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Urban Computing in the Wild: A Survey on Large Scale Participation and Citizen Engagement with Ubiquitous Computing, Cyber Physical Systems, and Internet of Things

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Abstract

With today's ubiquitous computing technologies, our daily activities are continuously traced by smartphones in our pockets and more of our everyday things are now connected to the Internet. This phenomena is changing the way we live, work, and interact. This creates, not only technological opportunities for smarter cities, but also interactional opportunities for the citizens. However, designing, developing, and deploying urban computing projects in the wild, outside the controlled research environment, is challenging, due to the complexity of the urban context as well as the people who live in it. What are the ways to trigger and increase the public towards active participation or technological uptake in urban computing? How to design and structure participation for urban computing research and technologies in the wild for it to lead to mass participation with its citizens? These are the questions that are investigated in this paper. We present a survey on existing approaches in engaging participations and devising interactions with a range of existing urban computing technologies: smartphones, public displays, cyber physical systems (including those with embedded systems, sensors, and actuators), and Internet of Things. Based on the reviews, we propose a taxonomy for categorising and characterising urban computing technologies and approaches with regards to the level of participation they stimulate, the participation scale they support, the manipulation and effects mode they enable, and the interaction mode and scale they enable. Finally, strategies for structuring and engendering participations and interactions based on our own experience from deploying small to large scale urban computing projects in the wild are presented in this paper.

Keywords

Urban computing, large-scale participation, cyber-physical systems, Internet of Things, smartphones, human in the loop, public displays, urban probes, public spectacle, urban interventions, crowdsourcing, crowdsensing, ubiquitous computing.

1. INTRODUCTION

It has been long acknowledged that cities constitute wicked problems (Rittel and Webber 1973) born from their heterogeneity and diversity (in contrast to rural settings). Since cities are growing, entangled spaces, ever-changing and in motion, and since their value is largely derived from hyper-local and highly contextual uniqueness, they cannot be designed with a "one-size-fits all" or "one-system-adapts-to-all" policy. Cities are "living organisms" (Foth 2009) with real-time "bits" (Mitchell 1996) flowing in their vein. Taking the analogy of the human body, the "cells" and "lifeblood" of cities are urban dwellers (Foth 2009) who introduce the complexity of "human fuzziness" (Foth 2009). However, most research in the field of urban computing regards "the city" to be homogenous and generic (Williams and Dourish 2006). Urban computing research needs to acknowledge that cities are *complex*, *dynamic*, and *messy*.

With recent trends and development of low-cost sensors, miniaturization of computing and electronics, actuation and control systems, nanotechnology, and wireless communication, there are emerging research areas in urban computing with overlapping themes and challenges. These technologies enable urban computing research to be deployed *in the wild*, in the real context of cities as the living laboratory, situated within public spaces, facilitating open interactions with individuals, groups, and communities.

1.1.Urban computing technologies and challenges for user participation

We live in the *ubiquitous computing* era, once envisioned by Mark Weiser as the time when computers are everywhere and start to disappear as they become part of everyday objects (Weiser 1999). With the rapidly increasing uptake of smartphones, human population will soon be outnumbered by the proliferation of these devices. Hence, *mobile and pervasive computing* research has become a prominent area in the last decade with multiple research challenges to address, such as accurate indoor and outdoor localization of users, context-aware computing and middleware, location-based services, mobile services, cloud and service computing, quality of service, security, privacy, and personalization. Another genre of technology that has become pervasive, particularly in urban environment, is *public displays or urban screens*, which is used mainly for communication, aesthetics, or marketing purposes. The active research into public displays (e.g. Reeves et al 2005; Memarovic et al 2012a, 2012b) suggests a rich variety of user engagement, interaction, and experience types with public displays, and these can be further investigated for application in urban computing in general.

Given the increasing sophistication of sensing, actuation, communication, and control, the *Internet of Things (IoT)* envisions a world of "smarts", with smart devices, smartphones, smart cars, smart homes, and smart cities (Stankovic 2013). Gartner (2013) predicts an era of *Internet of Everything (IoE)* by 2020, when more than 30 billion devices of a great variety will be connected and in use in daily life, an exponential growth from 2.5 billion connected devices in 2009, of which are mainly PCs, smartphones and tablets.

In the future era of IoE, there will be more highly-dimensional, high-volume data generated and exchanged by heterogeneous devices. How will our interaction with such a system look like in the times of IoE? Will citizens and visitors be more likely to participate in such a system in a larger scale? Will users be more accommodating in sharing their personal data?

The most recent research area that emerges is *Cyber-Physical Systems (CPS)*, which is interested in enabling physical world to merge with the virtual by integrating computation and physical processes (Lee 2008). However, research into cyber-physical systems are focused mainly on control and automation, through devising embedded and realtime systems, and distributed sensor network (Rajkumar 2010).

In an urban setting immersed with technologies and smart devices, the design of products, services, and applications often are driven by technological opportunities rather than the underlying needs. Stankovic (2013) describes the need for understanding the role and process of human in the loop in the era of Internet of Things, however the descriptions on research challenges are more fitting to systems that require humans' intervention to devise and exert controls. Schirner et al (2013) proposes a Human-in-the-Loop Cyber-Physical-Systems scenario where humans' intents, inferred from brain and body sensor networks attached to users, are fed directly into sensors and actuators in physical world, enabling automatic system adaptation to the users' needs. In this scenario, humans need to be instrumented and be an integral part of the system. This is a scenario that is still far from realisation and far from desirable, since individuals and the public's willingness to participate is still a major issue, and it is not discussed by Schirner et al (2013).

Most of real-world applications of urban computing involve people, and therefore require a comprehensive understanding of having all types of humans in the loop and all participation types. However, in this current age of IoT, when cities are becoming more *instrumented, interconnected,* and *intelligent* (Harrision et al, 2010) and people carry more sensors in their pocket than ever in the past, user participation on systemic and application levels decreases. This is because there are more apps, systems, and services being offered, that not only deplete user attention but also designed to reduce user interaction to bare minimums. For example, in some apps, clicking a single 'complaint' button constitutes the entire participation. (Morozov 2013).

Urban computing research should not focus only on solving the technical problems and challenges, but also on wider challenges requiring transdisciplinary inputs from computer science, engineering and technology, health science and medicine, social science and anthropology, architecture and design, urban design and planning, arts disciplines, and policy makers. In that way, urban computing would not merely aim to solve challenges of technologies in urban spaces, but rather it would explore a "*wider gamut of urban lives, from personal to the social, from the solitary to the crowd, emphasizing connectivity to celebrate the disconnect, from promoting passivity to inspiring activism, curiousity, and wonderment*" (Paulos et al 2008).

1.2. Interactional opportunities

Physical constraints and technological challenges in urban computing are not just issues requiring solutions, but can be regarded as factors and parameters that allow opportunities for participation (Hornecker et al. 2006) and serendipitous interactions and impacts to occur and be experienced by human in the loop. Bassoli et al (2007) argued that most research effort in urban computing has been directed to solve the issues of disconnection, dislocation, and disruption. Disconnection is addressed with mechanisms to provide "anytime, anywhere" access to information. Dislocation deals with accurate localization and indoor or outdoor positioning. Disruption is addressed by adopting context-awareness in the middle layer, that changes in the environment will be sensed and appropriated by the app or services. Thom-Santelli (2007) argued that the development of mobile social apps, although they could be used to facilitate serendipity, have instead been mainly focused on encouraging homogeneity, such as by looking for similar patterns in people's preferences and likings and promoting places through those similarities. Bassoli et al (2007) proposed that new generations of applications need to consider mobility in the city, not as an issue to be solved, but as the source of "*interactional opportunities*". This statement is true for many domain application areas, not only mobility, and for all technological spectrums of urban computing, not just in the context of mobile technology in cities. In this paper, the scope of discussion of urban computing is not only limited to smartphones, but also to sensors and computing capabilities embedded in the environment, city infrastructure, personal and corporate assets, smart homes, and our day-to-day devices.

In the light of both the technological context (Human-in-the-Loop Cyber-Physical-Systems) and the urban context (complex, heterogeneous environments) it's important to highlight that the potential for citizens' sense of disengagement and disenfranchisement, as a result of technologies that remove their direct agency and capacity to make creative decisions, tends to be regarded as an externality that remains unaccounted for in such systems. Urban computing needs to take a whole different angle and paradigm because while living in cities citizens currently have no obvious way to give informed consent to the technological infrastructures and experiments that are put in place on their behalf. Much as environmental costs and the depletion of natural resources are now accounted for in economic assessment of the production of physical goods, so to should the citizen engagement be accounted for in the design, deployment, management, and maintenance of technological systems in cities.

In this paper, we define participation as engagement and interaction between people with existing technologies used in urban computing, including smartphones, public displays, cyber physical systems, and Internet of Things, with different level of engagement, as discussed further in Section 3. To engender large-scale participation, provocations are required. How does one encourage citizens to participate, engage, and interact with urban computing, and what benefits does such participation offer? What are the future directions in citizen activation and public engagement?

We perform a survey on existing interactive and participatory approaches in urban computing. Based on the review of literature and our own experience, we present a taxonomy of approaches in engendering public participation in urban computing research and practical projects to categorize existing technologies used in urban computing according to the level of participation they stimulate, the participation scale they support, the manipulation and effects mode they enable, the interaction mode and scale they enable.

