Inclusive Smart Cities : theory and tools to improve the experience of people with disabilities in urban spaces

João Soares de Oliveira Neto

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M. João SOARES DE OLIVEIRA NETO

Composition du Jury :

Edson SPINA Professeur adjoint, Universidade de São Paulo	Président
Isabela GASPARINI Professeur adjoint, Universidade do Estado de Santa Catarina	Rapporteur
Thais Helena CHAVES DE CASTRO Professeur adjoint, Universidade Federal do Amazonas	Rapporteur
Nicolas SABOURET Professeur, Université Paris-Sud	Examinateur
Yolaine BOURDA PR2, CentraleSupélec	Directeur de thèse
Sergio TAKEO KOFUJI Professeur, Universidade de São Paulo	Co-Directeur de thèse

To Dona Deja, my mother,

To Helton,

inexhaustible sources of love and inspiration.

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A man, to be greatly good, must imagine intensely and comprehensively; he must put himself in the place of another and of many others; the pains and pleasure of his species must become his own. The great instrument of moral good is the imagination (...).

(Percy Bysshe Shelley, 1821)

ABSTRACT

Cities have employed technologies in several domains to improve the delivery of public services, attend citizens' demands, and measure the consumption of natural resources. Known as Smart Cities, these initiatives aim to increase the overall citizens' quality of life, and they have already had a positive impact on the way citizens interact with urban spaces, services, and with each other. On the other hand, urban spaces can be considered as a threat to the independence and autonomy of people with disabilities. In fact, according to the Social Approach, disability is not in the individual, but in society and the environment, which does not provide adequate conditions for the individual to fully participate and be a citizen of social, professional, educational, recreational activities, and so on. Society and the environment need to be corrected and their deficiencies compensated to include a significant portion of the population that is excluded from a range of activities when their abilities are not addressed in urban communication processes. Although this group of citizens has gained access to education, work and leisure, it is necessary to confront the city and all its challenges in order to enjoy these rights. Aiming to extend the benefits of Smart Cities to people with disabilities, we first proposed the idea of an Inclusive Smart City, which employs Smart Cities technology to provide a better urban experience for people with disabilities while overcoming accessibility barriers in urban spaces. To achieve this goal, we began using a multi-instrument approach to collect data from different stakeholders – people with disabilities, professionals that work with people with disabilities, accessibility-related experts, and policymakers –, aiming at understanding the obstacles that people with disabilities face when they are moving around the city, the strategies they use to solve unexpected problems, and how they interact with other people and with urban facilities. Based on an empirical observation, literature review and results collected using this multi-instrument approach, we first defined Inclusive Smart Cities. Then, we proposed some tools to support practitioners and researchers involved in the development of digital urban assistive technologies with the Inclusive Smart City's vision in mind: a list of requirements, a political structure, an implementation/operation methodology, a business model, a conceptual model, and a system architecture. According to the conceptual model we introduced, people with disabilities are able to interact with inclusive smart objects that are available in urban spaces to obtain information about the environment around them, enabling them to navigate and explore cities in an innovative way. In Inclusive Smart Cities, inclusive smart objects provide people with disabilities with user-adapted information and services, focusing on the individuals' abilities rather than their disabilities. Moreover, the system architecture is based on equipping users and the environment with smart technologies, aiming at supporting a symbiotic relationship between citizens and inclusive smart objects, a web-based user interface to enable public agents and local authorities to register and maintain the information required by the Inclusive Smart City platform, and the Cloud infrastructure, responsible for storing system data and processing user requests. Finally, we further demonstrated a Proof of Concept to assess the experience that people with disabilities would have when using an Inclusive Smart City solution. To accomplish that, we mapped a city block of Paulista Avenue, in São Paulo, Brazil, as a sequence of QR codes. In a simulated circuit, when users read each code, they received location-based information and services related to the object linked to the code. The participants evaluated the UrbanAssist application positively and recognized the relevance of the functionalities and resources provided by the application, which gave them an inventive interface to explore the urban environment in a new, safer and effective way. In conclusion, this new technology has the potential not only to improve the independence and autonomy of people with disabilities in urban spaces, but also to enable them to play a proactive role in society as a whole.

Keywords: Accessibility, Smart Cities, People with Disabilities, Assistive Technology, Internet of Things.

RESUMO

As cidades têm empregado a tecnologia em diversos segmentos a fim de melhorar a qualidade de serviços prestados, para atender as demandas dos cidadãos, e para medir o consumo de recursos naturais. Conhecidas como Cidades Inteligentes, estas iniciativas buscam aumentar a qualidade de vida dos cidadãos, e já têm causado impactos positivos na maneira como os indivíduos interagem com o espaço urbano, com serviços, e com outros indivíduos. Por outro lado, o espaço urbano ainda é considerado como uma ameaça à autonomia e à independência de pessoas com deficiência. De fato, segundo o Modelo Social, a deficiência não está no indivíduo, mas na sociedade e no ambiente, que não fornecem condições apropriadas para que o cidadão participe inteiramente de atividades sociais, profissionais, educacionais, recreativas etc. A sociedade e o ambiente precisam ser corrigidos e suas deficiências compensadas para que ocorra a inclusão de uma parcela considerável da população que é excluída de uma série de atividades quando suas habilidades não são consideradas nos processos de comunicação urbanos. Embora esses cidadãos tenham ganhado acesso a educação, trabalho e lazer, o acesso pleno a esses direitos exige ter que lidar com o espaço urbano e todos os seus desafios. Com o objetivo de estender os benefícios das Cidades Inteligentes às pessoas com deficiência, inicialmente propomos o conceito de Cidades Inteligentes Inclusivas, que utiliza tecnologias das Cidades Inteligentes a fim de fornecer às pessoas com deficiência uma melhor experiência urbana ao mitigar as barreiras de acessibilidade nas cidades. A fim de alcançar este objetivo, utilizamos um método multi-instrumentos para coletar dados de diferentes interessados nesta temática – pessoas com deficiência, profissionais que trabalham na área, especialistas em acessibilidade, e criadores de políticas públicas – para melhor entender os obstáculos que as pessoas com deficiência enfrentam quando estão se locomovendo nos centros urbanos, as estratégias que eles usam para resolver problemas inesperados, e como eles interagem com outras pessoas e com os objetos e instalações urbanas. Baseado em observação empírica, em revisão da literatura, e nos resultados coletados pelo método multi-instrumentos, elaboramos a definição de Cidades Inteligentes Inclusivas e propomos algumas ferramentas para apoiarem autoridades governamentais, profissionais e pesquisadores envolvidos com o desenvolvimento de tecnologias assistivas urbanas digitais: uma lista de requisitos, estrutura política, metodologia de implantação e funcionamento, modelo de negócios, e uma arquitetura de sistema. De acordo com o modelo conceitual que apresentamos, as pessoas com deficiência são capazes de interagir com objetos inteligentes inclusivos no espaço urbano a fim de obter informações a respeito do ambiente ao redor, o que possibilita navegar e explorar nas cidades de uma maneira inovadora. Nas Cidades Inteligentes Inclusivas, os objetos inteligentes inclusivos fornecem às pessoas com deficiência informações e serviços adaptados às habilidades de cada usuário. A arquitetura do sistema é baseada em equipar os usuários e o ambiente com tecnologias inteligentes; uma interface web que permite a agentes públicos e autoridades municipais a cadastrar e manter as informações necessárias ao funcionamento da Cidade Inteligente Inclusiva; e pela infraestrutura da Cloud, que é responsável por armazenar os dados do sistema e por processar as requisições dos usuários. Finalmente, demonstramos com uma Prova de Conceito a avaliação da experiência de usuário que indivíduos com deficiência têm ao usar soluções concebidas com a visão de uma Cidade Inteligente Inclusiva. Para tanto, mapeamos como QR codes os objetos e prédios de um quarteirão da Avenida Paulista, em São Paulo. Num circuito simulado, ao ler cada código os usuários recebem com informações baseadas na localização do objeto lido e os serviços associados ao objeto. Os participantes avaliaram positivamente a aplicação UrbanAssist e reconheceram a relevância das funcionalidades e recursos disponibilizados pela aplicação, que lhes proporcionaram uma interface inovadora para explorar o ambiente urbano de uma maneira mais segura e eficaz. Concluindo, essa nova tecnologia tem o potencial não somente de melhorar a independência e autonomia de pessoas com deficiência no espaço urbanos, mas, também de prover estes usuários com a possibilidade de desempenharem o papel de cidadãos proativos.

Palavras-chave: Acessibilidade, Cidades Inteligentes, Pessoas com Deficiência, Tecnologia Assistiva, Internet das Coisas.

RÉSUMÉ

Les villes ont eu recours à des technologies dans plusieurs domaines pour améliorer la prestation de services publics, répondre aux demandes des citoyens et mesurer la consommation de ressources naturelles. Connues sous le nom de Villes Intelligentes, ces initiatives visent à améliorer la qualité de vie des citoyens et ont déjà eu un impact positif sur la manière dont les citoyens interagissent avec les espaces urbains, les services et les uns avec les autres. D'autre part, les espaces urbains peuvent être considérés comme une menace pour l'indépendance et l'autonomie des personnes en situation d'handicap. En effet, selon l'Approche Sociale, le handicap ne réside pas dans l'individu, mais dans la société et dans l'environnement qui ne fournissent pas les conditions appropriées pour que l'individu puisse participer pleinement et être un citoyen d'activités sociales, professionnelles, éducatives et récréatives. La société et l'environnement doivent être corrigés et leurs handicaps compensés pour inclure une partie importante de la population qui est exclue de toute une gamme d'activités lorsque leurs capacités ne sont pas prises en compte dans les processus de communication urbains. Bien que ce groupe de citoyens ait eu accès à l'éducation, au travail et aux loisirs, il lui faut faire face à la ville et à tous ses défis pour profiter pleinement de ses droits. Dans le but d'étendre les avantages des villes intelligentes aux personnes en situation de handicap, nous avons tout d'abord proposé l'idée d'une ville intelligente et inclusive, utilisant la technologie Smart Cities pour offrir aux personnes en situation de handicap une meilleure expérience urbaine et surmonter les obstacles à l'accessibilité dans les espaces urbains. Pour atteindre cet objectif, nous avons utilisé une approche multi-instruments pour collecter des données auprès de différentes parties prenantes – personnes en situation de handicap, professionnels travaillant avec des personnes en situation de handicap, experts liés à l'accessibilité et décideurs politiques, – afin de comprendre les obstacles rencontrés par les personnes en situation de handicap. Nous avons étudié, lors de leurs déplacement dans la ville, les stratégies utilisées pour résoudre des problèmes inattendus ainsi que leurs interactions avec d'autres personnes et avec les installations urbaines. Sur la base d'une observation empirique, d'une revue de la littérature et des résultats obtenus avec l'approche multi-instruments, nous avons d'abord élaboré une définition du terme Ville Intelligente Inclusive, ainsi que nous avons proposé des outils pour soutenir les praticiens et chercheurs engagés dans le développement de technologies d'assistance numériques : une méthodologie d'implémentation et fonctionnement, un modèle conceptuel et une architecture de système sont proposés dans cette thèse. Selon le modèle conceptuel que nous proposons, les personnes en situation de handicap sont en mesure d'interagir avec des objets intelligents inclusifs disponibles dans les espaces urbains pour obtenir des informations sur l'environnement qui les entoure et leur permettre de naviguer et d'explorer les villes de manière innovante. Dans les Villes Intelligentes Inclusives, les objets intelligents inclusifs fournissent aux personnes en situation de handicap des informations et des services adaptés aux utilisateurs, en se concentrant sur les capacités des individus et non sur leurs handicaps. Ainsi, l'architecture du système repose sur l'équipement des utilisateurs et de l'environnement en technologies intelligentes afin de prendre en charge une relation symbiotique entre les citoyens et les objets intelligents inclusifs ; une interface d'utilisateur Web permettant aux agents publics et aux autorités locales d'enregistrer et de conserver les informations nécessaires à la Ville Intelligente Inclusive ; et l'infrastructure Cloud, qui est responsable du stockage des données du système et du traitement des demandes des utilisateurs. Finalement, nous avons également proposé une preuve de concept pour évaluer l'expérience qu'auraient les personnes en situation de handicap en utilisant une solution de ville intelligente inclusive. Pour ce faire, nous avons cartographié un bloc de l'avenue Paulista, à São Paulo, au Brésil, sous la forme d'une séquence de codes QR. Dans un circuit simulé, lorsque les utilisateurs lisaient chaque code, ils recevaient des informations et des services de localisation liés à l'objet encodé. Les participants ont évalué l'application UrbanAssist de manière positive et ont reconnu la pertinence des fonctionnalités et des ressources fournies par l'application, ce qui leur a donné une interface inventive pour explorer l'environnement urbain d'une nouvelle manière, plus sûre et efficace. En conclusion, cette nouvelle technologie a le potentiel non seulement d'améliorer l'indépendance et l'autonomie des personnes en situation de handicap dans les espaces urbains, mais aussi de leur donner la possibilité de jouer un rôle proactif dans la société dans son ensemble.

Mots clés: Accessibilité, Villes Intelligentes, Personnes en situation de handicap, Technologie d'assistance, Internet des objets.

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LIST OF ABBREVIATIONS

ADA	Americans with Disabilities Act
AT	Assistive Technology
BSI	British Standards Institution
BSR	Business for Social Responsibility
CASAGRAS	Coordination and Support Action for Global RFID-related Standardization Activities
CC	Cloud Computing
CRPD	Convention on the Rights of Persons with Disabilities
DfA	Design for All
DIY	Do It Yourself
DNS	Distributed Name Service
DOJ	Department of Justice
e-Gov	Electronic Government
ETSI	European Telecommunications Standards Institute
FSP	Full-Service Provider
G3ict	Global Initiative for Inclusive Information and Communication Technologies
GE	Generic Enablers
GIS	Geographical Information Systems
GPS	Global Positioning System
GSC	Green Smart Cities
HCI	Human-Computer Interaction
HDM	Hypothetico-Deductive Method
HPC	High Performance Processing
I/O	Input/Output

IaaS	Infrastructure As A Service
IBGE	Instituto Brasileiro de Geografia e Estatística
ICOST	International Conference on Smart Homes and Health Telematics
ICT	Information and Communications Technology
ID	Inclusive Design
IDE	Integrated Development Environment
IDEA	Individuals with Disabilities Education Act
IEC	International Electrotechnical Commission
IoT	Internet of Things
ISC	Inclusive Smart City
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
NFC	Near Field Communication
NIST	National Institute of Standards and Technology
ONS	Object Name Service
PaaS	Platform As A Service
PC	Personal Computer
PM	Particulate Matter
PoC	Proof of Concept
POI	Points-Of-Interest
POUR	Perceivable, Operable, Understandable, and Robust
PwD	People with Disabilities
QR	Quick Response
R&D	Research and Development
RFID	Radio-Frequency IDentification
RQ	Research Question

RSC	Resilient Smart Cities
SaaS	Software as a Service
SC	Smart Cities
SC4A	Smart Cities for All
SIG	Special Interest Group
SME	Small and medium-sized enterprises
SNPD	Secretariat for the Promotion of the Rights of People with Disabilities
SOA	Service Oriented Architecture
UA	Universal Access
UCD	User-Centered Design Approach
UD	Universal Design
UN	United Nations
URI	Uniform Resource Identifiers
URL	Uniform Resource Locator
USB	Universal Serial Bus
UX	User eXperience
W3C	World Web Consortium
WAI	Web Accessibility Initiative
WCAG	Web Content Accessibility Guidelines
WHO	World Health Organization
WSN	Wireless Sensor Network

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1

Introduction

Cities are the new computational platform. After the invention of mainframes, desktops and mobile phone, progressively from the middle until the end of the 20th century, Computing became omnipresent. In the paper entitled "*The Computer for the 21st Century*", it was predicted that in the next century technology would be so present in our daily life that it would disappear (Weiser, 1999).

In the city, this prophecy became true: considering the global proportion, everybody has more than one mobile phone – 103.5 cellphones *per* group of 100 inhabitants (ITU, 2017); there are displays and embedded system running their tasks everywhere; more and more speedy mobile networks provide users with continuous connection to content that is essential to perform their activities – even the more trivial ones. Despite the digital divide that still persists even in developed countries, technology has surpassed office's and home's walls to gain streets and avenues.

