A Survey on Smart Cities and Ageing

Rute Bastardo[1][a], João Pavão[2][b] and Nelson Pacheco Rocha[3][c]
[1]*Science and Technology School & UNIDCOM, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal*
[2]*Science and Technology School & INESC-TEC, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal*
[3]*Medical Sciences Department & Institute of Electronics and Informatics Engineering of Aveiro, University of Aveiro, Aveiro, Portugal*

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Abstract: During the last decades, local, regional, and national governments promoted the development of smart cities, aiming the integration of traditional urban infrastructures and information technologies to provide high quality and sustainable urban services. Smart cities' implementations may change the way the individuals experience the urban spaces. Looking specifically to older adults, smart cities' applications have the potential of promoting their autonomy, independence, safety, well-being, social participation, and inclusion. This paper presents a survey of the scientific literature aiming to analyse current evidence related to smart cities' applications to support older adults and to identify issues for future research.

1 INTRODUCTION

Due to the rural-to-urban migration, the urban population of the world has grown rapidly, having increased from 751 million in 1950 to 4.2 billion in 2018 (UN, 2018). Since 2007, more than half of the world population lives in urban areas and according to the projections of United Nations the proportion of the urban population will increase in the next decades, being expected to be more than two-thirds in 2050 (UN, 2018).

The urban population growth of the last decades reinforced the importance of cities as dominant centers of population, business locus and transactions. This growth also reinforced the difficulties and challenges of cities to minimize problems resulting from the congregation of large amount of people (e.g., scarcity of resources, traffic congestion or pollution), which tend to worsen (Rocha, Santinha, Rodrigues, Rodrigues, Queirós & Dias, 2021).

The advent of low-cost sensors capable of collecting vast quantities of data, data-actuated devices, wireless communication networks, and advanced data analytics (Santinha, Dias, Rodrigues, Queirós, Rodrigues & Rocha, 2019) promote the development of automate and intelligent processes. As such there is a trend for the integration of traditional urban infrastructures and information technologies (IT) to allow cities to provide high quality and sustainable urban services. Therefore, new urban strategies have emerged, which intend to take advantage of the technological evolution to surpass or minimize the difficulties of the cities and to answer to their challenges. These strategies emphasize the smartness and of the cities (e.g., smart city, intelligent city, knowledge city, digital city, or talented city) that is at the forefront of cities' social discourse, policy making and research (Hoffman, 2020; Nesti, 2020).

One of the challenges that cities needed to face is the population ageing. Since the ageing process impacts on the psychological well-being of the individuals, it is important to find ways to maintain the functioning and the quality of the participation in society of older adults (Rowe & Kahn, 1997). In this context, it is widely agreed upon that the adoption of IT solutions is fundamental not only to the optimization of existing support services but also for the mitigation of disabilities (Queirós, Silva,

[a] https://orcid.org/0000-0002-3207-3445
[b] https://orcid.org/0000-0001-9042-2730
[c] https://orcid.org/0000-0003-3801-7249

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Alvarelhão, Rocha & Teixeira, 2015; Queirós, Dias, Silva & Rocha, 2017). As such, intelligent applications such as the smart cities applications might support older adults, promoting their autonomy, independence, safety, well-being, social participation, and inclusion as full rights citizens. Therefore, it is worthwhile to analyse current evidence related to smart cities' applications to support older adults and to identify issues for future research. This was the objective of the survey of the scientific literature reported on this paper.

2 SMART CITIES

Smart cities are expressed through different definitions, meanings, and contexts, and a clearly and unanimously established vision does not yet exist (Talamo, Pinto, Viola & Atta, 2019). However, it is commonly accepted that smart cities presuppose the use of IT to improve the quality of life of the citizens, to optimize the efficiency of urban operation and services, and, consequently, to promote the competitiveness and sustainability of the cities while providing social inclusion. Therefore, one of the focuses of the smart city developments are technology-intensive cities or wired-cities, hence placing IT in the centre of the debate.