We also present five strategies learnt from our own experience in designing, developing, deploying and evaluating several urban computing projects in the wild, spanning from interactive urban environments, ambient spaces, urban spectacles, citizen-centric IoT. The outlined conceptual framework for structuring participation can help urban computing researchers, designers and developers to consider multimodal interactions with a wider range of connected *"things"* and ways to provoke large-scale participations in urban computing including where the incentive to participate may sometimes be seen paradoxical.

2. RELATED WORK

Several special issues on urban computing (Kindberg, Chalmers, Paulos 2007; Shklovski & Chang 2006; Dave 2007) confirmed that this area of research is thriving. The most recent survey on urban computing (Zheng et al 2014) focuses more on reviewing the technical challenges in dealing with big data from urban computing, mainly from smartphones and urban sensors (e.g. from taxis), and suggests the four major approaches required in practical urban computing projects, which are urban sensing, data management, knowledge fusion across heterogeneous data, and data visualization

(Zheng et al 2014), and it does not cover the issues and challenges of public participation and human interaction with such systems.

Although there is limited work that describes how one could design or structure individuals and community participation with urban computing, there are efforts in promoting participation in urban computing.

Reeves et al (2005) presented a taxonomy to classify public interfaces according to whether the extent of manipulations of the interface by the performers and effects experienced by the spectators are *"hidden, partially hidden/revealed, revealed, or amplified"*. The review was mainly focused on interactive installations and staged public performances. According to Reeves et al (2005), the spectator's view can be designed by revealing or hiding manipulations and effects. Reeves' categorization on manipulations and effects will be used to define one section in our taxonomy.

Memarovic et al (2012a) discussed a conceptual framework (Memarovic et al 2012a, 2012b) utilising public displays to stimulate three levels of engagement at public spaces that bring appeal to people: *passive engagement, active engagement and discovery* (Memarovic et al 2012a). Passive engagement is defined as a state when people observe from afar, or when short interactions occur, either through a couple of button presses or when people stop and read the content of the display. Active engagement occurs when people actively read the content of the display and start interacting with the display significantly longer. During active engagement, often social triangulation, a social interaction that spark a conversation between strangers about the display, occurs (Memarovic et al 2012a). Discovery takes place when people are highly stimulated by the content and information in the display that they start learning and appreciating the contents delivered to them. The three levels of engagement described are relevant mainly to public display research. Since our paper will cover multiple technologies used in urban computing, the three levels of engagement is not entirely applicable.

Hespanhol and Tomitsch (2012) reviewed methods for designing collective participation in public spaces with electronic art installations on their interaction goals (type of interaction, audience expectations, participation, and mediation) and content strategies (type of interaction, focal point, mapping of feedback, medium integration, tangibility, and situatedness).

The concept of shared encounters is introduced by Fischer and Hornecker (2012) in analysing the spatial configuration of public spaces, i.e. plaza, in relation to the structure of interaction with architectural sized media facades. Different types of spaces in shared encounters with urban intervention using media facades are identified: display spaces, interaction space, potential interaction space, gap spaces, social interaction spaces, comfort spaces, and activation spaces.

To our knowledge, there is no existing review on participation and general interaction strategies for engaging individuals and communities with different urban computing technologies and systems that are already deployed. The next section will investigate existing approaches in engaging user participation in urban computing projects and present a taxonomy that categorize them based on the existing technologies used in urban computing.

3. URBAN COMPUTING TECHNOLOGIES REVISITED

In this section, we focus on reviewing technologies that have been widely used in urban computing projects: smartphones, public displays, cyber physical systems, and Internet of Things.

3.1. Smartphones

Smartphones have evolved from being merely a communication device to a versatile companion device with multiple features that people in cities can no longer leave their home without one. Today's smartphones are packed with increasing computational processing capabilities and multiple sensors that can be used to monitor physical activities, ambient temperature and humidity, barometric pressure, health status, movements, and other ambient and environmental conditions surrounding the users. Therefore, location-based services, recommender systems, and "smart" services and apps that are personalised and contextualised to the users are the attributes that distinguish smartphones from feature phones (low-end mobile phones with limited capabilities). In addition, high definition smartphone displays have made this technology far more usable for users' information and entertainment needs. The display technology, combined with high quality front and back cameras and photo sharing apps, enable more digital images and videos to be captured and distributed rapidly. All these features, along with high speed mobile data network, makes a smartphone user to be a strong candidate participant for urban computing projects, as they can be engaged in various activities, such as data collection initiatives, reviewing urban information on the personal smartphone display, gathering crowdsourced feedback, or discovering other users and their physical environment in a cyber-physical social network (White et al. 2010, Ganti et al. 2008).

3.2. Public displays, urban screens, and media facades

These three have been used as a medium for communication and information and content delivery in public spaces. They are typically a screen-based display, made using LED technology or similar. The main difference between the three are the size and the placement of the screens, and also the type of content. Public displays is the most generic term. It can refer to small or large sized screens that are placed indoor (e.g. in a shopping mall) or outdoor (e.g. at tourist attractions, transit hubs), for public viewing and usage, and often are interactive to support information browsing and searching activities. Public displays has also been used to denote a sub-research area in ubiquitous computing. Urban screens are typically much larger, and situated as part of the architectural landscape (North et al. 2013), e.g. in a plaza or city square, and is used not only for information presentation, but also for broadcasting cultural, entertainment, and sport event coverage, and also advertising. Most urban screens are not interactive. Media facades are attached to or integrated with existing buildings, and become the second "skin" or outer layer to the building surface, hence, media facades may not be 2D or flat, as it is composed of an array of LED lights or screens, and can be considerably larger in comparison to general public displays and urban screens. Media facades are mainly used for advertising, branding, and/or aesthetics purposes. In this research, we are only interested in public displays, urban screens, and media facades that are interactive or allow user interaction with them. Therefore, throughout this paper, we refer to the interactive version of the three types of screen-based displays as *interactive public displays*.

3.3. Cyber physical systems

Cyber physical systems (CPS) bridge the physical world with the virtual (Lee 2008), enabling rich interactions between the two worlds through sensing and actuation (Wu et al. 2011). CPS originates in manufacturing industry, with industrial robots programmed to sense their environment and actuate according to the programmed responses. CPS has now been applied to many areas, including health care, intelligent transportation systems, rescue system, surveillance and monitoring, and many more.

Using open source microelectronics, such as Arduino, and their companion sensors, actuators, and interface components (LED lights, physical buttons, graphic displays) that can be connected to the main board, people can build their own CPS and sense their physical environment and control electronic appliances easier programmatically. Arduino is the first disruptive technology in the open source microelectronic markets, and ever since, there are many other companies that produce similar technologies, including Raspberry Pi and .NET Gadgeteer. The low cost of Arduino and the likes, easy to use Integrated Development Environment (IDE), and the open source community, with members sharing codes and know-how for deploying interactive electronics has enabled increasing number of urban computing projects involving urban sensing, electronic art installations, and interactive urban interventions.

3.4. Internet of Things (IoT)

IoT refers to uniquely identified computing devices that are connected to the internet and embedded into everyday objects (or “things) or attached to animal or people. In the early days, Radio Frequency Identification (RFID) is the minimum necessity for things to be considered as part of the IoT ecosystem (Atzori et al 2010), hence RFID was considered as the first enabler of IoT. RFID has used for identification, mapping, and localization purposes (Hahnel et al 2014). However, nowadays, IoT systems connect devices through many other communication protocols and wireless technology, including Near Field Communication (NFC) (Want 2011), WiFi, and ZigBee, which is also used for device localization (e.g. Salim et al. 2014).

The main difference of IoT and CPS is the focus. IoT focuses on connectivity of devices to the Internet infrastructure, whereas CPS focuses on sensing and actuation capabilities of devices to achieve certain goals on a particular domain application. For CPS systems to work, they do not need to be connected to the Internet, e.g. a closed loop robotic system in a plant, a smart grid system in a local area. Nowadays, these terms are often used interchangeably, especially in cases where IoT systems do not just embed digital identifier to devices, but also sensors and actuators, and when the devices are connected online and networked to each other.

The uptake of open source microelectronics kit, such as Arduino and the like, as discussed in 3.1.3, has also strengthened the growth of IoT systems. Due to the growth of Arduino and its open source community, more IoT-ready kits based on Arduino or similar technologies have been produced, for example, Air Quality Egg (http://airqualityegg.com/), SmartThings (http://www.smartthings.com/), Ninja Block (https://ninjablocks.com/), and are available directly to public. This leads to more citizens using and deploying IoT systems themselves, to monitor their homes, gardens, etc. This is the key difference between IoT and wireless sensor networks (WSN). The design, development, and deployment of WSN, e.g. motes (Mainwaring et al 2002), is managed by expert engineers and computer scientists, whereas, IoT has been deployed by people, experts and non-experts alike. Therefore, IoT can encompass WSN, but not otherwise.

4. REVIEW OF PARTICIPATORY AND INTERACTIVE APPROACHES IN URBAN COMPUTING AND TAXONOMY OF THEIR CHARACTERISTICS

In this section, we focus on reviewing approaches that have been used for engaging the public to use and interact with urban computing projects, using the technologies discussed in Section 3, with examples from literatures, as shown in 4.1, 4.2, 4.3, and 4.6. When the approach is newly defined and specific examples from literatures are limited, we substantiate the definition with examples from our own experience deploying urban computing projects in the wild, as shown in 4.4, 4.5, and 4.6. Finally, we propose our taxonomy in the last subsection.

