Chapter 10
Live Urbanism – Towards Senseable Cities and Beyond

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Abstract In the context of ubiquitous information services, the city shall not only be seen as a place of social interactions, financial transactions, a network of technology nodes, a geographical agglomeration area or as a political landscape, but more as an actuated multidimensional conglomerate of heterogeneous processes, in which the citizens are the central component. In other words, the city can be regarded as a complex near real-time control system, creating a feedback loop between the city itself, the city management and the citizens, which is achieved by pervasive sensing

10.1 Introduction

"In the next century, planet earth will don an electronic skin. It will use the Internet as a scaffold to support and transmit its sensations. […] It consists of millions of embedded electronic measuring devices. […] These will probe and monitor cities and endangered species, the atmosphere, our ships, highways and fleets of trucks, our conversations, our bodies – even our dreams." (Gross, 1999)

Following this comprehensive vision by Neil Gross (1999), it can be assumed that sensor network deployments will increase dramatically within the coming years, as pervasive sensing has recently become feasible and affordable. This enriches knowledge about our environment with previously uncharted real-time information layers.

This chapter focuses on pervasive sensing with a particular focus on urban environments, which poses a variety of challenges – as well technical and technological ones, as socio-political and privacy-related ones. This distinguishes urban monitoring applications clearly from other, less central scenarios like for instance ice thickness monitoring in the Antarctica (Delin et al., 2003) or gravitational mass-movement tracking for change detection of alpine permafrost (Paulsen, 2008).

There are many current questions regarding the urban environment that require addressing with increasing urgency. For example air quality regulations are commonly based on concentrations at a few measuring stations within a city. However these are only a surrogate for the impact of air quality on a population that is continually moving through a concentration field varying in space and time. A more pervasive sensing network offers great possibilities in assessing the real impact and its real cost to the community.

However, as research on urban dynamics revolves around people per definition, the city as a functional context for pervasive sensing systems is highly relevant in terms of direct impact on the individual, an thus even more complex and greatly volatile.

10.2 Augmenting Research on Multi-layered City Dynamics

Projections stated that the wide-spread distribution of high-speed internet connections will render geographical distance irrelevant (Cairncross, 1997 and Borsch, 2009), and that cities are not more than mere artefacts of the industrial age (Gilder and Peters 1995). As a side effect, cities were presumed to drastically decrease in importance as physical and social connections, and would play an increasingly ancillary role in socio-technical research.

In reality, the world developed completely differently – cities are back. In fact, a United Nations (UN) report, which has been released before the World Population Day in 2007, states that for the first time in history, more people now live in cities than rural areas (United Nations Population Fund, 2007). Thus, cities in their multi-layered complexity in terms of social interactions, living space provision, infrastructure development and other crucial human factors of everyday life have re-gained importance in scientific research. This arises from the fact – amongst others – that major developments of scientific and technological innovation took place in the urban context (Dierig et al., 2000 and Netherlands Organization for Scientific Research, 2007).

Here, especially real-time monitoring of urban processes is widely unexplored and has recently received a lot of attention due to the fast rise of inexpensive pervasive sensor technologies, which made ubiquitous sensing feasible and enriches research on cities with uncharted up-to-date information layers.

The reason for this lack of experience is that ambient and continuous monitoring is an enormous challenge, and this is particularly true in the urban context, which poses very specific challenges. These comprise well-known technological questions, but also significant social and political ones, which are rapidly gaining importance.

Figure 1 illustrates the monitoring concept of a WikiCity, which interprets the city as a “control system”, where the objects connect the physical environment with the digital space.

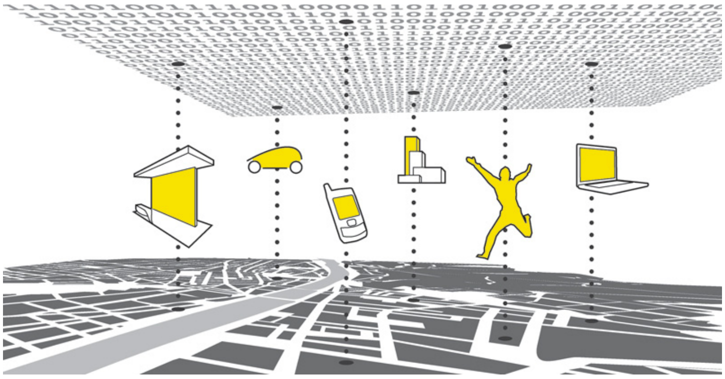

Figure 1: Urban Monitoring – the Connection between the Physical and the Digital World. (SENSEable City Lab, 2009)

This connection between the physical and the digital worlds illustrated Figure 1 can be established by ubiquitous sensor networks creating a digital representation of the real world. Consequently, these sensors introduce the possibility of a feedback loop – because sensor systems do not only view and analyse the city as a functional entity, but they can also influence urban processes in real-time, by coupling them with decision support mechanisms, location-based services (LBS) or other spatio-temporal technologies.

