Interaction in Smart Cities

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Abstract Smart Cities have gradually shifted their focus from just being technology hubs that simply collect information to be consumed by their citizens, to large scale interactive environments with their users being inherently considered as vital elements of the city. Therefore, the overall interaction paradigm has evolved to promote active participation and collaboration between different parties, and support their new roles and objectives. Already a variety of domains such as transportation, healthcare, entertainment, agriculture, economy, and government provide smart solutions and efficiently utilize the Smart City's resources, towards improving the overall quality of life of its citizens; this trend can only continue given the forecasted increase of the number of IoT connected devices. Within this promising world where citizens are the main players, natural interaction will be a critical need for the new generation of Smart Cities. The recent advancements in Information and Communication Technologies along with the emergence of innovative technologies (e.g. Augmented Reality, Artificial Intelligence, 5G) and the abundance of IoT devices empower the employment of various interaction modalities (i.e. presence, body posture and motion, eye gaze, speech, touch) able to accommodate different user abilities, context of use (i.e. public or private space), or device variations. Finally, the need for explicit

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interaction has started to minimize, since automatic knowledge inference already enables cities to take the appropriate actions, both proactively and reactively. This chapter initially defines the vision of a Smart City, present the main objectives that provide its foundation and the contributing technologies that promote its realization. Then, it outlines the key interaction paradigms encountered in Smart Cities and introduces a variety of use cases that highlight, from an HCI perspective, interactions of citizens with Smart City services and applications. Finally, it discusses the key challenges that engineers and official authorities should address in their endeavor to build truly efficient and well-accepted cities, and concludes by offering some closing reflections about their promising potentials.

Keywords Smart city · Human-environment interaction · Implicit interaction · Internet of things · Digital city · Ambient intelligence · Interaction

1 Introduction

The concept of Smart City has progressively become more and more popular in the scientific literature and in national and international policies [1]. A city is a relatively large, permanent settlement which generally has complex systems for sanitation, utilities, land usage, housing, transportation, etc. [2, 3]. Cities play a prime role in social and economic organization worldwide, and have a huge impact on the environment. Recently, the world has witnessed a rapid urbanization process, which has become a worldwide phenomenon [4]. According to the National Bureau of Statistics (NBS) [5], the proportion of the urban population to the total population (urbanization rate) was 60% at the end of 2019, 1.02 percentage points higher than that at the end of 2018. The number of urban residents stood at 848.43 million (Dec 2019), 17.06 million more from the previous year. In Europe, 75% of the population already lives in urban areas, and the number is expected to overpass 80%. In general, it is anticipated that the urbanization rate will continue to grow rapidly (expected to rise to 68% by 2050), particularly in developing countries [6]. The importance of urban areas, which offer citizens a better quality of life and greater opportunities [7], is confirmed by the densely populated cities of more than 20 million people in Asia, Latin America, and Africa.

The massive population movement towards cities leads to density of living facilities, utilities and infrastructure, which results in a number of challenges related to transportation, energy, water and waste management, climate change and air pollution. In particular, due to their increased population, cities nowadays consume most of the available resources, which on the one hand contributes to their economic importance, but on the other hand is responsible for their poor environmental performance. According to [1], cities consume between 60 and 80% of energy worldwide and are responsible for large shares of Green House Gas (GHG) emissions.

In the context depicted above, the concept of Smart City was introduced to refer to the process by which a city is able to make appropriate changes through technology to meet the above mentioned challenges [4]. Indisputably, the Smart City concept is linked to the digital adaptation required in domains such as infrastructure, governance, transportation, education, healthcare, workplace, etc., in order bring closer the city and its citizens [8]. However, since the term is spread across many sectors, there is no commonly accepted definition, which hinders the work of urban policy makers, that aim to lay the foundations towards creating "smart" cities [1]. According to [9], Smart Cities can be described as the cities utilizing human and social capital along with Information and Communications Technologies (ICTs), so as to enhance the quality of life of citizens and contribute to sustainable development, further enabled by wise management of natural resources and participative government [10]. Today, ICTs have already permeated urban areas and are considered to enhance the resilience and sustainability of Smart Cities [11], while at the same time they permit citizens to shape their urban environment and manage any urban-related issues by proposing or co-creating innovative solutions [12].

Smart Cities integrate smart technologies into an existing city [13] and provide services that benefit from the pervasive deployment of sensors, actuators, and smart objects throughout the urban environment [14]. The endless streams of data that deluge modern cities (e.g. traffic flow, crime incidents, waste disposal, noise, weather patterns, outbreaks of infectious disease) are either produced or consumed by such services [15], and are subsequently analysed and interpreted by sophisticated software. To that end, open data platforms are a key ingredient of Smart Cities, so that the generated data is not wasted without extracting potentially useful information and knowledge [15]. Therefore, a new generation of flexible and adaptable machine learning approaches are required to enable Smart Cities to instil useful information that can be used to improve the quality of life of their citizens [16]. However, the concept of the Smart City is not limited to the application of technologies to cities; on the contrary, the highly-dynamic nature of urban spaces led to the emergence of a new interaction landscape to mediate between people, places and things [17].

The design of future Smart Cities requires the creation of interactive, augmented and connected urban spaces [18], while it entails the optimal combination of automated systems, just-in-time delivery of relevant information and pervasive interaction interfaces to mediate with their citizens in a natural and unobtrusive manner (Fig. 1). However, according to [1], this endeavour is hindered due to the various limitations posed by the technology itself (i.e. absence of relevant user-friendly technologies), inaccessible infrastructures, and the lack of consolidated practices towards the realization of the Smart City vision [1].

The rest of this chapter is organized as follows: Section 2 defines the vision of a Smart City, the main objectives that provide its foundation and the contributing technologies that promote its realization; Section 3 outlines the key interaction paradigms encountered in Smart Cities and introduces a variety of use cases that highlight, from an HCI perspective, interactions of citizens with Smart City services and applications. Section 4 discusses the key challenges that engineers and official authorities should address in their endeavour to build truly efficient and well-accepted Smart Cities. Finally, Section 5 summarizes the chapter and offers some closing reflections about the promising potentials of Smart Cities.

Fig. 1 Within a smart city the infrastructure, the various services and applications interoperate in a seamless manner

2 Background Theory

2.1 Definitions of Smart Cities

A literature review revealed that currently there is no definition of a smart city that is generally acknowledged. On the contrary, the Smart City concept appears to differ amongst cities, let alone amongst countries. This is somewhat expected, due to the different levels of development of the cities, as well as the differences in their willingness to undergo changes, ability to reform, intended goals, and resource availability. Additionally, the diversity of citizens living in amongst countries or even cities of the same country, in terms of ambitions, goals and aspirations, explains the differences regarding the conceptualization of the Smart City. According to [19], the term "Smart City" would have a different meaning in India and in Europe, while even inside India, there is no way of providing a specific definition.

However, despite the fact that so far a universally accepted definition of Smart Cities does not exist, there are many attempts to define it (Table 1). Among those definitions, the term "Smart City" is fuzzy and used in ways that are not always consistent. At the same time, several approaches replace the adjective "Smart" with alternatives such as, "digital" or "intelligent", which equally illustrate the incorporation of ICT in the city. Nonetheless, an all-encompassing definition of the Smart City does not exist, nor specific guidelines to frame it.

Table 1 Definitions of a smart city, sorted by number of citations (descending order)

Definition	Source	Citations
A city is smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance	[20]	3642
A smart city infuses information into its physical infrastructure to improve conveniences, facilitate mobility, add efficiencies, conserve energy, improve the quality of air and water, identify problems and fix them quickly, recover rapidly from disasters, collect data to make better decisions, deploy resources effectively, and share data to enable collaboration across entities and domains	[21]	2161
A city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens. Smart city generally refers to the search and identification of intelligent solutions which allow modern cities to enhance the quality of the services provided to citizens	[22]	2081
A city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city	[23]	965
Smart city as a high-tech intensive and advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce, and an increased life quality	[24]	835
The use of Smart Computing technologies to make the critical infrastructure components and services of a city-which include city administration, education, healthcare, public safety, real estate, transportation, and utilities-more intelligent, interconnected, and efficient	[25]	769
The application of information and communications technology (ICT) with their effects on human capital/education, social and relational capital, and environmental issues is often indicated by the notion of smart city	[26]	732
Smart City is the product of Digital City combined with the Internet of Things	[27]	590
A community of average technology size, interconnected and sustainable, comfortable, attractive and secure	[28]	521

(continued)

Table 1, which is based on the work of [1] and [45], reports some of the different definitions and meanings given to the concept of Smart city. The table highlights that the Smart City concept is based on the one hand on the incorporation of technologies in the city environments, whilst on the other hand it also takes into consideration the needs of each individual resident and the community as a whole. In [46], the authors

Table 1 (continued)

Definition	Source	Citations
A smart city is understood as a certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth. These aspects lead to smart city conceptions as "green" referring to urban infrastructure for environment protection and reduction of CO_2 emission, "interconnected" related to revolution of broadband economy, "intelligent" declaring the capacity to produce added value information from the processing of city's real-time data from sensors and activators, whereas the terms "innovating", "knowledge" cities interchangeably refer to the city's ability to raise innovation based on knowledgeable and creative human capital	[29]	512
A smart city is a well-defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development	[30]	414
Smart Cities initiatives try to improve urban performance by using data, information and information technologies (IT) to provide more efficient services to citizens, to monitor and optimize existing infrastructure, to increase collaboration among different economic actors, and to encourage innovative business models in both the private and public sectors	[31]	299
Smart cities have high productivity as they have a relatively high share of highly educated people, knowledge-intensive jobs, output-oriented planning systems, creative activities and sustainability-oriented initiatives	[32]	266
(Smart) cities as territories with high capacity for learning and innovation, which is built-in the creativity of their population, their institutions of knowledge creation, and their digital infrastructure for communication and knowledge management	[33]	249
Smart cities are the result of knowledge-intensive and creative strategies aiming at enhancing the socio-economic, ecological, logistic and competitive performance of cities. Such smart cities are based on a promising mix of human capital (e.g. skilled labour force), infrastructural capital (e.g. high-tech communication facilities), social capital (e.g. intense and open network linkages) and entrepreneurial capital (e.g. creative and risk-taking business activities)	[34]	214
Being a smart city means using all available technology and resources in an intelligent and coordinated manner to develop urban centres that are at once integrated, habitable, and sustainable	[35]	161

(continued)

Table 1 (continued)

Definition	Source	Citations
Smart community—a community which makes a conscious decision to aggressively deploy technology as a catalyst to solving its social and business needs—will undoubtedly focus on building its high-speed broadband infrastructures, but the real opportunity is in rebuilding and renewing a sense of place, and in the process a sense of civic pride. […] Smart communities are not, at their core, exercises in the deployment and use of technology, but in the promotion of economic development, job growth, and an increased quality of life. In other words, technological propagation of smart communities isn't an end in itself, but only a means to reinventing cities for a new economy and society with clear and compelling community benefit	[36]	127
Creative or smart city experiments […] aimed at nurturing a creative economy through investment in quality of life which in turn attracts knowledge workers to live and work in smart cities. The nexus of competitive advantage has […] shifted to those regions that can generate, retain, and attract the best talent	[37]	116
Smart cities will take advantage of communications and sensor capabilities sewn into the cities' infrastructures to optimize electrical, transportation, and other logistical operations supporting daily life, thereby improving the quality of life for everyone	[38]	100
Two main streams of research ideas: (1) smart cities should do everything related to governance and economy using new thinking paradigms and (2) smart cities are all about networks of sensors, smart devices, real-time data, and ICT integration in every aspect of human life	[39]	99
Smart cities of the future will need sustainable urban development policies where all residents, including the poor, can live well and the attraction of the towns and cities is preserved. […] Smart cities are cities that have a high quality of life; those that pursue sustainable economic development through investments in human and social capital, and traditional and modern communications infrastructure (transport and information communication technology); and manage natural resources through participatory policies. Smart cities should also be sustainable, converging economic, social, and environmental goals	[40]	98
A smart city, according to ICLEI, is a city that is prepared to provide conditions for a healthy and happy community under the challenging conditions that global, environmental, economic and social trends may bring	[41]	51
Smart City is a city in which it can combine technologies as diverse as water recycling, advanced energy grids and mobile communications in order to reduce environmental impact and to offer its citizens better lives	[42]	not applicable
Smart city is defined by IBM as the use of information and communication technology to sense, analyse and integrate the key information of core systems in running cities	[43]	not applicable

(continued)

Table 1 (continued)

Definition	Source	Citations
Smart city [refers to] a local entity—a district, city, region or small country -which takes a holistic approach to employ[ing] information technologies with real-time analysis that encourages sustainable economic development	[44]	not applicable

clarify this aspect stressing that "the diffusion of ICT in cities has to improve the way every subsystem operates, with the goal of enhancing the quality of life".