With the wide spectrum of technological advances and multiple research frontiers in this arena, there also exist several different terms that describe public participation with different types of technology in urban computing. We use the following terminologies, some are popular terms taken from existing literature, to describe initiatives for engaging many users and public to interact and engage with urban computing: *mobile crowdsourcing and crowdsensing, urban probes, interactive public displays, interactive and participatory urban interventions, urban spectacles*, and *public IoT,* to encompass larger scale participation and crowd scale interaction with ubiquitous computing and Internet of Things in an urban context.

4.1. Crowdsourcing and Crowdsensing

Crowdsourcing was coined in 2006 by Jeff Howe (2006), who defined it as an act of outsourcing the tasks of developing new technology or application to the crowd through an open call. Using location services in smartphones, users can discover nearby places of interests and services, which can either be suggested by the application provider, or other users. In mobile crowdsourcing, the most common method of participation is to share information associated with a place or a geolocation (Hamilton et al. 2011). Among the most popular apps in iOS and Android stores are those populated with crowdsourced user generated content (Salim et al. 2010). Examples of these are Foursquare, Yelp, and Trip Advisor, where people collectively build a global database of Places of Interests (POIs) in different cities, or Waze, where traffic incidents are reported. People contribute to crowdsourcing activities because they collectively benefit from the information that are being shared, or they know they can get something done when they get their act together, e.g. Fix My Street, a site to report, view, or discuss local problems (such as graffiti, broken road surface, pothole, or street lighting).

With mobile crowdsourcing, the main information being shared is user knowledge and opinion, along with location as the only sensor information. In addition to GPS and connectivity data (WiFi and Bluetooth) that are used for localization, today's smartphones are embedded with physical motion sensors (i.e. accelerometers, gyroscopes, magnetometer), environmental sensors (i.e. temperature and humidity sensors, barometer). As a result, with many people carrying smartphones, large volumes of data related to human activities and their environment are produced daily. This evolution drives people-centric sensing research and has turned mobile phones into global mobile sensing devices, enabling thousands new personal, social, and public sensing applications (Campbell 2008). Citizens, collectively, can benefit from data from smartphone sensors. These data, if analysed and mined, could provide individual and community-based information about the trends and historic and emerging patterns of the city pulse, such as traffic congestion, mobility patterns, and environmental conditions.

The proliferation of smartphones leads to *mobile crowdsensing* (Ganti et al. 2011), which is categorised either as a *participatory sensing* or *opportunistic sensing.* In *participatory sensing*, as the name suggests, users willingly participate in submitting their sensor data in return for more sophisticated services they can receive from the collective statistical information mined from the data. The interaction mode occurs when users view the information being visualized. In opportunistic sensing, interaction with the app is minimal. The scale of participation in mobile crowdsensing could be on personal, group, or community level (Lane et al. 2010). *Personal sensing* is designed for individuals, such as to track for users' health and fitness goals. *Group sensing* is usually made for a group of friends or social networks to find each other and share sensing information. *Community sensing* occurs when there is a large group of mobile users participating in crowdsensing data from their smartphones (Lane et al. 2010) and which is sometimes a by-product of the main interaction. Waze is a popular app, with more than 50 million users worldwide. It combines crowdsourcing and crowdsensing together. Not only users can crowdsource traffic incidents and road conditions, but the app opportunistically gather users' movement to probe the traffic conditions, monitor congestion, and calculate travel time, and which at the same time aggregates location information of users to update the visualised information for all.

In mobile crowdsensing, to engage participation, the app needs to provide incentives for users to share the data. In other words, there should be a strong compelling reason or clear benefit experienced by users at the very first step, for them to be able to share their personal low-level data of their activities and ambient environment that can be monitored by sensors in their smartphones.

4.2. Urban Probes

Urban probes, coined by Paulos and Jenkins (2005), is a method to instrument urban artefacts to inspire the public to have a discussion about their urban landscapes. The idea is based on cultural probes (Gaver et al 1999) and technological probes (Hutchison 2003), but are situated on the street. This method helps researchers to gather qualitative data and responses from the public in relationship to daily urban life. Such probes help ethnographic study into understanding the use of technology in everyday's lives. This information could be used to inform the design of the appropriate urban intervention. The probes are designed to allow public or passers-by to have situated interactions with the urban probes.

The main difference between urban probes with interactive installations is that urban probes use daily urban artefacts (e.g. chair, table, light pole) and instrument them either with sensors, cameras, or display mechanisms to sense or gather feedback or responses. In (Paulos and Jenkins 2005), an everyday trashcan is instrumented with camera and projector to visualize the content of the trashcan is projected onto the street to provoke interactions with passers-by. Three methods of interaction where observed: active, passive, and mobile interaction with the trashcan (Paulos and Jenkins 2005).

An example where urban probes are used in large scale participatory civic project is Urban Mediaspace Aarhus project (Dalsgaard and Eriksson, 2013), where participatory design approaches are incorporated in the development of a large scale municipal infrastructure project, which include a new public library. In the early stage of this project, a range of participatory design activities were conducted using several urban probes. Firstly, in a design crits with collaborating partners to an open initiative, public are invited to record their voices on an interactive table. In later stage of the project, children and families are invited to experience interactive probes used for discovering the children library section and the related resources. In this project, participation is targeted towards a specific goal, which is to gather feedback and observations on the design and development of the infrastructure.

With urban probes, the scale of participation is limited to local community, as it is aimed to analyse citizens' situated interactions with daily urban artefacts, which are instrumented and monitored. It is also used to gather feedback on a particular civic issue.

4.3. Interactive Public Displays

Public displays are one of the enabling technologies for urban computing, used for communicating information directly to people in public spaces. However, for public displays to be engaging to end users, there needs to be some kind of reciprocal interaction. Kukka et al (2013) conducted a diary study that investigated people's attitudes towards technological changes in the city of Oulu and an ethnography study to understand people's engagement with interactive public displays. The diary study reveals the sceptical attitude to technological changes and overall negative tendency towards black screens with "brainwashing" content displayed to the masses (Kukka et al 2013). There is a tendency towards a negative perception with this type of "one-way" public displays. Kukka et al's prototype of an interactive white board (Kukka et al 2013) is more acceptable to the public, as it allows public to participate, and its evaluation proved successful in provoking curiosity and imagination of passers-by.

Vogel and Balakrishnan (2004) proposed an *interactive ambient public display* that allows both personal and public information to be communicated to users, and facilitates multi user interaction through implicit, explicit, public, and personal interaction with the public display.

Schroeter (2012) used urban screens to gather feedback from public on the issue of making their city a better place. Similarly, Hosio et al (2012) deployed Ubinion, a public display interface to gather feedback from local youth about municipal issues for submission to the city's youth affairs department.

Networked urban screens allow content sharing between multiple screens that are situated at different communities. For example, Fatah gen Schieck and Fan (2011) explored how connecting two remote locations with urban screens and interactive interface result in the following behaviours: urban encounters (walk up to the screen and interact briefly), shared encounters (passive observation of others learning about the screen), urban performance (observing and engaging with the screen and other observers onsite), playful encounters (engaging in a conversation with people across communities or different city), and magic moments (when playful encounters lead to meaningful conversations). These findings are similar and consistent with Fischer and Hornecker (2012)'s proposal on spatial aspects in designing shared encounters with media facades.

Screens in the Wild project, by North et al (2013), is another project exploring networked urban screens to analyse the tensions between the user-community and the technology and within the user-community itself and across different communities. In ScreenGram, multimodal interaction is enabled with users posting photos and submitting tweets on their smartphones or photos from Instagram, with specific hashtags, to change the content of the screen in front of them and the networked urban screens across communities (North et al. 2013).

The level of participation with interactive public displays range from individual to local community scale when non-networked, to global scale across communities when networked.

4.4. Interactive and Participatory Urban Interventions

City authorities and urban planning agencies often use arts and culture-related activities as a form of urban revitalization (Griffiths 1995). This initiative is often referred to as *urban intervention*, which is essentially an intervention that occurs at an urban context. Urban interventions always carry specific goals. Many existing forms of urban intervention do not involve elements of urban computing. In this paper, we refer specifically to urban interventions that are embedded with ubiquitous computing technologies.

Interactive urban interventions use a range of ubiquitous computing technologies to enable sensing, actuation, and interaction. Its main difference with interactive installations is in the presence of goals. For city authorities, urban designers and planners, the goal could be for behavioural change among the users, or for improving the built environment conditions. A series of interactive architecture projects are reviewed by Fox and Kemp (2009), however, many of these are designed mainly with aesthetic focus as a result of the integration between architecture, smart materials, and sensors and actuators. Interactive urban interventions can encompass interactive architecture and interactive art installations. However, the presence of a clear goal is the main characteristic that turns an interactive architecture or art installation to be an interactive and participatory intervention.

Interactive and participatory urban interventions can be deployed for smaller scale participation, for example at home or in an apartment block, or at a larger scale, e.g. in a public space or pedestrian areas.

With *participatory urban interventions*, participation is encouraged and is an integral part of the system design. The interaction effect may be hidden and delayed however, the manipulation is revealed or amplified (Reeves et al 2005). This means that this type of urban interventions provide a clear instruction for participants to manipulate the sensing and control features of the intervention, although the effect or impact of the manipulation may not be immediately seen. In contrast, *interactive urban intervention* usually employs hidden or partly revealed manipulation, but with revealed or amplified effects, to allow immediate feedback and continuous interactions (Reeves et al. 2005).

Since this is a term that we introduce in this paper, to further elaborate this idea, we present two interactive urban interventions: Responsive Resonance (Salim et al 2012), and Luminous Blanket (Khoo and Salim 2013) and a participatory urban intervention project: Natural Fuse (Haque Design+Research).