More than hardware and software, cities started to be supplied with intelligence. Sensors, actuators and a vast number of "things" are now interconnected by an heterogeneous network infrastructure fitted together with the purpose of addressing the needs of businesses, institutions, government, and especially citizens (Khatoun & Zeadally, 2016). Moreover, the rise of location-based application changed the way people interact with each other and with the city itself (Schmitz Weiss, 2013). Shortly, Smart Cities (SCs) take advantage of the most recent technologies to mitigate contemporary problems that reach most urban spaces, such as traffic flow, pollution, safety, search for public services – health, education, tourism, and so on. The word "smart" indicates that the core elements of this new concept – *technology, people, institutions and place* (Foth, Choi, & Satchell, 2011; Nam & Pardo, 2011) – not only coexist in the urban space but they must be wisely blended as a complement of each other in modeling and implementing solutions for urban problems.

SC initiatives have been remarked by the potential of spreading technological solutions for urban problems in a rapidly and broader manner, engaging citizens in reporting their questions and propositions to local authorities, and reaching minorities groups. People with disabilities (PwD) are one of the vulnerable sections of the society that can benefit from the advantages brought by SC technology (Townsend, 2013), particularly because they experience a variety of problems related to the urban space (de Oliveira Neto & Kofuji, 2016). Troubles to move from one place to another, lack of information about the right direction to take, absence of informative messages warning properly and earlier about dangerous situation or about facilities that are not working, and so on are some of the problems PwD experience. Indeed, accessing public spaces is such an important issue that promoting the development of Information and Communications Technology (ICT) services for disabled people is one of the topics that compose the Smart City Research Agenda proposed by the United Nations University (Estevez, Lopes, & Janowski, 2016).

In this thesis, a public space is considered a social space that is generally open to all citizens, for their use and enjoyment (Birch, 2008), sharable by a permanent or non-permanent group of people. Streets, roads, subway stations, parks, and beaches are typically defined as public spaces. Similarly, building’s entrance halls and corridors, and government buildings, which are open to the public, are also public spaces. On the other hand, a private space is a more restricted area permitted by law or right to one individual or to a small number of individuals. Someone’s home, a personal bedroom, and a corporate office are examples of private spaces. Public spaces are more susceptible to changes and more difficult to control their environmental variables – such as noise, temperature and luminosity. Conversely, private spaces are steadier and most of the time they are controlled according to their owner’s will. Unexpected events are more likely to happen in public spaces, which are more heterogeneous – different elements, facilities and equipment. While events that happen in private spaces are generally more predicted, and these environments are normally more homogeneous. Another aspect to be considered is privacy, which is lower in public spaces. Hence, the overall complexity of public spaces is in most cases higher than complexity of private places, meaning that problems concerning public spaces require more efforts and deeper analysis to be solved (Kumar, 2009; Want & Pering, 2005).

To ensure access to public physical environment for PwD, authorities worldwide have tried to implement specific laws and promote research and development of goods, services, equipment and facilities adapted to the needs of a person with disabilities (United Nations, 2006). To include PwD in the workforce and motivate the social diversity, some countries, such as Brazil and France, have required companies with more than a certain number of employees - 100 for Brazil and 20 for France - to fill a percentage of their posts with PwD proportionally to the overall number of employees (Brasil, 1991; France, 1987). Moreover, Brazilian authorities have systematically engaged policies to enlarge a scheme of quotas that allows the presence of people with impairments in universities and public agencies (Soares, 2015).

Such an endeavor is essential to promote the feeling of equality and higher social, political, economic, and civic participation to PwD; but it is not enough. If PwD want to benefit from their rights and if they want those rights to become a reality in their lives, such as enrolling in a course at the university, they have to be concerned with a variety of problems in the urban space, which directly aim them (de Oliveira Neto & Kofuji, 2016). As Figure 1(a) e Figure 1(b) exemplify, cities are essentially sensorial once they essentially have visual and sonorous information. Also, there are still some situations that cannot be ruled by laws, such as the existence of tactile floors or braille signs at least in public spaces. Getting lost in a neighborhood where you have never been before and trying to discover where the right bus stop you need to go are some of these situations. It is not easy to establish rules that prevent PwD from experiencing these kinds of problems. Unfortunately, cities were not, and still are not being, built having blind, deaf and ageing people in mind.

Figure 1 – Visual information in public spaces.

(a) Street (b) Subway station

Source: (de Oliveira Neto & Kofuji, 2016).

Last but not least, besides the rights acquired by quotas over the last years, all citizens are supposed to have unreserved access to public buildings - such as police stations, hospitals, public libraries, parliament chambers, courts, among others – so that they benefit from the public services offered. After all, PwD also pay taxes and should be able to enjoy the benefits provided to all other citizens. This means that people need to move around the city to put into use their role as citizens. This is why "democracy requires physical space for its performance" (Parkinson, 2012 p. 16).

Concerning PwD, the literature and business are vast on terms of devices and technological solutions to handle problems related to the physical world, as well as a well-established range of solutions for the access to the digital world, i.e. Internet websites, desktop systems, mobile apps, and others. A broader community of designers and developers started to have the need to go deeper into some issues, such as:

- *Accessibility* (Steinfeld & Maisel, 2012): provisioning access to physical and digital artifacts by people with disabilities making these artifacts equally accessible by everyone;
- *Universal Access* (UA) (Stephanidis, 2009; Stephanidis et al., 1999): one step ahead of the concept of Accessibility in terms of taking into account the

relationship between *techne* and *politeia*, meaning that technological development highly impacts the life of all citizens, which demands the adoption of theoretical, methodological, and empirical research based on human-centered principles and business-driven requirements;

- *Assistive Technology* (Scherer, 1996; WHO, 2011): any piece of equipment or product system that enhance the level of accessibility and increase the overall well-being by maintaining or improving PwD's functional capabilities.

Some institutions, for instance the World Web Consortium (W3C)[1] and the World Health Organization (WHO)[2], have undertaken a successful substantial work in pressing the adoption of specific laws, publishing web and mobile accessibility guidelines and standards, and promoting the development/deliver of standardized products/services. However, the still in-progress Information Society has displaced the data provision and consumption to outdoors. Objects and things arranged in the urban space have now the capacity of produce and consume data, competing for citizens' attention (McCullough, 2012). Despite this, there is still a gap related to the inexpressive number of assistive technology based on location-based applications in the context of urban spaces as support to PwD. Specifically, SC applications that are addressed to deal with needs and particularities of people with disabilities are still rare, demonstrating that this is a research area to be explored.

The aim of this thesis is to tie up the arguments, premises and outcomes of **Smart Cities** and **Universal Access** to create the idea of **Inclusive Smart Cities**. Briefly, an Inclusive Smart City uses digital assistive technology in the urban spaces in order to enhance the experience that people with disabilities have in these spaces, extending to a considerable number of citizens the gain envisaged by SC initiatives.

Once there are many different types of disabilities, in this thesis we are specifically considering sensory and physical disabilities – once the individual is able to operate independently an interactive device. Nevertheless, other society's sectors are also eligible to be covered by the achievements of Inclusive Smart Cities, for instance, ageing people, refugees, tourists, pregnant women, and certainly a wider

[1] https://www.w3.org/standards/webdesign/accessibility
[2] http://www.who.int/disabilities/en/

audience, because, according to Schmutz et al. (2016), implementing accessibility guidelines can also provide benefits to nondisabled users.

This PhD research is firstly driven to policy makers, IT professionals engaged in the development of software or hardware solutions for SC, as well as to accessibility professionals concerned with providing services to PwD in a more innovative way. But in a broader sense, this thesis can extend its outcomes to authorities, policy makers and professionals from other areas engaged in the development of SC initiatives, such as urban planners and designers, architects, managers, sociologists, geographers, and so on.

1.1 Motivation

The population of PwD has grown worldwide and in some countries, such as Japan and China, older people are more than 50% of the overall population (WHO, 2011). On the other hand, SCs provide a wide range of innovative services in several city sectors, for instance, in transportation, health care, public safety, traffic control, air pollution, waste management, energy, and emergency management (Santana et al., 2017). The SC literature rarely mention terms such as inclusion, people with disabilities, assistive technology; and when it does, it is often in a theoretical and shallow perspective. Therefore, practical mechanisms, models, hardware and software architectures, and technological tools are still expected to be created and to be developed in order to include this considerable portion of the population among the actual users and beneficiaries of the services provided by SC.

Cities are not just complex adaptive or social–ecological systems, they are also spatial systems (Hollands, 2008), and the appropriation of urban spaces is increasingly being mediated by Information and Communication Technologies (ICT) (Lemos, 2007). Hence, the development of comprehensive and urban-driven assistive technology can contribute to the civil engagement of PwD and can make possible to them to take equal advantage (as people with no-disabilities does) of the progress that SC has already brought worldwide. Indeed, as Sottile (2017) reinforces, assistive technology in smart environments represents empowerment, but also independence and dignity to PwD.

Hollands (2008) argues that a real SC would actually have to take much greater risks with technology, devolve power, and tackle inequalities. It is expected to use the technology – engineering and computational resources, process and tools – to make SC more open to look upon the diversity of its citizens. However, although technology and connectivity to networks are two of the Smart City's components, they are not the most important. Even developing countries with a very high level of infrastructure has limitations to offer Smart City applications to all citizens, mostly because those applications are not adapted for everyone.

Literature presents the citizens' empowerment as one of SC challenges and research opportunities (Khatoun & Zeadally, 2016; Nam & Pardo, 2011; Santana, Chaves, Gerosa, Kon, & Milojicic, 2017). Continuously and connected citizens can become smart citizens, the basis of SC initiatives. For example, they can participate in city's projects and access to municipality's digital services and applications through their smartphones. According to Naphade et al. (2001), citizens – including PwD – are at the center of the rising of a SC. Thus, researchers should model, understand, and influence human behavior offering location-aware applications, based on user experience, design, urban systems, social computing, among other fields. Some governments, such as in the European Community, have made clear their goals of defining and implementing measures addressing the specific circumstances of minority groups (as PwD, elderly people and refugees) in the global plans of building a smart and sustainable territory (European Commission, 2010). With the incentives of the government, researches should focus on what kind of information to present to a specific user – or group of users –, when and how to present it, and what reactions to expect (Goldsmith & Crawford, 2014).

Besides these technological and political reasons, another motivation to this thesis has ethical reasons: to produce resources capable to make cities qualified to provide opportunities for all, with equal access to public services to a broader range of citizens. Concerning equal access, SC applications must stride hard to achieve the progress that the Internet and mobile platforms had hardly achieved along the last decades on elaborating accessibility norms, principles, and guidelines. Hence, the Inclusive Smart City concept is an effort in the direction of getting progress in the digital accessibility issue.

1.2 Research question, hypothesis and objectives

Some of the current challenges of the Human-Computer Interaction (HCI) field are supporting the development of solutions that stimulate equal opportunities to every citizen (Salgado, Pereira, & Gasparini, 2015) and reinforcing the shift from the user experience to the community experience (Shneiderman et al., 2016). On the other hand, urban spaces are getting enriched with hardware and software components, and location-based applications are increasing their influence in our contemporary society. This thesis is the result of seeking to balance accessibility challenges with SC technology opportunities. Hence, the research question (RQ) that conducts this thesis is:

RQ: *How to support a better urban experience for people with disabilities?*

With the increasing potential and gain of attention of SC technologies, our main hypothesis in this work is that SC technologies can support a better urban experience for PwD.

The overall research agenda of this thesis has been created to broaden our understanding of accessibility beyond private and controlled spaces. Focusing on answering the research question and pursuing the aim of this PhD research, the overall research agenda is split up in the following objectives:

- Objective 1: Identify the challenges PwD face in urban spaces, as well as the opportunities SC technologies bring to inhabitants;
- Objective 2: Provide theoretical background to Inclusive Smart Cities;
- Objective 3: Propose a set of technological tools to help designers and developers to design Inclusive Smart Cities.

1.3 Methodology

In an attempt to answer the research question and to achieve its objectives, we employed qualitative methods and followed a multi-methods approach based on the User-Centered Design Approach (UCD) and on the Hypothetico-deductive method (HDM).

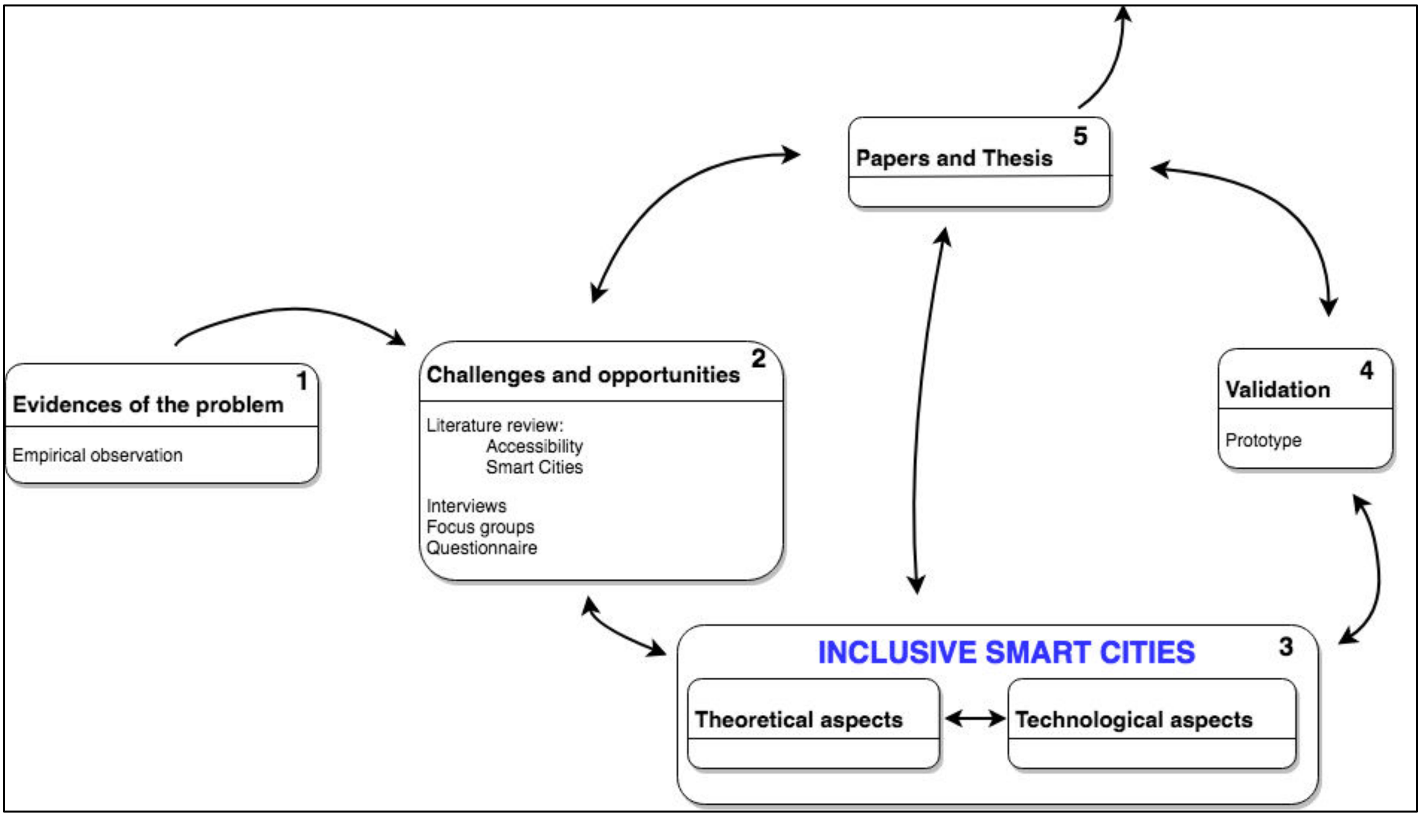
UCD emerged from HCI and it is also a software design methodology for developers and designers. Fundamentally, UCD helps them to make applications that meet the needs of their users through the following principles (Lowdermilk, 2013; usability.gov, 2017): the design is based upon an explicit understanding of users, tasks and environments; users are involved throughout design and development; the process is iterative; the design addresses the whole user experience; and the design team includes multidisciplinary skills and perspectives.