2.2 Smart City Goals

Beyond improving the infrastructure, Smart Cities aim to enhance the citizen experience and participation by operating at the intersection of the 3Ds: data, digital, and human-centred design [47]. The goal is to enable better decision-making through the use of data for all stakeholders (i.e. government, business, residents, visitors). To that end, the vision of the Smart City is to involve these diverse stakeholders in an intelligent, connected ecosystem built on a sensor-based physical infrastructure.

In a nutshell, the main goals of any Smart City should be providing benefits to its inhabitants, such as [48]:

- A better quality of life for residents and visitors
- Economic competitiveness to attract industry and talent
- An environmentally conscious focus on sustainability.

These three goals should be the basis of any Smart City initiative, while the creation of appropriate frameworks should lay the foundation towards enhancing several urban domains such as economy, mobility, security, education, living, and environment (Fig. 2).

Cyber-Physical Systems (CPS) are integrations of computation and physical processes, where embedded computers and networks monitor, control and coordinate such complex processes [49]. The Internet of Things forms a crucial CPS component, as objects can now carry digital information themselves and directly communicate with other objects via the Internet. Given the above developments, scholars have identified and categorized the main domains, along with several urban areas, that a Smart City aims to improve (presented in Table 2) through such "smart" enhancements [50].

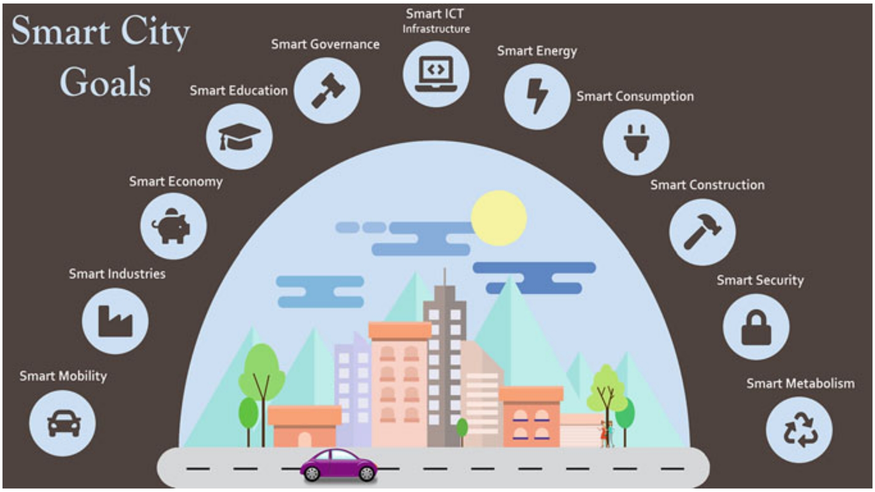

Fig. 2 Smart City Goals

Table 2 Key Urban Domains that Smart Cities aim to address (adapted from [50])

Smart ICT infrastructure. Establishment of broadband or wireless connectivity and communication compatibility between all urban citizens and institutions based on hardware and software components
Smart energy. Implementation of smart grid technologies that control energy consumption and optimize coordination between decentralized power generation and utilization of renewables
Smart mobility. GIS-based coordination of goods logistics and e-mobility nodes (cars, bikes, public transport) towards customized transport for citizens and companies
Smart economy. Direction of entrepreneurship and business development toward new fields of ICT and CPS application that shape future trends
Smart construction. Construction of buildings and settlements aiming to optimize the supply of amenities, consumption of resources, and living conditions
Smart industries. Selective integration of tailormade goods manufacture and related services into urban development, collocating production and consumption
Smart education. Inclusion of smart city-related ICT/CPS technologies in education and R&D activities towards supporting qualification and skills acquisition of people, independent of the social, economic and educational background
Smart governance. Full-scale provision of ICT-based public services to all residents ("e-government"), while offering ways to participate in political processes ("e-democracy")
Smart consumption. Broadening options for a sharing economy as well as public monitoring and display of environment data, activating a reflected and resource-conscious consumption behavior
Smart metabolism. Organization of a circular economy that optimizes the (re)use and recycling of resources, including water and waste management

2.3 Enabling Technologies

2.3.1 Internet of Things

The research and development challenges to create a smart world, i.e., a world where the real, the digital and the virtual are converging to create smart environments that make energy, transport, cities and other areas more intelligent, are enormous [51]. The Internet of Things (IoT) constitutes a new revolution of the Internet; it is a concept and a paradigm that considers pervasive presence in the environment of a variety of things (i.e. objects) that are able to network and interact with each other, in order to cooperate towards creating new applications/services and reaching common goals [52]. Its ultimate goal is to enable things to be connected anytime, anyplace, with anything and anyone ideally using any network, any service and any device [53]. In this context, physical objects enhanced with embedded technology that enables them to communicate, sense or interact with their internal states or the external environment, advertise their functionality, communicate information about themselves, access information aggregated by other things, or become components of complex services. Thus, they become "smart" by making or enabling context-related intelligent decisions. Table 3 presents the most common objects/sensors used in IoT.

IoT refers to the network of "smart" objects and the confluence of efficient wireless protocols, improved sensors and cheaper processors, while a bevy of companies developing the necessary management and application software has made the concept of the Internet of Things mainstream [53]. By 2030, internet-connected devices are expected to surpass 50 billion[1]; for every Internet-connected PC or handset there will be a dozen of other types of devices sold with native Internet connectivity [55].

Several application domains are impacted by the emerging IoT activities, such as medical and healthcare applications, agricultural applications, workplace applications, industrial applications, etc. One such application in the urban context is the Smart City, which promises to improve the quality and performance of urban services and the lifestyle of the citizens through the use of ICT (i.e. IoT, CPS). This is foreseen to contribute to the provision of better facilities and services, the cutback of the administrative efforts for management of the city and the more effective utilization of resources.

The services for which quality can be enhanced in a smart city include monitoring the strength of buildings, bridges and other constructions, waste management, air quality management, weather monitoring, noise monitoring, traffic management, parking management, energy consumption management and automation buildings, e-healthcare, logistics, monitoring, and intelligent transport [56, 57]. Several ongoing projects and research activities focus on the identification of smart city scenarios, the integration and interaction of various IoT data sources and systems, big data representations and analytics, as well as security and privacy issues [58–60]. The

[1] https://www.statista.com/statistics/802690/worldwide-connected-devices-by-access-technology/.

Table 3 Common Sensor Types Used in IoT (adapted from [54])

Sensors for…	Description
Air quality	Sensors that detect the level of air pollution in urban areas and assist the process of taking appropriate measures that protect people's health
Athletes	Sensors that monitor various physiological parameters (i.e. use an accelerometer and gyroscope are used to detect the severity of a hit to the head, which can be used to check for concussions)
Buildings	Sensors that monitor vibrations and material conditions in buildings, bridges and historical monuments provide 'early warnings' in case of damages
Vehicles tracking	Sensors that detect the geographical location of each vehicle in a fleet, so as to optimize routes and accurately estimate delivery times
Energy usage	Sensors that monitor energy usage can be used to verify the energy efficiency of "green building" and gain insight in further improving this efficiency (through follow-up analysis)
Green houses	Sensors that detect the micro-climate of a greenhouse or a plantation (e.g. air and soil temperature, humidity, CO_2 level, water quality), in order to maximize the production and optimize the quality of fruits and vegetables
Gunshots	Sensors that detect the sound of a gunshot are used to pinpoint the location in real time and dispatch police to that location immediately
Hazardous gases	Sensors that detect levels of explosive or toxic gases in industrial environments and indoor locations allow immediate action to secure the safety of people
Health	Sensors that measure vital metrics (e.g. blood pressure, heart rate, glucose level) are used to monitor patients as they live their lives. The data is used to schedule future doctor visits, improve patient adherence to prescribed therapies or address hazardous incidents (e.g. unexpected heart attack)
Item location	Sensors that detect the geographical location of an object are used to track objects to save valuable time searching for them or ensure their safety (e.g. prevent children reaching dangerous materials/object, detect theft)
Machines	Sensors that monitor the state of machine parts towards scheduling condition-based maintenance when it is needed, instead of in regular intervals independently from the status of the machine
Noise	Sensors that monitor noise levels and allow appropriate interventions, even in real-time (i.e. permission violations of entertainment venues, noise pollution due to heavy traffic or near a construction site)
Parking spaces	Sensors that detect parked cars are used to detect whether a parking space is free and guide drivers to the nearest available space
Perimeter access	Sensors that detect people in non-authorized areas and can trigger immediate alerts/actions on the right location
Public lighting	Sensors that detect motion of people and vehicles in a street and adjust the public lighting to the required level

(continued)

Table 3 (continued)

Sensors for…	Description
Rivers	Sensors that detect river pollution (e.g. leakage of chemical plants) in real-time allow for immediate actions that confine the damage to the environment
Road conditions	Sensors that detect the condition of a road (i.e. dry, moist, wet, ice/snow, chemical wet) to provide early warnings to drivers
Storage conditions	Sensors that monitor storage conditions (e.g. temperature, humidity) of perishable goods such as vaccines and medicines to secure the quality of products
Storage incompatibility	Sensors that detect objects (e.g. dangerous goods) that are not allowed to be stored/used together (e.g. inflammable goods and explosives, incompatible blood in a hospital's operating room)
Traffic	Sensors that detect the speed and the number of vehicles using public roads are used to detect traffic congestion and make suitable recommendations (e.g. suggest taking an alternative route, inform emergency services)
Waste	Sensors that detect to what extent a rubbish container is filled, to optimize the trash collection routes and to prevent trash being deposited on the street if a container is full
Water	Sensors that detect water leakages in the water distribution network in order to assist the definition of the maintenance schedule

primary goal is to understand and model Smart Cities by taking into account different system topographies, data types, user and business preferences, etc. [61].

From a technological perspective, two key requirements in a Smart City are: (i) the establishment of an intelligent and holistic approach that addresses interoperability and connectivity issues between billions of IoT devices at different levels (e.g. device, network, communication, application, and platform), and (ii) the achievement of low-power and low-cost communication, since currently the operation of the majority of IoT devices relies on a continuous source, rather than a battery [57].

2.3.2 Ambient Intelligence

The goal of Ambient intelligence (AmI) is to infuse intelligence into our everyday environments and make them sensitive to humans. The concept of AmI provides a vision of the Information Society where emphasis is on user-friendliness, more efficient services support, user-empowerment, and support for human interactions. It builds upon advances in the Internet of Things (IoT), Pervasive Computing, and Artificial Intelligence (AI) [62], and delivers an environment featuring intelligent intuitive interfaces—seamlessly embedded in all kinds of objects—promoting multi-modal and sophisticated interaction techniques. Such environments are capable of recognising and responding to the presence and activities of different individuals in a seamless, unobtrusive and often invisible way [63] in order to improve quality of life.

Hence, by exploiting the innovative infrastructure and components (i.e. sensors, smart objects, ubiquitous communication networks) in a wide range of Smart environments (e.g. homes, offices, hospitals, public spaces, and leisure environments), intelligent, individual and collective services are developed to accommodate user needs in real-time, through innovative multimodal interaction techniques (i.e. tangible interaction, mixed reality) [63, 64].