4.4.1. Responsive Resonance, 2012

Responsive Resonance (Salim et al, 2012) project was set out to transform a regular street in Melbourne, Australia with a kinetic canopy that responds to people's movement and proximity, interacting with them.

Prior to the intervention, we interviewed a number of pedestrians passing through the street and asked them what they thought about the current condition of the street and what if a responsive and kinetic canopy is installed on the same street. On the site that was considered "dead" (Figure 1) by a passerby, a group of students believed that this would "unconsciously draw a performance from people and as a flow-on effect, encourage and facilitate encounters and interaction between strangers". The city as it stood only offered a dystopic vision: a "decrease in person to person contact ... the breakdown of traditional relationships and an increasingly disconnected society … [the responsive model] would not be a grand statement on the larger city scale but seeks instead to be a small gesture addressing the larger issue of our Utopian fantasy, which is to bridge social disconnection and build stronger communities" (Salim et al 2012).

The project aimed to create an urban intervention that invites playful and performative social interaction by installing an interactive canopy that is able to interact with users or passersby using its random unchoreographed movements and colourful media display. Inspired by hand woven textiles, the canopy was made with flexible materials and actuated through a series of wheel-axle mechanisms, responding to movement sensors, enabling the canopy to undulate as pedestrians passed by (Figure 2). The installation provoked passersby to use, interact, and perform with the space, triggered conversations and helped create “accidental communities” around the site, that was otherwise “dead” with very little interactions.

Figure 1. The site, one of the main streets in Melbourne CBD, requiring interactive urban intervention (Credit: Victor Holder, Stephanie Farah, Phoebe Smith, Maya Grinberg, Flora Salim, Jane Burry, Jenny Underwood, Juliette Peers).

Figure 2. Passers-by interacting with Responsive Resonance (Credit: Victor Holder, Stephanie Farah, Phoebe Smith, Maya Grinberg, Flora Salim, Jane Burry, Jenny Underwood, Juliette Peers).

4.4.2. Luminous Blanket, 2013

Luminous Blanket is a sensory morphing skin that serves as a responsive intervention to revitalise an underused passageway (Khoo and Salim 2013). The development of Blanket involves investigation of a new lightweight synthetic material. *Lumina* is a soft kinetic material that is capable of sensing the ambient environment, morphing and changing forms, and emitting light (Khoo and Salim 2013), designed by Chin Koi Khoo in his explorations for new material system that embed sensing, processing, and actuation capabilities for applications in urban computing, particularly for morphing architectural building skins and organic user interfaces. The integration of materials with Nichrome wires, Shape Memory Alloys, glow pigments, and transparent silicone rubber brings together active and passive thermal and proximity sensing, lighting, and shape changing (Khoo et al 2011). The purpose of these selected materials is to use a passive and active design strategy to minimise energy usage for transformation and actuation processes.

Luminuous Blanket is a cylindrical envelope surface that is soft in its properties and performs responsive kinetic movements based on its responsive morphing system (Figure 3). The initial data collection prior to the installation reveals the potential for designing a responsive architectural intervention to revitalise the existing dull and dark conditions of the site. During the installation, Luminuous Blanket transforms the dark and underused passageway into a vibrant and bright interactive social space during the day and night.

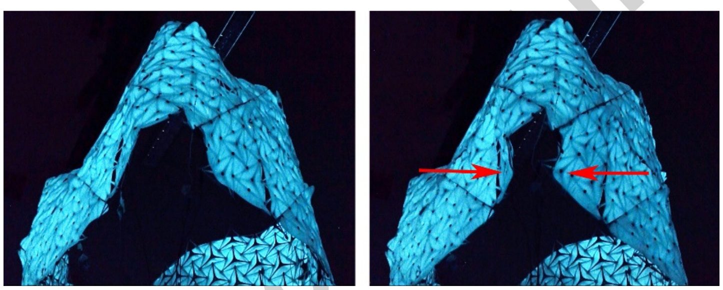

Figure 3.Partial skin of Luminuous Blanket contracts to respond to the proximity of moving object, as well as accommodating the object in the darker area by providing extra illumination (Credit: Chin Koi Khoo)

Luminuous Blanket responds to two stimuli of the site: pedestrian movement and light. Via its responsive morphing and illuminating capacities, Blanket attracts increased pedestrian movement, thus potentially rejuvenating the existing dark and quiet site condition to encourage more social activities and interactions (see Figure 4). The skin of Blanket also absorbs passive light energy during the day and performs morphing operation for tracking the daylight through the integrated responsive kinetic skeletons. The sensing skins of Blanket detect areas with higher lux levels, and the kinetic skeleton responds and morphs towards this area to absorb maximum light energy during the day. When the light level of the area is lower than 20 lux, Lumina illuminates the surrounding area without an external power source (Figure 5) (Khoo and Salim 2013). Luminuous Blanket is context-aware and adaptive to changes in the ambient light, hence is an example of calm technology (Weiser and Brown 1996).

Through proximity sensing, it creates reconfigurable lighting effects when human movement is detected. The atmosphere of the chosen site is revitalised through the performing lighting effects of Blanket to transform the existing environment into a dynamic place for social interaction.

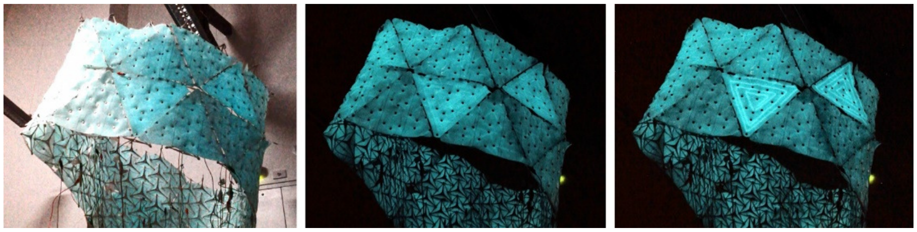

Figure 4. Passive and Active Illumination (Credit: Chin Koi Khoo)

User manipulation is hidden, through capacitive sensing (Khoo and Salim 2013), however the effects is amplified through shape shifting. When a user first approached Luminous Blanket, they can only perceive it as a light installation, but once they got closer and tried to reach to the installation, they often were surprised to discover that the surface deformed as they put their hands over it (Figure 5). This attracted people to interact with it and created social triangulation as defined in (Whyte 1980, Memarovic et al. 2012a).

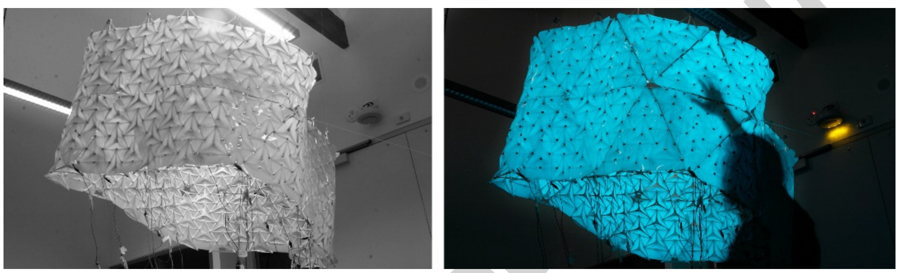

Figure 5. Proximity Sensing and User Interaction (Credit: Chin Koi Khoo)

4.4.3. Natural Fuse, 2009

Natural Fuse, a project by Haque Design+Research, is a micro-scale CO_2 monitoring and overload protection framework that works locally and globally, harnessing the carbon-sinking capabilities of plants. A power socket enables people to power or recharge their electrical appliances and devices while the plant's growth offsets the carbon footprint of the energy expended (Figure 6).

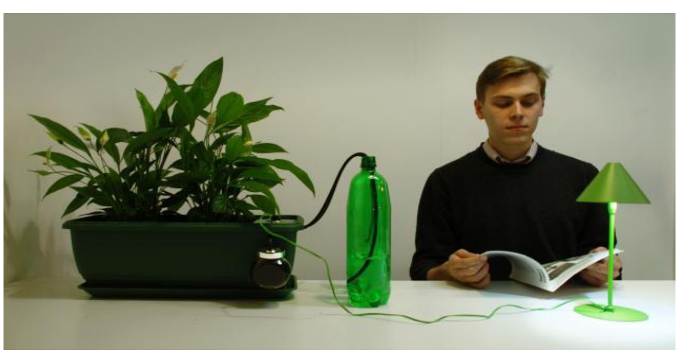

Figure 6. Recharging appliances through Natural Fuse (Credit: Haque Design + Research).

Since typical energy use requires more than one plant to offset an appliance's carbon footprint, Natural Fuses are networked so that unused carbon offsetting capacity in the network as a whole can be accounted for as necessary (Figure 7). Natural Fuses allow only a limited amount of energy to be expended in the system. That amount is balanced by the amount of CO2 that can be absorbed by the plants that are growing in the system. By networking them together, the units can "borrow" excess capacity from other units not currently being used in order to share their capacity and take advantage of carbon-sinking-surplus in the system as a whole, since it is likely that not all Natural Fuses will be in use at any one time.