10.3 The "City" as a Functional Context

This presumes that the term "city" comprises not only a geographical area characterised by a dense accumulation of people or buildings in the context of pervasive urban sensing. More, it is a multi-layered construct containing multiple dimensions of social, technological and physical interconnections.

10.3.1 A Set of Complex Multifaceted Processes

Thus, as Zardini (2006) states, a variety of terms have emerged to describe the evolving urban environment, including virtual city, city of bits, event city, cyber city, global city, network city, or renewable city. Naturally, these terms depend on the specific viewpoint representing the complexity of the phenomena being observed and analysed.

Peter Hall (1966) tries to characterise this multi-dimensional complexity covering culture, politics, trade, communications infrastructure, finance, technology and universities. In more recent work, Hall and Pfeiffer (2000) state that a *liveable* city has many facets, which revolve around quality of life. These are living space, elementary infrastructure, traffic and land utilisation.

Manuel Castells (1996) pursues another approach describing a city to be “not a place but a process”. In this context, processes are considered the connections between centres in a global network. Consequently, Castells argues that places of operation are called nodes and hubs. Nodes are places where important functions are performed linking localities into the whole network. On the other hand, communication hubs are places coordinating interactions across the network. Castells concludes that the analysis of (global) cities yields the most direct illustration of the space of flows in nodes and hubs.

A similar but more economy-driven view is presented by Friedmann (1986), who states that cities are the basing points of capital, and the resulting linkages create a complex spatial hierarchy. In his interpretation, the hierarchy is formed by taking into account a number of city characteristics: the importance of the city as a finance centre, corporate headquarters, international institutions, business services, manufacturing, transportation, and population size.

A very energy-centred description of urban environments is done by Droege (2006). The author sees the common aspect of cities in their foundation as “creatures of their energy regimes”. Moreover, Droege asserts that a large part of global financial transactions, trade, command and control, and cultural production occur in and among cities.

Mitchell (1996) also lays out a multi-dimensional definition of the term city, which is strongly motivated by technology. He states that the future city will be unrooted to any definite geographic place on the surface of the earth, constrained by connectivity and bandwidth issues rather than by physical accessibility and land values, widely asynchronous in its operation. The inhabitants are not humans, but agents, which Mitchell describes as “collections of aliases and agents”.

Places in the “City of Bits” will be constituted virtually by pieces of software instead of physically, and they will be connected by logical inter-linkages rather than by doors, passageways and streets. He imagines that computer networks become as elementary to urban life as street systems. According to the author, memory and screen space will become the rare resource, like a sort of future real estate. In consequence of the technological predominance, much of the economic, social, political, and cultural action shifts into cyberspace.

10.3.2 Assessment of Urban Dynamics

Despite their diversity of approach, all of the above studies reveal how the cities, in which we live, have changed. There is not a single universal and common way of describing cities and urbanity, but ways of exploring the city have changed together with their inhabitants. This is one reason why people have become the new centre of interest, as stated by Zardini (2006).

From an investigative viewpoint, there is growing interest in the environmental and ecological issues within cities, especially sustainability and bio-diversity. This is mainly because of a more profound faith in the efficacy of the tools and methods of urban design and monitoring, which can foster the understanding and re-design of the urban environment (Zardini, 2006). Thus, an upcoming challenge is not barely a re-adjustment of the technical instruments, but rather a conceptual change: a shift happened from Bocconi's "city that rises" to the "landscape that advances" providing more possibilities in monitoring and re-designing a city, than just in building it up.

In this context, it is evident that some of the most innovative approaches of the last decades exceeded existing technical knowledge and competence to realise them at the time. However today, they seem not only relevant, but also feasible as informed real-time decisions transform both the atmosphere of cities and the hierarchy of our priorities on a daily basis. For example, we are already using mobile smart phones, ubiquitous personal information devices, to coordinate and adjust our plans on-the-fly and at a distance by receiving up-to-date information on our environment.

Summarising, the significance of the described definitions of the term city in the context of this book is that the city as a functional construct shall not only be seen as a place of social interactions, financial transactions, a network of technology nodes, a geographical agglomeration area or a political landscape, but more as an actuated multi-dimensional conglomerate of heterogeneous processes, in which the citizens are the central component. In other words, the city can be seen as a complex near real-time control system (Resch et al., 2008), creating a feedback loop between the city itself, the city management and the citizens, which is achieved by ubiquitous sensing of a variety of parameters.