Other approaches complement the technology-intensive cities perspective. For instance, the focus on the community needs rather than on technology emphasizes the interaction among stakeholders and promotes the involvement of the community in the development of the city (e.g., governance or co-designing solutions) (Eskelinen, García, Robles, Lindy, Marsh, & Muente-Kunigami, 2015), and originated the 'human smart city' expression (Oliveira, Campolargo & Martins, 2015).

Since the topics covered under the smart city concept are quite broad and it can be foreseen impacts in different cities' sectors (Lazaroiu, & Roscia, 2012), it has become difficult to find an adequate organizing taxonomy (Albino, Berardi & Dangelico, 2015; Hoffman, 2020). In this respect, different authors have proposed different dimensions for the smart cities. Some of them emphasize the conditions for the development of innovative solutions (e.g., urban openness, service innovation, partnerships formation, urban pro activeness, smart city infrastructure integration, smart city governance (Dirks, Gurdgiev, & Keeling, 2010; Bajdor, & Starostka-Patyk, 2021), while others emphasize the sectors that are impacted by the smart cities services (e.g., economy, people, governance, environment, living, mobility and data (Sharifi, 2019), or smart business, smart living, smart education, smart citizen, smart government, smart infrastructure, smart utility, smart mobility, and smart environment (Vishnivetskaya & Alexandrova, 2019)). One of the well-known taxonomies was proposed by Giffinger and Gudrun (2010), and considers the following dimensions: smart economy, smart people, smart governance, smart environment, smart living, and smart mobility. This model was selected to frame the survey reported on this paper, which was specifically focused on smart living (i.e., quality of life of the individuals, namely health conditions, cultural and education facilities, housing quality, and touristic attractiveness) and smart mobility (i.e., local, national, and international accessibility, and the availability of communication infrastructure or sustainable and safe transport systems) dimensions, since the related applications might impact the quality of life of older adults living in the cities.

3 SMART LIVING

Viable ageing friendly infrastructures require the deployment of wellness, healthcare, and safety services for the maintenance of physical and psychological wellbeing (Normie, 2011). In this respect, since smart cities infrastructures facilitate the gathering of a large amount of personal and environmental data, they might be used to: support populations surveillance to stimulate response to emerging health problems, and to optimize the planning, implementation, and evaluation of health services and programs (Thacker & Berkelman, 1998; Pacheco Rocha, Dias, Santinha, Rodrigues, Queirós, Rodrigues, 2019); individuals' monitoring, both at home and public spaces, in a completely unobtrusive manner (Bryant, Spencer, King, Crooks, Deakin & Young, 2017); and to promote active ageing paradigms, namely by the deployment user centric applications to support citizens in their daily activities and to facilitate their participation in society (López-de-Ipiña, Klein, Vanhecke & Pérez-Velasco, 2013).

3.1 Population Surveillance

Real-time monitoring mechanisms allowing the individuals to send their data without disclosing their identity is an important issue of populations' surveillance (Patsakis, Clear, Laird, Zigomitros & Bouroche, 2014), which might be done not only for diseases surveillance (e.g., real-time urban scale virologic and epidemiological data monitoring)

(Rocha, Dias, Santinha, Rodrigues, Queirós & Rodrigues, 2019; Abusaada & Elshater, 2020), but also with other purposes such as physical activities (Clarke & Steele, 2011), emotions (Roza & Postolache, 2016) or environmental conditions (Guo, Al Shami & Wang, 2015; Federico, Ceballos, Rivera, Larios, Beltran, Beltran & Ascencio, 2017; Wray, Olstad & Minaker, 2018). Considering the amount and diversity of the data collected, data analytics tools should be used to aggregated and process the collected data to achieve relevant outcomes.

Regarding fitness activities surveillance, to surpass the lack of structured approaches for data collection and aggregation, Clarke and Steele (2011) proposed a conceptual architecture supported in fitness sensors, as well as the steps and developments that would improve the quality and usability of data collected. The types of usage of the collected data might range from urban planning and transport monitoring to more health focused aims such as the surveillance of the population health conditions.

Relevant affective states that can be detected individually and then aggregated into a global model of affect are being used to promote an affect-aware cities by mapping and correlating large-scale sentiment data to urban geography features, and consequently attempting to understand the main sources of happiness in the cities' landscapes (Roza & Postolache, 2016).