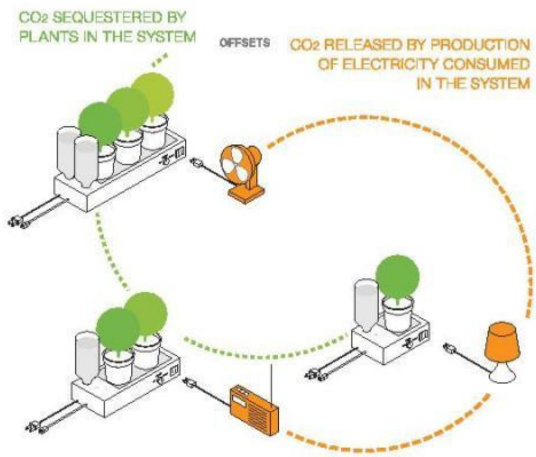

Figure 7. The interconnected Natural Fuse in an apartment block (Credit: Haque Design + Research).

Each participant is given a user manual on how to set this up in their homes. Each plant has a dial, which can be used to gauge the energy usage to one of the two modes: selfless and selfish. If people cooperate on energy expenditure and choose the selfless mode, they may only have less power usage allocated, but the plants thrive. Everyone may use more energy, while remaining carbon neutral. But if they people do not cooperate, the plants start to be killed, thus diminishing the network's electricity capacity as a whole (Figure 8). In Natural Fuse, the participation is mandated, and referring to Reeves et al. (2005), the method to manipulate of the "intervention" is revealed, through the use of the dial and the user manual.

Figure 8. The plant system is connected to the network with ‘selfless’ and ‘selfish’ mode (Credit: Haque Design + Research).

Natural Fuse has been experimented in households and galleries in New York, Incheon, San Sebastian, and Sydney. There were about 15 to 30 participants in each city who brought the plant system to their home. The demo unit that was left in the shop/gallery was often put in "selfish" mode. This was intended as such since when there was no specific owner of a unit, or where people could use the unit anonymously, there was more tendency to unfavourable use.

4.5. Urban Spectacles

Public installations, designed as artistic expressions or for aesthetic purpose, are often static, since many public installations are not designed for interaction. When public installations are designed to be participatory, citizens are given the affordance to influence and reconfigure the installations, often using collaborative means, at its most basic through rubbings shoulders with strangers. In this paper, we refer to this as *urban spectacles*, as the installations become the spectacles, and the individuals and groups interacting with the installations, influencing the behaviour of one another, also become part of the public spectacles (Reeves et al. 2005). Situated interaction with participatory public spectacles could grow to group-based interaction, to interacting with the crowd, which becomes part of the spectacles.

A strategy for designing a large scale interactive installation, such as for the interactive water installation (Pares et al 2005) in a theme park, is presented by (Parés and Parés, 2001). In theme parks, interactive installations need to deal with a massive flux of visitors, however it is still contained in a highly-engineered environment. However, to our knowledge, there is no existing research that presents the know-how for designing large scale interactive installations for mass participation of the public.

Two examples of participatory public spectacles projects, involving situated crowd interaction in a public place is presented in this section.

4.5.1. Open Burble, 2006

In Open Burble, designed by Haque Design+Research, members of the public come together to compose, assemble and control an immense rippling, glowing, bustling 'Burble' that sways in the evening sky, in response to the crowd interacting below. The massive structure, approximately 15 stories high, the form of which the public has themselves designed, exists at such a large scale that it is able to compete visually in an urban context with the skyscrapers that surround it (Figure 9). The Burble is constructed from a set of 140 modular and configurable carbon-fibre units approx. 2m in diameter. Each unit is supported by 7 extra-large helium balloons (for a total of about 1000 individual pixels) which contain sensors, LEDs and microcontrollers, enabling balloons and units to co-ordinate and create patterns of colour that ripple up towards the sky.

Just as the participants are the composers of the Burble's tall form, so too are they the ones to control it (Figure 10). They hold on to it using handles with which they may position the Burble as they like. They may curve in on themselves, or pull it in a straight line - the form is a combination of the crowd's desires and the impact of wind currents varying throughout the height of the Burble. As people on the ground shake and pump the handle bars of the Burble, they see their movements echoed as colours through the entire system. They see their own individual fragments, perhaps even identifying design choices they have made. Their individual contributions become an integral part of a spectacular, ephemeral experience many times their size that they have come together to produce. Part installation, part performance, the design and assembly by the public is as much a part of the project as the actual “flight time” of the Burble, as it enables people to contribute, at an urban scale, to a structure that occupies their city, albeit for only one night. Burble was deployed by the public in a city square in Singapore, Barcelona, London and Paris.

Figure 9. Open Burble (Credit: Haque Design + Research)

Figure 10. Crowd interaction with Open Burble (Credit: Haque Design + Research)

4.5.2. Marling, 2012.

In Marling, people become players on the urban stage, together bringing to life a large outdoor public space through their actions and sounds, and building a – sometimes indescribable – shared public memory of collaboration that lasts long after the event. Members of the public generate spectacular three-dimensional effects in an urban 'aurora' floating about a public square, using their voices to form a delicate, intricate ceiling of animated colour that hangs around and above the crowd (Figure 11).

Figure 11. Crowd interaction with Marling (Credit: Haque Design + Research)

Light patterns are generated based on sound input from a range of microphones, distributed to capture sound coming from different directions. The patterns are projected into puffs of fog that are created by machines that are positioned according to wind patterns of the given space.

As people traversed through the square, they started experimenting with their voices – some shouted, a few were singing and tried making harmonies with the echoes of their voices. In this project, the participant is a spectator, a performer, and a collaborator.

4.6. Public IoT

Although tools and technologies for Internet of Things have proliferated, the question is how to facilitate a forum for exchanging ideas, initiatives, data, and knowledge about connecting our personal and public environments and sharing local tacit knowledge about local community? *Public Internet of Things (IoT)* is an open public initiative for sharing realtime IoT data, distributing knowledge and ideas for IoT projects, and promoting large-scale participation in citizen-led initiatives from the ground up. Public IoT includes initiatives supporting citizen science (Paulos, Honicky, and Hooker, 2008) through making Internet of Things accessible to non-expert users.

We propose this term, Public IoT, since there is no fitting representation of the projects we have done that involve mass participants sensing the cities, and similar by others, that fit into existing terms. The closest term we can find that describes our intention is *participatory urbanism*, proposed by Paulos, Honicky, and Hooker (2008), as an approach to support the idea of citizen science, where public participation is critical to contribute to knowledge sharing through interconnected personal sensing devices or artifacts. The enabling technology are mobile devices and self-deployed sensors, such as air quality sensors in the scenario presented in the paper. Participatory urbanism, in Paulos, Honicky, and Hooker (2008), however focuses only on the potential of affording individual citizen's participation through their mobile phones, with the project initiators being responsible for deployment of sensors through handpicking participants in the community. Participatory urbanism does not consider interactions with cyber physical systems or instrumented controls. The interaction in participatory urbanism is personal or direct interaction with the app, sensing devices, or IoT. The scale of participation with participatory urbanism could be at local community or city scale, as exemplified by the projects reviewed in Paulos, Honicky, and Hooker (2008). The word urbanism, according to Mirriam-Webster dictionary, is defined as "*the characteristic way of life of city dwellers*" and "*the study of the physical needs of urban societies*". Unlike urban interventions, Public IoT does not have clear goals in the beginning, apart from sharing data from urban sensing, and may not be intended to study the city dwellers and the societies, hence the terminology "urbanism" does not represent the projects reviewed in this section.

In Public IoT, users are interacting with data and digital representations of the physical objects connected to the cloud, either shared individually, or as a group. The participation scale in Public IoT could be as small as a group of users from the same home or neighbourhood, to communities of users from the same country or region, to global worldwide participation.

Two projects that exemplify Public IoT are presented in this section.

4.6.1. Pachube, 2008 - 2011

Pachube (initially founded by Haque Design+Research, acquired by LogMeIn Inc in 2011 and relaunched as Xively) was a platform for storing and sharing Internet of Things data from a variety of sensors and internet-connected devices (Figure 12), aimed at IoT early adopters and enthusiasts. Sensor data can be streamed in realtime and managed centrally on the cloud (Figure 13), with RESTful API to access the data, making it as one of the first sensor cloud *Platform-As-A-Service (PAAS)*. Some also lauded Pachube as an early enabler of *Web of Things*.

Pachube, as a Public IoT platform, promotes crowdsourcing initiatives. Crowdsourcing also increases dramatically the chances that someone else will extract value from the data, or to engage other users to do something useful. Some Pachube users commented "*I don't know why my data might be valuable, but I bet somebody else will be able to help figure that out*". "*This isn't supposed to supplant 'official' data, it's supposed to complement"*. Data is only of any use when it is considered valuable by someone. Crowdsourcing also has the benefit of increasing the quality of tools for making sense of that data.

