CITIZENS AS REAL-TIME EMOTIONAL SENSORS IN SMART CITIES

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ABSTRACT Understanding how citizens experience their built environment would help us to develop and re-develop a smarter city. A city that not only serves the spatial purpose for which it is created but also demonstrates a dynamic nature to adapt to the ever-changing behavioural patterns of its citizens.

The focus should be on defining and quantifying a citizen's experience. While pedestrian flow simulations and conventional surveys have some understanding of a citizen's behavioural patterns within the city, they ignore the complex nature of environmental experience. Interactions amongst individuals, user goals and motivations all drive what paths they select, routes they take and where they choose to linger. Also, a plethora of research shows that subjective, self-report questionnaires may not accurately describe attitude nor emotional response towards the environment.

Simply put, self-report questionnaires remove the user from the environment, and require them to take an unrealistic evaluative stance regarding their perceptions and experience of the environment. Thus, by failing to describe the unpredictable, ever-evolving nature of human experience, current approaches leave us with potentially inaccurate data from which ineffective solutions are generated. By considering the real-time experience of the city, along with new technologies such as virtual reality (VR) and biometric data, this paper aims to demonstrate an innovative design protocol to more accurately and effectively create the road-map to understanding a citizen's real-time and true experience in the city. The "Emotional Mapping" (EM) tool aims to render a real-time map of the citizen's emotional status in the smart city.

1. Introduction

By 2050, 66% of the world's population is expected to live in urban areas, and there are a number of reasons for this including immigration, high population rates in urban centres, as well as the physical expansion of urban areas. This is putting huge pressure on the existing resources and infrastructure of existing cities. The challenge will be to not only to supply these populations with basic resources like safe food, clean water and sufficient energy but to maintain the expected level of service and expectancy for the citizens. The change in the citizens' expectancy of their experience in the city is what authorities need to get prepared for. In the case of smart Dubai, a citywide happiness index is used as part of an integrated system to create a seamless, safe, sustainable and citizen-oriented smart city for its citizens (SmartDubai, 2019).

A smart city is defined as an approach that starts with awareness and ends with executive policies. The variety of views about what a smart city is has resulted in broad definitions with no focus on specific technologies or sectors (CentreforCities, 2014). These definitions are categorized as,

- Generic definitions
- Data-driven definitions

- Citizen-focused definitions

Even though these categories are not exclusive, they reveal the importance of specific elements in smart cities, data and citizens.

Data are the fundamental component of smart cities and smart city initiatives. Data in the form of big data (Lim *et al.*, 2018) shapes the infrastructure of a smart city. This big data are mined from existing data sets and systems already in place in our cities, in the form of platforms such as smart grids and Information and Communication Technology (ICT), and virtual platforms such as smartphones and social media.

The missing data set is one which reflects citizens' real-time interaction with their physical and virtual environment. Availability of such data will enable the stakeholders in smart city initiatives to have a better understanding of the citizens and thus move towards a human-centred (where human-centred design approaches solutions to problems by involving the human perspective in all steps of the process) environment through smart policies and executive strategies.

Whilst environmental data are provided by city-wide integrated sensors which feed existing platforms, the "Emotional Mapping (EM)" initiative would use citizens as

real-time live sensors that would feed live emotional data into the system through emotional computing procedures (Khan and Lawo, 2016).

The emotional data would then become the most significant part of the big data and would be used to define the emotional reference baseline in smart city initiative evaluation and would represent citizens' true experience throughout the process.

2. Smart Cities

The term 'smart cities', follows with certain keywords, including (but not exclusive to) data-driven operation, efficiency, improved sustainability, enhanced quality of life factors and smart energy grid system.

In fact, there is no single universal definition for smart cities. Instead, there are various definitions coming from project-specific proposals. These projects and initiatives usually target certain geographical zones and aim to address their vital concerns through the implementation of smart methodologies. These methodologies are defined in the framework of smart cities initiatives. Overall, the term 'smart city' is used to visualize a road-map for an urban structure where technological advances are utilized to shape a holistic and sustainable development strategy for the future of such structures.

Figure 1. Smart City & Emotional Awareness

However, it is important to note that becoming a 'smart city' may not be a laudable goal for all urban centres, and there may be exclusivity of smart approaches to city-life. This includes, but is not exclusive to citizens without access to mobile technologies, the reliance of WIFI and power for these

systems, the knowledge of these technologies within the citizen population, cost of these systems (both in relation to infrastructure and smart devices), thus consideration needs to be given to whether this will be feasible for all (both from an individual perspective, as well as economically – for example, in low/medium income countries).

3. Smart Citizens

The Oxford Dictionary defines citizen as:

1. A legally recognized subject or national of a state or commonwealth, either native or naturalized
2. An inhabitant of a particular town or city.

It is important to note that, for the purpose of this paper, the second definition is adopted to reflect the true nature of a city and its inhabitants, which include non-native or naturalized persons as a result of varying immigration status, travel, and 'international' spaces such as airports.

