Urban Pulse: The Application of Moving Sensor Networks in the Urban Environment: Strategies for Implementation and Implications for Landscape Design

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Abstract

The applications of environmental data for city design are many and varied, relying primarily on their accuracy, density, and frequency. The key factor limiting these aspects are feasibility and cost of implementation (LEE 2009). Drawing on previous research in the field of spatial sensor deployment, this paper seeks to propose strategies for the efficient deployment of low-cost moving sensor networks in urban spaces of the city. The resulting data has the potential to reveal not only the performance of typical ambient environment of urban areas, but also the nature of their flux and variation. The manner of this implementtation, relying on existing city infrastructures, implies direct applications for the realms of Landscape Architecture, Urban Design, and GeoDesign.

1 Introduction

Fundamental to this continued research is the aim to better understand the performance and function of our living environments. With more than half of the worlds population now living in cities (UN 2010), increasingly difficult challenges are faced in the generation of new cities, and entirely new strains are placed on existing and historical urban centres. As cities continue to transform, so do the climates in which they are situated, resulting in as yet unforeseeable constellations of built fabric and micro-climate, and the resulting development of new fields of study such as Urban Climate Resilience (FRIENDA 2013).

Sensing the city is by no means a new concept, with sensor data being collected for largely meteorological purposes for over a century. While there is a large amount of research into the effects and influence of urban planning regulations on the resulting micro-climate (YAHIA 2013), examples of the opposite influence are not as common, the likely reason being that sensor results tend to remain too local and anecdotal to effect large scale planning policy. The urban sensor research examples themselves demonstrate that the results tend to remain isolated and specific (MILLER 2013), as the density of the studies increase, such as the uScan project in Tokyo (ONO 2007). Nevertheless, field data could play a crucial role in the large-scale simulation of the built environment (CAMILET 2012).

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The main aspects mitigating widespread urban sensing are the expense in time and resources required, and the ability to collect readings over extended periods of time, in order to adjust for local meteorological fluctuations. Such a segmented, point-based data set can be useful to refine simulations, yet does not otherwise produce a coherent or nuanced image of the urban micro-climate (CAMILET 2012).

The general premise of this paper has been developed during the previous work by the research team in the field, where various modes of sensor-based networks were applied in varied urban contexts, such as Barcelona, Stockholm, Berlin, Zurich, and London. (FRAGUADA 2011, 2012). The common factors to these research methods were the reliance on low-cost, sensors, capable of extended prolonged periods of data capture, and the movement of these sensors to reduce the number of required sensors within a large scale environment.

The aim of this research paper is to propose the basis for a framework for an efficient, citywide data capture system, providing varied possibilities to further understand and improve living conditions and function in our cities.

2 Sensing the City: Data Generation and Application

2.1 Spatial sensing in urban and regional environments

This paper argues that a spatial and temporal awareness of our urban and regional environments are crucial for guiding future planning initiatives and understanding the impact of changing climates on the lives of inhabitants. For example, many European cities were designed and evolved through centuries with different climates than what we experience today (JOHNSON 2013). It follows that the planning of these cities should recognize pressures (both existing and new) on the built environment in order to understand how to adapt zoning as cities grow, or begin to merge with the industrial periphery. We qualify new pressures on the built environment as phenomenon that might have always existed as a result of urbanization, yet previously were either difficult to quantify (due to available data fidelity, cost of service, etc), or were not significantly noticeable as affecting the general comfort on a city (MOONEN 2012), such as urban heat island effect. Today, through the use of low energy sensor networks, these pressures can be quantified, visualized, and utilized in guiding the evolution of our built environments.

The form of data acquisition that is proposed in this paper is essentially a data, information, and knowledge machine; an applied experiment in progress. In such a system, the process of data collection characterises the nature of the data and the manner in which it can be applied. An idealized sensing system would be one where there is high data density, high data redundancy, verifiable data fidelity, and easy data accessibility. Still, opportunities for useful data acquisition do exist when compromises force a less than idealized system. For example, one could imagine a system where data accessibility would need to be compromised in order to achieve a higher data density or fidelity. Certain compromises in the overall sensor network architecture could yield systems where understanding data trends takes precedence over data fidelity and density.