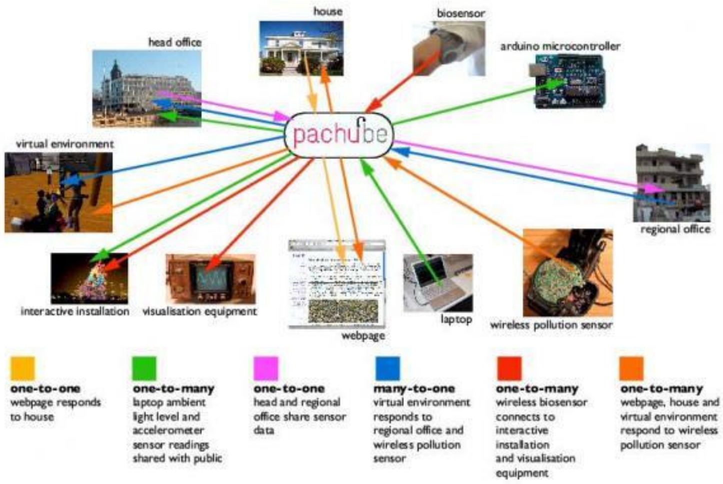

Figure 12. Pachube connectivity diagram (Credit: Haque Design + Research)

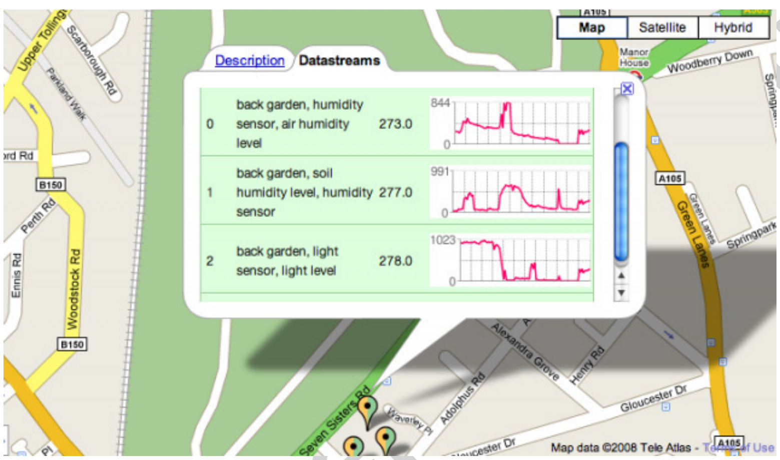

Figure 13. The realtime data streams on Pachube sensor cloud (Credit: Haque Design + Research)

It came into prominence in Japan following the radiation crisis at Fukushima, when Pachube was used by the Japanese community as one of the earliest aggregators of citizen contributed realtime radiation data (Figure 14), giving rise to a number of questions about the value of citizen-contributed data (high resolution, low calibration) in contrast to official datasets (low resolution, high calibration). The participation of this citizen-led initiative in producing and curating the data after the Japanese earthquake was country wide, with worldwide participation from users accessing, mashing up, and visualizing the data for the global community.

With the radiation data on Pachube in Japan, where there were sudden peak levels of radiation data appearing at different geolocations, all at slightly different times, one could infer the movement of wind pushing raised levels towards different areas at different speeds. Through a quick visualisation, end-user communities were able to see at a glance the differing radiation levels. So crowdsourced data gives you a much better picture, in more detail, of tendencies, changes, fluctuations, although the accuracy cannot be ascertained.

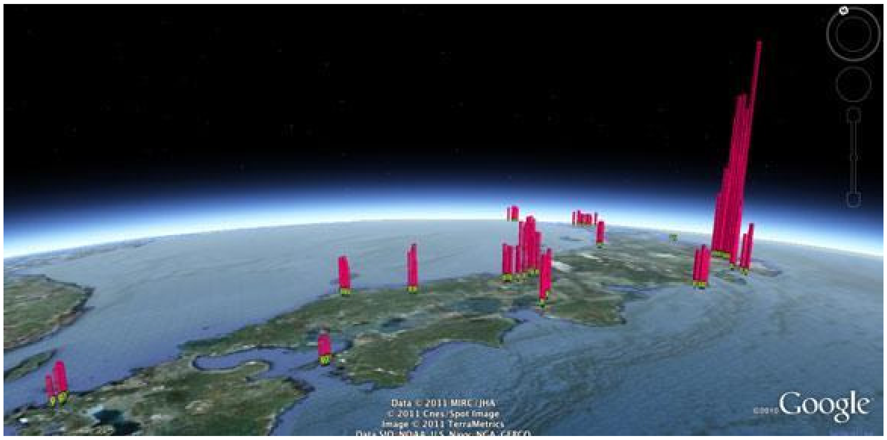

Figure 14. The radiation monitoring during Japanese earthquake, enabled by Pachube (Credit: Pachube community)

Since Pachube, there have been other similar platform launched, such as Smart Citizen Kit (https://smartcitizen.me/), however, unlike Pachube which is an online platform and cloud-based service for IoT that allows any types of IoT devices to be connected to, Smart Citizen Kit is mainly a sensing device based on Arduino microcontroller, prepackaged with several onboard sensors, and an online monitoring service that can only be connected to and used by Smart Citizen Kit devices and users.

4.6.2. Thingful, 2014

Thingful, a project by Umbrellium, is a search engine for the Public Internet of Things (Figure 15), providing a geographical index of where things are, who owns them, and how and why they are used. Today, millions of people and organisations around the world already have and use connected 'things', ranging from energy monitors, weather stations and pollution sensors to animal trackers, geiger counters and shipping containers. Many choose to, or would like to, make their data available to third parties – either directly as a public resource or channelled through apps and analytical tools. Thingful organises 'things' around locations and categories and structures ownership around Twitter profiles (which can be either people or organisations), enabling citizens to discuss why and how they are using their devices and data.

Explicitly built for people, communities, companies and cities that want to make the data from these 'things' available and useful to others, Thingful aggregates and indexes public information from some of the major IoT platforms and data infrastructures around the world, providing direct links to datasets and profile pages for the public things that it knows about.

Public open data is valuable and useful, but only if you know where to find it, and you know why, where and how the data was collected, as well as by whom. There are plenty of tools for building closed networks of connected sensors and devices, but the real value of open networks is founded upon their discoverability. In order for the Internet of Things to be truly transformative we believe that people need the tools to discuss, make sense of and share the data that their connected devices are generating. Thingful provides visibility to all those things out there (Figure 15), makes them more easily discovered and helps break down conventional IoT silos (structured according to industry vertical, device domain or data platform) that are an obstruction to the creation of a truly Public IoT that functions as a real public resource.

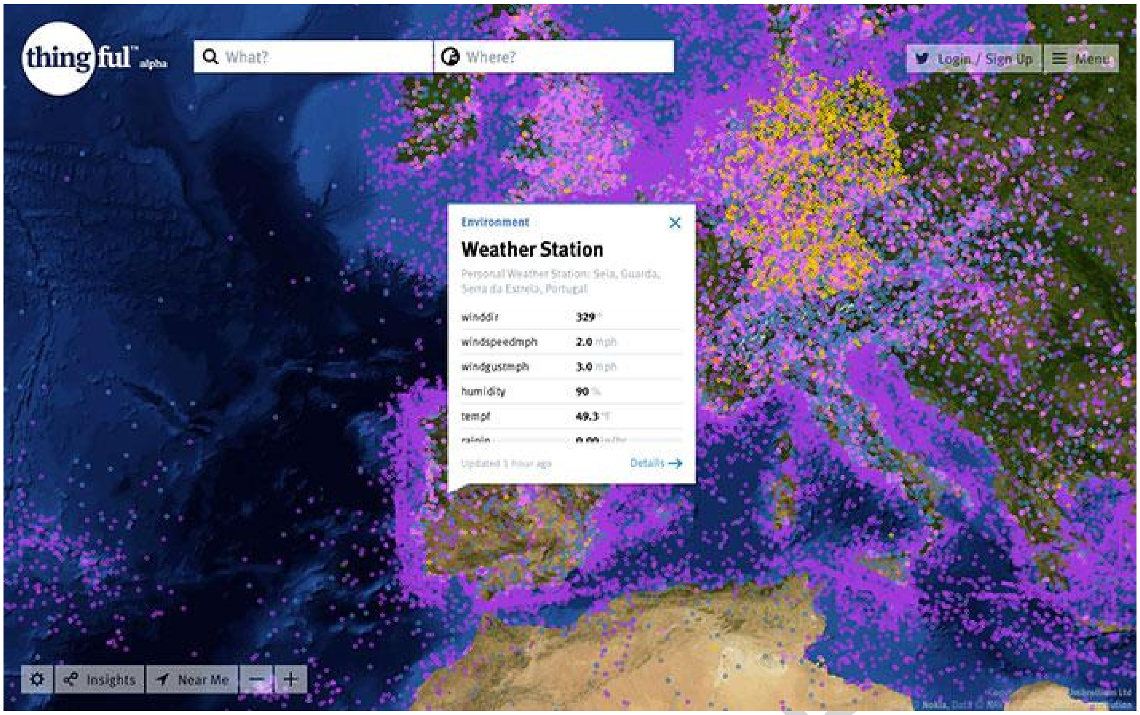

Figure 15. Thingful website (Credit: Umbrellium)

4.6. Taxonomy and Discussion

In this section, we present a taxonomy that describes the approaches for large-scale participations that arise from interactional opportunities with urban computing technologies based on the technologies used, the level of participation they stimulate, the participation scale they support, the manipulation and effects mode they enable, the interaction mode and scale they enable.

4.6.1. Level of participation

The lowest level (aware and consent) is where participants or users are fully aware of their involvement and provide their consent (e.g. for data provision) but their interaction with the system is minimal or passive. The next level (engaged) is where users are actively engaging with the system or involved in authoring their own experience through exploring the interactional opportunities with the system. The highest level of participation (collaborative) is where individuals' active participation provokes interactions with other users, and enable collaborative participation and interactions with the systems to generate an entirely new performer/spectator experience (Reeves et al. 2005). Or in the case of crowdsourcing and crowdsensing, the collaborative level is reached when users actively scavenge or hunt for more data and better data coverage in data collection activities.

4.6.2. Participation scale

The scale of participation can be gauged or measured at individual, group (a few individuals), local community, city, or global scale.