HDM, or simply scientific method, is used to produce scientific theories, as well as the theories used to design the tools for producing theories (instruments, algorithms, etc.). According to Dodig-Crnkovic (2002), the HDM is a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge. Versions of the method vary, but the basic steps are (Godfrey-Smith, 2009):

1. Use the personal experience to consider the problem, try to make sense of it, gather some observations, and look for previous explanations;
2. Formulate a hypothesis as a tentative to solve the problem;
3. Deduce consequences and make predictions;
4. Test the hypothesis in a specific experiment/theory field;
5. When consistency is obtained, the hypothesis becomes a theory and provides a coherent set of propositions that define a new class of phenomena or a new theoretical concept.

Figure 2 shows an adaption of this PhD work to the HDM with its six phases and the approaches employed. The cycle should be understood as iterative and the different activities can be overlapped. Firstly, we used an empirical observation to evidence the problem, i.e., the obstacles that cities pose to PwD. Secondly, based in a literature review of relevant references and the specialized literature, it was formulated the hypothesis that the Inclusive Smart City concept can improve the experience of PwD in urban spaces. Thirdly, as a result of combining the literature review and other qualitative methods – interviews, focus groups and questionnaire – we propose the theoretical aspects of Inclusive Smart Cities. Fourthly, after analyzing the theoretical aspects in conjunction with the results of the literature review and the qualitative methods applied in the previous step, we propose the technological aspects of the Inclusive Smart City vision. Both theoretical and technological aspects of ISC, proposals that come from and are in accordance with de SC vision, are consequences of the hypothesis, which means that they are possible alternatives to address some of the problems that PwD face in urban spaces. Fifthly, a prototype of the ISC is implemented, which can then evaluate the functionality of the ISC vision. During the research cycle, scientific papers are produced and submitted to conferences and scientific journals.

Figure 2 – Research methodology.



As it is described in Table 1, Phase 1 and Phase 2 are performed to address the Objective 1. Phase 3 produces the results expected in Objective 2 and Objective 3. Finally, Phase 4 matches the expectations of Objective 4. It requires adding the results from the previous phase to the list of methods of data collection informed in each subsequent phase – except for Phase 1, obviously. For instance, the results and knowledge acquired in previous phases, especially Phase 3, are the entries and source of data to Phase 4.

Table 1 – Approach, objective and result of each research methodology phase.

	APPROACH	OBJECTIVE	RESULT
Phase 1 Evidences of the problem	Empirical observation	**Objective 1:** Identify the challenges PwD face in urban spaces, as well as the opportunities SC technologies bring to inhabitants	Chapter 2
Phase 2 Challenges and opportunities	Literature review		Chapter 3 and Chapter 4
	Workshop with experts in accessibility; Delphi method; Interviews; Questionnaire; Focus groups		Chapter 5
Phase 3 Inclusive Smart Cities: theory and tools		**Objective 2:** Provide theoretical background to Inclusive Smart Cities	Chapter 6
		Objective 3: Propose a set of technological tools to help designers and developers to design Inclusive Smart Cities	
Phase 4 Assessment	Design, and development, of UrbanAssist as a Proof of Concept	Assess the hypothesis	Chapter 7
Phase 5 Papers and thesis			Appendices

1.4 Document organization

This thesis is divided into 5 chapters:

- In Chapter 2, Evidences of the problem, we present some manifestations of the real problem, namely, accessibility issues in urban spaces, and its extension, impact in the downtown area of the city of São Paulo, Brazil, as well as some opportunities that can be explored in order to improve the urban experience of PwD;
- In Chapter 3, Smart Cities, we summarize definitions, discuss enabling technologies, and examine challenges and opportunities of this technological concept which has grabbed the attention of professionals

in different fields, due to the way it impacts how people interact with urban spaces;

- In Chapter 4, Accessibility, firstly, we describe concepts, principles, definitions, and approaches related to accessibility. Secondly, we discuss some laws, policies, technical standards, and guidelines that are the basis of advancements in accessibility issues and that influence the development of accessible solutions. Thirdly, we summarize the related research and projects with respect to accessibility in urban spaces;
- In Chapter 5, The experience of PwD in urban spaces, we describe the multi-instrument research approach we adopted aiming to build the big picture of the process to create policies related to accessibility in the urban context, how PwD use digital technology in urban spaces, the obstacles they have in cities and the strategies they employ to solve such barriers;
- In Chapter 6, Inclusive Smart Cities: theory and tools, we describe our proposal, the theoretical background and the tools that can enable local authorities and professionals to implement Inclusive Smart City solutions;
- In Chapter 7, UrbanAssist, we describe the design and evaluation of the UrbanAssist prototype to explore how mobile application may help PwD to navigate and explore the urban environment. We report on quantitative and qualitative results that show how UrbanAssist allowed participants to have a better experience when moving around urban spaces;
- In Chapter 8, Conclusion, we summarize the contributions of this thesis, limitations, and future work.

2

Evidences of the problem

The everyday life in big cities is often very busy, and people are most of the time so submerged in their own thoughts and things-to-do that they do not realize the existing details in the cities, especially the way cities can "communicate" with people. In fact, as Latour (2005) explains, human beings usually put daily living activities in a "black box" and perform them in a mechanical and automatic manner. When something goes wrong, people then open this black box and try to think about the way things work – or the reasons why things do not work appropriately. That is what happens with the subway transportation system, for instance. When people enter a subway station, they do not think about the functioning of all machines that are around them and how the trains work. They act in an automatic way. This movement is detoured when something goes wrong, such as a problem or the delay of a train, and people rethink about the complexity of the subway transportation system.

Considering the context of Brazil, according to the Brazilian Ministry of Cities, in the last decades, the national model of urbanization has produced cities characterized by fragmentation of space, and social and territorial exclusion. The disorderly growth of peripheral zones associated with deep inequality between poor areas, that are deprived of all urbanity, and rich areas, where urban equipment and infrastructures are concentrated, reinforces the social injustices present in the cities, making them unfeasible for everyone to live in. Such a reality contributes to the violence and the impossibility of the emergence of citizenship (Brazilian Ministry of Cities, 2014).

This chapter is an exercise of observing how a big city can hide information from PwD, causing the exclusion of this group of citizens. We rise up some situations, some communication actions between the city and their inhabitants, that are mechanical for most of the citizens, but are simply not perceived by PwD. Taking these imperceptible communication actions out of the black box materializes the problem based on its evidences. This is the first step in order to solve the problem.

2.1 Methodology

As a qualitative and exploratory research, this empirical observation supports a study in the phase where the problem is still not completely envisaged; it has not been clearly defined yet and has to be "discovered" (Carroll, 2003). The main purpose of this empirical observation is to try to find a situation in which the independency and autonomy of PwD are questioned, sometimes leading to dangerous circumstances. Moreover, we aim to gain familiarity with the relation between accessibility and urban spaces. The exploratory approach helped us to acquire experience with the difficulties faced by PwD in their daily routine, such as when moving along streets, avenues, buildings, squares, and interacting with some urban equipment. As this research subject is relatively still new – namely, how Smart City initiatives could be inclusive – the exploratory research allowed us to learn, while the theories are still being formulated.

With 11.8 million inhabitants, São Paulo – see Figure 3 (a) – is a representative example of a contemporary megalopolis. This municipality in the Southeast region of Brazil is the most populated city in the country, in the Western Hemisphere, and in the Southern Hemisphere. Capital of the state of São Paulo, one of the 26 constituent states of the Brazilian republic, it is the 13th largest city in the world in terms of population, and it is also the wealthiest city in Brazil. Having the largest economy in Latin America and the Southern Hemisphere, São Paulo attracts people from other regions of Brazil, South America, and maintains expressive communities of other continents, such as the Japanese, Italian, Arab, Jewish, Chinese, Korean, and African (IBGE, 2016).

We have chosen a 1-km route in São Paulo's city downtown area, as depicted in Figure 3 (b), in order to explore (i) what kind of information is showed in a very confused area of a huge city, (ii) what kind of assistive technologies are found in the urban space, and (iii) opportunities to employ technologies to adapt the urban digital layer so that the urban space can be more inclusive.

Figure 3 – (a) Map of the city of São Paulo, and (b) the studied area in
São Paulo's city downtown area.

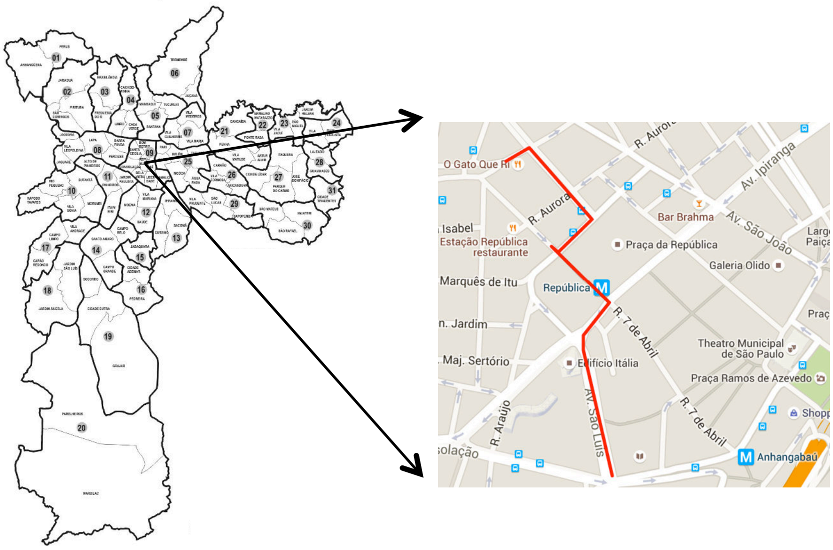


Fig. 1 (a) Fig. 1 (b)

Source: (IBGE, 2016) and Google Maps.

In order to better observe the dynamics of the city concerning the publicized information, as well as to observe the presence of accessibility equipment in the urban space, such as, tactile floor, ramps, and so on, we visited the chosen route three times, during around 1 hour each time, between June and September 2014 – twice during the week and once at the weekend. Qualitative data – in the form of pictures, audio recordings, and descriptive notes – were gathered to register the perceptions of the urban environment, the obstacles, and potential opportunities for the development of assistive technology in the urban space. The result of this documentation process can be seen in the following section.

2.2 Findings

After analyzing the set of data collected – 95 pictures, 26 minutes of audio recordings, and the descriptive notes – the following issues aroused:

- The urban landscape is made by layers of sensorial information (sight and hearing, most of the time). As it is presented in Figure 4, these multi-layers are overlapped in perspective;

Figure 4 – Overlapped information layers.

- Extremely important information shown in the city is mostly textual. PwD, blind people, elderly persons, and foreign people cannot access this navigational information at all or may have great difficulty in discovering what places and objects are in the city – as it is the case of the information displayed at bus stops and corner signs, shown in Figure 5;

Figure 5 – Some very important information is not accessible to all citizens – bus schedule and guidance signs.

- Low floor and tactile floor indicator can be very useful for people with reduced mobility/wheelchair users and visually impaired people. Yet, as shown in Figure 6, sometimes they seem to float on the sideway: no warning or sign of how blind people could access them is displayed – especially to blind people;

Figure 6 – Low floor without a warning/sign.

- There are some places that even people with good sight are not able to find or places that deserve special attention, such as touristic and historical places, as shown in Figure 7. These places have to be made reachable by PwD, too;

Figure 7 – Touristic places.

- Some well-known alert mechanisms concerning dangerous situations are mostly not accessible to PwD: warning sounds at the exit of an underground parking can be misheard due to street noises; textual messages addressed to escalator users cannot be seen by visually impaired persons, as shown in Figure 8 ("Keep the left side free" warning along the escalator);

Figure 8 – Emergency situation warnings.

- Entrepreneurs miss commercial transactions with PwD once that holiday sales, renting and selling signs, as well as advertisement messages – as Figure 9 depicts – do not reach a significant part of the population that has valuable income. Another accessibility barrier is the identification of business and stores: PwD are simply unable to identify stores they are in front of, or to be *flâneurs*[3] in the streets and shopping malls;

[3] The German philosopher Walter Benjamin, analyzing the poesy of the French poetry Charles Baudelaire, describes the flâneur as the essential figure of the modern urban spectator, an amateur detective and investigator of the city. The flâneur has been the subject of a remarkable number of appropriations and interpretations. The figure of the flâneur has been used, among other things, to explain modern, urban experience, and to explain urban spectorship (Benjamin, 2006).

Figure 9 – Business opportunities.

- Urban facilities that are present all over the cities, such as bus stops, taxi stations, police stations, hospital, and restrooms, are not easily found by PwD, as shown in Figure 10. Most of these places are identified only by signs and, sometimes, even by text written on the street pavement.

Figure 10 – Urban common facilities.

- In large cities, the subway is a very important modality of transport. The larger the subway station is, the more confusing the identification of the direction becomes. Finding information is a very hard task; even for people without disabilities. As presented in Figure 11, navigation information is essential in such a confusing environment. That explains why in a subway station PwD usually depend on volunteers and subway personnel to help them to move inside these complex "universes".

Figure 11 – Subway station.

In addition, during the empirical observation, sound was perceived as an important element in the city dynamics. People move around using the audible information of the environment as referential, as well as their source, direction and intensity. Whistles, car horns, ambulance sirens, warnings and announcements inside stations and inside subway cars, and sale advertisements, among others, make up an automatic navigational and routing system that guide people along their journey from one place to another, making them avoid obstacles and dangerous situations.

2.3 Discussion

The data collected and shown in Section 2.2 reinforces the idea that cities still do not make important information accessible to all. In many cases, it is not just secondary and superficial, but vital information to guide citizens in the urban space – such as, in the cases of information about escape routes, emergency warnings, dangerous obstacles in streets, potholes and gaps, among others. Some aspects observed in the selected route determine that the urban space is still a complex system concerning the needs of PwD. On the other hand, these aspects establish that cities are a source of research opportunities regarding the improvement of assistive technology that are already installed and/or the development of new products and services developed to PwD, which could allow them to fully use the urban space.

Hence, the problems noticed in this empirical observation open space to innovative assistive solutions, as well as to the improvement of existing assistive resources for accessibility in urban spaces. Such an opportunity requires a citizen-centered approach that combines pervasive technologies (hardware and software) and the Universal Design methodology in order to enhance the PwD's urban experience.

Since the urban space is an environment mostly based in visual, audio and spatial data, PwD have to face the obstacle of not perceiving one (or several) of these information channels. A blind person, for instance, does not perceive what is drawn in a traffic sign a few meters from him/her. If he/she does not know the place, he/she probably will not find where a public bathroom is, for example, even though the sign shows the appropriate location.

2.4 Chapter summary

A Smart City should enable every citizen to use all the services offered, both public and private, in a way that best suits his/her needs. PwD are part of the city and have to take full advantage of accessing products, urban equipment, services and information. Based on the empirical observation held in a 1-km route in São Paulo's city downtown area, we noticed several situations in which PwD were denied to have a better interaction with the city, because important information and instructions were not available to them. These facts have indicated that the city can be a source of opportunities to employ innovative technologies, aiming to improve the urban experience for PwD.

3

Smart Cities

Although the term “Smart Cities” has be coined in the half of the first decade of the 21st century, it can be considered as a result of the technological evolution of the last years of the 20th century. In the beginning of the 90’s, the popularization of the Internet motivated the rising of the Information Society, in which the creation, distribution, use, integration and manipulation of information has a distinguished economic, political, and cultural role (Masuda, 1980). Aware of the new value assigned to information, governments, citizens, and industry begun to rethink their processes and the way they performed their activities in order to take advantage of this new model of society. The Electronic Government (e-Gov) era brought to citizens the desire of a participatory democracy and better access to public services; the pursuit of cost reduction and agility to governments, and the opportunity of more business with governments and the industry (Lan & Falcone, 1997).

The rapid development of telecommunications and the emergence of interconnected networks gave rise to Information Cities (Hepworth, 1991), in which information could flow in a decentralized way on digital networks, but still privileging the industry. The next step is characterized by a massive digitalization of public services, interaction and communications among government and citizens, and the notion of a physical city and its counterpart: the virtual (or digital) city. Indeed, the Digital City started to be seen as an augmented space of the physical city, over which is added an information layer (Hiramatsu & Ishida, 2001), but it is still strongly anchored on the Web and desktop paradigm. It was the beginning of the 21st century when people started to use annotated maps: physic places enriched with information provided by official sources but also by ordinary citizens. In fact, Sproull & Patterson (2004) outlined that more than providing information and public services over the Internet, designers should support and motivate the active participation of citizens in the digital layer of the city. According to Sproull & Patterson (2004), eliminating the face-to-face interaction was not enough to a Digital City; designers and governmental departments should innovate and add value to the new modality of interaction with citizens. At the same time, other terms, as Hybrid Cities, Wired Cities, Cybercities, and Intelligent Cities coexisted together indicating the game of forces of the different fields in the Computing and Engineering areas that were behind the growing interest on urban technologies: Wired Cities driven to mobile networking and communication issues, while Intelligent Cities were related to the use of tools and algorithms provided by Artificial Intelligence (Angelidou, 2015). Large companies in the Information and Communication Technology (ICT) sector – such as IBM, Cisco, Siemens, and Microsoft – guided marketing campaigns and proposed tailored technological solutions grounded in their vocation, business strategies, and target clients. Also, governments played an essential role in creating specific commissions, defining priorities and policies, suggesting implementation plans, and launching funds all based on their particular needs and goals (Domingue et al., 2011), which contributed even more to contour the terms of the pantheon of urban technologies concepts.

