City of the Future: Urban Monitoring based on Smart Sensors and Open Technologies

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Abstract: Developments in the field of microelectronics and the increasing willingness to use open technologies offer a variety of opportunities to significantly increase both understanding and public participation in the sustainable design of our cities and living spaces. Urban environmental monitoring on the basis of smart sensors and open technologies with the participation of citizens and local actors not only allows a better understanding of urban transformation processes but also increases the acceptance and resilience of a sustainable urban development towards the city of the future. What will the cities of the future look like? What is certain is that the future of cities will become more digital, with sensors, apps and citizens networking. So, how can smart sensors and open technologies help us better understand our environment? What do we need to know about our environment and the city we live in? Based on the developments of recent years, it is now a matter of course to book tickets for buses and trains with your smart phone or to look for the best restaurant. But what if citizens and local actors want to play an active role in urban development or monitoring?

1 INTRODUCTION

1.1 The City as a System: A Global Challenge

Global changes, climate change or a constantly growing world population living in growing cities and urban agglomerations have an impact on regional and natural spaces as well as economic, political and social structures. Figures from the German Federal Initiative for National Urban Development Policy (BMVBS, 2008) and the German Federal Ministry of Building, Urban Affairs and Spatial Research (Milbert and BBSR, 2015) show that in Germany about 40% of all inhabitants already live in small and medium-sized towns and 30% in large cities. In addition, about 80% of all working people work in cities, and the trend continues to rise.

Today's cities are undoubtedly undergoing change, but are also competing for citizens and investors, so that not all cities are recording positive growth rates. This transformation of cities is influenced by a multitude of specific location factors and the decision for or against moving is often made dependent on the prospect of an improvement in one's own life situation. The trend toward urbanization is by no means a phenomenon of industrialized nations. In a global comparison and especially in developing countries, the proportion of the population living in cities is increasing, even though the reasons for urbanization may differ. In the meantime more than half of the world's population lives in cities (see Figure 1), with far-reaching consequences for people and the environment.

In view of the increasing number of people living in cities and the associated social, economic and ecological impacts, the demands placed on the city of the future will be different from the previous ones. Public health care, in particular, will become increasingly important. This also includes the recording and analysis of environmental conditions with the aid of spatial data. The transformation into the city of the future will therefore be accompanied by a small-scale

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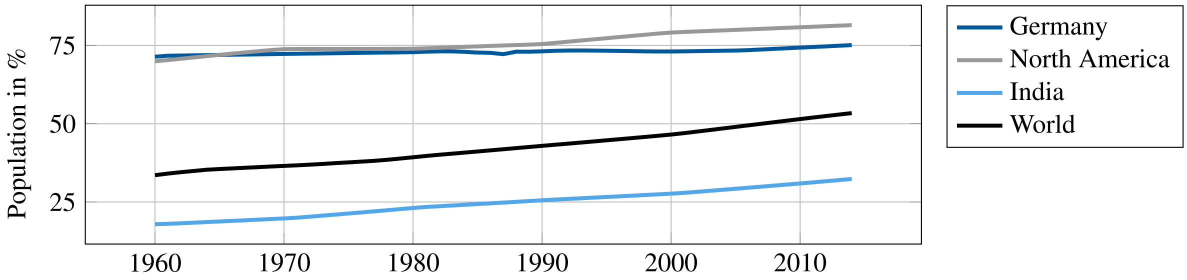

Figure 1: Share of the population living in cities in the total population. It should be particularly emphasized that since 2008 more people worldwide live in cities than in rural areas (The World Bank, 2015).

monitoring of microclimatic characteristics of urban space. Last but not least, a context-related assessment will be increasingly carried out by citizens and local actors and will be shared, discussed and valued with specific context knowledge via social networks and digital platforms. This process will be decisively influenced by the already high willingness to share information and content digitally. Examples include Wikipedia, OpenStreetMap or Mundraub.org[1]. The digitalization of everyday processes and the high availability of networked devices as well as the innovations and services derived from them will meet with acceptance in broad sections of the population similar to the introduction of smart phones.

2 THE SMART CITY OF THE FUTURE

2.1 Risks and Opportunities

The changes and challenges that arise when more and more people live in cities can already be seen today in modern metropolitan regions. What is certain is that urbanization does not only bring disadvantages. Cities and urban agglomerations are centers of innovative developments that permeate society as a whole. The initiators of these social, cultural, technical or economic developments are often those actors who shape their respective environment at the local level through individual action. Increasing digitalization in almost all spheres of life opens up new possibilities for the acquisition and provision of information as well as for social participation. Specialized services and a multitude of mobile sensors will change urban life in the future. The cities of the future will be networked, and their citizens will be able to access the information they need as *Digital Natives*.

Cities offer an attractive infrastructure and guarantee a better education, health and energy supply compared to rural areas. Assuming an environmentally conscious urban development, the city of the future can make a significant contribution to environmental and climate protection (Dosch and BMUB, 2015; United Nations, 2012). On the basis of this prognosis, the transformation to a livable, sustainable and resource-efficient city could also succeed, which in future will meet social, ecological and economic requirements in the same way (see Figure 2).