In past years, many research projects have applied the paradigm of AmI to a variety of environments such as the home, classroom, workplace, museum, department store, hospital, etc., revealing its potential to support various aspects of living (e.g. work, leisure, education, healthcare, transportation) [65]. Many of the aforementioned environments constitute core components of the city as we know it and live it. Therefore, AmI is expected to improve urban life specifically and the commonwealth in general [66]; that is why the design of Smart Cities heavily relies on the vast opportunities offered by Ambient Intelligence (AmI) and other emerging technological innovations [67]. The link between Smart Cities and AmI becomes more apparent when considering that they share the same agenda, which entails improving the quality of life inside homes, hospitals, airports, etc. According to [66], Ambient Intelligence enables human beings to take advantage of most of the city environment by unlocking opportunities that were not known or let alone perceived just a few years ago [66].

2.3.3 Big Data

Smart Cities connecting billions of devices provide a massive amount of information and data for analysis, including information from surrounding environments, public data, user private data, etc. [57]. Given the above, Smart city initiatives are particularly interested in the collection and management of such data and their analysis towards optimizing city functioning in an intelligent and informed manner. However, they need to address two fundamental challenges that inherently emerge: (i) the large volume of data (i.e. Big Data) and (ii) the process of examining it (i.e. Big Data analytics).

Big Data are a large pool of unstructured data that can be captured, stored, analysed and managed. This large set of data is not useful until it is examined and assessed through Big Data analytics which uncover the unknown correlations, hidden patterns and other valuable information [68]. New technologies provide the opportunities to gather and effectively use Big Data to enhance information awareness, facilitate prompt decision-making and offer opportunities for social interaction (Fig. 3). Within a Smart City, Big Data, collected through various sensors and sophisticated software agents, allows the automation of a number of real-time services which can improve the quality of life, such as finer urban management by using intelligent traffic light patterns during peak hours, efficient routing of garbage collection trucks, reduced water consumption in parks, monitoring of the use and condition of public infrastructure, etc. [69, 70].

Fig. 3 Big data are mined in Smart Cities to enhance various city services

However, for Big Data to be successfully employed in a Smart City, the following major issues must be addressed a priori [57]: (i) protection of user privacy during data analysis, (ii) anonymization of sensitive data, (iii) establishment of appropriate infrastructure to collect, store, and analyse the huge amount of data and (iv) provision of the required computation power to extract new knowledge from them.

3 Interaction Within Smart Cities

In the first generation of Smart Cities (referred to as ‘Smart City v1.0’) citizens were mostly considered consumers of data, therefore the most prevalent approaches of the past decade mainly focused on interaction paradigms that aimed to accommodate information consumption. Nevertheless, with the emergence of the ‘Smart City v2.0’, in which users are inherently considered to be vital elements of the city, interaction approaches evolved so as to support these new roles and objectives (i.e. permit active participation and collaboration) [71]. The rest of this section briefly reports the most common interaction paradigms encountered in a Smart City and then present various relevant examples and case studies.

3.1 Interaction Modalities

The varieties of sensors which are available on the market can sense the environment and enable many different types of interaction modalities. Such sensors include touch and light sensors, motion detection sensors, microphones and cameras, Bluetooth / RFID scanners for presence sensing, Global Positioning System (GPS), the Global

System for Mobile Communications (GSM), WLAN-based location sensing, etc [72].

Especially with respect to user interaction in public spaces, two different types can be distinguished: explicit and implicit. In explicit interaction the user tells the computer at a certain level of abstraction what she expects it to do; in implicit interaction the user executes/describes an action, which is not directly meant to trigger an interaction with a computer, but is nevertheless considered an input and interpreted accordingly. For example, a user may walk through a door, causing the lights to go on. Similarly, she may type on a keyboard, and her typing patterns may be used to authenticate her. Table 4 presents the main modalities appropriate for interaction in public spaces within Smart Cities [72].

3.2 Explicit Interaction with the Smart City

Information nowadays is rich, interconnected, not enclosed in a specific system, but rather omnipresent in our surroundings, especially in the context of a Smart City. Therefore, the adoption of interactive visualizations holds a key role in providing insights on Big Data and IoT [73]. Both administrators and the public require intuitive visualizations [74] which provide access to the city's Big Data and illustrate information in an easily perceived manner, about various domains such as energy management, networking, decision support systems, traffic monitoring and logistics [75]. However, when deployed in Smart Cities where the general public is expected to interact with them in diverse contexts, such visualization tools (e.g. Visual Analytics, Dashboard, Geospatial Visualizations) should be implemented following the User-Centred-Design (UCD) [76] principles, so as to ensure that they will be effective, efficient and used [77]; Experience-Oriented Design [78] has been applied in the context of a Smart City as well, with positive findings.

3.2.1 Visual Analytics & Dashboards

Visual Analytics (VA) aid the design of the cities by providing appropriate visual representations that link various city aspects (e.g. locations, infrastructure) with their related tasks, as well as reflecting the quality and added value of the urban design [79]. Moreover, visualizations based on web technologies constitute an integral part of displaying cross-platform visual analytics in a manner familiar to both administrators and the general public [75]. Table 5 lists some examples of services available in Smart Cities and the corresponding use of VA. For example, by combining chart representations, cartography, augmented and virtual reality, web analytics are successfully applied for gaining insights on statistical characteristics of IoT infrastructure and metrics [80], representing spatial data [81], and conducting urban design [82].

Table 4 Interaction modalities in Public spaces (adapted from [71], [73] and [72])

Modality	Description
Presence	A wide variety of sensors allows for sensing the audience in the vicinity of a display, such as cameras, microphones, Bluetooth and RFID scanners, pressure sensors, etc. Presence sensing is mainly used to trigger implicit interaction, often with the aim of getting the user involved into interaction with the display
Keyboard	The aforementioned modalities are often not easily understandable at first glance, especially when it comes to explicit interaction. In contrast, a standard keyboard or mouse provides easy means for enabling interaction with a public display (e.g. ATM)
Touch	Touch-based interfaces have been increasing popular with the advent of the iPhone and other mobile multi-touch devices. At public displays, touch sensors enable direct interaction, since users can explicitly interact with the screen by manipulating objects
Remote Control	Controlling displays is not always possible through direct interaction (i.e. long distance, too large displays); to that end smartphones or tablets can act as a mediator between users of a public space and various types of displays (e.g. billboards, media façades). In addition to their ease-of-use, they minimize a participant's public exposure and consequently are relatively effective in encouraging opportunistic interaction
Body position and posture	2D or 3D Cameras, pressure sensors in the floor, motion sensing devices or low-frequency waves can be used to detect presence and determine the exact position and posture of a person in front of a display. Knowing the position allows for a more sophisticated way of interaction by displaying or updating content close or in relation to the user's position. Moreover, body orientation and proximity can detect whether the user approaches a display to interact with it (i.e. faces it) or passes by
Body and Hand Gestures	Several technologies enable gestures (accelerometers, touch sensors, mouse, gaze-tracking cameras) while interacting with public displays. In particular, hand gestures are used for in-direct, explicit interaction (e.g., for manipulating objects or controlling the screen), while body-based gestures allow interaction with digital systems to take place without the presence of any specific device operated or worn by the user, leveraging from people's innate skills of using their bodies to interact with the world
Gaze	Knowledge about the user's direction of gaze, along with precise trace of a user's gaze path can be used to measure attention (e.g. exposure to digital signage) or learn audience preferences (e.g. preferred content in different situations)
Speech	Microphones in the vicinity of a display can be used to sense keywords of ongoing conversations, estimate the number of people close by (single person, pair, multiple people), thus allowing content to be either adapted implicitly or voice commands could be used to let users explicitly control the displayed content

(continued)

Table 4 (continued)

Modality	Description
Facial Expression	Nowadays a variety of software and hardware is available which allows for recognizing facial expression and mood (e.g. happy, sad, surprised, angry). Such information is used to customize interaction based on the user's psychological and/or mental state (e.g. supress less important messages when the user is stressed)

Table 5 Available services in the Smart Cities and the corresponding role of VA [83]

Services	Indicative VA uses
Maintenance and management of asset(s)	Asset performance index, optimal intervention points analytics
Connected and involved citizens	Citizens satisfaction levels, citizens awareness levels index
Infrastructure based on sensors	Data quality index, transportation conditions index, traffic forecast
Smart land-use	Observed rates for different land uses and travel between zones, land value transportation index, zone accessibility index
Business models strategy and partnering	Percentage of private sector investment, number of partnerships, improvement in service delivery, private-public sector interaction and money investments
Urban automation	Percentage of automated vehicles within the entire citywide convoy, percentage of automated vehicles in use by city public and private groups, proportion of deliveries made by automated vehicles, proportion of passengers carried by automated transit
User centric mobility	Citywide mobility index, user satisfaction index, transportation service delivery reliability index

In addition, given that such visualizations quite frequently present Big Data comprising multidimensional data sets, various approaches and advanced visualization methods enable interactive filtering and provide a clear view of the data from different perspectives, with Online Analytical Processing (OLAP) through pivot tables [84], plots [85], tree maps, circle packing, sunburst, parallel coordinates, streamgraphs and circular network diagrams [86], being indicative examples. In particular, when designing an interactive urban VA aiming to assist with the design of a Smart City [79], the following features could benefit the overall process: (i) geo-visualization of the city design in 3D or 2D maps or various sorts of virtual environments to aid city designers and users to experience the design from different perspectives [87], (ii) layout of the city networks for understanding the interaction among users and their actions/movements [88], (iii) social media integration to reflect the users' communication in the real and virtual design of the city [89], and (iv)

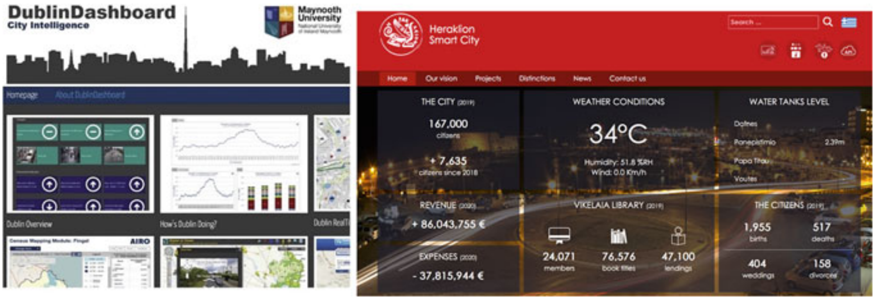

Fig. 4 Dashboards deployed in the Smart Cities of Dublin[2] and Heraklion[3]

sustainable planning based on the feedback given by users towards the improvement of the designs [90].

On the other hand, a growing interest in collaborative models of Smart City governance ('Smart Cities v2.0'), where the curation and management of data assets aims to support a city's strategic priorities, resulted in digital dashboards becoming extremely common management tools [71]. In particular, by providing access to a number of linked services and software, key performance indicators and metrics have in turn informed the design of a number of urban data platforms. These tend to function as 'data showcases', and feature a wide array of data visualisations from public or private service providers, intended for wide audiences (Fig. 4). Such systems usually offer windows that integrate live data feeds from official, observational and social media data into a single interface, thus summarizing what is happening in a city [71].

As literature suggests, Visual Analytics tools and methods encourage collaboration and communication between entities, enable the provision of innovative services from many sectors of a Smart City, improve customer's experiences and enhance business opportunities [79]. In particular, numerous use cases reported in the recent literature highlight their usability; e.g.: (i) Smart grids enable researchers to integrate, analyse, and use real-time power generation and consumption data along with various environmental data (e.g. weather conditions), (ii) Smart Healthcare related analytics allow specialists to collect and analyse patients' data, (iii) Smart transportation help the improvement of the transportation systems in terms of minimizing traffic congestion (e.g. provide alternative routes when needed), (iv) Smart governance data analytics help governments implement policies taking into consideration the needs of the people in terms of health, employment status, social care and education, or (v) comprehensive data snapshots that provide 'windows' into understanding, the city, delivered, through map or grid views [71].

Ultimately, the design and implementation of a city dashboard should reflect which of these functions are the most important ones to its intended audience. For example,

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[2] http://www.dublindashboard.ie/pages/index.

[3] https://smartcity.heraklion.gr/en/home/.

if a city dashboard has been developed as a community engagement tool, but is simply publishing an open data catalogue without facilitating online or offline discussion with stakeholders, then it may be seen as ineffective. Similarly, if a dashboard is developed as a reporting tool by the government, but fails to publish underlying data assets, then it may be subject to criticism [71].