The role and engagement scope of a citizen in a smart city is an important component of smart city initiatives. The concern is if citizens being in smart cities is reduced into mere numbers in smart algorithms and the generated data stream from the Internet of Things (IoT, the interconnection of everyday devices via the Internet, enabling them to send and receive data) which focuses on optimizing resources and increasing operational efficiency. The fundamental question is if the smart city of the future is driven by technological advancements or by human-centred design principles. Or in other words, if data oriented and automated decision making will adversely impact citizen engagement (Allessie, 2016).

On the contrary, a human-centred smart city is not technology driven but utilizes technology to reflect the needs of citizens and the challenges they face. Access to an unlimited stream of data should enable a smart city to reach a level of understanding of its citizen which was not feasible before. Using ICT infrastructure, citizens generate data by sharing their emotional status in response to their environment using social media such as Twitter, Instagram and Facebook. They also generate behavioural data when they use Google Maps, Uber and any smart device application. The generated data stream in the smart city could be categorized as:

- Data generated from the citizens (e.g. the data extracted from citizens in-app digital behavioural patterns)
- Data generated by the citizens (e.g. the data shared by citizens using social media)
- Data generated for the citizens (e.g. the data shared by authorities for public evaluation)

A smart citizen engages and participates in all types of generated data in a smart city.

3.1 Citizens as Emotional Sensors

Smart cities operate under continuous monitoring that occurs through the interconnected system of sensors and processors that are integrated within the infrastructure. Sensors receive and transmit data and communicate with each other by connecting to the internet. The interconnection and fusion of smart sensors enable the IoT to achieve context awareness. Smart sensors are capable of both receiving the data and distributing to digital infrastructure platforms provided by ICT. Sensors communicating to each other in real-time will strongly link the cyber and real world (Bacic *et al.*, 2018).

Citizens constantly experience and evaluate their environment using their senses. They process the data and unconsciously emotionally respond to it. Their cognition of the environment depends on their culture, their unique life experience, their characteristics, gender, age and their emotional status (Li *et al.*, 2018). Thus, each individual citizen has their own unique emotional response to the environment. Recognizing citizens as emotional sensors and extracting citizens real-time emotional data provides the opportunity of a holistic understanding of the city from citizens emotional standpoint.

4. Emotional Mapping

The Emotional Mapping (EM) initiative collects real-time biometric data from citizens. This data are processed and interpreted into the emotional status and shapes an emotional database. EM focuses on the human's interaction with the built and unbuilt environment. While IoT creates a communication platform for smart objects, EM aims to represent citizens' true user experience in correlation with the virtual and physical environment that they are interacting with. By definition, EM is not a direct component of smart city initiatives, but is a tool to provide a better understanding of citizens for stakeholders.

EM has a role as the hub of, and link to, the automation process that connects context oriented data to operational control systems in a smart city. EM would introduce human-centred design values to smart city performance evaluation. If citizens emotional experience is representing their true being in the city, all smart city values should be evaluated in reference to the value that matters most, citizen's real-time emotional experience in the city.

4.1 Inclusiveness

"Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody" (Jouili *et al.*, 2017).

Citizens are the most important part of any city. Any definition of a city, smart or not will be meaningless if the citizens and their wellbeing in the city is not accounted for. Smart city initiatives collect data from citizens to shape the big data that are used by smart city protocols. The data are mostly collected by tracking and analyzing citizens digital behavioural pattern. This exposes the smart city initiatives to the risk of not being inclusive regarding data collection from all citizens. The smaller digital footprint of the citizens would introduce a new category of minorities and underrepresented citizens in the

smart city. The EM initiative enables the smart city to reach a higher level of inclusiveness in the emotional recognition framework. The emotional framework would allow the smart city to understand the true wellbeing of all of its citizens and be aware of a change in their emotional state and thus to adjust the policies and the strategies to best suit their real-time citizens.

4.2 Methodology

The challenge in understanding citizens' emotional status is the imperceptible nature of it. Translating this experience into quantifiable data is achievable due to recent advancements in biometric sensors and in cognitive neuroscience frameworks.

The EM initiative uses real-time biometric data using non-intrusive biometric sensors. Smart wearable sensors are considered as example data collector devices. Human emotions could be recognized by mapping specific patterns of the measured bio signals based on physiological responses promoted by an emotional perception. Data processing capabilities of EM lies within ambulatory emotion recognition which is made feasible by advancements in sensing technologies, networking technologies and emotion recognition methodologies (Hui and Sherrat, 2018).

The biometric data collected in the process is unbiased in nature, due to being generated autonomously from the central nervous system. In general, these signals can be collected from the activity of the subject's cardiovascular system, respiratory system, electrodermal activities, muscular system and brain activities as well as from body language and behavioural response.