The monitoring of environmental conditions by smart cities' infrastructures is being used for several purposes. For instance, Guo, Al Shami and Wang (2015) presented a mobile application to estimate the level of ultraviolet radiation exposure each individual was subjected to at any given time and location, Wray, Olstad and Minaker (2018) suggested a micro-level monitoring network of static devices to measure harmful air pollutants and ultraviolet radiation exposure levels, and Federico et al. (2017) proposed an application to monitor individual environments (e.g., infrastructure, weather, or social interactions) to better understand the link between genetic traits and disease by using genome-wide association studies.

3.2 Individuals' Monitoring

Individuals' monitoring aims to enhance and build a more comprehensive and predictive picture of individuals' wellbeing and health conditions to sustain better health outcomes and to deliver early interventions to anticipate needs (Bryant et al., 2017). Moreover, monitoring older adults' interactions with the built environment might be useful to determine if a dangerous situation is occurring (e.g., abrupt changes of the heart rate or a sudden acceleration, followed by a state of quiet that might be a sign of fall or fainting) (Bellagente, Crema, Depari, Ferrari, Flammini, Lanfranchi, Lenzi, Maddiona, Rinaldi & Sisinni, 2018) or support interventions to minimize stressful interactions (Lee, Choi, Ahn & Lee, 2020).

In addition, open data services available in the smart city technological infrastructure together with the collection of personal data might be used to track the location of older adults while performing outside activities, including falls detection, unmet needs, visited points of interest or some activities performed, such as visiting a family member, or usage of public transportation (Kötteritzsch, Koch & Wallrafen, 2016; Medrano-Gil, de los Ríos Pérez, Fico, Montalvá Colomer, Cea Sáncez, Cabrera-Umpierrez, & Arredondo Waldmeyer, 2018). Outdoor localization services are important) to protect older adults (Chen, Sakamura, Nakazawa, Yonezawa, Tsuge & Hamada, 2018, specifically wandering individuals more vulnerable to experiencing adverse events than the healthy ones, ranging from falling, getting lost, elopement or boundary transgression to emotional distress (Lin, Liu & Wang, 2018). To minimize wandering-related adverse consequences, virtual boundary delineated around areas of interest that can be created with a variety of different technologies, such as wireless communications, and Global Positioning System (GPS) (Lin, Liu & Wang, 2018).

3.3 Promotion of Active Ageing

With the expansion of smart cities, enriched information access promotes the development of intelligent services that might facilitate active ageing paradigms. For instance, innovative tourism and self-service travel (Encalada, Boavida-Portugal, Ferreira & Rocha, 2017) make the decision process easier for older adults and make their transportation, visits, and leisure activities less difficult (Liu, Sokhn, Le Calvé & Schegg, 2016), particularly if the accessibility of public spaces is part of the smart city design (Nowak Da Costa & Bielski, 2018).

Active ageing also encompasses the adoption of healthy lifestyles. Specifically, physical activity affects health conditions and the current recommendations advice older adults to perform regular physical activity. Therefore, among the extensive body of research on technological solutions to promote the integration of physical activity into daily life (Simões, Silva, Amaral, Queirós, Rocha & Rodrigues, 2018), some authors are focused on the promotion of physical activity in the context of smart

cities. For instance, Trencher and Karvonen (2017) present a real-world case study on the Japanese smart city of Kashiwanoha based on data monitoring supported by wearable sensors used to capture continuous lifestyle data to allow the individuals to receive feedback and advice, educational activities (e.g., walking, diet, or socializing), and gamification to incentive the best performers. In turn, Stibe and Larson (2016) introduced the concept of "persuasive cities" supported in behavioral change through gamification. Moreover, in (Lindqvist, Rutberg, Söderström, Ek, Alexandrou, Maddison & Löf, 2020) is presented the Smart City Active Mobile Phone Intervention (SCAMPI), which evaluates an application to promote physical activity together with data acquisition related to behaviour, mode of travel, duration, and speed. The application collects data in real time on location and travel speed using GPS. Moreover, accelerometers are used to provide an objective assessment of physical activity. The primary outcome is moderate-to-vigorous intensity physical activity, while secondary outcomes include time spent in active transportation, perceptions about active transportation and health related quality of life.

