digital representation of the physical world, with the addition of data, collected from anything from building systems through to social and environmental feeds that can be viewed and acted upon. They are like looking at a mirror of our world, a mirror that not only reflects the environment but also displays the invisible: the flows of data. These of course are represented on a display, currently the most common being the computer screen, tablet or mobile phone. However, screens are changing and systems such as Virtual Reality and, perhaps with even more potential, mixed reality, will allow us to see these mirror worlds within our actual environment, or as a model city with data overlaid. At different scales, data and reality can be mixed, viewed and shared.

Given the pace of technology, the creation of Digital Twins is inevitable, allowing the digitalisation of our world and thus opening up the benefits of viewing and aggregating data in a spatial context. Indeed, the recent report 'Data for the public good' by the UK's National Infrastructure Commission (NIC)<sup>10</sup> proposed the creation of a 'Digital Twin' to unify the management of data concerning transport, rail, power, water and communications infrastructures alongside meteorology and demographics across the whole of the UK. One such example is the linking of environmental data with a three dimensional model of the Here East building at the Queen Elizabeth Olympic Park. Carried out by Oliver Dawkins, a PhD student at The Bartlett Centre for Advanced Spatial Analysis and sponsored by the

<sup>10</sup> [Lihhttps://www.nic.org.uk/wp-content/uploads/Data-for-the-Public-Good-NIC-Report.pdf](https://www.nic.org.uk/wp-content/uploads/Data-for-the-Public-Good-NIC-Report.pdf)



Ordnance Survey. Oly installed sensors and linked the digital feeds back to a 3D model with updates in realtime, twinning the worlds.

The coupling of a physical system with its digital representation allows any relevant change of state in the physical system to be detected, and triggers a flow of data that causes a corresponding change in the state of its digital counterpart. New information generated by the Digital Twin can then be fed back into the physical system through direct actuation or through visualisation for users who may intervene.<sup>11</sup>



Figure 15. Sensors

Digital Twins are able to hold a mirror to data and thus allow us to see our connected environments in direct context. They allow us to move away from numbers and computer code into a form that is understandable to people who aren't data scientists. This is important as data

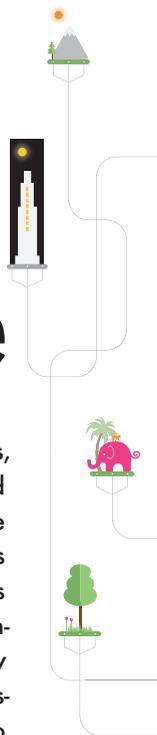
<sup>11</sup> Living with a Digital Twin: Operational management and engagement using IoT and Mixed Realities at UCL's Here East Campus on the Queen Elizabeth Olympic Park. Available from: [https://www.researchgate.net/publication/324702983\\_Living\\_with\\_a\\_Digital\\_Twin\\_Operational\\_management\\_and\\_engagement\\_using\\_IoT\\_and\\_Mixed\\_Realities\\_at\\_UCL's\\_Here\\_East\\_Campus\\_on\\_the\\_Queen\\_Elizabeth\\_Olympic\\_Park](https://www.researchgate.net/publication/324702983_Living_with_a_Digital_Twin_Operational_management_and_engagement_using_IoT_and_Mixed_Realities_at_UCL's_Here_East_Campus_on_the_Queen_Elizabeth_Olympic_Park)



Figure 16. Model

needs to be available and easy to understand by decision makers, and those on the ground who are operating the systems. From the public at home through to managers in offices and commercial buildings, emergency services in public spaces, through to local councils and upward to City Mayors and politicians at a national level, all need to see, understand and use data linked to our connected environment.

# State of Play and the Future



Though the connected environment includes buildings; bats, IoT creatures, gnomes, orchids, and trees might not be the first things that spring to mind when you hear the phrase ‘Smart City’. Normally, one might expect the focus to be on infrastructure: ‘smart’ lampposts, rubbish bins, autonomous vehicles and other arguably unimaginative IoT devices. Yet it is the objects hidden in plain sight that hold the true potential of the connected environment, enabling the world around us to sense itself as it becomes digitally enabled. As issues around power and networking become less of a question, computational devices are about to be everywhere. Small and easy to deploy, as we noted, the number of IoT devices in the wild is about to top 75 billion by 2025<sup>12</sup> - opening up both opportunities for understanding the world in which we live but also presenting threats to our privacy and issues around which devices to trust. It will reach a point of saturation, where almost everything will have a computer chip and be able to connect to a network.