4.6.3. Manipulations and effects

As proposed by Reeves et al (2005), manipulations and effects of interactive installations or systems can both be *hidden, partially hidden/revealed, revealed, or amplified*. Manipulations are hidden when ways or methods to interact or manipulate a system is discrete, whereas it is revealed when users can easily recognise the interface and how to use it. Effects are hidden when manipulations to the interface do not provide any or immediate feedback. Effects are revealed when changes directly occur and can be seen, heard, or experienced by the manipulators. Amplified means the manipulations or effects are exaggerated.

4.6.4. Interaction modes

The interaction with the deployed urban computing system can either be a private, situated, or public interaction. Private interaction means users interact with the systems individually, e.g. on their own smartphone screens, in their own private (or non-public) spaces, such as from home or work. Situated interaction means the interaction occur physically at an urban context where the urban computing system or intervention is situated, and other people at the site will be able to see the interaction. Public interaction means the interaction occurs at public realms, and other people will be able to witness the interaction either physically or digitally.

4.6.5. Interaction scale

The scale of interaction can be at personal, group, or crowd level. Personal interaction scale means users interact with the system and nobody else while interacting with the system. Group interaction scale means the interaction occurs with the system while other users are also interacting with the system. This allows social triangulation to occur. Crowd level interactions scale is when users interact with the system as part of a mass participation in a crowd.

Table 1 presents the taxonomy of urban computing research approaches, the enabling technologies, and their characteristics.

Table 1. Taxonomy of interaction and participation in urban computing

Technologies used	Crowd-sourcing	Crowd-sensing	Urban Probes	Interactive Public Displays	Interactive Urban Interventions	Participatory Urban Interventions	Urban Spectacles	Public IoT
Smartphones	X	X						X
Public Displays			X	X				
Cyber Physical Systems					X	X	X	
Internet of Things			X			X		X
Level of Participation	Crowd-sourcing	Crowd-sensing	Urban Probes	Interactive Public Displays	Interactive Urban Interventions	Participatory Urban Interventions	Urban Spectacles	Public IoT

Low (aware and consent)		X	X	X	X	X		
Medium (engaged)	X	X	X	X	X	X	X	X
High (collaborative)	X	X		X			X	X
Participation scale	Crowd-sourcing	Crowd-sensing	Urban Probes	Interactive Public Displays	Interactive Urban Interventions	Participatory Urban Interventions	Urban Spectacles	Public IoT
Individual				X	X	X		X
Group	X	X	X	X	X	X		X
Local	X	X	X	X	X		X	X
City	X	X					X	X
Global	X	X		X (if networked)				X
Manipulation	Crowd-sourcing	Crowd-sensing	Urban Probes	Interactive Public Displays	Interactive Urban Interventions	Participatory Urban Interventions	Urban Spectacles	Public IoT
Hidden		X	X		X			
Partially hidden		X			X		X	
Revealed	X	X		X		X	X	X
Amplified						X		
Effects	Crowd-sourcing	Crowd-sensing	Urban Probes	Interactive Public Displays	Interactive Urban Interventions	Participatory Urban Interventions	Urban Spectacles	Public IoT
Hidden						X		X
Partially hidden	X	X	X					X
Revealed	X	X	X	X	X			X
Amplified					X		X	
Interaction mode	Crowd-sourcing	Crowd-sensing	Urban Probes	Interactive Public Displays	Interactive Urban Interventions	Participatory Urban Interventions	Urban Spectacles	Public IoT
Private	X	X	X			X		
Situated	X	X	X	X	X		X	X
Public			X	X	X		X	X
Interaction scale	Crowd-sourcing	Crowd-sensing	Urban Probes	Interactive Public Displays	Interactive Urban Interventions	Participatory Urban Interventions	Urban Spectacles	Public IoT
Personal			X			X		
Group	X	X	X	X	X	X		
Crowd	X	X		X			X	X

This taxonomy can be used by designers, developers and researchers of urban computing to explore several different configurations in their projects that can be enabled to achieve different participation and interaction characteristics.

Upon reflecting through these projects, further, we have constructed a five-step strategy for structuring large-scale participation in urban computing. The framework consists of five steps that need to be performed while designing urban computing projects that are aimed at large-scale participation. This is presented next.

5. HOW TO STRUCTURE PARTICIPATION: STRATEGIES AND LESSONS LEARNT

Our strategies for structuring large-scale participation in urban computing projects consists of five steps:

1. Identify needs and dilemmas
2. identify stakeholders
3. identify incentives
4. gather evidence and experience
5. provide tools and affordance

The method can be used for designing projects that require participation from a group of users. The steps are not necessarily sequential, they can run in parallel. The outcomes of each step can iteratively inform and influence the other steps in the process. This method has been iteratively evaluated through our experience conducting urban computing projects, such as those discussed in Section 4.

5.1. Step 1: Identify needs and dilemmas

The first step involves identifying needs and dilemmas. In any group of people there will be a number of apparently conflicting needs and desires and in order to foster participation it is important to understand where these conflicts might arise.

For example, in Karachi, a city well-known for its traffic congestion, most people agree that the traffic is a problem: it creates pollution, consumes energy and adds stress to every journey. Most people also agree that, if people just drove more carefully, everyone would benefit. So, if everyone agrees on both the goal and a means to achieve it, why don't they just do it? They don't because the first mover is the one who suffers the most. Whoever attempts to drive "better" is the one who gets stuck on the road as others take advantage of the gaps that this leaves. Even if you believe that altruistic behaviour is the "right" thing to do, it is unlikely (or even impossible) that everyone will believe the same thing at the same time, and therefore it is unlikely to succeed because each potential participant disbelieves that anyone else will participate. This dilemma (reflected in so-called "prisoner's dilemma") appears in deliberations concerning climate change as well: which ever country or company makes the first step towards ameliorating environmental conditions will be the one who takes on the most risk and will be (in the short term –and it's the short term that usually matters most to individual decision makers) most economically disadvantaged. Whether that risk is real or not is irrelevant: it is the perception of risk that prevents the action. Step one acknowledges this limitation, as you cannot rely on the end goal being incentive enough to encourage individuals to participate and cooperate on achieving the end goal, and proposes that dilemmas be accepted and planned for instead.

It is easier to attract participants and motivate them to increase their level of participations when the needs are greater than the dilemmas. A successful crowdsourcing and crowdsensing app such as Waze is an example where the need (to know the fastest way of getting from A to B without being stuck in traffic or delayed by incidents) is greater than the dilemma (of sharing personal sensing and mobility traces data). In this instance, meeting users' needs is the most significant priority, in order to get them to compromise with their dilemma.

5.2. Step 2: Identify stakeholders

Stakeholders tend to be those most affected by the dilemmas identified in Step 1 and identifying them involves understanding those most in need of incentives to participate.

Urban settings remain challenging for experimentation and deployment due to ownership and participation issues (Kindberg et al 2007). To place a sensor in a city, permissions from many stakeholders are often required. Participations in an urban setting is complex, as people are constantly entering and leaving urban spaces and sensors that capture their location or actions amass datasets that could potentially have many stakeholders claiming ownership.

Sherry Arnstein's theory on a ladder of citizen participation (Arnstein 1969) included eight levels of participation on the spectrum based on the relationships between powerholders and citizens, the mechanisms of participation employed by powerholders in engaging citizens, and the extent of citizens' power in determining end products. At the top of the ladder are three levels of citizen power, where citizens fully participate, provide decision making and managerial mechanisms. To some extent, the rise of social media has facilitated this level of citizen participation in a limited fashion. Through ICT-facilitated initiatives such as crowdsourcing, open government or gov2.0, and mobile apps, the role of citizens have changed from passive consumers to active producers of data and services (Linders 2012), although the ownership of that data remains a question. The popularity of social media platforms such as Twitter, which was first invented as a microblogging service, have facilitated serendipitous activities in citizen-led initiatives, such as the Arab Spring movement, and production of realtime data and sentiments, facilitating researchers to use data from Twitter for assessing natural disasters and incident prediction, monitoring, and management (Cameron et al 2012).

The identified dilemmas and stakeholders could lead to different provocation modes in urban computing. In the projects reviewed in Section 4, we found there are three provocation modes: *purposely-designed*, *opportunistic*, and *demand-led participation*. With purposely-designed participation, the designers of urban computing projects need to consider how potential users can be provoked to engage with the projects. An example of projects with purposely-designed participation is Responsive Resonance and Marling. In opportunistic participation, end users have some control in how they participate in the project, and see the opportunity to participate in a way that benefits them. An example of projects with opportunistic participation is Natural Fuse. In demand-led participation, such as in the Fukushima radiation monitoring project, enabled by Pachube, end users and community have full control to the crowdsourcing initiative, triggered by a specific demand and need in the community. In this case, it was the urgent need in knowing the status and emerging behaviours of the radiation in order to stay alive and well.

5.3. Step 3: Identify incentives

In almost all situations complete agreement cannot be found among stakeholders. A participatory system therefore needs to have intermediary, short term incentives from which participants can gain tangible benefits. This both provides motivation and helps build trust. By enabling participants to engage on a short term basis, it does not require them to commit to the end goal, as they can "opt out" easily after taking that first step. Not requiring commitment opens the door to much wider participation. Even better, it enables those who do take the first step to act as "evidence", to those who do not, that participation does actually result in tangible benefits (albeit short term).

Participatory systems should therefore be designed such that incremental participation results in incremental gains; they cannot depend on an “all or nothing” situation. If a proposition depends on everyone initially agreeing; if there is no possibility of movement before everyone has agreed to move; then the likelihood of any movement at all is significantly reduced. It is important to structure participation so that individuals may benefit immediately from participation in some small way, so that even if they decided not to participate further they will still have had some benefit. This gives them the trust that simply taking a step towards participation is beneficial. Even better is to design a system in such a way that the gains are logarithmically tied to the extent of participation; i.e. so that if three individuals participate, they each get more tangible “benefit” than if only two did. This is similar to the network effects that arise in online viral growth in services like Twitter.