2.2 Spatial applications

The data acquisition issues discussed previously should be guided by the eventual applications for which the data is intended. One of the basic premises of this paper is that large scale data collection should play a more significant role in the planning of urban spaces. That is not to say that data is entirely missing from the planning process. For example, building or infrastructure location and foundation will be guided by the data acquired from geological surveys dealing with soil composition, compaction, settlement, and density (U.S. D.O.D. 2005). In this previous example, where the domain under consideration has a specific timespan, well established mathematical models have been created which point to optimized conditions for a given structural load over time. Similarly established protocols derived from data analysis exist for many aspects of planning new buildings or urban extensions such as wind load calculations, right to light requirements, flood analysis, etc. In fact, we could say that zoning ordinances, masterplanning, and building construction codes are no more than a series of generalized guidelines that have been informed by the conclusions of data collection and analysis. Therefore, the data acquisition model proposed here is compatible with existing norms and serves to effectively increase the resolution allowing a more localized understanding of a given site. When appropriate, the very models of evaluation by which these norms are established should be challenged in order to ensure any new and relevant data is taken into account.

While it has been established that data does play a key role in the shaping of our urban spaces, the resolution and rate at which this data is evaluated in one issue of contention. Continuously evaluating ambient conditions which reinforce established norms has not always been feasible. Only recently have we seen the application of continuous data acquisition with respect to detecting building structural pathology (BARRO 2009) which recognizes that the established guidelines for designing building foundations are only relevant as a best practice at the time of designing, and not necessarily useful for understanding issues of maintenance on a built structure. Continuous data acquisition systems can also play a role in mediating the thermal comfort of a building after initial guidelines regarding climate zone considerations are taken into account in the design of heating and ventilation systems of a building. While the performance considerations between a building and an entire city differ, we feel there is adequate motivation for establishing a continuous evaluation methods for larger urban areas which are continuously affected by new developments.

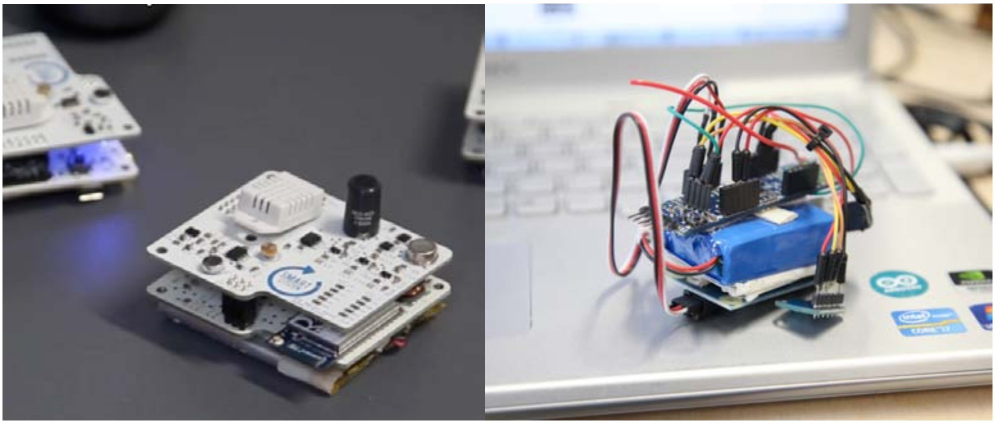


Fig. 1: Various sensor combinations from previous research, each based on specific considerations such as nature of sensor readings, weight, mobility, etc. Pictured are the pre-manufactured SmartCitizen and a custom JeeNode based sensor, both used in the SmartGeometry 2013 workshop (FRAGUADA 2013).

3 Transport Infrastructure as Urban Sensing Network

3.1 Sensing the Movement Network

In order to provide an alternative to municipalities considering a large regional deployment of sensor networks, we propose utilizing the existing public transportation infrastructure as a large scale sensing network. This proposal has a number of advantages over deploying static sensor nodes including:

- The necessity for a generally lower number of sensor nodes for covering a larger geographic region
- Public transport infrastructures already render the functional and geospatial morphology of a city, thus the sensors would be capturing data of the most utilized, densely populated areas of a city
- Public transportation infrastructure is typically a network topology optimized for reaching a wide distribution area in the most efficient manner
- Variable data density corresponds with human usage patterns and represents areas of high density as key components in intelligent space management

3.2 Strategies for Sensor Network Deployment

Utilizing public transportation infrastructures also facilitates typical issues related to large scale sensor network deployments such as the effort of installing distributed nodes. In the case of transportation infrastructures, vehicle depots could be leveraged in order to install and maintain a large number of nodes in a centralized location effectively lowering the overall cost of the system. In such a network deployment, a common set of sensors could be applied in any city (temperature, humidity, barometric pressure, sound, light intensity, etc) and a secondary set of sensors to understand localized phenomenon (such as CO and NO2 for combustion based air quality metrics, Dust and PM for health related metrics, radiation, etc). Communication could be leveraged from existing GSM, GPRS, 3G, or 4G networks already deployed within cities.