3.2.2 Geospatial Visualisations

The significance of spatial data was mentioned in 1970 by Tobler's first law of geography [91], where "everything is related to everything else, but near things are more related than distant things" regardless of information interconnections. As such geospatial big data constitute a significant portion of Big Data [92], geo-spatial data visualisation becomes a powerful instrument for interactive Visual Analytics by placing geo-spatial data in a visual context and identifying trends and patterns that usually go unrecognised in text-based data [79]. Further, Geo-Visualisation (GV) techniques help in presenting geo-spatial data in more sophisticated formats, beyond the typical spreadsheets, charts and graphs, by using infographics or maps (e.g. bars, pie and fever charts, sparklines, hyper maps, heat maps, 3D globes); such approaches can communicate relationships between the geo-spatial data values more effectively [79], by displaying information with regard to their location in space. In terms of interaction, geospatial representations allow for map projection, panning and zooming actions [93]. Moreover, interactive GV can be combined with automated analysis techniques, thereby assisting in the easier understanding of geo-spatial data

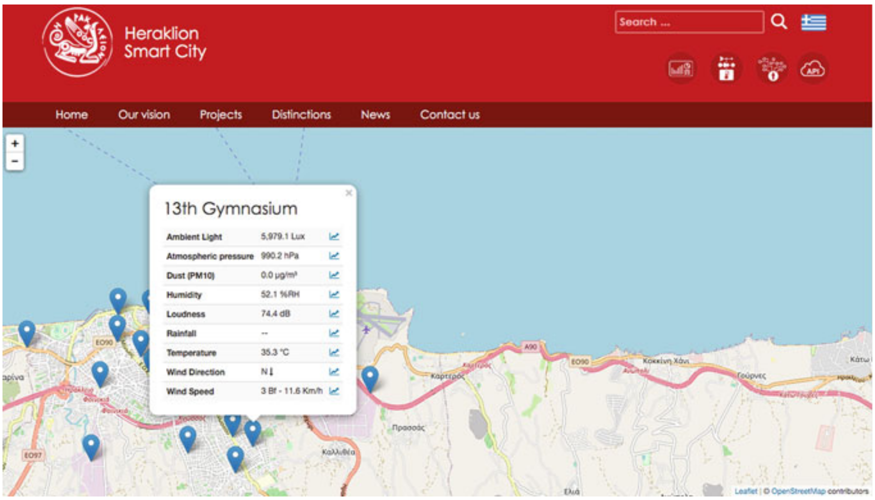

Fig. 5 Visualization of the Heraklion Smart City IoT infrastructure[4]

along and supporting decision-making (e.g. divide the city into several components varying over space, time, spatial scales) [79]; such an example is presented in Fig. 5.

In terms of utility, GV and VA collectively support cooperation and interaction between different entities of the smart city and provide various services that help in better customers' experiences and growth prospects [79, 94, 95]. Together, they have a predominant potential for many social applications in the Smart City such as disaster response, disease surveillance, climate change, weather monitoring and forecasting, infrastructure management, transportation and navigation [79].

With respect to visualization, the techniques that are mostly used for visualising sensorial data are scatter plot, heat maps, height maps, survey plot, logic diagrams, parallel coordinates, multiple line graph, summon plots and multi-dimensional scaling, polar charts,, quartile chart, trees, networks and glyphs [79]. Moreover, the combination of the time and space dimensions provides temporal and geo-spatial correlation and helps in interactive visualisation. Examples are population development over time, epidemic spread over time and movements of various sorts (e.g. traffic, animals, pedestrians, hurricanes, particles) [96, 97].

Recently, 3D visualization has gained increasing interest in various different domains, due to its ample advantages over 2D approaches [98]. Geo-spatial data can be visualised in 3D as 3D globes, vector maps or by rendering to 2D maps [79]. In particular for urban modelling, 3D visualization becomes a necessity, as the results need to be analysed and presented directly at the building object, thus such views provide more realistic results and help in comprehensive city planning activities (e.g. flood modelling), visibility of impacts and clarity of new developments [94, 99, 100]. As a consequence, spatio-temporal visualizations play an important role in understanding and discovering predictive patterns, supporting decision-making and better representing the real world [101].

3.3 Implicit Interaction & Proxemics Within a Smart City

Communication between humans is based on implicit contextual information, such as gestures, body language, and voice [102]. In more detail, human-to-human interaction, and the entire context under which the interaction takes place, carries information that is often implicitly exploited in the exchange of messages [103]. The interpretation of such messages can be achieved by observing both actions of the individuals and the events ongoing in the surrounding environment. In order to describe such interactions, that differ from traditional purposeful and attention demanding ways of interacting with computers, the term Implicit Interaction was introduced [104].

As opposed to the idea of invisible computing, traditional Human–Computer Interaction requires frequent user interventions in order to indicate every action to the computer [105]. According to Mark Weiser's [106] definition, Ubiquitous Computing is characterized by having many devices throughout the physical environment that

[4] https://smartcity.heraklion.gr/en/open-data/#!/infrastructure-map.

are invisible to the user who uses them without even thinking about their presence. Indeed, research in pervasive and ubiquitous computing has established the fact that the ‘computer’ is no longer associated with a single device or a network of them, but rather the entirety of situated services originating in a digital world, which are perceived through the physical world [107].

Within such technologically-enhanced physical environments the following can be observed: (i) sensing and controlling the physical world can be accomplished via a huge variety of sensors and actuators, (ii) applications and services exploit context of use and existing knowledge to deal with dynamic environments and changing resources and (iii) technology can make inferences about the situationl hence, “explicit interactions” no longer proliferate. Instead, implicit interaction replaces a part of explicit interaction, where a system’s behaviour towards achieving specific goals is guided by the users intentions, rather than by the users actions [104]. The novel interaction paradigm of Ambient Intelligence facilitates implicit interaction by entailing a shift from conventional interaction and user interfaces towards human-centric interaction and natural user interfaces (e.g., direct and indirect communication with all sorts of everyday objects) [108], while acting adaptively and proactively to intelligently respond to user needs. In particular, AmI environments support natural (i.e. implicit) forms of communication attuned to human senses, such as facial expressions, eye movement, hand gestures, body movements and postures, speech and its paralinguistic features, and psychophysiological responses.

Context-aware systems utilize such implicit forms of communication to acquire information as input for interaction and interface control, enhance their computational understanding of interaction with users and adapt their behaviour accordingly to satisfy their users’ needs in a timely, intuitive and effortless manner. Indeed, nonverbal behaviour, which constitutes an inherent part of direct human communication, plays a significant role in conveying context by providing a wealth of information about the user’s emotional, cognitive, and physiological states, as well as actions and behaviours. According to [107], depending on the type and number of involved entities, the following modes of implicit interaction can be defined:

- **Person-to-Person**: technology acts on behalf of people, once a certain relation (e.g., spatial relation like ‘close to each other’) has been verified; e.g. friend finder applications, lost and found systems.
- **Person-to-Artefact**: technological artefacts (e.g. a virtual object, a software agent) are provided with functional autonomy in the name of the entire system, but the control still remains with user. The beneficiary is still the user, but they interact with a digital object, instead of a person on the other side. Example applications are variants of smart spaces like intelligent classrooms, interactive kitchens etc., or smart applications like smart cabinets, smart appliances, etc.
- **Artefact-to-Artefact**: autonomous digital objects interact with each other to achieve certain goals on behalf of the human user or the system itself. The end user does not necessarily need to be involved in the interactions among artefacts; this can happen unobtrusively in the background (e.g. a smart fridge automatically orders goods that will soon run out from the local groceries store).

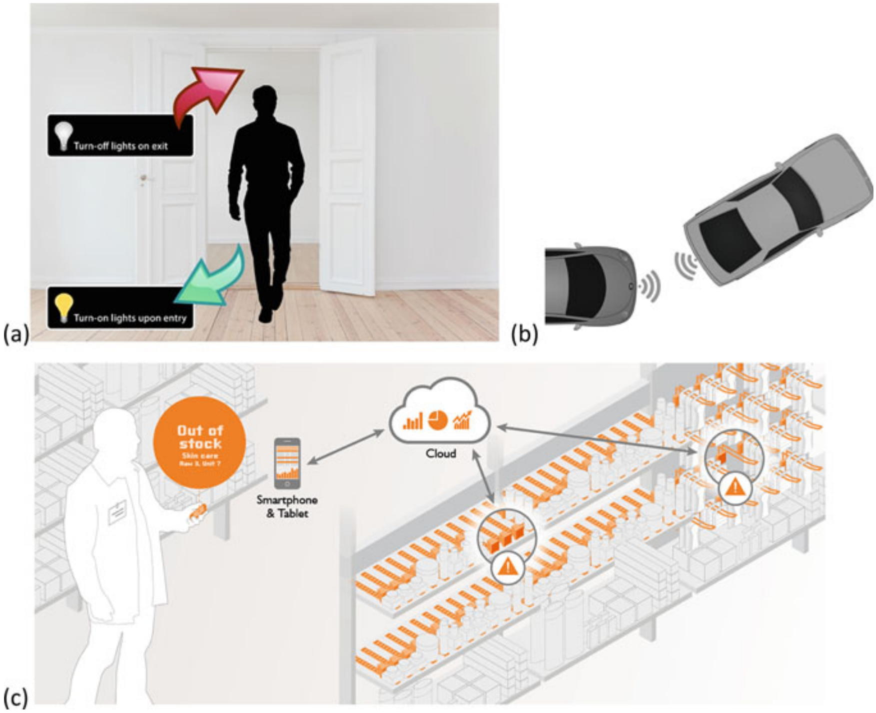

Fig. 6 Presence sensing examples: **a** human presence, **b** vehicle presence and **c** in store items location[5]

3.3.1 Categories of Information Exploited for Implicit Interaction

Based on the kind and amount of information an application uses to trigger and steer implicit interactions [107], it is expected to use data from any of the following categories:

- **Presence**: information regarding the presence or absence of people or things. Examples of systems that accommodate implicit interaction based on presence recognition (Fig. 6) are: (a) automatic lighting as user walks in a room: presence sensors detect the user and the lights turn on [109]; (b) automatic vehicle detection to help in parking: both vehicles generate alarms as they approach each other [110]; (c) a smart shelf indicating in-stock and out-of-stock status of items [111].
- **Identity**: input is not the mere presence, but the recognized identity of the entities involved in the interaction (e.g. the person's ID, the serial number of a product, the MAC address of a network node). Example of systems that offer implicit interaction based on identity sensing include (Fig. 7): (a) access control: only an authorised user is allowed to enter an area [112]; (b) Automatic toll payment: cars

[5] https://www.imco-berlin.de/en/.

Fig. 7 Examples of identify sensing[6]

do not need to stop at the tollhouse; the identity of licensed vehicle is sensed and the amount is automatically debited from the driver's account [113]; (c) personalised controls: car offers personalised settings based on the identity of the current driver [114, 115].

- **Proximity**: information about the mutual spatial relationships among entities involved in the interaction (e.g. distance, direction, topology). Examples of systems that use proximity related-date to enable users to implicitly control them include (Fig. 8): (a) a public wall display, which based on the proximity (nearness) of the user changes appearance and contents [116]; (b) a car adopting the right cruising speed with respect to the preceding car, or generating an alarm as it senses another vehicle approaching too close [117].
- **Profile**: predefined self-description of the entities involved in the interaction (e.g. associations, preferences, tastes, habits, goals, needs, capabilities, emotions). The self-descriptions of objects are encoded as metadata, which when related to an

[6] Daimler AG.