If on the one hand the virtual infrastructure – the extension of the physical infrastructure of the city – was getting more sophisticated, on the other hand, Computer Science ripened a paradigm shift. In 1991, Weiser foresaw “The Computer of the 21st Century” and outlined the principles of Ubiquitous Computing (later also known as Pervasive Computing) (Weiser, 1991): computers should provide access to the Internet anytime, anyplace, and anywhere. The omnipresence of computers should be invisible, quiet, and the extension of the user’s unconsciousness, meaning that even though predicting user’s next steps, computers would not demand his/her focus or attention. As a consequence, academia and industry developed lighter and smaller hardware and software, enhanced the performance of existing ones, and came with new interaction modalities to support the Pervasive Computing paradigm. Handheld devices, mobile phones, mobile networks, Wi-Fi connections, touchscreen, and voice interactions are some of the technologies that were largely disseminated and that became massively known – and even popularized in a substantial part of the World.

The beginning of the 21st century kept the pace of technological evolution and revolution, producing new concepts such as Big Data, Internet of Things and

Cloud Computing. Around 2005, the set of required components to forward computing to the urban scale was assembled. The Smart City vision emerged with the purpose of orchestrating the intrinsic complexity of putting together citizens, government and industry – all of them struggling to solve their everyday problems in the urban context.

3.1 Definitions

Establishing a unique and universal definition to the term Smart City is not a trivial task. One of the reasons for that is due to the multiple academic fields and industry sectors orbiting around the subject "Smart City", studying and making advancements sometimes in a collaborative way, and other times in a very distinct and field-driven way. Smart City vision is one of the rare research and industry topics capable to bring together areas that are normally seen as unrelated, such as Computer Science, Anthropology, Geography, Urban Planning, Tourism, Engineering, Sociology, Politics, and Economics (Angelidou, 2015; Khatoun & Zeadally, 2016). Even considering a distinct area, Computer Science, for instance, it will have a multitude of aspects that are partitioned in several fields, such as Human-computer interaction, Networking and Distributed Systems, Multimedia, Security, Database, Artificial Intelligence, Software Engineering, and Hardware.

A seminal concept to define Smart Cities is the idea of Urban Informatics, that establishes its elementary components: place, technology and people (Foth et al., 2011). Place is related to the physical infrastructure, the urban space, the tangible constituent of the hybrid city – the physical reference that can be enriched by its augmented counterpart in the digital layer of the city. The city, as a set of places, is a complex system that must be modeled in order to have the computational representation of its behavior, inhabitants, utilities, facilities, interactions among its components and the environment.

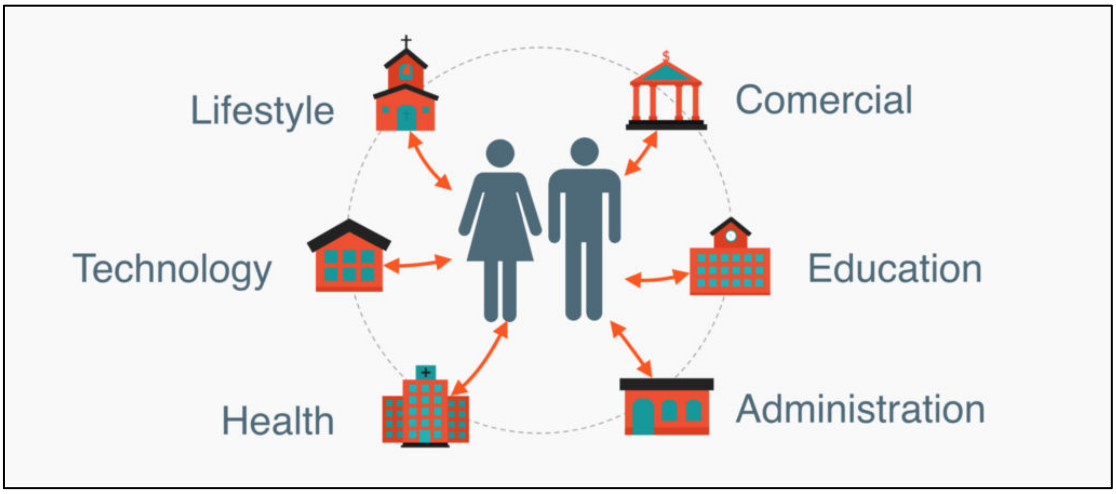
Still according to Foth et al. (2011), technology is the way to augment experiences of places. Technology can provide ubiquitous experiences, as a place-independent interactivity, but it can also provide mobile and locative experience, in the sense of place-specific information and services. Technology is also responsible for instrumenting the city, such as with sensor networks and tags; attaching annotations to places, such as Geographical Information Systems (GIS) technology; accessing the digital layer, such as mobile devices; and to implement and maintain the digital layer of the city, such as using software and security methods. All blended together in order to make available systems and applications in a ubiquitous/pervasive way (Nam & Pardo, 2011). Moreover, technology can change the way the urban space is perceived, understood, and how citizens interact with places.

The third component, people, is the core of the city, according to Foth et al. (2011). Individually or collectively, people need to communicate and to interact both in the physical and digital world. In fact, the expansion of the physical layer to the digital counterpart brought socio-cultural, economical, and political domains transformations, even creating or empowering ideas, such as collective intelligence and participatory democracy. Moreover, citizens should benefit of the urban technological infrastructure to develop creativity and innovation (Nam & Pardo, 2011), two features that characterize the contemporary societies.

Smart Cities vision complements the Urban Informatics vision by adding the component institutions (or Governments), which are in charge of Governance, Policy, regulations, and directives (Nam & Pardo, 2011). This is an extremely important contribution brought by SC vision, because the complexity that exists in the physical layer of city is transposed do the digital layer counterpart. Governance, policies, rules, and regulation are required in order to align diverse stakeholders. With the Governments dimension, SC are much closer to be like real cities, which are required to have an administrative environment that is responsible for arranging and integrating different interests, as well as dealing with the relationship between government agencies and non-government parties. Nam and Pardo (2011) analyze that information and technological propagation *per si* is not an end itself, so, institutions and governance, in addition to a clear building plan are essential to the success of SC projects. Government must take advantage of technology, must be transparent and motivate collaboration across their departments in order to provide innovative, dynamic and efficient services to citizens and to business. Furthermore, Governments must identify citizens' needs – even anticipate these needs and how to solve them, placing citizens in the center of operations and strategic plans (Paskaleva, 2009).

Concerning the people component, SC projects are expected to take advantage of the technology to support social infrastructure. People should be able to enhance the way they interact, collaborate and engage to political and social causes. In addition, as illustrated in Figure 12, they should have access to lifestyle, technology, health, commercial, educational and municipality administration services. This perspective configures the citizen-driven SC vision. As an example of a citizen-driven SC vision, IBM proposed key domains in cities whose services would improve the citizens' quality of life (IBM, 2011), such as, water management, public safety, improvements in traffic, buildings, and energy. Each municipality would decide the priority of each domain in developing services to citizens according to its budget and political strategy. IBM recommended not implementing services to all domains at the same time. For instance, a city should tackle the water management issues and, then, focus on improving the traffic congestion problems.

Figure 12 – Citizens as the core of Smart Cities initiatives.



Source: (Liquid State, 2017)

Creativity and participation can be the key to find solutions to contemporary cities' problems. Smart citizens are pointed at the same time as the basis and the result of Smart Cities initiatives (Balestrini, Diez, & Marshall, 2014; Oliveira, Campolargo, & Martins, 2014). People can participate in a more proactive way, for example, providing feedback on the quality of services or the condition of roads and the built environment, adopting a more sustainable and healthier lifestyle, volunteering for social activities or supporting minority groups (United Kingdom, 2013).

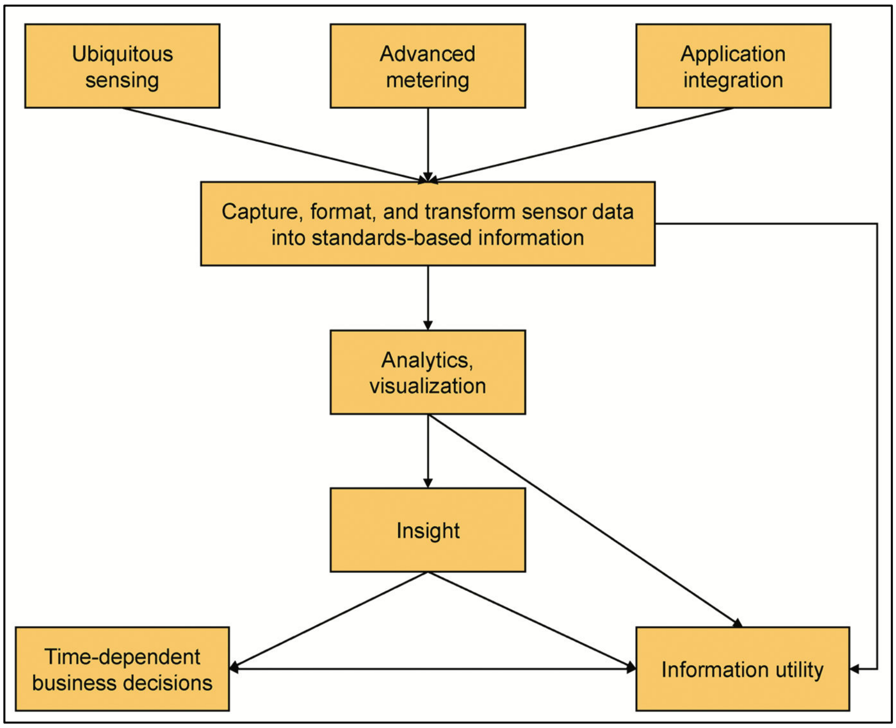
Hence, people, place, technology, and government are the key components of Smart Cities vision. They are inseparable, and this statement is already a seminal definition of Smart Cities. Infrastructure is necessary but not enough to switch a city in a smart city. Still according to Nam and Pardo (2011), IT infrastructure and applications are prerequisites, because without real engagement of citizens and without the cooperation between public institutions, private sector, and voluntary organizations, there is no smart city.

Another aspect frequently cited along the definitions of Smart Cities is the support to the process of decision-making. The smartness of a city is connected to gather integrate, analyze, optimize, make decisions, and support human decision-making based on operational data (Harrison et al., 2010). As shown in Figure 1, the physical world is instrumented by the use of sensors, kiosks, meters, personal devices, appliances, cameras, smartphones, implanted medical devices, the web, and other similar data-acquisition systems, including social networks as networks of human sensors, which enable the capture and integration of live real-world data. Then, a combination of public and private networks, as well as software systems and city's services interconnect and integrate this data to the government systems. The association of instrumented and interconnected systems has the consequence of connecting the physical world to the virtual world.

Moreover, the analysis of the interconnected information can produce new insights and predictions that drive decisions and actions and that improve the process outcomes or system, organization, and industry value chains. Insights are outcomes that have the peculiarity of positively changing the end-user experience or yet bringing innovation to processes and services – that explain why insights represents a paradigm switch and why they are pursued.

As depicted in Figure 13, cities can provide different levels of smartness. Some applications can be developed upon only interconnected data, resulting in basic functionalities to users. Other applications are fed by the result of analysis, leading to more resources to users. And, finally, other more sophisticated applications can use insights and predictions to provide a considerable level of knowledge, adaptation, personalization, and even event prediction.

Figure 13 – Conceptual flow of data and information in a Smart City Project.



Source: (Harrison et al., 2010)

Supporting citizens and governments in their decision-making process is considered by Batty et al. (2012) a critical feature of SC initiatives due to the complexity of cities and the exponential growth of urban problems. In reality, it could not be different, since along the last decades, people are increasingly moving from rural to urban areas in such a rapid way that cities cannot readjust themselves in the same velocity. According to the United Nations, since 2008 more than half of the world's populations live in cities (United Nations, 2012a). This mismatch between the increase of urban population and the lack of efficient governance produces undesirable effects, such as crowded neighborhoods, housing, congestion and transportation, air pollution, unemployment, waste of natural resources, traffic accidents, crimes and violence, difficult access to public services – for instance, education and health services. And the United Nations' predictions are not encouraging: in 2030, 5 billion people is expected to be living in cities, challenging even more the governments and the whole society to establish means of efficiently share resources and urban spaces.

Owing to sensors, smartphones, tags, actuators, GIS (Geographic Information Systems) devices, embedded systems, and microcontroller kits – such as

Arduino and Raspberry Pi – cities have become instrumented and a wide range of data have been collected and made available to municipalities, enterprises, and even ordinary citizens. Those instruments, as anticipated by Weiser, are everywhere: in buses, cars, trees, houses, streets, on the top of buildings, on the air, attached to birds, on the streets, on lakes and even in the sea; besides, they can be stationary or mobile. They can measure air pollution and noise levels, waste disposal, traffic flows, local weather, and transport network availability, among many others (Batty et al., 2012). That is how cities are already monitored in real time, or how natural phenomenon can be *in situ* tracked, or different kinds of patterns can be detected, and human behavior can be observed. The provision of relevant information can help citizens to get informed about different alternatives to solve their concerns and make better decisions. Also, relevant information is the basis to support city managers to quickly recognize and fix the occurrence of any abnormality.

Harrison et al. (2010) enumerate some benefits achieved based on information collected in the urban space and the smartness obtained from it. To name a few: information about traffic and road conditions can help drivers to make decisions about which routes to follow; real time information can help consumers to make decisions about energy consumption and the best time to use washing, heating, and cooling machines; emergency responders share a common view of the situation and make decisions considering the actions that other agencies are taking.

Achieving such a level of smartness is not an end-point, as the UK Government argues (United Kingdom, 2013). According to its institutional vision, Smart Cities are not a static concept, neither they have an absolute definition, but they are a process, a series of steps towards a more "livable" city and with SCs it is possible to respond quicker to new challenges and to the constantly changing cities. Thus, a Smart City should bring together hard infrastructure, digital technologies, and social capital – including local skills and community institutions. Still according to the UK Government (2013), Smart Cities should provide a flexible information-driven approach characterized by the following requirements:

- A modern digital infrastructure, combined with a secure and open access approach to public re-useable data, which enables citizens to access the information they need, when they need it;

- A recognition that service delivery is improved by being citizen centric;
- An intelligent physical infrastructure;
- An openness to learn from others and experiment with new approaches and new business models; and
- Transparency of outcomes and performance, for example, city service dashboards to enable citizens to compare and challenge performance.

These five requirements in conjunction with the commitment to offer to citizens what they need summarizes the vision of the United Kingdom Government to a flexible Smart City approach that provides attractive environment for business, and improves the quality of life of all its citizens.

Actually, the raise of “quality of life” is referred as one of the reasons and the final goal of Smart Cities initiatives (Naphade, Banavar, Harrison, Paraszczak, & Morris, 2011). Since the urban problems are already settled and, as previously pointed out, the scenario tends to get worse, technology can play an important role in mitigating the consequences of these problems in citizens’ life, for instance, providing relevant information and alternatives to make specific, informed choices in order to contour these problems and their side effects (Lee, Hancock, & Hu, 2014; Sánchez et al., 2013).