3.3 Implementation – practical considerations

In order to ensure accurate data readings at a dependable rate, we should consider phenomena which would affect the normal operation of the specified sensor node, both from previous research results (Figure 1), and from other documented sources. There exist several standards and guidelines for the design of the sensor node and enclosure, notably the Ingress Protection specifications as well as several military design manuals which tackle issues of interference, and weatherproofing. First, considerations of radio interference should be taken into account. While this should not affect the transmission of data over established telecommunication networks, radio interference or electromagnetic fields could affect the electronics and thus affect the quality or frequency of data captured. The inverse is also true, depending on the instrumentation, the sensor node could have adverse effects in the operation of surrounding electrical devices. The latter has been addressed in several regulatory documents including United States Department of Defense standard MIL-STD-461 (U.S.D.O.D., 2007), the United States Federal Communications Commission Title 47 Code of Federal Regulations Part 15 (U.S. F.C.C., 2012) and several other electromagnetic compatibility standards worldwide including EN61000 (E.P.S.M.A., 2010). Designing the sensor node enclosure should take into account the effects of vibration on the electronics and should attempt to dampen any vibration when possible.

Weatherproofing for the proposed instrumentation should adhere to Ingress Protection standards which ensures protection from dust and dirt, as well as significant protection against water ingress. Finally, the power source must be considered. It is recommended to power the sensor node from the vehicle to which it is mounted, with an optional rechargeable lithium-ion battery as a backup.

4 Case Study: Zurich

4.1 Zurich City, Transport, and Climate

The research case study reviews the issues and potential of integrating such a sensor network in the city of Zurich. While not exhaustive, the case study highlights the key technical issues and potentials. The city of Zurich was chosen as test case as it represents a city with both an historical centre and industrial outskirts, which are currently under redevelopment into residential areas, particularly in the former light-industrial and commercial areas of Kreis 4 and 5. Such developments carry many benefits to the local economy and urban diversity, yet potentially juxtapose urban spaces predominantly designed for industrial vehicles with increasingly large numbers of the local population. A newly revised tram and bus route ensures that these areas are nevertheless connected to the inner city, and to potential sensor access.

4.2 Sensing Zurich – Strategies

The local transport network of Zurich is a dense, well maintained combination of tram and bus routes, covering much of the CBD. The Tram network would be the focus of such a sensor proposal, for several key reasons, in addition to those mentioned in 3.2:

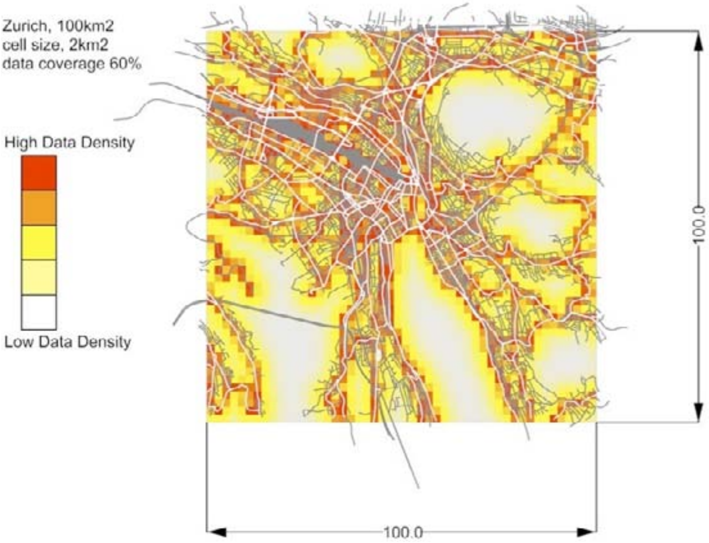
- Relatively reliable low impact of vehicular congestion
- Modern system which is relatively silent
- Trams tend to stay on certain routes, rather than being switched
- Multiple suitable locations for sensor attachment on roof or sides

There are currently around 290 trams in service during peak periods in the city of Zurich, on 15 tram routes, averaging to around 20 vehicles per route. Adding sensors to every second tram on a particular route would result in a data density of 15 minutes between readings at any particular point on the route, and sections of the route where trams share the route with other tram lines would further raise the frequency of data capture. The frequency of the sensor board data capture is more flexible, the minimum interval being in milliseconds, or determined by specific sensors (eg. many air sensors require a ‘warm-up’ phase before taking a reading), aside from issues of power consumption or longevity.