10.4 Augmenting Human Senses

This also means that the sensorial dimension beyond the prevalence of the vision – acoustic, olfactory, touch and other senses – which have not yet been integrated into urban spaces, shall play an increasingly important role towards the development of "sensorial city planning". (Zardini, 2006)

This integration of additional senses is not only relevant for city planning, but also for city management. To obtain a complete picture of the processes in the city, it has to be experienced with all senses. The Live Geography approach presented by Resch et al. (2009) does not consider the term "senses" a solely human uniqueness, but also suggests the integration of non-human senses for experiencing the city.

10.4.1 Pervasive Urban Monitoring – The Technical View

From a technical viewpoint, pervasive urban sensing encompasses a wide range of diverse technologies. This involves sensors, communication infrastructure, data manipulation and analysis, sensor fusion, the creation of meaningful outputs, the provision of information in user-sensitive visualisations, and appropriate delivery structures.

Additionally, a key requirement for achieving meaningful analysis results in geo-processing systems is high quality of underlying data. Quality criteria for geospatial data comprise accuracy, completeness and topicality. While the first two parameters have traditionally received a lot of attention, the topicality parameter is still neglected in most cases. This is partly due to the fact that geo-data is per definition historic and so far, geospatial processing has focused on analysing static data, with low temporal fluctuations. (Resch et al., 2009)

Furthermore, an overarching aspect is that all components of measurement systems are currently undergoing both great performance enhancement combined with drastic price reduction (Paulsen and Riegger, 2006). This has led to the deployment of a number of geo-sensor networks. On the positive side the growing establishment of such networks will further decrease prices and improve component performance. This will particularly be so if the monitoring policies enforced by super-national directives move from a mathematical modelling base to a more pervasive monitoring structure. Thus, it can be assumed that sensor network deployments will increase dramatically within the coming decade – especially in cities.

This raises the issue that real-time integration of heterogeneous data sources will be of particular importance in urban environments as a broad spectrum of diverse actors establishes their systems, often measuring the same parameters. This evidently distinguishes urban monitoring applications clearly from other, less connected scenarios, as mentioned in the introductory section.

10.5 Spatio-temporal 4D-Analysis for Public Health

In deploying a real-world pilot we aimed to demonstrate the capabilites of a mobile sensor network. 10 bicycle mounted sensors were used in the city of Copenhagen, Denmark to collect environmental data (CO, NO_x, noise, air temperature and relative humidity) together with time and the geographic location using GPS – from which velocity and acceleration can be calculated. In this experiment of ubiquitous mobile sensing, we used the Sensaris City Senspod, a relatively low-cost sensing device. The deployment in Copenhagen was a combined effort of the MIT SENSEable City Laboratory, and Københavns Kommune, Denmark.

The first observation stemming from the data was the very extensive coverage obtained by just 10 sensors. Sensor information was obtained over a wide area (of order 50 km^2) with detailed spatio-temporal granularity. Substantial temporal and spatial variations were evident. The ability to determine the regions where several of the pollutants (including here noise, temperature, humidity as well as chemical pollutants) were all large allows for assessing the health impact of the environment as a whole rather than assessing individual contributors and assessing them individually. As a simple example of this we can expect that the chemical pollutants of NO_2 and CO might both be sourced from automobile, particularly in regions where the vehicles were accelerating away from an intersection. The same scenario would likely produce fine particulate matter – a pollutant of particular and growing concern – and be a major source for noise pollution of a predominantly unpleasant type. Any non-linearity of the impact of these pollutants individually and/or any enhanced impact due to the combined effect of exposure to multiple pollutants at the same time may produce significant amplification of the impact that may not be addressed when the pollutants are treated (in a regulatory context) one at a time. The use of pervasive sensing for multiple simultaneous pollutants with comprehensive coverage and detailed granularity will allow the assessment of the real impact on the population and the quick identification of "hot spots", an issue of topical current concern. Such information is probably essential for determining resource allocation from public health services for building remediation near hot spots.

Additionally the pilot experiment allowed for the determination of typical exposure over a period of time and as the sensor moves through space; exposure is often a more appropriate metric than point-wise concentrations averaged over a range of timescales. Using this methodology, cycle-based sensing with GPS positioning offers the possibility of producing a different "cut" through the state of the urban environment.

The developed analysis component performs a spatial Inverse Distance Weighting (IDW) interpolation on temperature measurements, which will be used in further research efforts for correlation operations with emission distribution or traffic emergence, and for the detection of urban heat islands. The basic heat map of the GPS traces and the output of the interpolation process – an interactive navigable map – are shown in Figure 2.