Cities became the stage where human beings perform the four basic functions of modern life: to live, work, have fun, and go around (Freitag, 2006). People move to cities seeking quality of life in one or more of these basic functions. In order to meet these expectations, Smart Cities are concerned about the quality of life of its inhabitants and they can be described as (IBM, 2011):

- A well-managed city that works to create an optimal urban environment for citizens, visitors, and industries. These cities provide better performing and reliable city services that enable simplified and integrated access to services;
- A healthy and safe city that addresses the health and safety of residents and visitors through innovations in local healthcare networks, disease management and prevention, social services, food safety, public safety, and individual information privacy;

- A sustainable city that implements concrete measures toward sustainability. Possible measures that can make a city sustainable include urban planning principles for mixed land use, architecture and construction principles for buildings, and methods to use rainwater instead of treated water;
- A city with good governance that struggle to improve the quality and efficiency of city services. It provides the means to listen, understand, and respond to the needs of its citizens and businesses;
- A city that incorporates culture and events, attracts visitors and keeps citizens interested in the city through investments in arts, culture, and tourism;
- A city that is focused on its citizens and that looks to address their needs by providing information and access to city services in a convenient and easy-to-use manner.

In IBM's point of view, when this roadmap is followed, both citizens and the city government can benefit: citizens can access information and services when needed and they give to the city a way to share important information and obtain input from their citizens in a timely manner. However, as Freitag (2006) notes, cities are historical formations, each one with its individuality and the specific culture of its time. Thus, the term "quality of life" can be imprecise, considering the diversity of cities in the world, and defining it can be a hard and elusive task.

In order to pursuit such ambitious goal, the International Organization for Standardization published the ISO 37120:2014 *Sustainable development of communities Indicators for city services and quality of life*, which is a norm that compounds a set of standardized indicators that conduct and measure the delivery of city services that impact in the level of citizens' quality of life (International Organization for Standardization, 2014).

The indicators are grouped in 17 themes – different sectors and services provided by a city – as shown in Table 2. Admitting the specificities and the differences in resources and capabilities of cities worldwide, indicators can be grouped together for analysis when taking into consideration holistic characteristics of a city; indicators can also be aggregated to larger administrative areas (for example, by region, metropolitan areas, among others).

Table 2 – Themes and indicators presented in ISO 37120:2014.

Themes	Indicators
Economy	▪ City's unemployment rate; ▪ Assessed value of commercial and industrial properties as a percentage of total assessed value of all properties; ▪ Percentage of city population living in poverty.
Education	▪ Percentage of female school-aged population enrolled in school; ▪ Percentage of students completing primary education; ▪ Percentage of students completing secondary education; ▪ Primary education student/ teacher ratio.
Energy	▪ Total residential electrical energy use per capita (kWh/ year); ▪ Percentage of city population with authorized electrical service; ▪ Energy consumption of public buildings per year (kWh/m^2); ▪ Percentage of total energy derived from renewable sources, as a share of the city's total energy consumption.
Environment	▪ Fine Particulate Matter (PM2.5) concentration; ▪ Particulate Matter (PM10) concentration; ▪ Greenhouse gas emissions measured in tons per capita.
Finance	▪ Debt service ratio (debt service expenditure as a percentage of a municipality's own-source revenue).
Fire and emergency response	▪ Number of firefighters per 100,000 population; ▪ Number of fire related deaths per 100,000 population; ▪ Number of natural disaster related deaths per 100,000 population.
Governance	▪ Voter participation in last municipal election (as a percentage of eligible voters); ▪ Women as a percentage of total elected to city-level office.
Health	▪ Average life expectancy; ▪ Number of in-patient hospital beds per 100,000 population; ▪ Number of physicians per 100,000 population; ▪ Under age five mortality per 1,000 live births.
Recreation	▪ Square meters of public indoor recreation space per capita; ▪ Square meters of public outdoor recreation space per capita.
Safety	▪ Number of police officers per 100,000 population; ▪ Number of homicides per 100,000 population.
Shelter	▪ Percentage of city population living in slums.
Solid waste	▪ Percentage of city population with regular solid waste collection (residential); ▪ Total collected municipal solid waste per capita; ▪ Percentage of the city's solid waste that is recycled.
Telecommunication and innovation	▪ Number of internet connections per 100,000 population; ▪ Number of cell phone connections per 100,000 population.
Transportation	▪ Kilometers of high capacity public transport system per 100,000 population; ▪ Kilometers of light passenger public transport system per 100,000 population; ▪ Annual number of public transport trips per capita; ▪ Number of personal automobiles per capita.
Urban planning	▪ Green area (hectares) per 100,000 population.

Wastewater	▪ Percentage of the city population served by wastewater collection; ▪ Percentage of the city's wastewater that has received no treatment; ▪ Percentage of the city's wastewater receiving primary treatment; ▪ Percentage of the city's wastewater receiving secondary treatment; ▪ Percentage of the city's wastewater receiving tertiary treatment.
Water and sanitation	▪ Percentage of the city population with potable water supply service; ▪ Percentage of the city population with sustainable access to an improved water source; ▪ Percentage of the population with access to improved sanitation; ▪ Total domestic water consumption per capita (liters/day).

Source: (International Organization for Standardization, 2014).

The indicators contained in this International Standard are applicable to any city, municipality or local government, although for data interpretation purposes, cities shall take into consideration contextual analysis when interpreting results. City managers can use this set of indicators to track and monitor a city's progress on service performance and quality of life, and to assist cities in defining targets and monitoring achievements.

The notion of gathering efforts to pursuit citizens' quality of life is the element that was missing towards the steadiest definition to Smart Cities up to the present moment. With the collaboration between the International Organization of Standardization and the British Standards Institution (BSI), the ISO/IEC 30182 consolidates the definition of Smart Cities as a combination of six key aspects (International Organization for Standardization, 2017):

- A modern digital infrastructure, combined with a secure but open access approach to public re-useable data, which enables citizens to access the information they need, when they need it;
- A perception that service delivery is improved by being citizen centric: this involves placing the citizen's needs at the forefront, sharing management information to provide a coherent service;
- An intelligent physical infrastructure to enable service providers to use the full range of data both to manage service delivery on a daily basis and to inform strategic investment in the city/community;
- An openness to learn from others and experiment with new approaches and new business models;

- Transparency of outcomes/performance to enable citizens to compare and challenge performance; and
- The commitment to deliver the necessary change to enhance the citizens' quality of life.

This definition summarizes the most important elements that already appeared in previous definitions and incorporates some aspects that characterize our contemporary society in a flexible way, such as, citizens' quality of life improvement, transparency, and open access.

3.2 Enabling technologies

Urban problems are inherent to cities since the man decided to live in groups and to settle in a specific place (Krier, 1993). They changed along the centuries and even from country to country there are different problems ranging from hygiene to transportation, immigration, foreign attacks, bad weather conditions, housing, among others. These issues are as old as the rising of cities themselves. However, only from the middle of the last decade of the 20th century to the middle of the first decade of the 21st century, and with the development of a set of computational advances, these problems could be treated with the scale, territory extension and complexity that they present.

Smart Cities enabling technologies provide computational resources in order to tackle citizens' needs and to mitigate urban problems. They allow the design, maintenance, and implementation of SC initiatives. Three of these SC enabling technologies are especially important, considering the scope of this thesis: Internet of Things, Ubiquitous Computing, and Cloud Computing.

3.2.1 Internet of Things (IoT)

Two billion people use the Internet for navigating in websites, talking to other people, watching movies, playing games, visiting other places remotely, listening to online music, getting instructions from maps to arrive to the right place, getting in contact with their social network, and many other communication and interaction tasks. However, as claimed by the French philosopher Bruno Latour and his colleagues in the Actor-Network Theory, modern societies are formed, in a very brief way, by hybrid networks of human beings and things (or objects), i.e., the actors (Callon, 2013; Latour, 2005). Things can be people, animals, objects, devices, cars, institutions, computers, smartphones, sensors, wearables, and other inanimate nonhuman things. They are as active as humans are in the interconnected network, acting mutually, interfering and influencing one another's behavior, with the difference that nonhuman things can be adjusted by and according to the human needs. The Internet of Things is the resulting global network that interconnects heterogeneous objects, allowing them to take place as users of the Internet infrastructure, as people do, including all the hardware and software technologies necessary to make this endeavor real (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012). Based on the proposal of the CASAGRAS consortium[4] members, IoT is the infrastructure that connects physical generic objects to virtual objects, as well as the architectures that provide the connection between the physical and the virtual worlds (CASAGRAS Consortium, n.d.). Hence, objects can communicate to computers and to each other, providing services to the benefit of the human kind in a variety of domains, such as transportation and logistics, healthcare, smart environment, personal, and social.

The heterogeneity aspect remains as one of the main concerns related to the development of IoT. However, Internet standardized protocols, such as the TCP/IP, UDP and HTTP, make possible the deployment of independent services and applications, which, in the end, perform the tasks and results that users need no matter the platform or operating system, since they are running over the Internet infrastructure. In reality, the word “Internet” in the “Internet of Things” term is related to the Internet standardized protocols (Atzori, Iera, & Morabito, 2010).

Objects can have different levels of smartness (Gubbi, Buyya, Marusic, & Palaniswami, 2013). In the simplest vision of IoT, objects do not do anything actively, they cannot communicate with each other, and they do not have any degree of intelligence. In the most sophisticated vision, objects are identifiable, they are able to communicate and interact among themselves and also with people. To become a smart object, an ordinary thing (Miorandi et al., 2012):

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[4] CASAGRAS Consortium is a Coordination and Support Action for Global RFID-related Standardization Activities involving, in particular, organizations from China, Japan, Korea and the USA.

- Must have a physical embodiment and a set of associated physical features – e.g., size, shape, etc.;
- Must have a minimal set of communication functionalities, such as the ability to be discovered and to accept incoming messages and reply to them;
- Must have a unique identifier;
- Must be associated to at least one name and one address. As it happens with the naming rules for the Internet resources, the name is a human-readable description of the object and can be used for reasoning purposes, while the address is a machine-readable string that can be used to communicate to the object;
- May have some basic computing capabilities. This can range from the ability to match an incoming message - as in passive RFIDs - to the ability of performing rather complex computations, including service discovery and network management tasks – as in microcontroller boards;
- May possess means to sense physical phenomena – e.g., pollution level, temperature, light – or to trigger actions having an effect on the physical reality (actuators).

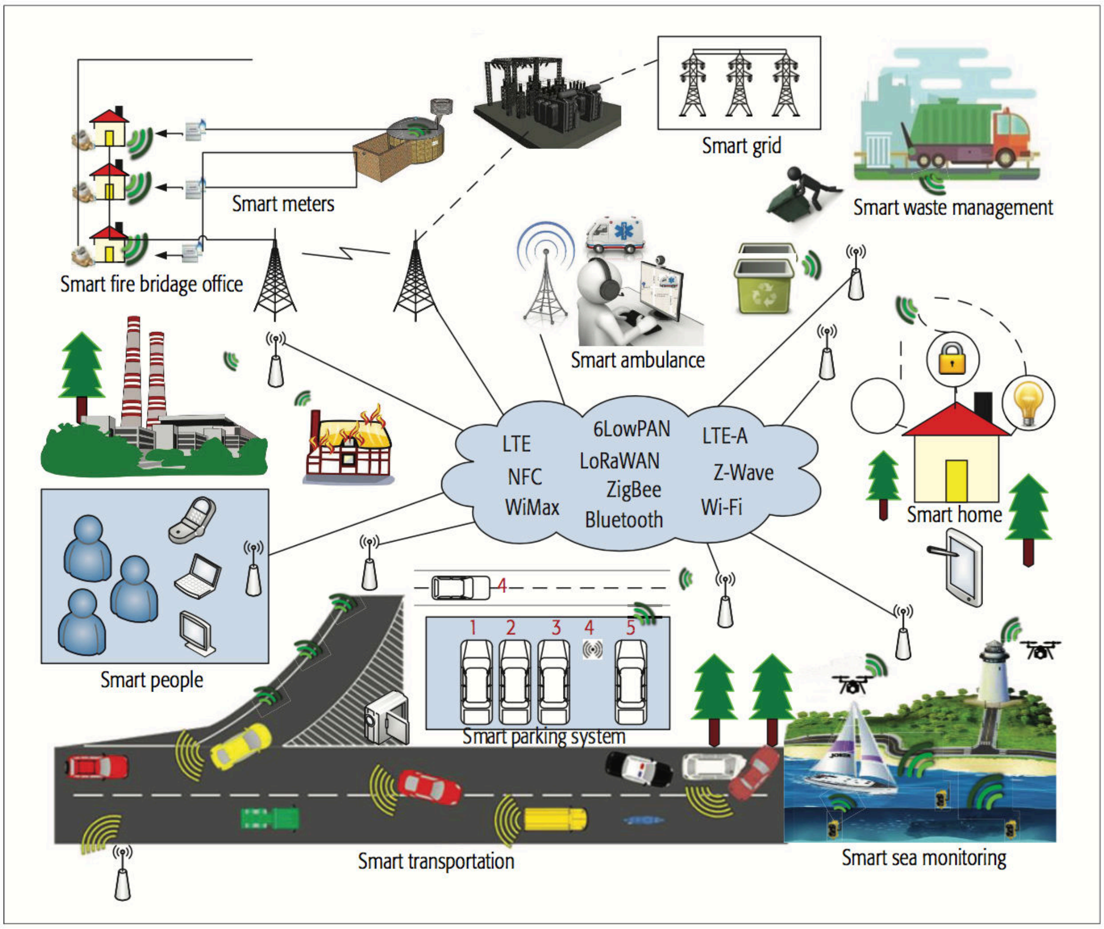
The first feature, physical embodiment, is what makes the object a real and a perceptible entity. Communication functionalities can be embedded to an object – such as sensors and Arduino microcontrollers with a Wi-Fi module integrated attached to trees collecting and sending information about the forest areas to a central platform[5]. But it can also be a resource-constrained object that is identified by a tag and that has its tag detected by a mobile app that works as a proxy and that can establish a Wi-Fi connection to access remote information about the object. Such information can be obtained using an NFC tag placed, for example, in a bottle of wine that, when detected by the mobile app, accesses complementary information, such as review and market price of the wine for supply chain tracking[6]. Therefore, as Borgia (2014) outlines, the backbone of the IoT network communication is composed by a

[5] http://www.treemetrics.com/

[6] https://captag.solutions/

wide range of wired, wireless, cellular, and hybrid technologies. As Figure 14 depicts, some communication technologies, such as LTE, NFC, WiMax, 6LowPAN, LoraWAN, ZigBee, Bluetooth, LTE-A, Z-Wave, and Wi-Fi are in the core of IoT technologies, that fasten all other technologies together, and that is in a steady progress.

Figure 14 – Communication facilities gluing other IoT Technologies and SC applications.



Source: (Yaqoob et al., 2017)

IoT communication technologies are chosen according to some parameters and application requirements, such as data rate, range, network topology, operating frequency, power consumption, and security, among other aspects.

The importance of the next IoT feature, identifiers, is that they allow billions of devices to be uniquely reached by other IoT entities, enabling any kind of interaction among devices (Gubbi et al., 2013; R. Want, Schilit, & Jenson, 2015).

Nowadays, IPv6's 128-bit addresses are the most flexible and the best alternative as identifiers for a global network of devices. To incorporate the identifier to the physical structure of the object, identifiers can be encrypted in (CASAGRAS Consortium, n.d.):

- Low-cost codes, such as barcode and QR Code;
- Tags, such as RFID and NFC (Near Field Communication);

Since any object is eligible to get connected to the IoT infrastructure, the growth and scalability of the global network must be monitored in order to assure the functioning of objects, the reliability of the data and the effective use of the devices from the user interface. Essentially, these issues are addressed by the Uniform Resource Identifiers (URIs), which include both locators and names, providing a higher-level concept that bridges those devices to the existing Web technology. Next, the Uniform Resource Locator (URL) is used in conjunction with the Object Name Service (ONS) – similar to the traditional Web Distributed Name Service (DNS) to route and connect to objects' services.

The development of single-board controllers and microcontrollers kits – such as Arduino[7], Raspberry Pi[8], and Dwengo[9] – brought to objects the capability of computing and performing. The miniaturization of electronic components allowed these microcontrollers to be equipped in a preassembled form with a microprocessor, digital and analog input/output (I/O); serial interfaces, such as Universal Serial Bus (USB); stored program memory, and Flash memory; interfaces to network connection, such as Wi-Fi and ZigBee; sensors and actuators; among other powerful resources (McEwen & Cassimally, 2013). As they are usually low-cost, offer an Integrated Development Environment (IDE), and support the most known programming languages, these prototyping embedded devices have popularized not only among technology professionals and nerds but also among amateurs, hobbyists, and ordinary people, spreading the Do It Yourself (DIY) philosophy. In a few minutes, even novices can create devices that interact with their environment using sensors and actuators.