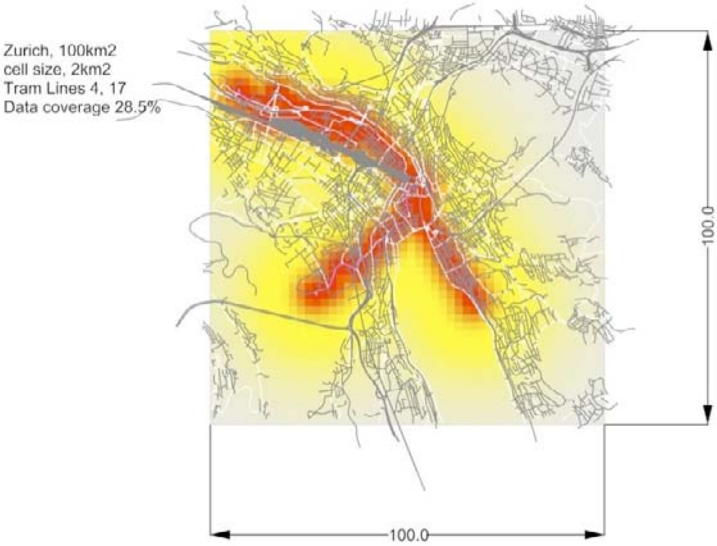
A proposed initial deployment on 2 intersecting tram lines (in the case of Zurich, trams 4 and 17 are proposed, due to their connecting role of the developing areas of Kreis 4 and 5) would provide a minimum test case, with a common storage depot and identical vehicle characteristics (Fig 2b).

4.3 Zurich – Sensible Future Development

The following figure (Fig. 2a) describes the potential data density that could be leveraged in the city of Zurich if a mobile sensor network were deployed on the public tram and bus infrastructure, on a fraction of the public transport stock. In a potential sample area of 1 square kilometer, 60% of the sample area could be covered via the public transport infrastructure. Further variations on such a scenario review the potential for reduced implementation, to deal with phasing, reducing the potential overheads of such a sensor network, and to focus with a dense sensor network on key areas of city development, or areas of the city identified to perform below expectations.



a)



b)

Fig. 2a + 2b: (a) Zurich transportation network density, entire transport network; (b) Potential initial deployment, tram lines 4 and 17

One direct application of the acquired sensor data is the verification and further development of climate simulation models. The KLAZ – Climate Analysis Report of the City of Zurich – is a Canton-wide simulation of various local climate nuances. Certain of these simulation results could benefit directly from the application of long-term sensor data, such as the urban heat-island effect (CARMILET 2010). According to these results, within the city of Zurich alone a local heating/cooling variance of 8° Kelvin is simulated, ranging from -3 to +5. A more fine-grained refinement of this simulation, based on sensor data, would allow more accurate appraisal of the performance of the local micro-climate, and its future development. The overlay of the transportation network and projected readings demonstrates the potential for simulation refinement, directly applied to the key areas of interest (Fig. 3).

Fig. 3:
Zurich transportation network and potential resulting sensor points – here shown in combination with the KLAZ Report data demonstrating the local heat island effect (sample area of simulation data, between +1 and +5 Kelvin temperature difference in shown (PARLOW 2010).

The KLAZ report elaborates the specific nature of the heat-island phenomenon in Zurich in its relationship to the cooling influence of the neighbouring forests, and the predicted role of the Sihl and Limmat river corridors in transporting cool air into the city. One possible application of such small-scale, dynamic data would be the optimization of the overall performance of the built-fabric, specifically in the refinement of future consumption of heating and cooling energy

5 Implementation and Outlook

This paper serves as an outline for a proposal for implementation of this process in a specific urban environment. The resulting method and data shows promise for varied and complimentary applications, affecting the disciplines of Landscape Architecture and

GeoDesign (ALBERT 2012). Amongst the applications we propose to elaborate are the verification and refinement of urban environment simulations (MOONEN 2012), direct dissemination of the data to the public, via online and smartphone applications, leading to increased public awareness of the city environment and its performance (CAMBELL 2008).

The presentation of this paper shall focus on animated examples of the possible deployment and implications of such a sensor network or the future development of the city. The continuation of this research is proposed with a view to application within the city of Zurich, and to other urban centres where city development and micro-climate extremes coincide.

As implied by the title of this research paper, this ongoing research addresses the city as a continuous dynamic system, in order that we may better understand and interface with the complexity of the future development of the urban fabric. Detailed understanding of the nuances of the urban environment allow deeper insight into the design potential of public space. Continued environmental monitoring over time, and deeper understanding of the performance of our cities will allow the impact of Landscape Architecture and GeoDesign methods to be assessed, further refined, and lead to the development of new methods in spatial design.

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