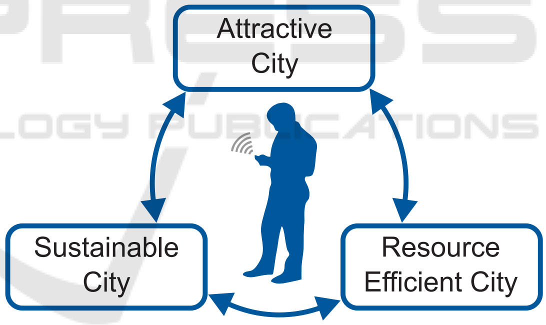

Figure 2: City of the future: Transformation into an attractive, sustainable and resource-efficient city. The digitization of cities can make a significant contribution to meeting the growing demands of increasing urbanization.

2.2 The Citizen of the Future: Smart Sensors and Digital Health

The inhabitants of the cities of the future differ from today's city dwellers not so much in their characteristics as in the amount of opportunities they have to obtain information and actively shape both the city in which they live and social processes. The increased demand for information can already be seen today in the widespread use of smart phones and the mobile Internet. Today it is an everyday picture that weather information is retrieved using a smart phone or the

[1] http://mundraub.org, which offers an open platform where users can share locations of freely accessible fruit trees via an integrated map service. More than 30,000 active users are now registered.

ticket for public transport including the connection is obtained via an app.

Examples such as fitness apps, wearable sensors for monitoring body functions or smart weather stations show not only the willingness but also the need to measure oneself and one's environment. This willingness is primarily based on the need to understand one's own body and environment and is a rather individual motivation. The technical measurement of body functions or the individual measurement of e.g. air pollution help to better understand and optimize oneself and one's own actions, but also to prevent health risks in general.

Mobile sensors and smart phone apps that provide these services are already commercially available, but have not yet penetrated the mass market. Therefore, the recording of personal (individualized) environmental impacts has not yet been established either.

Figure 3: Schematic representation of a provision of environmental information based on mobile technologies for mobile and individualized monitoring.

The organism as a living system reacts directly to changing environmental conditions. In order to be able to correctly assess a threatening (health) risk, it is necessary to also record the prevailing environmental conditions and their effects, which is still a challenge from the point of view of environmental measurement technology, especially in cities. This is not least due to the fact that the (local) climate in urban areas is characterized by a high degree of heterogeneity and dynamics due to different buildings, different forms of use or varying emission properties of the surfaces. As a result, even within a small area, different environmental conditions have a complex effect on human well-being and important vital functions. In addition, the feeling of comfort and the health burden differ from person to person and are influenced by numerous boundary conditions. From a scientific point of view, the question arises as to how this experienced situation can be measured and what needs to be measured to form a reliable database. From a meteorological point of view, it must be considered which parameters can be measured with sufficient accuracy and which methodical and financial effort is required.

Due to their low spatial resolution, conventional approaches in the field of environmental monitoring are not able to map the dynamics and local characteristics of urban space in all their complexity. For example, in Leipzig, the largest city in Saxony (Germany) with 297.6 km^2, three stations are available for the collection of fine dust measure PM2.5, whereby there are significantly more polarizing fine dust sources in the city. However, this relatively low compression of measuring stations reflects the current state of the art in the field of environmental monitoring, which is not least due to the cost- and maintenance-intensive measuring technology.

Although measurement technology should not be discussed here in detail, it should be noted that political decision-makers, municipal companies and service providers, as well as scientists and committed citizens, are confronted with the challenge of correctly interpreting the special features and problems of a city, their city, and developing sustainable solutions on the basis of the resources available to them. The overarching question is therefore how such complex (eco-) systems in their entirety and heterogeneity can be recorded, evaluated and better understood and therefore protected (Mead et al., 2013; Duyzer et al., 2015). This requires new strategies and monitoring concepts for the holistic consideration of processes that take place in the environment and are related to each other.

In the field of environmental research, this results in the necessity to develop cross-scale and above all adaptive measurement and monitoring strategies. It can also be stated that, in addition to the classical approach of institutionalised or official environmental monitoring, numerous social activities and initiatives will also make a significant contribution to environmental monitoring in the future. This will open up new approaches for proactively shaping the urban transformation process (Banzhaf et al., 2014). Citizen Science (Bonn et al., 2016; Kolok and Schoenfuss, 2011) and the increasing use of mobile technologies in the urban context (Smart City) are examples that show the high potential for further developments in this area. For the sustainable design of cities and urban spaces, location-based monitoring data in the sense of an advanced urban development at local, regional and international level therefore form an important basis for decision making (Eltges and Hamann, 2010), in short: the city of the future.