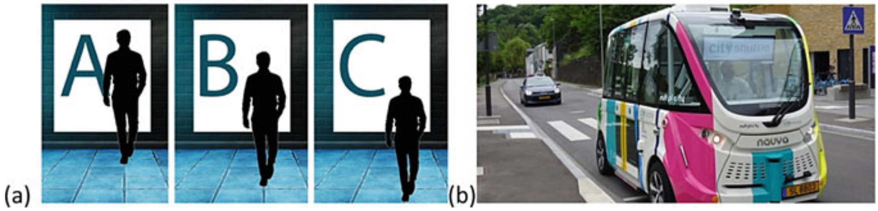

Fig. 8 Examples of proximity sensing

object may cover material properties, object structure and general physical characteristics, whereas when referring to a person could indicate physiognomic properties of that person, personal preferences, likings or habits, intents, capabilities, goals or even emotions. The exchange of profiles is automatically triggered among co-located objects and their analysis enables systems to best adapt the interaction to the individual counterparts. Examples of profile-based implicit interaction include (Fig. 9): (a) in person-to-person interaction, exchanged 'business profiles', could help to check the level of 'compatibility' between two people [118], (b) in artefact-to-artefact interaction, an application may assist in alerting about a situation in which a container with certain contents must not go with a container with incompatible contents, (c) in person-to-artefact interaction, public display systems that can present content that 'matches' the interest of the nearest or the most "promising to interact" user [119].

Context: any available information that describes the situation of entities involved in the interaction. A context-aware system can be designed to be reactive or proactive. For example, a reactive context-aware system could be the heating indoors system which reacts and adjusts the thermostat as the temperature outdoors changes [120]. An example of a proactive context-aware system is a system that identifies recurring patterns of user activities from sensor data time series, and -learning from this experience-estimates the user preferences and acts accordingly [121].

Human Context [50]**:** for a Smart City to provide services and applications tailored to improving people's lives (e.g. healthcare, transportation, energy use, education, entertainment), it must be able to sense and monitor the people themselves through human context sensing. Human context sensing is structured into four categories that holistically capture the user's condition and their interaction with the world around them:

Physiological Context: involves measuring biological signs that are vital for sustaining a healthy life. Tracking vital signs is critical to the detection, prevention, and treatment of diseases (Fig. 10).

Emotive Context: refers to sensing the emotional state of an individual, including for example stress, happiness, engagement, and general emotional intelligence, has far-reaching consequences beyond just determining if someone is happy, or sad, or inattentive (Fig. 11). In particular, emotive context can be used to identify, diagnose and react to the user's physiological context (e.g. assist a fast-breathing individual

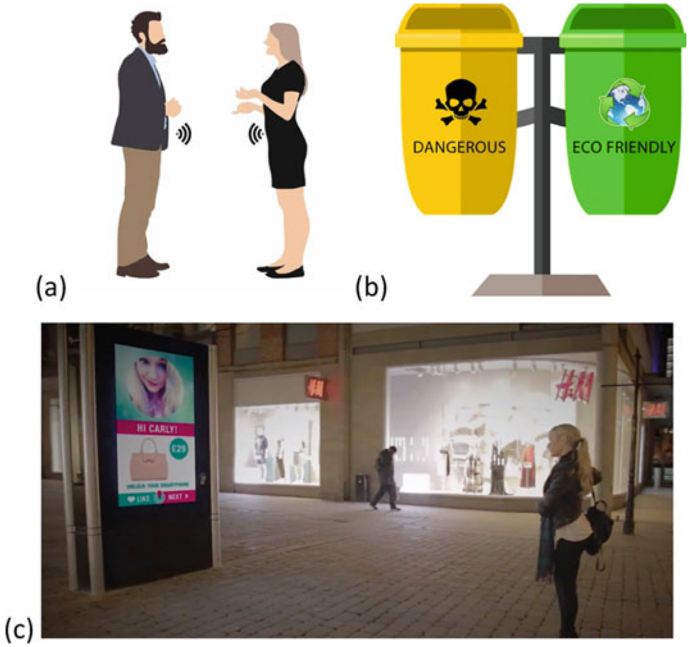

Fig. 9 Examples of profile sensing[7]

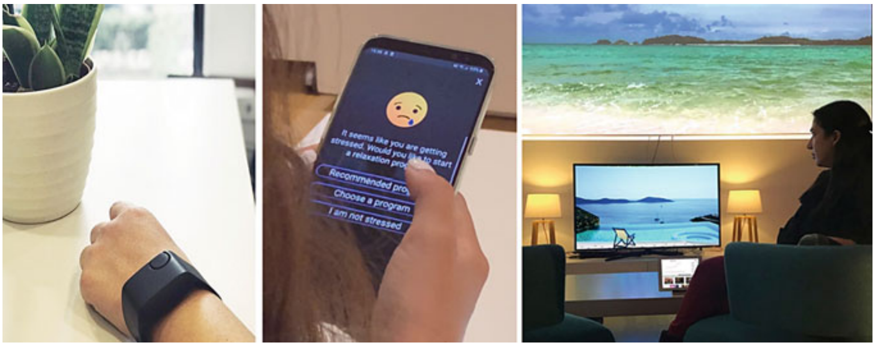

Fig. 10 The CaLmi system [122] monitors physiological context to assist users in managing their stress level

when being stressed as opposed to when exercising, prevent a distracted user from crossing a busy intersection). Moreover, in the future emotive context can affect larger domains such as online advertising and recommendation, education, entertainment (i.e. video games industry), mobility (i.e. vigilance while driving), and health (i.e. depression).

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[7] http://www.offermoments.co.uk/.

Fig. 11 The LECTOR framework helps teachers to monitor students' attentiveness [123]

Fig. 12 A variety of functional context encountered in a city

Functional Context: is the detection of the state of a user's activity and ability that can help assess activities of daily living (ADL) that individuals perform (Fig. 12), including a huge variety of them such as eating, walking, and recurring daily routines. Knowing the functional context enables the development of applications that can assist individuals in their daily life (e.g. assisted living of elderly), diagnosis of medical conditions or prediction of health challenges (e.g. cognitive decline), personal energy accountability, citizens in improving their personal skills, etc.

Location Context: concerns the identification of a person's whereabouts and any nearby smart objects (e.g. devices) or spaces (e.g. a smart building) with which that person could interact at that location. This information is often combined with additional context (e.g. profile), so as to deliver location-sensitive personalized services to a user (e.g. navigate safely foreigners within a city they are visiting for a first time, guide patients back to their room in a hospital, encourage wasteful users to change their behaviour by prompting them to turn-off the heat when leaving home).

3.4 Interaction in Public Spaces

The widespread use of mobile devices has unlocked new potentials on how ICT can improve numerous aspects of daily life. In combination with the emergence of Ambient Intelligence and Ubiquitous Computing and the growing interest in applications of interactive technologies in various public settings such as museums, schools, galleries, theatres, shopping centres, clubs, etc., interaction with computers has become a public issue with various extensions (i.e. universal access). Consequently, crafting interaction for public settings raises new challenges for Human–Computer Interaction (HCI), widening the focus of design to extend beyond an individual's interaction with a single system, to also consider the ways in which interaction affects and is affected by third parties (e.g. spectators, bystanders) [124] and the physical surroundings.

Interactive public spaces have been the focus of extensive academic research in the past decade [125]. Increasingly, HCI studies have expressed interest in the design and implementation of digital applications that are socially situated, highly context dependent, often not task oriented and addressing scenarios outside of the traditional realms of home and working environments, in an emerging trend that has been referred to as the third-wave of HCI [126–128].

Many research approaches focus on providing digital urban interventions, ranging from interaction with shopping windows [129], virtual fitting rooms [130], multimedia kiosks [131], digital walls [132] and situated public displays [133] to large-scale artistic installations [134, 135] and media façades [136].

3.4.1 Types of Interfaces

According to [125], users interacting in public settings fall under two main categories: Performers (those engaging in the interaction) and Observers (those passively watching from the outside), while three types of interfaces can be identified:

Performative Interfaces. They encourage direct manipulation by a limited number of participants and take the form of screen-based interactions (media façade, digital billboards, interactive walls, etc.) within delimited interactive zones. They promote not only isolated interaction, but also cater for small groups of simultaneous performers, who -during their shared session- transform the presented content in a collaborative manner. Such interfaces occasionally serve as a conversation starter between observers (i.e. ICT-mediated social triangulation).

Allotted Interfaces. They are usually large interfaces that can accommodate multiple participants interacting simultaneously with the system, scattered along the full extension of the interface. Due to the physical dimensions of the interface, individuals, despite being aware of the fact that they belong to a broader group, usually tend to focus the centre of their interaction on themselves and pay less attention to the actions of any other peers nearby, thus leading to an individualization of the interface usage.

Responsive ambient interfaces. Such interfaces are purposely designed to appear non-interactive despite responding to input from the audience. In particular, rather than giving passers-by direct feedback and inviting them to engage in performative interaction, the design aims to spread their focus to elements on the surrounding environment, thus making participant unaware of their 'performance'. On the other hand, external observers perceive that the responsiveness and interaction with the interface is indirect.

3.4.2 Phases of Interaction

The *audience funnel* models the different phases of interaction with interactive public displays [137] and can be used to decompose the observable audience behaviour into multiple phases, where a threshold must be overcome for people to pass from one phase to the next [72]; these are properly adjusted to raise attention, attract curiosity, or motivate people to start interacting. The *audience funnel* can be applied beyond display-based interaction and guide the design of any interactive public system in the context of a Smart City:

- **Phase 1 (Passing by)**: A system should be aware of and monitor all people passing by (without knowing whether they intend to interact with it or not), as they could potentially attempt to interact with it
- **Phase 2 (Viewing and Reacting)**: If a system detects that a user's attention has been successfully attracted (e.g. they look towards it or react to it by smiling or turn their head), then it should get ready to respond to any implicit or explicit user actions
- **Phase 3 (Subtle Interaction)**: When a system recognizes that a user wishes to start interacting with it (i.e. subtle gestures or movement through which a user checks the effect of her actions on the system), it should immediately inform about its availability, in a multimodal manner
- **Phase 4 (Direct Interaction)**: When the user engages in more depth with the system (i.e. position themselves closer to the system), then it could make use of contextual information (e.g. user profile, available devices) to further enhance interaction (e.g. personalization)
- **Phase 5 (Multiple Interaction)**: The system should anticipate that interaction might be interrupted unexpectedly and permit the users to seamlessly resume with their task using the any instance of the system (i.e. same or different, co-located or not) after a break
- **Phase 6 (Follow up Action)**: Finally, when a system detects that a user is about to depart, it should try to achieve closure by offering context-sensitive follow-up actions (e.g. take a photo, share in social media, suggestion to migrate the task to a personal device).

3.5 Mobile Crowd Sourcing

The continuous advancements in ICT technologies along the emergence of various disciplines such as Ambient Intelligence, IoT, Ubiquitous Computing, Artificial Intelligence, etc., have enabled a shift towards measuring numerous aspects in a decentralized manner, rather than relying on expensive centralized infrastructure. This direction is further compelled by the fact more people are gathered in urban areas, thus making monolithic solutions unsustainable. Meanwhile, users own several smart devices (e.g. smartphone, smartwatch, in-vehicle devices) equipped with various sensors (e.g. accelerometer, gyroscope, digital compass, light sensor, Bluetooth), with advanced computational facilities and networking capabilities, which can be used as important sources of sensed data instead.da

Consequently, mobile crowd-sensing (MCS) is defined as a category of applications "*where individuals with sensing and computing devices collectively share data and extract information to measure and map phenomena of common interest. Here citizens and/or their mobile devices act both as sensors and actuators, thus making the cities smarter though citizen's active participation*" (p. 237). Based on the sensing pattern, crowd-sensing applications can be classified into (i) personal sensing (i.e. data are captured from the device of a single user) and (ii) community sensing (i.e. data are collected from many individuals in order to monitor environmental phenomena around a region) [50].

With respect to user involvement in MCS, the following user-centric paradigms can be identified [138]:

- Participatory (personal or community) sensing: users join the task of sensing on demand, using their devices to collect and share information
- Opportunistic (community) sensing: mobile applications opportunistically seamlessly exploit all the sensing technologies available in the environment without any direct user interaction
- Opportunistic (community) mobile social networks: users directly generate and share content with nearby users in real time by exploiting the physical interactions of their devices.

With respect to their application domain, crowd-sensing applications for Smart Cities are classified into the following categories [50]:

- Infrastructure: large-scale phenomena related to public infrastructure are monitored (e.g. travel planner, public parking space availability, bike sharing)
- Environment: participatory sensing is used to monitor natural environment (e.g. pollution, water levels, wildlife)
- Social: individuals share sensed information among themselves (e.g. a community of diabetics who watch other diabetics and control their diet or provide suggestions).