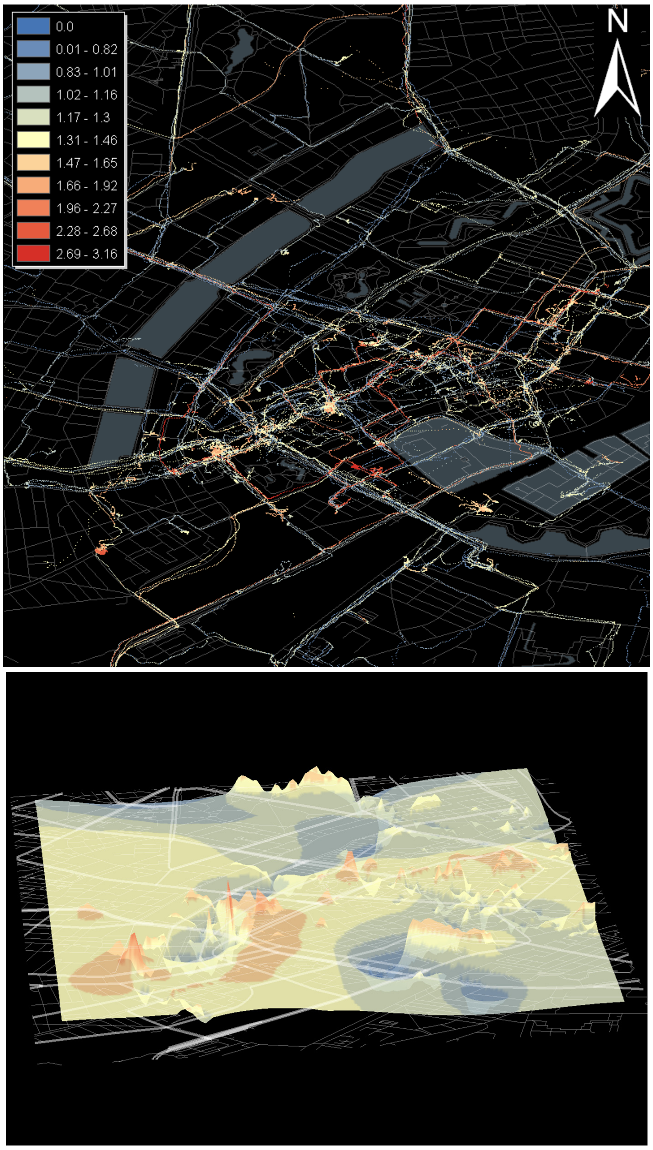

Figure 2: Spatial Distribution of CO Values in the City of Copenhagen.

Integrating real-time measurement data allows for performing a spatio-temporal analysis over a period of time. In order to achieve a coarse overview of pollutant variability, we used CO data captured by the mobile sensors mounted on bicycles as described above. This allows for correlating temporal measurement data fluctuation to traffic density, weather conditions or day-time related differences in a very flexible way.

Preliminary findings show that CO concentration is characterised by very high temporal and spatial fluctuations, which are induced by a variety of factors including temperature variability, time during the day, traffic emergence or weather conditions. However, the detailed interplay of these parameters still has to be investigated in a next step.

10.6 Discussion and Conclusion

In the context of ubiquitous information services, the city shall not only be seen as a place of social interactions, financial transactions, a network of technology nodes, a geographical agglomeration area or as a political landscape, but more as an actuated multi-dimensional conglomerate of heterogeneous processes, in which the citizens are the central component. In other words, the city can be regarded as a complex near real-time control system, creating a feedback loop between the city itself, the city management and the citizens, which is achieved by pervasive sensing.

This urban context poses many challenges to pervasive real-time monitoring: apart from well-known general monitoring challenges, very particular issues arise for geo-sensor network deployments in the city. These range from physical sensor mounting to social and privacy implications. Furthermore, the sensitive urban political landscape including heterogeneous interests of a variety of stakeholders has to be accounted for, which might cause unforeseen challenges.

Another central issue in deploying sensor networks in the city is the impact of fine-grained urban monitoring, as terms like “air quality” or “pollutant dispersion” are only surrogates for a much wider and more direct influence on people, such as life expectation, respiratory diseases or quality of life. Another example is the elevated temperatures that are to be found in urban areas when compared with more rural environments. This urban heat island impacts the community through health effects of elevated temperatures and the effects on energy required to reduce those temperatures. Again pervasive temperature sensing allows for a better understanding f the urban heat island and possible strategies for its mitigation e.g. green roofs.

This raises the demand of finding the right level of information provision. More accurate, finer-grained or more complete information might in many cases not necessarily be worthwhile having, as this could allow for drawing conclusions on a very small scale, in extreme cases even on the individual. This again could entail a dramatic impact in a very wide range of areas like health care, the insurance sector, housing markets or urban planning and management through the establishment of “senseable cities”.

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