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[7] http://www.arduino.cc/
[8] https://www.raspberrypi.org/
[9] http://www.dwengo.org/

The last IoT feature is related to the roles played by sensors and actuators. Sensors can collect characteristics from the environment, these data are processed somewhere remotely, and then, based in the result of this processing, actuators can modify the status and conditions of the context where they are. Borgia (2014) cites a wide range of application of sensors and actuators in a Smart City: free parking space, air pollution, street lighting, vehicle traffic, water level, vehicles parked illegally, presence of potholes, slippery, not draining roads, and so on. Using sensors in urban spaces has some peculiarities, such as outdoor climate conditions and the broadness of the area covered that must be sensed, which sometimes requires a large number of sensors. Using Wireless Sensor Network (WSN) can help address these issues. In a WSN, each sensor is a node, which sometimes pre-processes the collected information and then transmits it to a remote server via other sensor nodes (Hancke, de Carvalho e Silva, & Hancke, 2012).

Thanks to IoT, the essence of objects, their purpose and functionalities that traditionally have characterized them has somehow changed – or, better, have been augmented. A tree, for instance, is no longer limited to producing fruits and photosynthesizing, it can also collect information such as temperature, humidity and luminosity, providing information for a more precise weather forecast. A mirror that besides reflecting images can also display the weather forecast, the time and date, and recent news headlines[10]. A plant can monitor the soil moisture itself and when needed it will water itself[11]. A dress that changes the color of one of its electronic components according to the heart signals of the person that is wearing it[12]. Now, objects have intentions (Rozendaal, 2016). Lemos (2013) states that IoT brought a new meaning and importance for ordinary objects: they are capable to communicate information in a global network in accordance with protocols and standards.

On the other hand, distributing smart objects everywhere increases the risks to information security. Indeed, security and privacy is one of the challenges and they still have open issues related to the IoT technology (Atzori et al., 2010; Khatoun & Zeadally, 2016). Atzori et al. (2011) emphasize that enabling objects to communicate represents a danger to our future, for instance, hidden smart objects can be used as

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[10] https://medium.com/@maxbraun/my-bathroom-mirror-is-smarter-than-yours-94b21c6671ba

[11] https://www.hackster.io/soil-control/plant-monitor-waterbomb-797e47

[12] http://www.instructables.com/id/Monitor-Dress-Connect-Heart-Signals-to-the-IoT/

surveillance mechanisms against people and environments; also, since cars have become equipped with embedded systems, they are increasingly susceptible to hackers' attacks, which could put lives at risk. Summarizing, in a distributed architecture, pitfalls are distributed as well: disturbing the network availability; propagating erroneous data into the network; accessing personal information, among others. All IoT components are vulnerable to such attacks and, according to Gubbi et al. (2013), cryptography is the most important resource against data corruption. Basically, encryption enhances data confidentiality against outsider attacks, and message authentication codes ensure data integrity and authenticity. However, encryption does not protect against insider malicious attacks; in this case, non-cryptographic means are needed, particularly in WSNs.

The benefits pledged by IoT technology are many. Taking advantage of these benefits in an effective way is not simple. The broadness and scale of IoT, which are at first a considerable profit, reveals also an obstacle. Particularly regarding the Human-Computer interaction (HCI), and User experience (UX) fields, Ganesh & Malhotra (2014) explain that designing for the IoT scale, an ecosystem of machine-to-machine and human-machine interactions is one of the challenges that must be tackled with a human-centered, human-valued perspective. Developers, designers, businesses, policymakers, and citizens must understand the implications and assumptions that enable the IoT, as well as the consequences of personal data sharing, in order to design safer solutions and more usable experiences. Even the notion of time is modified with the possibility of using a range of different devices to stay connected most of time. Users' attention will be constantly disputed, and the possibility of interrupting a task to the detriment of starting a second task, may compromise continuing and finishing the first task. According to Schraefel et al. (2017), one possible solution is to be transparent on how user's data is used, which will make users consent, and as a consequence, the IoT's use has the potential to be more meaningful.

Everyday objects, digital services, and human beings – the IoT ecosystem – are increasingly interconnected. Rozendaal (2016) points out that development of new objects and exploring new uses for existing objects are formidable opportunities to HCI professionals. Since IoT enabled objects to have new purposes – different use than they were initially bounded to – designers must focus on how to provide spontaneous collaborations between humans and non-humans. Collaboration implies two other essential words, still according to Rozendaal (2016): delegation and control – concepts also presented in the Actor-Network Theory (Latour, 2005). Thus, designing IoT interactive solutions is related to answering the following questions: how tasks and judgements are delegated between humans and non-humans? Who takes the initative? When? Can behaviors be overruled? How? So far, these kinds of issues were not among the main concerns of designers and developers. However, they are now crucial when conceiving IoT solutions.

3.2.2 Ubiquitous Computing

The evolution from a centralized and ambient-driven to a distributed at all scale network access revolutionized the use of ICTs. Thanks to the network access everywhere, heterogeneous smart objects are capable to communicate and become interconnected directly through heterogeneous networks (Miorandi et al., 2012). Besides providing connectivity everywhere, Ubiquitous Computing permits smart objects to take advantage of mobility to perform their tasks and interact – on the move – with the network and with other smart objects, allowing SC initiatives to better simulate the variation of objects' movements and locations as it happens in real cities. After all, cities are dynamic.

Nevertheless, the ability of performing tasks in a distributed manner is not enough to characterize a SC solution. Besides distributed connection and mobility features, Ubiquitous Computing provides to SC solutions the ability of determining, with a certain degree of accuracy, the location of things, places and people. One of the most used technologies for determining location is the Global Positioning System (GPS), a global navigation satellite system that provides geolocation and time information to a GPS receiver, and that operates independently of any telephonic or internet provider (MIT OpenCourseWare, 2012; Wikipedia, 2017). Nowadays, even ordinary smartphones are equipped with GPS capabilities, enabling citizens to engage in a timely environment monitoring, disaster contacting, and even reporting potholes and illegal trash dumping to local authorities[13]. These applications also bridge the communication gap between inhabitants and local governments to increase civic responsibility and improve citizen services, since they pinpoint where and what the

[13] Pothole 311 app: https://play.google.com/store/apps/details?id=com.shake

problems are, which helps authorities to make better decisions to solve them. This bottom-up and informal sensing approach (Jiang et al., 2016) has its potential increased when combined with dynamic maps, tools that represent graphically, live and in colors the situation of the city related to different indicators – for instance, air quality[14], noise pollution[15], wind[16], traffic[17], and level of accessibility to places[18] – sometimes showing time lapsed videos to testify the indicators' fluctuation.

Identifying where the user is, GPS coordinates aids to define the context where the user is, allowing applications to operate, personalize and adapt the interaction considering what is more appropriate to the specific user at a specific location. The association of informational content/communication facilities, technologies and physical/digital spaces is defined as a locative media (Wilken, 2012). This set of practices and studies aims to delivery information and content that is important to users to better explore and appropriate the space around them. Lemos (2007) argues that cities are creating generalized and permanent connected zones, the informational territories, intersection areas that link the urban space to the digital services and content, digitally augmenting the physical perception of the place. Thus, the adapted and personalized aspect of locative media filters the scattered, distributed, and neutral aspect of Ubiquitous Computing.

Summing up, Ubiquitous Computing provides the distributed infrastructure necessary to enable the development of SC applications. However, the SC vision broadens the initial Weiser's definition[19] adding the term anything, meaning that any smart object or smart thing is eligible to access remote content and services, to collect data, and to interact with other smart objects.

3.2.3 Cloud Computing

The instrumentation of cities and the embedded technology plugged to the urban space have turned them into open-air computers and vast data factories. Cheap

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[14] http://aqicn.org/map
[15] http://www.noisetube.net/
[16] https://www.windy.com/
[17] https://maps.google.com
[18] http://accessnow.me/
[19] As previously showed, Weiser (1999) states that computers should provide access to the Internet anytime, anyplace, and anywhere.

and easy electronic communication has increased the number of users and the demand by efficient *in situ* informational content and digital services to help people better experience the city. The huge quantity of data collected by sensors and smart objects as well as the digital services provided by SC initiatives – and in which inhabitants rely to do their daily tasks – require equivalent computational resources to address a massive data processing, to transform raw data into insightful information, and to produce the expected results (The Economist, 2012). Cloud Computing (CC) is a technological paradigm that promises to deal with these SC challenges.

According to the National Institute of Standards and Technology (NIST), Cloud Computing is "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell & Grance, 2011). In other words, CC enables a group of users/organizations to share pools of dynamically configurable hardware and software resources. This third-party vision allows organizations to focus on their core business and to improve their business efficiency, since CC may avoid wasting time with technological issues. Considering the SC scenario, municipalities are exempt from worrying about the creation and maintenance of infrastructures that are often costly and inadequate, if they use the CC technologies (Suciu et al., 2013). In this new paradigm, computing resources are similar to utility, and organizations pay as they consume the resources, proportionally to their usage and flexible in line with the organizations' seasonal demands.

According to Mell and Grace (2011), the CC paradigm has the following characteristics:

- On-demand self-service: a consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider;
- Broad network access: capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, tablets, laptops, and workstations);

- Resource pooling: the provider's computing resources are pooled to serve multiple consumers. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify the location at a higher level of abstraction (e.g., country, state, or datacenter). Examples of resources include storage, processing, memory, and network bandwidth;
- Rapid elasticity: capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward proportionally to the demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time;
- Measured service: Cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriated to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service.

The resources provided by CC technologies, also known as services, can be arranged in three models (Mell & Grance, 2011; Obaidat & Nicopolitidis, 2016): i) Software as a Service (SaaS), ii) Platform as a Service (PaaS), and iii) Infrastructure as a Service (IaaS). In the SaaS model, the end-user software application is the resource offered in a subscription style for both end consumers and organizations. SaaS simplifies the deployment model of software since users do not need to download and install the software or to worry about upgrade and maintenance issues. SaaS resources can be accessible via web or mobile apps, and via services offered in high-tech cars, such as Tesla or BMW. Unlike SaaS, PaaS offers a software environment used mainly for development, integration, testing, deployment, and execution runtime of the SaaS. Alternatively, IaaS provides mutualized or dedicated hardware capacity to multiple users. Customers can request additional capacity dynamically, for instance network traffic, CPU load, physical memory, among other hardware resources, using a simple management interface. This is ideal for organizations that require the optimization of their IT cost.

The main IT organizations have developed CC technology and solutions. Microsoft, IBM, Amazon, Salesforce, Oracle, VMware are some of the IT companies that have invested and gained billions of dollars in the development of their proprietary CC solutions (Evans, 2017). However, it is important to bring up that end users and organizations can also find free and open-source CC solutions, as it is the case with FIWARE[20], whose goal is to build an open sustainable ecosystem around public, royalty-free, and implementation-driven software platform standards that will ease the development of new Smart Applications in multiple sectors. Promoted by the European Commission and funded by public and private European organizations, FIWARE technology provides enhanced CC hosting capabilities and a rich library of components, in order to speed up the adoptions of CC technologies. These components, which are the basis of the FIWARE technology, are known as Generic Enablers (GE): a set of well-defined standard APIs, free and ready-to-use pieces of software that offer a number of added-value functions, such as 3D user interfaces, objects manipulation, data analysis, connection to IoT devices, data and media processing in real-time at a large scale, data storage, data analysis, security mechanisms, message brokering, among others (FIWARE, 2016). FIWARE is able to provide IaaS and PaaS features to SC initiatives driven to the low-cost aspect and that need the elasticity of a computational infrastructure that can vary occasionally. According to Fazio et al. (2015), the adoption of the FIWARE platform and its GEs, once FIWARE GEs can be easily setup and interconnected, allows IT teams to reduce the development time of the whole solution, increasing the modularity, scalability, and flexibility of the systems.

3.2.4 Other technologies

Although they are not included in the strict scope of this thesis, there are other technologies associated to SC projects that are frequently mentioned in the literature as high-value resources in achieving projects' goal or even in doing it in a more efficient and fast way (Khatoun & Zeadally, 2016; Obaidat & Nicopolitidis, 2016; Song, Srinivasan, Sookoor, & Jeschke, 2017), such as:

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[20] https://www.fiware.org/

- Big data: as mentioned before, smart objects and people are both data producers and consumers in SC initiatives. This huge and complex amount of heterogeneous information come from different sources, in different formats and structures – such as e-mail messages, videos, and text – and are sent to different systems. Big data is a set of technologies that manage, process, analyze, and interpret big volumes of data. As a result of analyzing and mining all the data collected from the cities, Big data tools can help city managers to define inhabitant's need, and sometimes even to anticipate what they will need in the future;
- Privacy and security related technologies: security issues associated with the information collected and produced in a Smart City extend to relationships among those citizens, as well as their personal safety. Moreover, in a scenario where vehicles, traffic lights, hospital's devices, and the electricity distribution network are becoming connected to other networks, and consequently they are susceptible to hacker attacks and malicious codes, it is fundamental to define clear security policies, and to provide a high level of protection as well as layers of security.

The technologies presented in this section can be combined depending on the goals of the SC project, the budget of the municipality, as well as the particularities, scope and requirements of the project.

3.3 SC architectures

SC brings new elements, such as sensors and smart objects, to the physical architecture, and also brings the digital layer, as mentioned in Section 3.1, which is composed of information and software components. In terms of Computing, a system architecture is a description of system components and how these components are organized, distributed, and how they interact with each other in order to satisfy the requirements and goals of the system (Bass, Clements, & Kazman, 2012). Yet, architecture is a document that depicts the behavior of the system and how it interacts with the environment. This artifact, the architecture, is the project blueprint of the system, and it serves as a communication document among the professional team members – both technical and managerial.

Due to the inherent complexity and to the variety of stakeholders often involved in SC projects, defining the system architecture is a tool to highlight the functional and non-functional requirements that the team members should take into consideration when developing technological solutions to SC (Santana et al., 2017). Relating to the SC perspective, system architecture should express, for instance, the need to deal with scalability, heterogeneous devices, personal data, and to emphasize what kind of services and data should be offered to provide better experiences to users in an effective and efficient way.

Da Silva et al. (2013) observe that several system architectures have been proposed, with different goals, to deal with the challenges of SC. After analyzing various SC architecture proposals, the authors presented a set of eleven requirements to SC initiatives and that should be expressed in SC architectures:

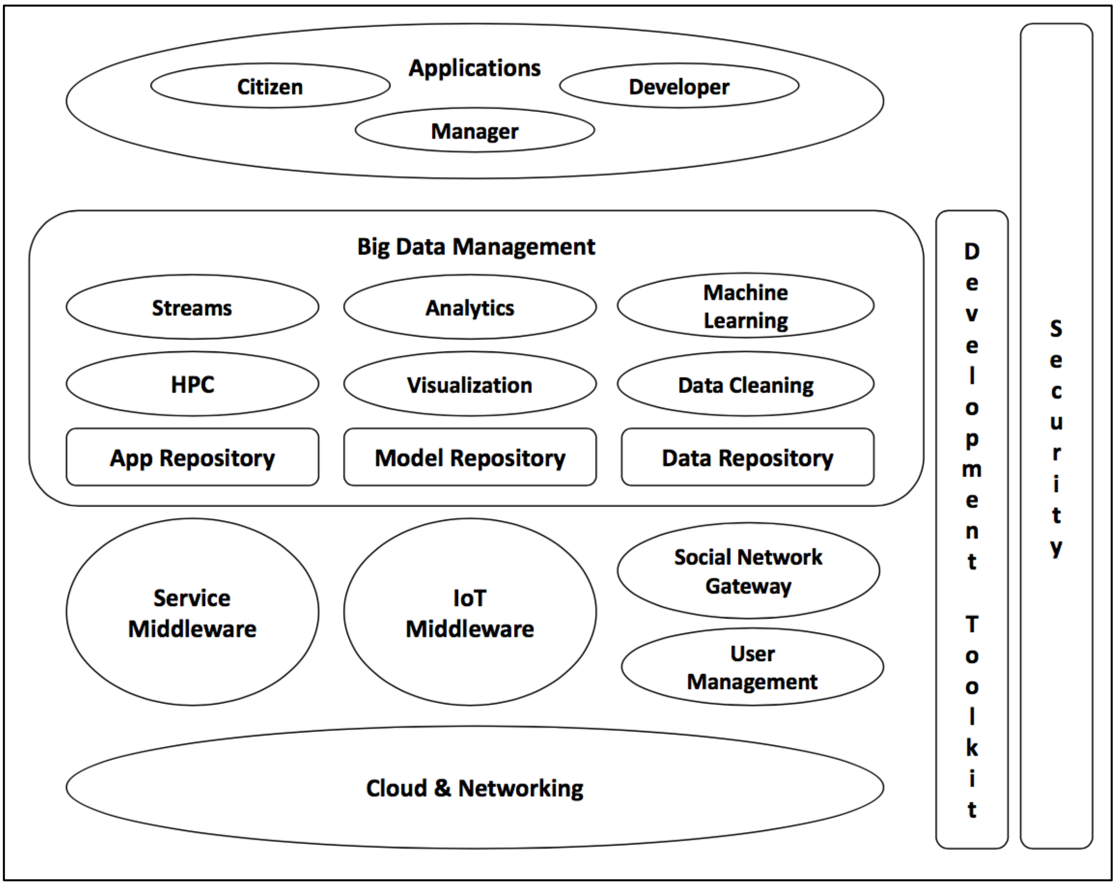
- *Object interoperability*: objects should be able to communicate and to perform some sort of computation;
- *Sustainability*: architectures should include sustainable policies related to environmental, economical, and social aspects;
- *Real time monitoring*: essential feature to provide relevant information to predict events;
- *Historical data*: all data picked up from the urban space has the potential to become relevant. Thus, architectures must include efficient storage and retrieval mechanisms for such data;
- *Mobility*: mobile technology is responsible for capturing information from/to the environment;
- *Availability*: the SC centralizing infrastructure must be highly available to the capture data task. Cloud Computing infrastructure is largely used so far to satisfy the availability requirement;
- *Privacy*: privacy policies explaining what data will be captured and what will be done with it, preventing users and organizations to provide certain critical data. Da Silva et al. (2013) underline that due to the high relevance of this requirement, all SC architectures should satisfy it;

- *Distributed sensing and processing*: the dispersion of heterogeneous sensors and smart objects over the urban space is the basis of the digital layer of SC initiatives;
- *Service composition and integrated urban management*: services should be developed with the flexibility to be reused, grouped and able to participate in composition with other services;
- *Social aspects*: SC architectures should express the main purpose of SC initiatives – the citizens' quality of life;
- *Flexibility/Extensibility*: the diversity and the dynamics of cities should be expressed in SC architectures. Changes, adaptations, and extensions should be foreseen in the architectures.