Other studies explore context-aware features to offer personalized recommendations of exercise routes to older adults according to their medical conditions, personal preferences and real-time environment information (e.g., air quality, ultraviolet radiation, wind speed, temperature, and precipitation), without disrupting their routines (Casino, Patsakis, Batista, Borràs & Martínez-Ballesté, 2017; Rodrigues, Santos, Queirós, Silva, Amaral, Gonçalves & Rocha, 2018).

4 SMART MOBILITY

Navigation tasks through an environment constitute an essential activity in our daily lives. However, for impaired people, these tasks might represent tremendous difficulties. In this respect, the information provided by smart cities might be used by applications to facilitate the mobility of older adults.

Smart cities promote the establishment of communication channels between the citizens and authorities, which might support the acquisition of accessibility data to be available for the planning and management of the urban spaces or to support individuals in adverse situations. Moreover, different types of applications can be foreseen to assist the mobility of older adults, be them pedestrians or drivers.

4.1 Urban Accessibility

Some studies (e.g., (Mirri, Prandi, Salomoni, Callegati & Campi, 2014; Cortellazzi, Foschini, De Rolt, Corradi, Neto & Alperstedt, 2016; Mirri, Prandi, Salomoni, Callegati, Melis & Prandini, 2016)) propose applications to allow citizens to provide information about public and private places of the city with respect their accessibility. The aim is to promote the involvement of social players and citizens in the identification of urban accessibility issues, which is intended to be used by the citizens to facilitate their mobility and by city managers to identify and solve accessibility issues.

The collection of accessibility information might be supported in crowdsourcing or crowdsensing services. The application presented by Cortellazzi et al. (2016) use crowdsourcing to allow citizens to review the accessibility of public spaces, and these reviews are used to determine alternative pedestrian routes avoiding as many barriers as possible (Cortellazzi et al., 2016). In turn, assuming that a mobile user can be at the same time a consumer and a provider of the sensing services, Mirri et al. (2016) used both participatory sensing (i.e., mobile users actively engage in sensing activities by manually determining how, when, what, and where to sense) and opportunistic sensing (i.e., fully automated sensing activities without the involvement of the users) to collect that about the accessibility conditions of the urban spaces exploiting, for example, GPS coordinates. Moreover, Mirri et al. (2014) argued that although any instance of the crowdsourced and sensed data may be unreliable, aggregating a large amount of information related to the urban area makes the data more trustworthy (i.e., an error made by a single sensor, or a single user, become less significant as the volume of data increases). Additionally, the data quality might be increased when considering their aggregation with accessibility reviews conducted by experts.

4.2 Mobility Assistance

The availability of data related to urban accessibility might be used to provide older adults with personalized and accessible pedestrian paths and maps (Mirri et al., 2014), or support older adults who travel by bus in the city by providing real time information about transport availability and accessibility facilities.

Some studies (e.g., (Vargas-Acosta, Becerra, Gurbuz, Villanueva-Rosales, Nunez-Mchiri & Cheu, 2019; An, Wang, Wang, Yang, Pu, Ke & Chen,

2020)) integrated various technologies, including location-based services, augmented reality, and crowdsourcing, to provide personalized and accessible pedestrian paths and maps (Mirri et al., 2014), real time information about transport availability and accessibility facilities (Mirri et al., 2014), accurate map information service and travel route planning (An et al., 2020), or to assist older adults during their travels within a city and to mitigate their risks (e.g., being caught in traffic congestion, getting lost, or being involved in a crash) (Vargas-Acosta et al., 2019).

Moreover, it is envisaged collaborative support for individuals with disabilities and older adults in adverse situations from qualified agents and volunteers (Matos, Matter, Martins, da Rosa Tavares, Wolf, Buttenbender & Barbosa, 2021). In concrete, the proposed mobile application allows users to ask for assistance by sending a notification to agents and volunteers who are nearby.