Figure 2. Geo-Located Biometric Data Collection

The biometric data could be mined through the following response channels (Ajay *et al.*, 2017),

- Physiological systems, Includes electroencephalography (EEG), skin temperature measurements, photoplethysmography (PPG), electrodermal activity (EDA) and electromyography (EMG) (Girardi *et al.*, 2017)

- Facial emotional recognition
- Voice and speech recognition

Figure 3. Wearable Sensors - Empatica E4

The greatest challenge is that people experience emotions differently, both mentally and physiologically. The impacting factors include cultural differences, age, gender and individual’s metabolic baseline. A combination of datasets from the above-mentioned response channel and self-assessment reports would validate the data and remove anomalies from equations, if not automatically validated.

Machine learning and artificial intelligence (AI) algorithms provide significant advances in automated recognition of physiological patterning. In this process, the machines are trained to recognize emotions based on provided training datasets and generate and adjust algorithms accordingly to achieve optimum accuracy (Jang *et al.*, 2014).

Figure 4. Machine Learning Process

4.3 Sensor Fusion Platform

Sensor fusion is combining a sensor network and creating an interconnected platform of sensors that communicate with each other. The interconnected platform allows the data stream from each sensor network to validate each other and provide a complementary stream of data. This approach would reduce the uncertainty of the data.

EM introduces a sensor fusion platform to merge emotional data stream with context-oriented data coming from IoT in a smart city (Karimi, 2018). The sensor fusion platform provides the opportunity of the understanding the citizen’s emotional response with regards to the environmental context they experience in real-time. Such understanding enables smart city initiatives to apply human centered design principles in the policies and strategies. Furthermore, it allows such initiatives to automate the operations and control systems through holistic data mining and cognition.

Figure 5. EM Methodology Infographic for Passenger with Limited Accessibility in an Airport Terminal

4.4 Virtual Reality (VR)

Virtual reality (VR) has made its way into mainstream psychological research in the last two decades. This technology, with its unique ability to simulate complex, real situations and contexts, offers researchers unprecedented opportunities to investigate human behaviour in well-controlled designs in the laboratory (Diemer *et al.*, 2015). Recent researches indicated the similarity of citizens’ emotional responses in VR in comparison to the same real-world experience (Jeon, 2017).

Figure 6. Validation of Emotional Data in VR and Real-World

EM uses VR simulation for evaluation of design and operations from a citizen's emotional experience standpoint prior to execution. This approach turns VR simulation into a laboratory of change and replacing the experimental approach for an intervention with non-linear impact nature. This is an evolutionary opportunity to understand the future of any planned impact prior to the capital investment in a sensitive context such as a city. This unique potential of VR leads to creating a human-centred oriented digital twin of a smart city.

Figure 7. Integration of VR Data in Total Emotional Awareness

5. Potentials and Concerns

In adopting EM, it is important to recognize that biometric data are not necessarily infallible / neutral (e.g. wearing smart sensors may in themselves change people's emotions and behaviour), and thus this must be considered as a tool amongst other means of data collection (e.g. supplementing the EM methods with qualitative methods, such as walk-along interviews), that can help to further understanding of citizen experience.

In summary, EM is not to be considered as the target in smart city initiatives but as a tool to achieve and maintain a human-centred smart city vision. By revealing citizens true experience in the city, EM highlights a city's strengths and limitations through a real-time emotional map of the city. The emotional map guides and prioritizes investments in the city by empowering local businesses where required and citywide

adjustments where necessary. Furthermore, EM has the potential to be developed into a more holistic tool and become an emotional, smart grid an equivalent of a smart energy grid in smart cities but sensitive to changes in the emotional status of the citizens. EM also could lay the foundations for a human-centred oriented digital twin of a smart city and enables stakeholders to understand the impact of any political, financial and operational from citizens emotional experience perspective.

Specific privacy and security protocols are required to the process and use of sensitive data which reveals certain personal characteristic. Biometric data and information from an individual could lead to people being identified based on specifics and distinguishing signs (Deliversky and Deliversky, 2018). EM should be cognizant of the sensitivity of such collected data and deploy adequate procedure to ensure anonymity and security of the collected data. One methodology for this is aligning with industry and governmental best practices in data security and privacy, such as the General Data Protection Regulation (GDPR) in the European Union.

The transformation from a technology-oriented approach to smart cities to a human-centred is a complex road that requires a change in the mindset of all stakeholders of the smart city. Investing in EM is an investment for the future that requires consistency to maintain the real-time understanding of the citizens. It is also easier and more convenient for authorities to deal with digitized data streaming from IoT rather than understanding the complex nature of emotional response data that represent the true nature of citizens (Jacobs, 1961).

This is an opportunity to look at EM beyond current applications in relation to signage / wayfinding (Gartner, 2011), with real-time feedback and opportunity for creating adaptive buildings. Data collected can help to identify trends, cultural behaviours, etc. that are beyond code and which allow people to respond to design in a more informed manner.

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