3.6 Examples and Case Studies of Smart City Applications

When we think about a Smart City where the management and control of the city's resources is performed through intelligent information systems, we need to consider the food, energy, and water nexus. The development of IoT-based systems that aims to address these concerns, as well as the Big Data stemming from such systems, is critical for the optimal provisioning and efficient utilization of the city's resources. In addition, providing smart solutions for transportation, healthcare, convenience, agriculture, economy and government are the main premises of a Smart City [15].

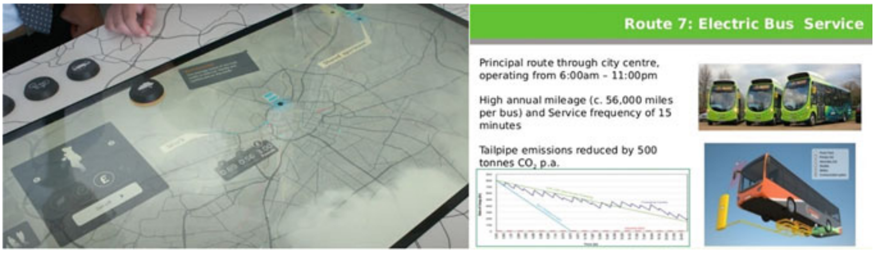

Fig. 13 Applications developed in the context of the Milton Keynes Smart project[8]

3.6.1 Smart Environment

As mentioned in Sect. 2 (i.e. "Enabling Technologies"), the abundance of sensors that is currently available and can be deployed within a Smart City can assist towards improving the overall natural conditions, monitor pollution and supports environmental protection [11]. To that end, various approaches have been developed towards collecting such information and delivering it to citizens and local authorities, in order to get a better picture of the city's environmental landscape and uncover potential issues that need to be addressed.

The Milton Keynes Smart project [57] developed a data hub (Fig. 13) within the city that collects and manages data received from several smart devices. The project emphasized controlling carbon emissions and supporting sustainable growth without deploying additional infrastructure. Also, it delivered transportation system, water usage, and smart energy solutions and a set of applications that promoted business, education, and community engagement activities.

Air Quality is another environmental aspect that needs to be closely monitored in order to improve the quality of life of the citizens. To that end, [56] and [138] deployed in the city customized sensing stations, built using IoT technologies, so as to monitor temperature, humidity and CO_2. In particular, the SmartCitizen app [138] presents on a map the air quality index not only to citizens but also to expert users as well, such as employees of the local municipalities, so as to enable informed decision-making with respect to that matter. Along the same lines, [139] constitutes an example that shows how even a single scheme introduced by the city and embraced by the citizens through incentivization can produce various infrastructural, societal and business values. Specifically, it introduced a "smart car controller", which constitutes a device able to remotely locate a vehicle, monitor its emissions, and possibly start, stop or restrict its movements, providing the possibility to better plan and manage the overall city traffic.

Finally, noise pollution is an important problem that a Smart City aims to deal with, through the integration of fundamental IoT elements [57] or crowd-sourcing [140]. In general, noise-specific data are collected around the city, which is further analysed based on the temporal and spatial noise level to identify noise sensitive regions and

[8] http://www.mksmart.org/.

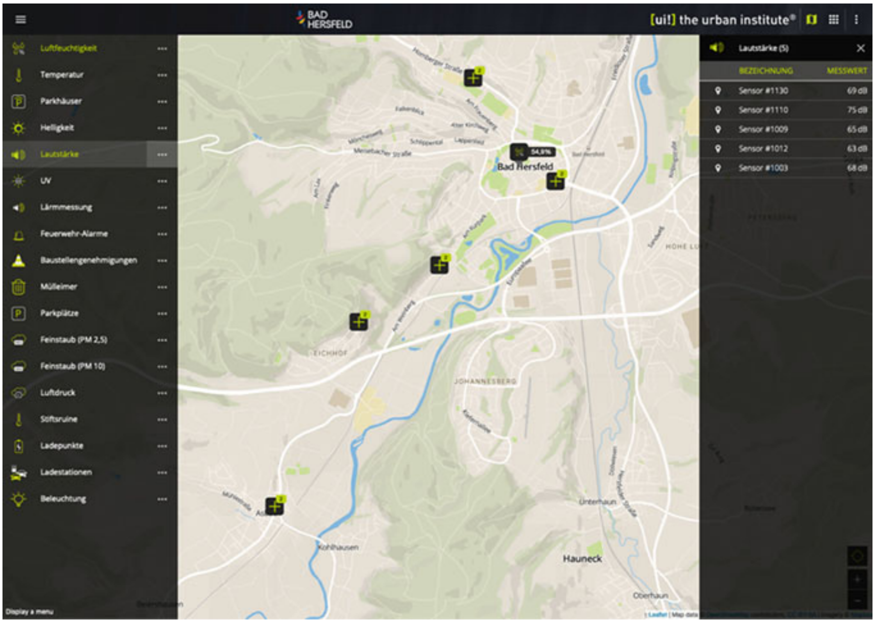

Fig. 14 Live noise pollution in Bad Hersfeld[9] [140]

causes of the noise. In particular, when crowd-sourcing is applied, appropriate noise management components can be integrated into mobile devices to perform offline noise data collection and analysis, while the noise management system only infers meaningful information, such as: (a) identify noise and its event, (b) location-based noise intensity analysis, (c) noise intensity and location-based heat map, and (d) visualization on map and time stamp-based graph generation (Fig. 14).

3.6.2 Smart Grid

Energy conservation is a daily concern for people and energy utility service providers. Around one third of electricity usage is consumed by the residential sector in the European Union, and the demand for energy is predicted to double in the next decade [141]. Energy providers can monitor consumers' energy usage profile and provide suitable feedback to decrease the high peak power load using modern electricity meters (i.e., smart meters) that are installed at customers' premises (Fig. 15). Smart meters can also be connected to smart home systems to cooperate with other devices toward energy management at the smart home level using appliance load monitoring (ALM) [15].

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[9] https://badhersfeld.urbanpulse.de/#!/map/BDHEnvironmentHumidity,BDHEnvironmentNoise.

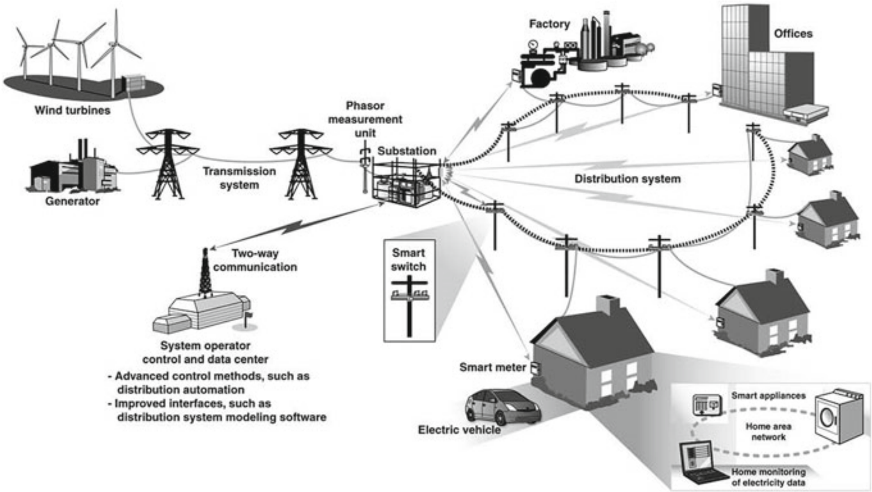

Fig. 15 The concept of a Smart Grid[10]

In this context, each electrical device is equipped with a smart power outlet and appropriate algorithms observe the environment including the energy usage profile of electrical devices, the ambient temperature, the light intensity, and the status of motion detectors, and combine it with other situational factors (e.g. task at hand) in order to learn the best policies towards adjusting the domestic energy consumption based on various conditions within the building (such as temperature and lighting) [142, 143].

In addition to individual consumers, the smart grid can be applied at a city-wide scale to optimize energy consumption; for example, in the content of the Padova smart city project [144], various sensors have been installed on each post, so as to check the correct operation of the public lighting system and collect various information concerning the urban environment.

Finally, from a policy-making perspective, the usage of smart energy in the context of the smart grid has proven its payback as in the case of smart grid in Chattanooga, Tennessee, where using the smart grid helped in faster repairs after a severe storm outage in July 2012 [15].

3.6.3 Water Management

Analytics of big data from city temperature and humidity sensors, weather forecasts, prediction of water usage, and the available water resources can help secure water for drought periods. Moreover, monitoring the level and quality of water in creeks using crowdsensing data along with data from other IoT-based approaches such as smart

[10] https://www.gao.gov/products/GAO-12-507T.

water meters can help achieve efficient and sustainable water provisioning. Using smart water meters can contribute to fine-grained monitoring of water consumption at the house level as well as at the city level. In general, this sort of intelligence has the potential to greatly impact the entire city, as in the case of Kalgoorlie-Boulder, Australia, where the installation of smart meters on the water pipelines led to early detection of leaks, which in turn resulted in 12% reduction in water consumption in one year [15].

3.6.4 Emergency and Crisis Training

A Smart City in many cases has been transformed into a giant educational field, where high-performance teams or coordination of multiteam systems can be trained in emergency response contexts (e.g., pre-hospital and trauma teams) in a high-fidelity real-world live simulation (e.g. instrumented emergency response scenarios such as a staged car accident scene through transport of the patient several miles to the local hospital) [145]. Apart from learning, the installation of such facilities has the potential to unwind new opportunities at an operational level towards improved provision of services such as patient care and hand-off between teams, crisis management, etc.

3.6.5 Waste Management

Waste management is one of the most important challenges for municipal corporations all over the world, while waste recycling is still perceived as a cumbersome task, and people around the world are often struggling with it [146]. In the waste domain, numerous solutions have been proposed towards improving the overall process ranging from isolated smart waste-bins [147] and outdoor dustbins [148], integrating sensors that measure the weight of waste and the level of waste inside them and inform the collection department, to complete IoT-based systems that make use of complex sensor networks towards efficiently monitoring the process of tracking, collecting, and managing solid waste [149]. At an individual level as well, various efforts exploit mobile applications as a way for engaging users in better recycling waste [146].

3.6.6 Smart Economy

Smart Cities aim at improving the quality of life of their citizens not only directly, but also indirectly by creating the necessary infrastructure to improve the efficacy of city management and local business opportunities. Starting from single buildings such as “The Edge”, the greenest office building in the world located in Amsterdam [150], to entire cities such as the Busan Green u-City (ubiquitous city) in South Korea [57] or the City of Edmonton in Canada [151], ICTs empower the establishment of high-tech business-led growth in joint with government and local firms and the development

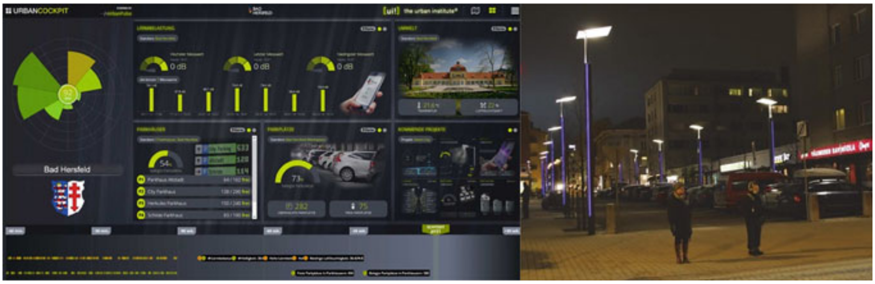

Fig. 16 UrbanPulse cockpit[11] on the left and a pathway in Oulu powered by LightStories on the right

of innovative IoT applications. Moreover, reasonable taxes, low cost to live and to do business, along with an improved transportation system, e-healthcare services, increased jobs and business opportunities, and improved information accessibility through various devices and communication sources, are among the smart attributes that contribute towards providing a strong pro-business environment [150].

3.6.7 Smart Living & Governance

For a Smart City to increase people's quality of life, technical innovations alone are not sufficient, and the social dimension needs to be taken into account as well. Civil society must be actively involved in making Smart Cities become reality. The main focus must be on education, lifelong learning, culture, health, safety of individuals, economic development, plurality of society and social cohesion [152]. Urban everyday life provides sufficient leeway to promote people's creativity and competences, while networking and self-management are major pillars of society without which Smart Cities would be doomed to fail [153].