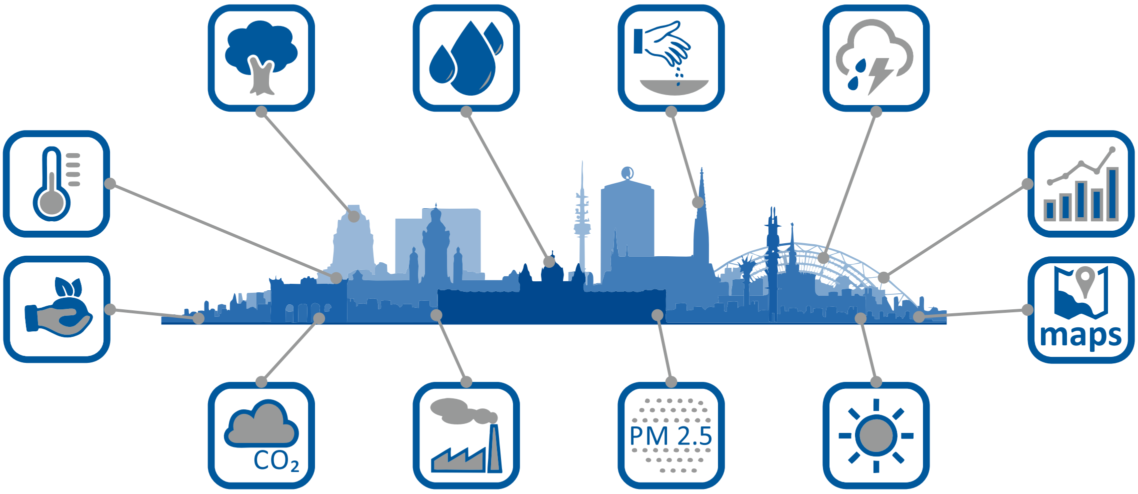

Figure 4: Environmentally related parameters of a city can be of different interest depending on the issue and the user. The challenge is to make the right information available for specific users.

2.3 Surveying the City: How Sensors Can Help Improve Quality of Life

The transformation of grown urban development structures towards a sustainable management and an increased interest in the individualized recording of environmental influences for personal health purposes are evidence of the need of different user groups for intelligent and service-oriented environmental monitoring (Su et al., 2015; Reis et al., 2015).

Digital change is increasingly changing the approach to social and ecological issues and at the same time pushing the boundaries of what is informally feasible. Driven by buzzwords such as Industry 4.0, Smart City or the Internet of Things, the digitalization of our everyday lives continues to progress. The constantly increasing number of sensors in almost all areas of life and ever more powerful computers will offer the possibility in the future to create an unprecedented image of the environment and the complex system interrelationships that take place within it. Due to the large number of people who use smart phones on a daily basis, innovative services can already be offered today that transmit location-, time- and context-specific information to hundreds of users according to their needs. The evaluation and analysis of spatial data is used, for example, in the field of traffic planning, including minute-by-minute information in the event of traffic delays or in the planning of people movements during major events. The high information content is based in particular on the high number of users within the research area and the fact that the measuring object, here the geographical location, as well as the measuring device (mobile phone with GPS receiver and mobile Internet) can be clearly described at the time of data collection. The processes and algorithms for evaluation based on these data can thus access a consistent amount of data and provide the desired information with low latency.

When recording environmental and health risks, the context-related evaluation and analysis includes not only the location and time but also other influencing factors, local characteristics and historical data. With the help of this context information, complex systems can also be recorded and environmental risks can be derived with regard to the individual person and his or her individual burden. Despite official measuring systems and a considerable amount of installed sensors and available sensor information, it is difficult to determine a user-specific, individual burden. This can not least be attributed to the fact that classical approaches are based on equipping the test persons with different sensors and measuring systems, but the data obtained are not sufficiently related to the prevailing environmental conditions. In addition, commercially available systems usually represent isolated solutions and complicate an integrated monitoring approach across several scales. Often the measuring systems themselves are limiting factors. For example, due to the necessity that the test persons have to carry corresponding measurement systems with them at all times in order to be able to determine an individual load. It would therefore be logical to equip each person with an appropriate sensor in order to be able to record the individual stress of a person. However, this approach will not become established in the future either, since reliable environmental measurement technology does not fit in size on the one hand and, on the other hand, an increased technical and methodological knowledge of the user would have to be assumed.

3 CONCLUSION – POTENTIAL AND PROSPECTS FOR THE CITY OF THE FUTURE

For the city of the future, the question arises as to how it can be possible to link official measurement systems with sensor information from the population. The main issue here is the integration of innovative sensor technology into existing structures and approaches for environmental monitoring, which is particularly important for urban areas. A major challenge here is the greater involvement of different actors and social groups. In addition to public authorities and research institutions, social initiatives and committed citizens will be increasingly involved in answering environmental and social science questions and will play a decisive role in shaping the city of the future. The linking of sensor data with increasingly important context and meta information as well as the specific provision are therefore central tasks to be solved. This is the only way to capture the complexity and heterogeneity of a city holistically and ultimately to make a general contribution to improving the quality of life in urban areas.

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