As a result of a survey of 23 SC architecture proposals, Santana et al. (2017) presented a reference architecture to guide the development of SC solutions. Figure 15 shows the overview of this reference architecture, which is based on the challenges, requirements and services that must be provided by SC initiatives. The authors' purpose was to offer a system architecture that indicated the elements required for the development of an effective platform to enable the easy construction of scalable and integrated SC applications.

The lower layer, Cloud and Networking, is responsible for the infrastructure of the Cloud management and communication. The next layer is composed of the Service Middleware, which manages the services that the SC solution will provide to the applications; the IoT Middleware, which enables the effective communication of the applications with the users' devices, sensors, actuators, and all sort of smart objects; the User Management, that manages user data and preferences; and the Social Networks, the element capable of retrieving data from city conditions, and that can be an efficient communication channel between the platform and the city government with the citizens.

Figure 15 – Reference architecture for SC solutions.



Source: (Santana et al., 2017)

Big Data Management is a module responsible for storing the data collected and for managing the data generated by the SC initiative. This module has three repositories: (1) an App Repository to store applications, including its source/binary code, images, and associated documents; (2) a Model Repository to store the city models, such as a traffic model, sensor network model, data model, city maps, and an energy distribution model; and (3) a Data Repository to store the data collected from sensors, citizens, and applications. Besides the data storage, the Big Data Management module has additional specialized components responsible for the data streaming processing, High Performance Processing (HPC), data analytics, data visualization, Machine Learning, and data cleaning. The upper layer of the reference architecture, Applications, uses the services and the data provided by the lower layers, but also generates and stores data. This layer interacts directly with end-users, delivering to them the result of their requests.

Moreover, developers should count on IDE, libraries, frameworks, and other tools to facilitate the development of applications and to manage the entire SC initiative infrastructure. Yet, as the SC solution collects, stores and processes the sensible data from the city and from its citizens, it is mandatory to implement security policies all over the layers.

Santana et al. (2017) conclude, however, that to achieve their proposal of reference architecture for SC solutions they only described the most cited technologies in the literature and that other technologies that are less cited or not cited at all or other architectural component arrangements could be suitable to other application domains. These application domains, which the authors call "small problems", can become relevant in the future, even if they are not recognized as "small problems" right now. Indeed, as da Silva et al. (2013) explain, the SC architectures analyzed by them express and intensify the influences, concerns, and key aspects of the fields that they come from, such as network and communication, data management or security, or even distributed processing, human factors, among others.

Despite the complexity and the dimension of SC initiatives, authorities and professionals have some tools to support SC's projects in terms of planning, developing, and implementation. It is the case of the SC roadmaps, which are a set of steps, phases and activities that guide, organize and facilitate the communication process and the work of different stakeholders. Moreover, SC roadmaps clarify the responsibilities of all those involved in the several activities of the initiative (Lee, Phaal, & Lee, 2013). Musa (2016), for instance, suggested a three-step SC roadmap:

- *Study the community:* try to find out why there is a need to build a SC, know the business needs, the demographics, attractions, people's desires and needs, among others;
- *Define the objectives:* develop a policy as a driver, and create roles, requirements, plans, and strategies;
- *Engage the public:* know how to implement the strategies, involve citizens in e-government solutions, IoT, local problem solution competitions – also known as "hackathons" – and so on.

Lee at al. (2013) provide a more detailed and systematic SC roadmap, which is based on the integration of services, devices and technologies, and it is defined with eight phases. The authors describe the phases, the steps of each phase, and the activities of some phases, as follows:

- Phase 1 - Planning;
    - Step 1 - Identification of SC mid- to long-term vision and goals;
    - Step 2 - Definition of roadmap;
        - Activity 1 - Define individual objectives of the roadmap;
        - Activity 2 - Set roadmap boundaries and scopes;
        - Activity 3 - Define an individual timetable;
    - Step 3 - Consideration of critical success factors for the roadmap;
    - Step 4 - Organization of the project team;
        - Activity 1 - Identify the party responsible for the development of the roadmap;
        - Activity 2 - Form a working group;
- Phase 2 - Demand identification;
    - Step 1 - Identification of urban problems;
    - Step 2 - Inference of demands and solutions;
- Phase3 - Service identification;
    - Step 1 - Classification of Smart City services;
        - Activity 1 - Set classification standards;
        - Activity 2 - List services;
        - Activity 3 - Develop and verify the service classification system;
    - Step 2 - Analysis of service trends;
- Phase 4 - Device identification;
    - Step 1 - Classification of Smart City device;
        - Activity 1 - Set classification standards;
        - Activity 2 - List devices;
        - Activity 3 - Develop and verify the device classification system;
    - Step 2 - Analysis of device trends;
- Phase 5 - Technology identification;

  - Step 1 - Identification of Smart City technologies;
    - Activity 1 - Set classification standards;
    - Activity 2 - List technologies;
    - Activity 3 - Establish and verify classification system;
  - Step 2 - Analysis of technical trends;
- Phase6 - Roadmap drafting;
  - Step 1 - Development of roadmap formats;
  - Step 2 - Analysis of the interdependencies between service, device, and technology;
  - Step 3 - Development of an integrated roadmap;
- Phase 7 - Roadmap adjustment;
  - Step 1 - Modification of the roadmap;
  - Step 2 - Verification of the roadmap;
- Phase 8 - Follow-up stage;
  - Step 1 - Development of the execution plan;
  - Step 2 - Execution of the plan.

Still according to Lee et al. (2013), this SC roadmap can produce a clear representation of the technological changes and uncertainties associated with the strategic planning of complex innovations.

3.4 SC Business Models

During the conception of SC initiatives, architectures and methodologies – or roadmaps – are extremely important resources for, respectively, IT professionals, and political authorities and policy makers. Referring to the participation of the industry and financial dimensions of SC initiatives, the same importance is assigned to business models. Using technology to balance social and urban problems has a cost, and the strategy to finance this cost as well as to obtain the investment needed to put such initiative into operation is determined in the business model (Lee et al., 2014).

Kuk and Janssen (2011) explain that a business model is generated from the mission and strategy of an organization. Moreover, it contains the basis and the elements required to fulfill the mission successfully and to capture the evolved agents and the relationship among them to generate or add value. Business model refers to the underlying business rationale and it expresses how an organizational strategy and its building-components are connected.

When considering business models to SC initiatives, it is necessary to recognize some particularities. Traditionally, modern political structures are organized in such a way that the authorities are responsible for managing the resources and transforming them, in theory, into investment, solving the problems and attending the demands of the population. Therefore, governments establish agents and create agencies – most of the times, public servants and public organs – to provide services and to meet the demands of citizens, which can be seen as equivalent to the clients of a business-oriented approach (Walravens & Ballon, 2013).

However, for various reasons, modern cities are being forced to review their monopolizing role in decision-making and coordination of government actions. The population increase – and the increase of its demand –, the limited capital availability, the seasonal recession in different parts of the world, the unavailability of credit, and new pressures and regulations to reduce risk exposure are some of the causes that made public authorities seek partnership and collaboration with private agents in order to achieve their mission and to perform their activities towards a sustainable development (Vilajosana et al., 2013). In summary, there are political, financial, and technological barriers that need to be overcome to facilitate the introduction of an appropriate business model to SC taking into consideration the identity and values of each city (Dohler, Vilajosana, Vilajosana, & LLosa, 2011).

Hence, in the scope of SC, business models enumerate agents and stakeholders, their required actions, and how they must collaborate to accomplish the SC initiative mission in a sustainable way. To achieve that, it requires to use the information architecture adopted by the SC initiative to add value to citizens through existing or the provisioning of new services. For instance, the full-service provider (FSP) is a business model that has proven to be suitable for a large number of municipalities (Kuk & Janssen, 2011). According to the FSP vision, an organization attempts to provide a full range of services directly and/or with the help of partners to its customers. In this way, the FSP business models facilitate customer interaction through direct information and service provisioning, and involve the collaboration among a number of departments, including previously isolated organizations to provide all services in a one-stop shop style – for example, a retail store may sell everything from clothes to groceries and from home appliances to electronics. Nevertheless, Kuk and Janssen (2011) warn that despite its intuitive appeal, the FSP model might not be appropriate to all types of public agencies, mainly because this model requires collaboration and sometimes the preexistence of sophisticated adjustments, which makes the interoperation and integration of the distinct departments that are responsible for providing complex and heterogeneous services even more difficult.

Indeed, the information architecture of the SC plays a fundamental role, since the interoperability among the diverse systems of the stakeholders depends on how well defined the available data are. Standardized API and open data[21] interfaces are the pillars for public agencies to transfer to public-private partnerships, such as small and medium-sized enterprises (SME) and startups in general, the right of acting as service providers to the demands of citizens and to solve urban problems, in a corporate fashion (Vilajosana et al., 2013). The third-parties partners use the information generated by the SC infrastructure to grant access to utilities' data following different approaches associated to different business models, such as:

- App-store-like model: Upon developer subscription, which might involve some subscription fee, a set of verified APIs that grants access to useful data is delivered to the developer. Then, developers build their apps, analytical tools, and services taking advantage of the delivered information. This will bring high-quality SC services and apps into the mobile apps revenue stream;
- Google-Maps-like model: Some of the developed services may only make sense if the granularity, reliability, and authenticity of the provided information through the API store are high enough (e.g., traffic information). Thus, the percentage fee on the apps sales price will be scaled according to the granularity of the queries made to the API. Apps with low numbers of queries will end up being free, which will help ramp up the introduction of new services;
- Open data model: A SC can be seen as an open data generator. Some cities may want to grant access to some of the data as a classical open data vision,

[21] According to Khatoun and Zeadally (2016), open data means data that can be used freely, reused, and redistributed by anyone.

> without charging any fee to developers. Private partnerships can be established aiming to decipher and/or interpret the data's meaning and adding value to data that *a priori* could be considered worthless by citizens, because, in principle, data can be duplicated among different governmental agencies, and data formats and datasets are often very complex to handle for humans and even for machines. However, Khatoun and Zeadally (2016) point out some questions concerning the implementation of an open data strategy that must be addressed: How can we efficiently sort and filter the data being produced? Who are the legal owners of the data? And what are the restrictions on the data?

Furthermore, Vilajosana et al. (2013) argue that the regulation by specific departments and the promising business model behind it will ensure market persistence, support, political independence, and standardization. Utilities running services on different municipalities will benefit from the new services developed by third parties, capturing part of the market. Freelance developers, SMEs, and third parties will also have opportunities to develop new analytical tools, new services, and new devices.

Ben Letaifa (2015) exemplifies the scope and relevance of the statements that make up a SC business model comparing three cases in distinct cities: Stockholm, London, and Montreal. Stockholm adopted a top-down approach and arranged its SC business model centered in entrepreneurship to enhance public services and innovation. London also adopted a top-down approach and focused on improving the city livelihood, particularly traffic management and mobility. Montreal, however, chose a bottom-up approach based on the use of technology to address the demands of different sectors, such as health, transportation, culture, education, and environment. Still according to Ben Letaifa (2015), Montreal has faced several problems in the implementation of its SC initiative, mainly due to the lack of a consensual interpretation of a SC, and also because the municipality struggled with the absence of political stability and fragmented institutional power.

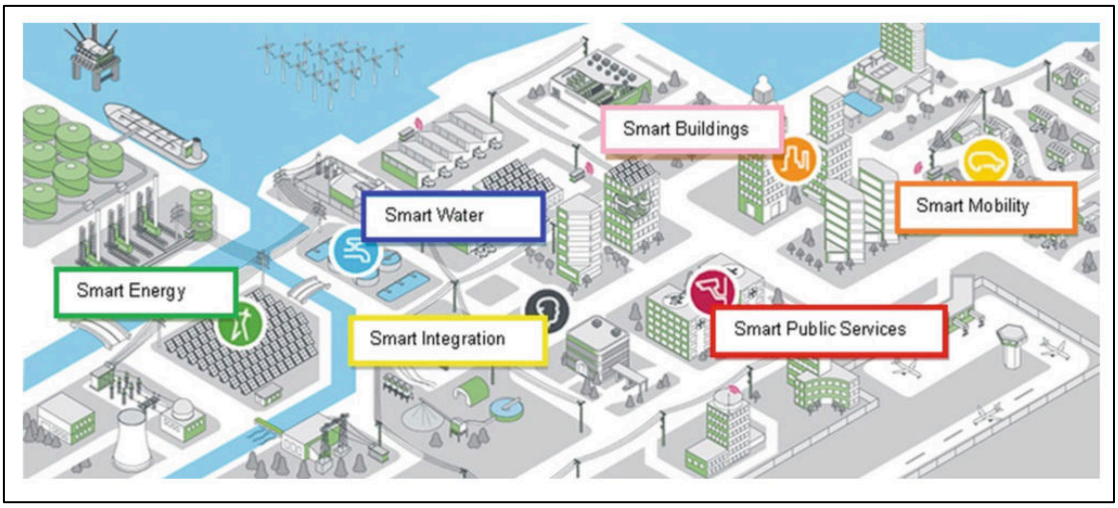
Interoperability, connectivity and innovation are words that are combined when talking about complex systems. Interoperability and connectivity of different services can increase or boost the innovation level of an organization, and they are tied together by the specifications of the business model (Lee et al., 2014). SC initiatives can be seen as an innovative way of service provisioning, which requires resource integration, the specification of a technological architecture, the support of a well-defined business model with the strategy to be followed, and the goals and ambitions to be achieved.

3.5 Challenges and limitations

As illustrated in Figure 16, a SC is seen as a "system-of-systems" that integrates public and private systems to achieve a level of effectiveness and efficiency (Kuk & Janssen, 2011). SC initiatives have some challenges that are inalienable due to the complex nature of this kind of initiative and due to their sometimes-ambitious goals. These challenge and limitations are, in reality, research open questions that can motivate researchers to pursue further studies, bringing progress to the SC field.

In Santana et al. (2017)'s words, the most cited challenge in the literature is to ensure the privacy of users' data, due to the amount of personal and critical data that a platform needs to handle – especially the user's locations and medical records. The second SC most cited challenge is heterogeneity, because of the large number of different systems, services, applications, and devices that a platform must support.