Incentives become highly relevant when long term participation is required. Given the timescale, out of all the urban computing approaches in Section 4, mobile crowdsourcing and crowdsensing are the only ones that require long term participation. Devising incentive mechanisms for individuals to participate in mobile crowdsensing has been a recent research topic. Lee and Hoh (2010), Yang et al (2012) proposed models for devising monetary incentives for users to participate in mobile crowdsensing.

One popular method to incentivise smartphone users to contribute to crowdsourcing and crowdsensing activities is through gamification (e.g. Crowley et al 2012, Ueyama et al 2014, Das et al 2009). An important lesson can be learnt from the success and decline of Foursquare app, which was once one of the top apps in Apple and Google Play stores. Before mid 2014, users of Foursquare can "check-in" to places in the city, "shout" their status, and share tips about a place. If a place did not yet exist in the app, users can create new place, add tips about the place, and add it to existing categories (i.e. restaurant, entertainment, education, transportation infrastructure, shopping, and so on). Active and ongoing participation in crowdsourcing is successfully engendered given two main aspects of the app: gamification and location-based social networking. Foursquare employed a gamification approach where people who check-in and share tips have all kinds of rewards and badges and can advance them through the ranks, and make them become virtual “mayors” of the place. In a few places, mayors receive special offers physically from the shop owners (e.g. discounts, free drinks). However, most of the app users share their personal check-in data, tips and likes about a place, because they can “gamify” the system. Once Foursquare decided to move the gamification and social elements to another app, called Swarm, the download rate of Foursquare slumped (Bell 2014, Shontell 2014). This demonstrates that gamification as a form of incentivising users is a useful strategy to larger and longer participation.

5.4. Step 4: Gather evidence and experience

Difficulty in fostering cooperation comes from a lack of trust, and so the question is how to build that trust. Trust largely comes from evidence; and self-constructed evidence is the best of all because it doesn’t require second-hand knowledge. It also makes participants more directly aware of the issues and limitations of a system. In Public IoT, a platform to measure their environments is about helping find ways to engage with that environment, questioning the standards of evidence, partly in order to 'doublecheck' but also so as to understand what 'evidence' actually is. Measuring something means you start to understand better your capacity to affect the environment, but also understand what you can do to improve your own situation. If a participatory system relies on short term incentives, then evidence of those incentives, and evidence that those incentives will be gained, are most important of all. Therefore, often monetary gain is not a good incentive mechanism to sustain participation in the long term.

With large scale participations, the crowd itself could be an incentive enough to encourage participations from individuals. Crowd attracts participation, as exemplified in the scenario of herd behaviour in (Banarjee 1992). If there are two restaurants side-by-side, a potential diner who has never been to both restaurants will instinctively choose the restaurant that has more people in it, although this potential diner may have received an information that the other restaurant, that looks empty, is a good one. In the context of promoting large-scale participation in urban computing, if individuals can sense that they are part of a larger community, and their participation contributes to a better urban environment or society, the sense of ownership of a cause or initiative championed by "the crowd" can evoke the statesmanship and social responsibility from within and empower them to continue to participate. When ubiquitous computing is involved as elements of an urban intervention, it becomes interactive and situated, and triggers *social friction* (Jensen and Lenskjold 2004). Social friction occurs when people act and express themselves in ways that are out of the norm and surprising, as a result of social encounters (Jensen and Lenskjold 2004). When social friction is employed as a strategy, this can motivate active participation.

The experience of being part of the crowd, making experimental changes to the urban setting, is often found to be rewarding. The concepts of *familiar strangers* is introduced by Paulos and Goodman (2004), with reference to (Milgram 1972). As pointed out by Georg Simmel, "strangers' indifference gives city dwellers unprecedented freedom and autonomy to move about and develop as individuals". With daily encounters with familiar strangers, eg. people who share the same bus as you but you are not acquainted to the them in person, an urban intervention that could provoke playful interactions between these familiar strangers could evoke feelings of affinity or connections, and memories.

Situated experience with interactive urban intervention or participatory public spectacles could produce mnemotic narratives in participants' mind. Mnemonic narratives is "an urban application which is incorporated within the space around it can trigger memories which intertwine media and place in new ways" (Bassouli et al 2007), and menemotic narratives of in urban computing can be triggered by incorporating IoT and digital media with physical space . When designing urban computing projects for large scale participation, it is useful to consider how one reinterprets a space to a place of a social, cultural meaning that takes place in our memory (Dourish et al 2007).

The notion of sharing has also changed with the rise of social networks. Digital technologies allow footprints of experiences to be recorded, enacted, shared, and re-experienced. Experiences and sentiments could be easily shared through social media such as Facebook and Twitter. Recently, Instagram has become one of the most popular social media platform for sharing experiences that cannot be captured by words alone, as media and visuals takes the centre place. In cyber physical spaces, where parts of the cities around us have become more instrumented than ever, it is important to consider how sentiments and sensory experience with physical means and spaces, eg sharing my self-driving cars, can be facilitated to promote participation.

In a nutshell, potential participants require evidence of a rewarding experience and memories from other participants, and memory, experience, and shared experience can sustain participation in urban computing projects for longer than short-term incentives.

An example of this is in Burble project, one participant wrote in a web page "*Hey, that's my baby up there*". And there was a blog post about the project being "hers". This is an indication of deeper involvement and sense of ownership than usual.

5.5. Step 5: Provide Tools and Affordance

Gathering evidence requires tools for aggregating and assessing. Making such tools available to participants (rather than just presenting them with evidence) enables them to question the standards by which the evidence was amassed and enables them to gather the kind of evidence that they feel best answers their own questions. They are also more likely to formulate their own hypotheses around the need for participation.

Affordance in urban computing projects is one of the most crucial element of designing urban computing projects. What are the best ways to engage participants by giving them the "handle" (Norman 2002) to engage with the urban artefacts, interactive installation, or public spectacle? This handle could include ways and tools to experience, interact, participate, or contribute to the urban computing project.

So one of the most important tasks in designing and building a participatory system is to design and build the tools that enable intended-participants to construct their own evidentiary rationales for participating. Determining indicators for success is crucial because if people convince themselves that short-term participation is good for them then there is less need for large incentivisation schemes. For example if noise pollution is a dominant issue, providing some means for evaluating the noise level rather than just providing completed (and in many senses obscuring) datasets will foster deeper and more meaningful engagement. In this example, such a means might be technological (a sound level meter) or it might just be practical ("see whether you can be heard from across the street above the traffic noise").

Successful tools will continue to provide engagement through generating curiosity and satisfying curiosity (Bassoli et al 2007). Therefore, any IoT-based intervention needs to be creative, and tools for IoT needs to be open and flexible to allow serendipity outcomes and effects beyond the original intention of the design.

Urban computing can become agency for serendipity, when initiatives are made citizen-centric, and citizens are identified as the most important stakeholders. In this scenario, active production of data and knowledge about urban living (Bassouli et al 2007) can continuously occur, leading to shared community intelligence and new interactional opportunities and experience, not only in digital spaces, but also in physical spaces, public urban spaces, and the crossings between the cyber and physical - the augmented world. This will take place if citizens are able to access tools and datasets for making sense of and experiencing the city and sharing them with the crowd and community around them.

6. CONCLUSION

We have presented a taxonomy of urban computing, specifically addressing modes of user interaction, provocations, and scale of participation, in mobile crowdsensing, urban probes, participatory urbanism, interactive public display, and also in interactive urban intervention, participatory public spectacles, and citizen-centric IoT. The latter three categories are proposed in this paper since the projects reviewed in this paper employs IoT or cyber physical systems with participations at a larger scale and do not fit into the existing terms or categories. There are certainly overlaps between different categories, however, putting one project against one category that is more prominent can help the designers, clients, owners, and policy makers of urban computing to understand the technologies and tools that need to be employed, and the possible methods of interaction, and scalability of the participation.

This paper also presents the five-step strategies to structure participation in urban computing projects. The lessons learnt from designing interactive urban intervention, participatory public spectacles and citizen-centric IoT were presented in the discussion of the framework.

With interactive urban interventions, the dilemma becomes the basis for the projects, and therefore formulates the goal of the intervention at the outset. With urban spectacles, the evidence of rewarding experience and social encounters is the essential element. Future work includes devising projects that could integrate different possibilities across different categories, such as an interactive urban intervention that acts as a public spectacle, connected to the cloud, allowing global remote users to interact and participate with the crowd performing situated interactions with the responsive urban artefacts.

Future work in the area of Public IoT includes the capabilities and techniques for combining, analysing, and correlating 'official' and 'crowdsourced' data. It can be cascading, when people see others measuring what they need, then they want to get involved too, with concomitant network effects.

This paper has not included the review of interactive and participatory urban computing projects using recent and emerging wearable computing technologies, such as eyewear (e.g. Google glass) and activity trackers. This will be investigated and reviewed in our future work.

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Highlights

- We perform a survey on interactive and participatory approaches in urban computing projects
- We categorize existing technologies used in urban computing according to the level of participation they stimulate, the participation scale they support, the manipulation and effects mode they enable, the interaction mode and scale they enable.
- We present a taxonomy of approaches in engendering public participation in urban computing research and practical projects
- We present five-step strategies to help engendering participation in urban computing, derived from our experience with deploying urban computing projects in the wild.