Smart Cities have the potential of introducing a number of innovative participatory spaces, where the physical and the digital are blended together, and through which citizens are able to actively engage with processes that shape public services and policy. Such spaces include hackathons, living labs, fablabs and maker spaces, Smart urban labs, citizen dashboards, Smart citizens labs, gamification, open datasets and crowdsourcing [154]. Towards such objectives, various approaches, coming in different shapes and forms, aim at stimulating the active participation of citizens in generating and sharing useful contents related to the quality of life in their city (Fig. 16).

The SmartCitizen app [138] is an application that aims to motivate citizens in collecting and sharing data related to the environmental conditions of the city of Pisa; LightStories [155] is an online participatory lighting design tool that allowed for the city users to construct a design from eight different pre-defined static or dynamic

[11] https://badhersfeld.urbanpulse.de/.

lighting effects, which was used to create story-based exercise games for children. The UrbanPulse cockpit [140] has different tiles which present real-time information related to individual digital solutions such as environment management, waste management, traffic management, parking management, noise pollution monitoring etc., which citizens can use on demand (e.g. predict the status of street lights and traffic congestion, get notified about unwanted situations). People's Smart City Dashboard [156] introduces a novel form of public governance that takes traditional devolution further by switching roles between people and government and therefore turns citizens into actions' leaders and governments into followers. This new form of governance uses blockchain technology as an enabler, since its embedded 'community-led by design' mechanisms are essential for community-led approaches. Finally, in rural regions, villagers can communicate with local government by acquiring key information and conducting cost-effective e-gov services efficiently [157], or empowering better access to information regarding products and services [157].

In addition to citizens, city administration can use such platforms that can integrate different smart services into one so as to monitor the conditions of the entire city and recommend geographically differentiated policy actions accordingly [158]. Smart governance is defined as "*the process of collecting all sorts of data and information concerning public management by sensor or sensor networks. New technologies are used to strengthen the rationality of government by using more complete—and more readily available and accessible—information for governmental decision-making processes and the implementation of these decisions*" (p. 400) [158]. Above all, the key aspect of smart governance is "*smart urban collaboration between the various actors in the city, across departments and with communities, helping to promote economic growth and at the most important level making operations and services truly citizen-centric*" (p. *400*) [158], while "*citizen engagement allows two-way communication and enables collaboration and participation, thereby increasing the quality of the relationship between citizens and governments*" (p. 532) [159].

In order to support city officials in administrative activities, advanced visualization techniques (e.g. VR, AR) are used to deliver highly effective ways to simulate the spatiotemporal dimensions of cities in digital reality, while by streaming sensor-based reality data into these environments and bringing the time dimension into a contextualized virtual environment, the space–time domain is extended with an additional context dimension. Such an environment, where real and simulated data are both spatiotemporally generated, creates exciting opportunities for real data analysis and contextualization, as well as testing simulated "what if" scenarios. For example, the "Digital Twin City of Atlanta" is a virtual reality VR-based platform containing a fully modelled city in three dimensions in the virtual space; thus, it facilitates the discovery of interactions and interoperability of its human-infrastructure systems and enables reciprocal spatiotemporal feedback between physical infrastructure and human systems and their virtuals [160].

3.6.8 Smart Mobility

Transportation is an alive sector, and therefore it is essential that it caters for the new mobility requirements and interests of people in the near future, especially since it has to cope with many demands and competing factors, such as comfort, cost, availability, speed, convenience, safety [50], and, most recently, also social distancing [161]. To that end, various solutions have been proposed to enable citizens to reach their destinations efficiently and safely.

Effective and efficient real-time traffic management is a key objective within a Smart City (Fig. 17); therefore, various IoT-based solutions [162] aims to accomplish that task. The city of Bonn uses training data including traffic condition, street light status, construction sites, etc., to predict future traffic condition and construction sites to design a new route and recommendation for users [140]. Smart Santander in Spain [57] is equipped with approximately 20,000 smart IoT devices that perform several intelligent tasks such as measurement of temperature, humidity, speed and position of vehicles, traffic intensity, public transportation conditions and timetables, air quality, and water networks. Ecoconscious cruise control for public transportation offers eco-saving considering the location of the bus, the road slope and the speed of other vehicles on the route, and extracts knowledge in real-time out of the data streams contributing to the situational awareness both regarding the buses and other vehicles in Madrid [143]. In the city of Aarhus, Denmark, a Travel Planner app [163] proposes optimized routes based on the preferences of the user, which taking into consideration factors that impact this optimization (e.g. road, weather, maintenance works, traffic intensity, people density, pollution, air quality, irregularities in traffic schedules, etc.) together with different preference parameters, such as preferred travel time, convenience, total cost, environmental impacts, and personal health. Finally, traffic-related data can be combined with a Smart Streetlight Management System that collects the climate data from the web and/or public weather data, in order to change the colour temperature and intensity of LED streetlight dynamically, thereby improving the drivers' visibility towards preventing traffic accidents [164].

In a smart city, autonomous driving technologies will allow saving time for the user. This technology would help speed up the flow of traffic in a city and save parking space by parking the cars closer to each other. Through a combination of radar, cameras and ultrasonic sensors located around the car, an autonomous car can detect anomalies all around and trigger an alert that automatically activates the emergency brakes to prevent accidents or collisions. Moreover, the Intelligent Transport System could calculate the best route in real-time by connecting different transport modes to save time and reduce carbon emissions [144]. Bus transportation [165] and autonomous taxies [166] that promote urban mobility can benefit from the infrastructure of a Smart City in a variety of ways: (i) computation of travel time and passenger demands in an efficient and economical way, (ii) analysis of passenger transit patterns enabling the detection of causal relationships for delays, and (iii) support of transportation officials in decision making through advanced interactive visualization environments.

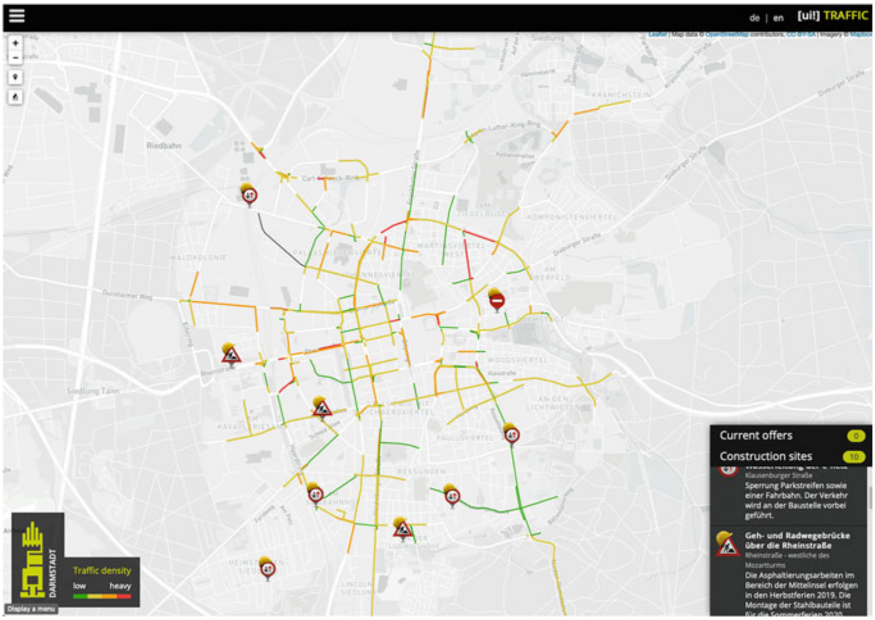

Fig. 17 Live traffic congestion in Darmstadt[12]

In addition to public transport, car sharing is expected to become a quite popular option, since it allows the reduction of urban congestion, of polluting emissions (gas and noise), and in the employment of public space, while fostering a new push towards the use of public transport [167]. Findings also show, following the adoption of car-sharing, a modal shift to other alternative modes of transport with respect to the private car, such as walking or cycling [167]. In particular, free-floating electric carsharing-fleets could become an integral part of future Smart Cities, as they constitute a globally emerging phenomenon with constantly-increasing environmental gains [168].

Parking is another mobility aspect that a Smart City aims to improve. In Bonn, a real-time parking monitor reduces the effort to search for parking as well as increases the parking revenues via monitoring [140]. The San Francisco Park [151] application uses smart sensors to gather data and communicate timely information to the users and minimize waiting for a parking space, while in Aarhus users can find a public parking space easily with a certain degree of probability in different locations, thus reducing the driving time and the environmental impact (CO_2 emissions and noise) via a custom mobile app [163].

[12] https://datenplattform.darmstadt.de/verkehr/apps/uitraffic.

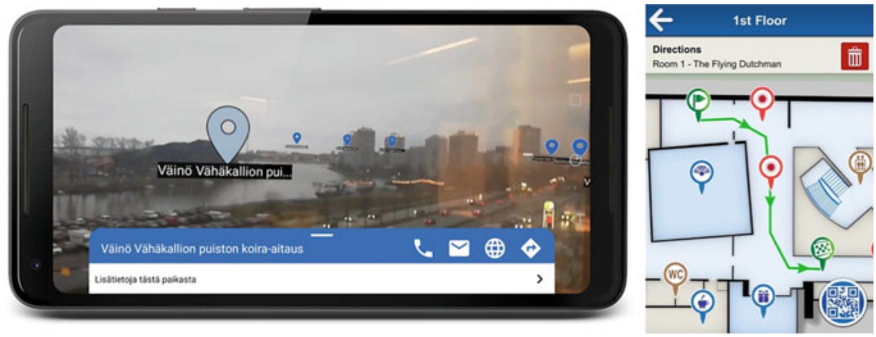

Fig. 18 Service Location[13] and Museum Guide[14] mobile apps

3.6.9 Tourism

Amongst the various domains that may benefit from the introduction of ICTs within a Smart City is tourism. In a nutshell, a 'Smart Tourism Destination (STD)' aim is to utilize the system to enhance the visitors' tourism experience and improve the effectiveness of resource management towards maximizing both destination competitiveness and consumer satisfaction, while also demonstrating sustainability over an extended timeframe [169].

To that end, the key characteristics of an STD include: (i) digitization of systems, processes and services, (ii) a higher level of interface between the tourist and the destination, which takes into account the local community and government among other sectors, (iii) a higher level of engagement of local residents in the provision of the products/services, (iv) a higher level of data generation and use through integrated smart systems and above all, (v) a better orientation towards managing tourist experiences (Fig. 18). Creating and managing tourist experiences in essence is one of the main goals of smart tourism systems. This is possible when, for instance, different tourists interact with a single destination product leading to heterogeneous individualized unique experiences derived from the same product or attraction [170, 171].

An indicative example of the above can be found within the various applications implemented within the 'Smart Dubai Initiative' [172], since Dubai has grown in the use of technology-based solutions in managing key tourism products, services and resources in general, including major infrastructural components such as airport, hotels, transportation, and, in broader terms, in the configuration of specific products and services that deliver value to tourists, which in turn make Dubai being considered as one of the most competitive tourism destinations in the world [171].

Illustrative applications that make use of the amenities of a Smart City, amongst others, include [171]: (i) mobile tour guides which offer a pictorial display of key

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[13] https://play.google.com/store/apps/details?id=com.suomifi.palvelutietovaranto&hl=da.

[14] https://ami.ics.forth.gr/en/project/museum-guide/.

tourist landmarks en route accompanied by an audio commentary, (ii) the use of the traveler's smart phone as a passport, including connection with the e-gate services with the objective of easy clearance during emigration, along with the provision of smart airport services like smart trolleys, which double as a personal guide through interactive, real-time information. Besides applications and services, artifacts or events, entire spaces are modelled to integrate ICTs in order to promote tourism services within a city. An intelligent digital kiosk with a form factor that resembles a totem structure that constitutes an appropriate medium for providing event-aware and localized information to the right audience at the right time and facilitates this citizen-city communication. As a main characteristic, the smart kiosk presents a modular construction constituted by a set of sections that can be assembled as needed using various components (e.g. display panels, speakers, light projectors, tactile screen), each of which is in charge of a specific task and includes the necessary elements to create interactive nodes able to drags people's attention and provide urban services [18]. Examples of the latter case are the Tourism Information Centres of Heraklion[15] and Hersonissos,[16] which have been enhanced with various modern technologies and innovative interactive systems, so as to promote what the island has to offer and provide visitors with novel ways to access information [173]. Such installations usually combine technology with visual arts, so as to as to enhance the overall user experience (i.e. pedestrian way in front of the building).