Though the potential is immense, not everything will be useful, and many things will be either insecure, untrustworthy, a threat to our personal privacy, pointless, or indeed all of the above. Perhaps not the most pleasant term but the phrase ‘the Internet of Shit’<sup>13</sup> is widely used to describe such devices - and there are many. It is here where standards, kite marks for security and

<sup>12</sup> Statista.com, Number of Connected Devices World Wide (2018), <https://www.statista.com/statistics/471264/iot-number-of-connected-devices-worldwide/>, accessed November 2018.

<sup>13</sup> Internet of Shit <https://twitter.com/internetofshit?lang=en>, accessed November 2018. Some great examples from this Twitter account include IoT thermostats that leave your house cold unless you pay the monthly subscription (<https://twitter.com/internetofshit/status/1059939831558627328>), a coffee mug that requires software updates (<https://twitter.com/garywhitta/status/937044861215051777>), and Phillips’ magnificent architecture diagram for their smart lightbulb system (<https://twitter.com/internetofshit/status/986006653605687296>).

trust, public-facing advice on how and when to trust devices, are especially needed. Yet amongst the masses of incoming devices there is such potential to move into a new era of the science and develop a deeper understanding of our environment. With a push to not always do the norm, to be cross-disciplinary, to be brave and collect data where data has not been collected before, the new world of connected environments is the one that will create the Smart Cities, the Smart Homes and impact our everyday lives. From health care, transport, wellbeing, empathy, social understanding, environmental impact, climate change, economics and beyond the linking of location, data, quality control and spatial analysis links back to the breakthrough of John Snow, but now networked, joined, connected with Artificial Intelligence on the Edge.

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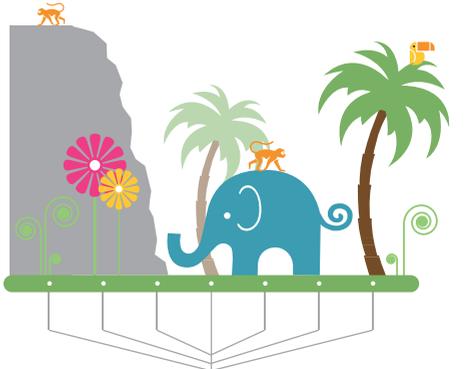
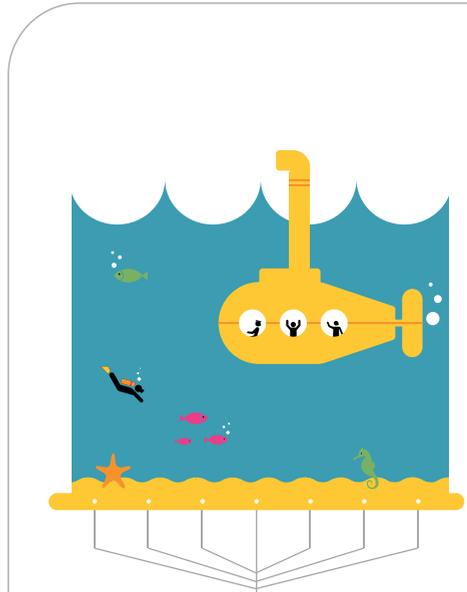
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Living with a Digital Twin: Operational management and engagement using IoT and Mixed Realities at UCL's Here East Campus on the Queen Elizabeth Olympic Park. Available from: [https://www.researchgate.net/publication/324702983\\_Living\\_with\\_a\\_Digital\\_Twin\\_Operational\\_management\\_and\\_engagement\\_using\\_IoT\\_and\\_Mixed\\_Realities\\_at\\_UCL's\\_Here\\_East\\_Campus\\_on\\_the\\_Queen\\_Elizabeth\\_Olympic\\_Park](https://www.researchgate.net/publication/324702983_Living_with_a_Digital_Twin_Operational_management_and_engagement_using_IoT_and_Mixed_Realities_at_UCL's_Here_East_Campus_on_the_Queen_Elizabeth_Olympic_Park)

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