Older adults face many issues when it comes to parking in urban areas which include the limited availability of spaces allocated for their use and the unauthorized usage of such spaces. In this respect, smart parking management systems might take advantage of the capabilities of mobile devices to allow users to find, reserve and access real-time parking availability information (e.g., using occupancy sensors) (Lambrinos & Dosis, 2013). These systems might be used not only to present the real-time availability of parking slots in an area of interest, but also to provide information to city authorities for usage monitoring, law enforcement or planning purposes (Lambrinos & Dosis, 2013).

Other smart cities applications are being designed to promote safe driving by alerting drivers of potential dangers (e.g., the proximity of vulnerable road users such as cyclists or pedestrians) or by providing driving assistance (Ksiksi, Al Shehhi & Ramzan, 2015; Hernandez-Jayo, De-la-Iglesia & Perez, 2015; Hernandez-Jayo, Perez, De-la-Iglesia & Carballedo, 2016; Joshi, Singh, Moitra & Deka, 2016; Taha, 2017; Lee & Gutesa, 2017).

Concerning vulnerable road users, the proposed information systems use different sensors, wireless vehicular communications, and mobile communications to detect their proximity to provide more time to the drivers to take the appropriate manoeuvres. In turn, in terms of driving assistance, the possibilities range from providing routes that include safety metrics (Ksiksi et al., 2015) or keeping drivers informed of changing road and traffic conditions (Ksiksi et al., 2015; Taha, 2017) to helping effective lane changing (e.g., using GPS coordinates) (Joshi, 2016) or to perform safe and smooth crossings at the intersections (Lee & Gutesa, 2017).

5 CONCLUSION AND FUTURE CHALLENGES

The survey of the scientific literature shows that there is an ongoing effort to take advantage of the smart cities' paradigm to make cities more ageing friendly. For that, different types of technologies are being used to collect data (e.g., a broad range of sensors) to transmit these data (e.g., wireless communications) and to retrieve information (e.g., data analytics).

This diversity of technologies tends to promote the heterogeneity of the solutions, which means that the interoperability of the different applications is a real challenge. However, looking specifically to smart cities' applications targeting older adults, the issues related to data interoperability, standardization and aggregation are poorly addressed (Rocha, Bastardo, Pavão, Santinha, Rodrigues, Rodrigues, Queirós & Dias, 2021).

Another question that deserves special attention is the data privacy, integrity, and confidentiality (Pacheco Rocha, Dias, Santinha, Rodrigues, Rodrigues, Queirós, Bastardo, Pavão, 2022). The privacy of the individuals is at risk when they are monitored by different types of sensors, due to the acquisition and communication of personal data. Using sensors to constantly monitor individuals has the potential to put their privacy at risk, due to the communication of personal data. Therefore, secure data protection mechanisms are required to guarantee the acquired data would only be accessed by individuals who are authorized. Due to its relevance, data privacy, integrity, and confidentiality is object of significant research in the topic of smart cities, but it is an issue that, in general, is not conveniently addressed by the articles reporting smart city application' to support older adults.

A potential reason for this mismatch could be the fact that developing smart city applications is quite complex, their requirements have not yet been comprehensively extracted and systematized, including different scenarios and concerns, leading to a great variability in terms of design, implementation and required technologies, while, seldom, the research groups, namely academic research groups, do not have specialized knowledge to deal with all that complexity and variability.

The low maturity level of the applications being reported in the literature also must be carefully

analysed. A significant percentage of the studies developed proof-of-concept prototypes. This means a general difficulty in evaluating the impact of the proposed applications on the potential users, namely by implementing user-centred evaluations. The lack of user-centred evaluations can be considered a major barrier for the dissemination of the developed applications.

Future developments of smart cities applications must consider effective evaluation and validation of smart cities applications. This requires not only various types of resources (e.g., technologies and physical or virtual infrastructures) but also a diversity of stakeholders. Despite the existence of models aiming to optimize smart city implementations (e.g., (Taratori, Fiscal, Pacho, Koutra, Pareja-Eastaway & Thomas, 2021), the coordination of these resources and stakeholders requires experience and a large amount of effort that must be guaranteed so that large trials might be conducted to evidence that smart cities' applications effectively fit the older adults' needs.

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