3.6.10 Smart Healthcare

Health is a key contributing factor towards improving people's quality of life. Towards that objective, a Smart City aims at delivering services of various kinds in order to make healthcare smarter [174]. These services extend beyond the traditional ones offered by the healthcare domain such as tele-diagnosis, remote management, etc., and mostly concern the promotion of a healthier and safer lifestyle within the city. For instance, the SIMPATIC project [175] analyses a citizen's mobility patterns in order to detect and communicate abnormalities to patients and care providers (i.e. unusual movements of a certain user, unsafe wandering), while offering guidance of the individual back to their home.

Citizen sensing and crowdsourcing allows diagnosis to become a community effort, and intervention to be boosted by a community support system. People with serious and chronic illnesses turn to social media to share their illness experiences as well as to seek and offer support [176, 177]. For some of these individuals, physically attending support groups is not practical, but they find a sense of community in online settings. Along the same lines, many commercial applications aims to promote a healthy lifestyle by motivating users to remain active; i.e., they compute the walkability index for a location based on distance to nearby amenities including schools,

[15] http://ami.ics.forth.gr/installation/info-point/.

[16] http://ami.ics.forth.gr/installation/tourism-information-center-municipality-of-hersonissos/.

parks, stores, community centres, restaurants, etc., and prompt citizens to walk or cycle instead of using their car [178, 179].

Towards a similar objective, various solutions enable users who prefer doing activities in healthy areas, and most of them are used to compare their experiences and performances through dedicated or online social networks, to directly record activity paths in the city and associate quality information derived from the monitoring network with each path, which users can further customize; these features allow users to share information about the specific paths and areas in the city. For instance, RunWithUs [13] is a service deployed in the Ubiquitous Oulu Smart City, with the goal of motivating citizens to practice jogging, while the SmartCitizen app [138] integrates similar features for sports users who are generally interested in the environmental conditions for their outdoor activities.

Finally, social media outlets can play an even more central role in smarter citywide healthcare. For instance, researchers have detected influenza epidemics based both on individuals posting symptoms [180] and querying about symptoms [181], while the wording and content of Twitter posts have been used to infer heart disease mortality at a county level [182], as well as obesity at a country level [183].

4 Challenges

The recent advancements in ICTs along with the proliferation of IoT and the newly introduced interaction paradigms induced by state-of-the-art technologies (e.g. AR, VR) have led to the identification of several research issues and challenges regarding the adoption of such technologies by Smart Cities [57]. According to [139], one of the most important issues that all Smart Cities have to deal with is the orchestration of a large amount of heterogeneous infrastructural elements in a way that actually improves quality of life. A summary of the main Smart City challenges is provided below. Interestingly, these same challenges, when examined from the citizen's (i.e. user) perspective, offer novel research directions in the domain of Human–Environment Interaction [184] within a Smart City.

- **Interaction in public spaces**: Public spaces host citizens of diverse personalities and background, while in such places there is little or no external crowd control mechanisms. Additionally, they also allow for mutual observation of acts by users not directly involved in the interaction [72]. These aspects are known as open accessibility and open multisensory policing respectively, and raise many challenges regarding user interaction in public spaces: (i) interactions should be fluid and short-term, as people can walk in and out of interactive zones at any time; (ii) urban environments should be self-explanatory, so that first-time or one-time users need no prior introduction or training; (iii) interactive systems should cater for a wide variety of potential participants, diverse in age, gender, cultural background and familiarity with technology; (iv) social pressure should be taken into account, since it constitutes another factor discouraging many people from engaging with the interactive environment in such spaces, due to anxiety for not complying with tacit social roles or fears of social embarrassment or damage to their social acceptability.

- **Intuitive Interaction:** The interaction-attention continuum (Fig. 19) outlines the relation between user's level of attention, the interaction type: (i) focused, (ii) peripheral and (iii) implicit interaction) and the respective interaction characteristics: (i) conscious and intentional, (ii) subconscious and intentional and (iii) subconscious and unintentional [185].

Given that most interaction systems occupy the two ends of the continuum, i.e. focused or implicit interaction, the potential gap between them (i.e. peripheral interaction where information is presented and actions are performed in a subtle manner) should be bridged to allow seamless integration of interactive technologies into everyday routines. To that end, interactive systems should be developed in a way that support operation at various levels of attention, enabling interactions to shift along the interaction-attention continuum as desired by the user or appropriate to the (ambient) context of use [108, 186].

- **Motivating the users to participate (in MCS model)**: For crowd-sensing in Smart Cities to be effective, the following aspects need to be properly addressed [50]: (i) task assignment (i.e. appropriate distribution of smaller tasks to the crowd), (ii) user profiling and trustworthiness (i.e. user reliability and trust-based categorization ensuring correctness of collected data), (iii) design of incentive mechanisms (i.e. encourage reliable users to provide trustworthy data), (iv) localized analytics (i.e. local data pre-processing before sending it to the server to minimize network traffic), and (v) security and privacy (i.e. address important concerns from citizen's point of view, such personal data sharing).
- **Context Awareness & On-Device Intelligence**: Contextual information should be integrated with raw data to get more value from them by performing more accurate reasoning and proper actuation (i.e. detecting a sleepy face could lead to totally different actions in the contexts of driving a car and relaxing at home) [15]. To that end, designers of such environments should be supported with appropriate

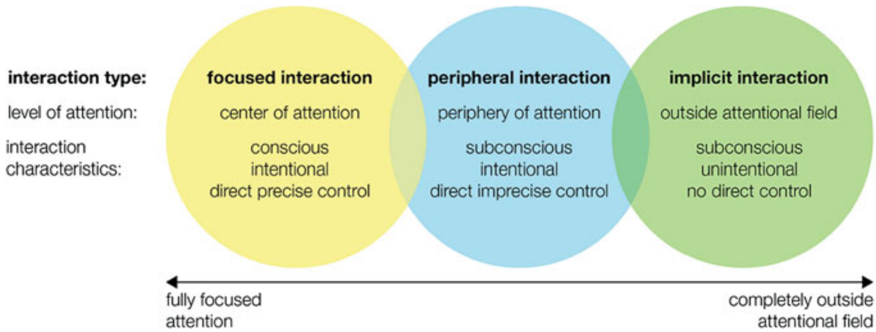

Fig. 19 Interaction types versus Level of attention [185]

toolsets in order to build intelligent and hard real-time, yet lightweight software (i.e. deployable on resource-constrained devices), which improves the quality of life within a Smart City [187].

- **Improvement of quality of life**: Given the emerging importance of human capital, Smart City initiatives have shifted from following a techno-centric top-down approach, where technology has been the driving force and the main contributor to innovation. Instead, a major objective will be the improvement of the well-being of their citizens, through service transformation, innovation in management style (e.g. enhanced interorganizational coordination, user-centred leadership) and appropriate change of policy direction. Technology will still remain a necessary condition for a Smart City, nevertheless a User-Centred design process is a 'conditio sine qua non' to guarantee citizens' acceptance and overall success of such initiatives [188, 189].
- **Human role**: In Smart Cities v2.0, humans are consider key stakeholders, since they play an important role both as producers (i.e. collection) and consumers (i.e. analysis, decision-making) of data. [11]. To that end, during technological development, considerable social and institutional transformations should take place towards supporting the "human interface" and "human role" (e.g. abide by the policies of data collection and retrieval, provide feedback to improve the overall system).
- **City models**: Effective and efficient city models are required in order to fully understand them from an engineering perspective [187]. In particular, such models are essential for observing and interpreting city activity, so as to make intelligent decisions [190] that will improve quality of live. In particular, modelling promotes the sharing of the vast amount of collected data among the city's applications and services [191]. In order to ensure that Smart Cities are User-Oriented, an effective Smart City model should include the citizens as primary actors.
- **Social cohesion, inclusiveness and solidarity**: Securing that the benefits of Smart Cities are equally gained by all every member of the society [150] should remain of paramount importance in the overall research agenda.
- **Interoperability/Heterogeneity**: Smart Cities include IoT devices from various domains (e.g. smart metering, e-healthcare, logistics, monitoring, and intelligent transport), therefore interoperability is mandatory to enable connectivity among devices operating with different communication technologies [57]. Moreover, the different devices, sensors and services deployed across a Smart City generate diverse data [27, 187], hence their proper management should rely on standards across heterogeneous devices, systems, and domains [4]. Given that many Smart City applications a depend on mission-critical communication, interoperation and data exchange to ensure reliability (e.g. health care, public safety), appropriate tools are needed to support the designers, developers and integrators of such applications to better address the diversity of these aspects [187].
- **Scalability**: In order to address the ever-growing number of connected devices, services, users and data, Smart Cities will require the associated software platform(s) and visualization tools [187] to be large-scale and extremely efficient [27], in order to facilitate the analysis of the huge amount of data expected to be

collected (e.g. Barcelona is foreseen to need more than 1 million sensors to cover the entire city, generating more than 8 GB of data/day).

- **Privacy**: Protecting the privacy of individuals, enterprises, organizations, etc., that do not wish their information to be publicly available is an important factor [15] for Smart Cities. To this end, it should be ensured that the data collected from the city's services are not available to unauthorized individuals. Hence, there is the need to implement appropriate end-user solutions that simplify their management [187].
- **Data management**: Efficient and scalable data storage is required for storing the large amount of data collected by Smart Cities, while sophisticated processing algorithms are also required. The collected data must be further analysed in order to extract useful information that can be used to improve quality of life. Since this is not a straightforward task, data analysis is also considered a challenge. Additionally, being able to distinguish which of the collected data are correct poses a challenge known as data trustworthiness. Hence, advanced visualization techniques should be applied to support users (mainly city officials) while being engaged with such tasks [187].
- **Lack of Testbed**: Finally, the lack of testbeds is cited as a challenge to the development of platforms for Smart Cities. Testbeds are platforms appropriate for conducting thorough testing of scientific theories, computational tools, and new technologies. Such mechanisms allow for experimentation in order to reveal the real issues that deploying a Smart City platform will present. The implementation of Smart City Simulators [187] could be a much lower-cost alternative solution for experimentation.

5 Summary

The number of IoT connected devices worldwide is forecasted to reach 50 billion devices by 2030 and more and more cities are expected to ride the wave of becoming 'smart', thus turning the concept of a Smart City into the norm, rather than the exception. Within this promising world, a variety of domains such as transportation, healthcare, entertainment, agriculture, economy, government and the big data that stems from such systems will provide smart solutions and efficiently utilize the Smart City's resources, towards improving the overall quality of life of its citizens.

During this well-anticipated transformation, natural interaction with humans will be a critical need for the new generation of smart city systems, since citizens are their main players [15]. To that end, the abundance of IoT devices will empower the employment of various interaction modalities (i.e. presence, body posture and motion, eye gaze, speech, touch) able to accommodate different user abilities, context of use, or device variations. Moreover, both implicit and explicit interaction need to be supported to cater for different scenarios of use. These interaction paradigms should incorporate appropriate mechanisms to support convenient interaction in public spaces. In addition, exploitation of artificial intelligence is expected to minimize the need for explicit interaction, by automatically inferring knowledge that subsequently drive appropriate actions, both proactively and reactively.

Nevertheless, the recent advancements in ICTs along with the emergence of innovative technologies (e.g. AR, IoT) expose several research issues and challenges in adopting IoT for Smart Cities. Probably the biggest practical challenge that all contemporary Smart City visions need to address is the scale and diversity of infrastructural elements that need to be managed and interoperate in a scalable manner. However, these same challenges, when examined from the citizen's (i.e. user) perspective, offer novel research directions in the domains of Ambient Intelligence and Human–Environment Interaction within a Smart City.

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