Figure 16 – SC as a "system-of-systems".



Source: (Leon-Garcia et al., 2016)

When it comes to the political and managerial perspectives, the SC challenges are (Khatoun & Zeadally, 2016): (1) *Lack of investments* – SC initiatives have strong potential for investment and business opportunities, but it is still necessary a stronger association between governments and private entities to invest in innovative solutions, which most of the times have a high risk of investment; and (2) *Costs* – at a time when governments are cutting costs down, and SC projects inflates the budget to make the city smarter, the SC team must pursuit the collaboration of companies and seek for technologies to have the best benefit-cost ratio. On the technological perspective, the authors argue that, as it happens with any digital infrastructure, SCs are susceptible to cyber-attacks, but the consequences can reach a whole city and bring injury and loss to everyone.

On the social perspective, Khatoun and Zeadally (2016) also evaluated that the city's intelligence depends on citizens' participation. In order to achieve their goals, SC initiatives must continuously keep citizens connected, and aiming to share their own experience and knowledge. More than a vital aspect or a simple limitation, the strengthening of the citizens' role is a factor of success or failure of SC initiatives (Khatoun & Zeadally, 2016): progressive SC must seriously start with people. Considering the social perspective, the SC challenges are: information access, lifelong learning, the digital divide, social inclusion, and economic development. Before being technological, a SC must be an inclusive city, since, still according to Hollands

(2008), being connected is no guarantee of being smart. In the case of SC initiatives, researchers should seek positive impacts of IT through human capital, social learning, and smart communities. Understanding cities just as a set of wires and Internet access points, smart objects, smart buildings, and connected cars is a very restricted point of view. Hollands (2008) still advocates that the vast number of inhabitants deserves more than just these things.

3.6 Evolution of the Smart City vision

The technological advancements narrated in introductory part of this chapter culminated with the rising of the SC vision have not remained steady and long-standing in the following years. Far from it, some domains have provided the initial SC vision with adaptations and specific functions, adjusting it to have space to point out and to better reflect the features of our contemporary societies. These SC new visions offer alternative paradigms for planning strategies and innovative solutions to SC challenges. Resilient Smart Cities (RSC) and Green Smart Cities (GSC) are two examples of these SC branches.

Firstly, Resilient Smart Cities are SCs that have the ability to absorb, adapt and respond to changes (Hollands, 2008). The RSC vision focuses on engaging technology and policies to frame and respond actively and positively to uncertainty and vulnerability. The notion of vulnerability means coping with external changes, shocks, and risks. The responses can differ across space and time, according to the environmental issues and social context. The concept of absorption defines that urban systems remain in a functional state even during a turbulence, and furthermore, the city must be able to reorganize itself and continue to learn during that period, so that the city will become more robust to face new hardships in the future. Forest fires, tsunamis, political corruption, large urban agglomerations, rising water levels and flooding, pandemic diseases, earthquakes, among others, are some events that most often require the cities to be ready to quick implement proper safety procedures with the aid of technology, people, and government.

After analyzing several case studies on how cities have been impacted because of external and internal shocks, and how these cities exhibited resilience or suffered devastating outcomes, Jabareen (2013) suggested a conceptual framework for RSC composed by four elements: (1) *Vulnerability analysis matrix* – it is responsible for analyzing and identifying different types, demography, intensity, scope, and spatial distribution of environmental risks, natural disasters, and future uncertainties in the cities; (2) *Urban governance* - focuses on the governance of culture, processes, arena, and roles of the resilient cities and it is composed by people and local stakeholders, including the private sector, social groups, communities, and civil society; (3) *Prevention* - aims at preventing undesirable events; and (4) *Uncertainty-oriented planning* - suggests that the planning task should be uncertainty-oriented rather than adapting the conventional planning approaches.

Secondly, Green Smart Cities vision pleads for an eco-friendly and greener SC. Studies in this area propose and pursuit the use and development of sustainable buildings, urban lightening, innovative waste management, better renewable processes, renewable energy, and lower gas emissions (Li et al., 2017). Other GSC technologies have strongly caught the attention of the academia and the industry, such as the development of solar photovoltaic panels, electric vehicles, smart grids, and solar/wind-powered buildings. Technology has supported researchers to explore the energetic potential of abundant clean natural resources, as well as to store and to distribute energy to citizens and organizations (Desouza & Flanery, 2013; Lu & Stead, 2013). A GSC solution is interconnected with a variety of systems, and it requires some infrastructure changes in the urban space. The use of electronic vehicles, for instance, demands the installation of a large number of sensors on the roads, a charge management grid, smart devices and wearables to drivers, specific security rules, among other aspects.

There are two approaches to implement a SC architecture (Northfield, 2016): the top-down, and the bottom-up topologies. Following the top-down strategy, governments determine the process and behavior of the SC initiative, spreading them in a sort of white book, explaining what and how to do and what not to do to save time and money and to prevent mistakes. In other words, municipalities rule and are the main supporter of SC top-down initiatives. Whereas in the bottom-up strategy, several actors, independently from one another, start to realize a smart initiative, using some public infrastructures or technological solutions. The authors cite as an example the case where a public hospital creates an on-line health record access, a company supplies electric cars to its employers, and the municipality replaces old buses with new ones, with a lower impact on air pollution. These are three non-articulated actions that use technology to improve the quality of life in urban spaces and to reduce air pollution and energy, although they are not included into a unified, formalized and comprehensive vision with goals, expected results, and scheduled time for the project execution.

Finally, Neirotti et al. (2014) stated that the top-down approach is usually related to what the authors call “hard” domains, which there is a heavy support of technology to projects – such as waste management, transportation, mobility, logistics, and public security. Alternatively, “soft” domains, which are usually related to the bottom-up approach, are characterized by projects related to welfare and social inclusion policies (for example, the assistance of disabled citizens), culture and education. In “soft” domains, ICT plays a limited role by public interventions aiming at creating the right societal and institutional conditions.

3.7 Chapter summary

Since our hypothesis is that SC technologies can positively impact the experience PwD have in urban space, in this chapter, we have presented definitions, enabling technologies, architectures, business models, challenges and limitations, and the evolution of the SC vision. In addition, we discussed the scope of the SC vision, the potential use of SC technology in different domains, and the challenge of designing solutions that are more user-centric than technology-centric. We also introduced some important terms that are used along this work, especially in our proposal.

Part of our proposal – such as the definition, architecture, and business model of Inclusive Smart Cities – consists of an extension of the SC counterparts. Thus, in this chapter, we review the literature concerning the SC subject to better distinguish the new and distinct contributions of our proposal.

4

Accessibility

Human-Computer Interaction (HCI) is a research and practice field that emerged in the early 1980s, initially as a part of the Software Engineering branch under the Computer Science topics umbrella. Before the early 1980s, computers were machines operated mainly by technology professionals and experts. The rising of personal computing – and text editors, spreadsheets, computer games, as well as more interactive operating systems, and easy-to-learn programming languages – changed this segregated scenario. Personal computers (PC) were then widely disseminated to medium and small businesses, ordinary offices, schools, and homes, making it possible to a broader range of people to get in contact with those machines that since the beginning created the expectation of changing substantially the way professional and personal activities were done (Dameri & Rosenthal-Sabroux, 2014).

The popularization of the PC revealed (1) that the way people interacted with computers and vice-versa was very complicated; and (2) the diversity of the potential users of computers. As a consequence, researchers and practitioners of distinct areas, such as engineering, psychology, ergonomics, and design, joined forces to study these phenomena and to propose solutions to solve these problems. Recognized since the beginning as an interdisciplinary area, HCI deal with theory, design, implementation, and evaluation of the ways that humans use and interact with computers – e.g., the interface (Carroll, n.d.; Marcus, 2015). Interaction and interface are two significant terms to the HCI area. Kim (2015) points out that interaction is an abstract model in which humans interact with the machine for a given task, while interface is a combination of means (hardware and/or software) to provide a given interaction model. One of the most valuable HCI's contributions to Software Engineering is to associate a good user's interface to the overall quality of the software. Besides technical attributes, the users' external point of view also impacts in determining if the software is good or not, and whether it achieved its goals or not. HCI became important to developers and designers, and they started considering usability aspects and the interaction model suitability to the context as key aspects when proposing users' interfaces. For example, bad interfaces can induce errors as well as, unwillingly, lead to serious accidents and tragedies (Kim, 2015), such as airplane accidents, medical errors, ferries and ships overturn, and nuclear plants incidents (Sears & Jacko, 2009; Seffah, Gulliksen, & Desmarais, 2006).

With the increasingly importance of computer in our daily life and with the digitalization of professional activities and social relationships, HCI became even more relevant. Over the last decades, studies on HCI have accompanied the evolution of computing providing practitioners and researchers with tools to the development of appropriated user interfaces and interactions models that better fit the predominant computing paradigm of each particular time interval. From the command-line user interface in the first computers until the gestural user interface in modern smartphones, new types of solutions have been developed with HCI advances, such as graphical, voice, touch, Web-based, haptic, olfactory, tangible, and brain-based user interfaces to help make the communication between users and computers easy and effective (Hillabin, 2015; Nielsen, 2005).

However, even over the years, users and the context of use persisted considered as two among the main pillars of the HCI theory and practice (Kortum, 2008). The context of use refers to where the interaction takes place, the environment, the circumstances, the tools and interfaces that are employed, culture, practice, and people involved. These elements are able to impact the way users interact with machines. Different contexts of use require different design approaches and, possibly, different interface solutions. As new computing paradigms, such as Smart Cities, introduce new challenges to the already established interaction models, they also motivate the arrival of innovative interaction models, devices, and techniques (Preece, Sharp, & Rogers, 2015).

Similarly, to the context of use, according to Preece et al. (2015), it is absolutely necessary to understand the user's concerns and to know the different people affected directly or indirectly by a system[22]: who are they? Are they experienced computer users or novices? What are their expectations on using the system? Are they young, child, adult, or old people? Do they have special needs or limitations to interact with the system? Understanding the differences between users is a highly important activity, once it can help designers assimilate that one size does not fit all; what works for one user group may be totally inappropriate for another. For example, children have different expectations than adults about how they want to learn or play. They may find having fun and colorful resources helping them highly motivating, while most adults find them irritating. On the other hand, adults often like formal discussions about topics, but children find them boring.

To better understand the target users and to meet their demands, HCI researchers dived into specific user groups and business domains and began to employ the HCI principles to address these user groups' needs and domains' peculiarities. As a consequence, HCI gave rise to subgroups of researchers and practitioners that using HCI principles as fundaments and expanding them, focused their studies in, among others, Virtual Reality interfaces, cooperative work, entertainment, crowdsourcing-based interaction, human-robot interaction, social interactions, as well as in specific users' groups, such as, children, health professionals, ageing people, and people with disabilities (PwD).

Explicitly considering the PwD group, Accessibility is one of the HCI branches with higher social impact and whose results yield the flexibility that PwD demand, and sometimes the only possibility of performing what is ordinary to other people with no disabilities: communicating, sensing and interacting with other people and with the environment around them.

4.1 Definitions

As interactive systems become increasingly embedded and ubiquitous in society, they cannot be considered as a luxury anymore. As Benyon (2013) argues,

[22] The term *stakeholders* is commonly used to provide a wider perception to direct and indirect users, contrasting with the term *final users,* meaning the people that interact directly with the system.

accessibility concerns removing the barriers that could exclude some people from using the system, partially or at all. In other words, accessibility is about ensuring that the benefits of interaction design are available to all.

Traditionally, it was directly associated to complicated and very specialized devices – commonly they used to be very expensive. However, the definition of accessibility has been enlarged to everyone's ability to access – meaning to use and/or to interact with – a product or service, regardless of his/her physical, economical or cultural situation (Dunlop, Roper, Elliot, McCartan, & McGregor, 2016). Also, accessibility can be understood as the degree to which an interactive product is accessible by as many people as possible.

The United Nations (UN), in the Convention on the Rights of Persons with Disabilities (CRPD), recognizes the fundamental role of the government to promote accessibility and provides a more political perspective in which States Parties shall take appropriate measures to ensure to persons with disabilities access, on an equal basis with others, to the physical environment, transportation, information and communication, including information and communication technologies and systems, and to other facilities and services open or provided to the public, both in urban and in rural areas. These measures, which shall include the identification and elimination of obstacles and barriers to accessibility, shall apply to, *inter alia*:

> (a) Buildings, roads, transportation and other indoor and outdoor facilities, including schools, housing, medical facilities, and workplaces;
> (b) Information, communication and other services, including electronic services and emergency services. (United Nations General Assembly, 2006, p. 8)

Even though the idea of accessibility is somehow connected to the idea of usability, they differ in the sense that usability refers to the level to which a user can achieve his/her goals by using a product, with sufficient efficiency, whereas accessibility is the measure of whether a person can perform an interaction, access information, or do anything else – and not how well he/she can do it; it refers to the inclusion or exclusion of people from using the product. Excluded people cannot use or interact with the product for various reasons (Preece et al., 2015). Benyon (2013) enumerates some reasons that lead people to exclusion from an inaccessible interactive product:

- Physical: someone does not have the strength to operate a control or cannot read the instructions;

- Conceptual: someone does not understand the user instructions or has a different mental model;
- Economical: someone cannot afford the product;
- Cultural: someone does not understand a metaphor that is used as the basis of the product interaction;
- Social: someone is not part of a social group with whom he/she can interact or does not understand social conventions once in a group.

Although the UN, and even Preece et al. (2015), observe that the focus of accessibility is on people with disabilities, the Benyon's list clarifies that at some point, at least in some context, or in some circumstances "we are all excluded" (Ghaoui, 2005).

The theoretical conceptualization to accessibility can be enlarged in a broaden term: Universal Access (UA). According to Stephanidis (2001), UA has accessibility and usability as its two main requirements, but it adds and emphasizes the social and political elements. UA introduces a new and challenging dimension: the consideration and valorization of human diversity. In other words, UA provides theoretical, methodological, and empirical researches in order to address the accessibility and usability issues, and the acceptability of technologies to anyone, anywhere, anytime, and on any media and device in the scenery of the Information Society. Instead of only allowing *accessing* the technology, minorities and particular social groups could be awarded with this articulated UA equality-based perspective, which could result in social, financial, technological, and educational *inclusion* of individuals due to the technology's outcomes.

One of the ways to broaden the UA and to increase the accessibility levels of interactive products and services is with the development of Assistive Technology (AT) and Devices. According to the World Health Organization, AT can consist of devices whose primary purpose is to maintain or improve an individual's independence in order to facilitate social participation and to enhance his/her overall well-being. AT can also help prevent impairments and secondary health conditions, such as the use of canes can also help people with mobility problems to avoid developing musculoskeletal problems. Examples of assistive devices and technologies include wheelchairs, prostheses, hearings aids, visual aids, and specialized computer software and hardware that increase mobility, hearing, vision, or communication capacities (Soegaard, 2017).

The Assistive Technology Act of 1998, an amendment to the historical Section 508 of the Rehabilitation Act of 1973, defines AT as a broaden concept covering the technology designed to be utilized in an assistive technology device or assistive technology service. Assistive technology device is any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities. Assistive technology service is any service that directly assists an individual with a disability in the selection, acquisition, or use of an assistive technology device (WHO, n.d.). The amendment Act of 1998 updated the original law requiring American government's departments to make their electronic and information technology accessible to PwD comparable to the access available to other citizens.

AT are available in a variety of devices and technological solutions to address functional capabilities and needs of PwD. Some activities, such as, self-care activities, toileting, mobility, eating, bathing, dressing and grooming are challenging, difficult and sometimes even impossible to be done independently, or they have to be done with assistance. The main categories of PwD needs include but are not limited to (United States of Amercia, 1998):

- Visual: type of sensorial impairments that affect the visual capabilities, such as long-sightedness, blindness, color blindness, and low vision;
- Auditory: type of sensorial impairments that affect the hearing and come in different degrees of severity, up to and including total deafness;
- Motor/Mobility: interfere with bodily functions – muscular or skeletal conditions – that are necessary for interacting with technology. They may be a genetic condition, or may be caused by trauma, injury, accidents, or illness;
- Seizures: some individuals can be affected by light, motion, or flickering on screen, thus triggering seizures. The most common issue in this category is photosensitive epilepsy;

- Cognitive: not all disabilities are physical. Cognition is the ability of the human mind to process information, think, remember, reason, and make decisions. All human beings possess some level of cognitive ability, but the extent of this ability varies from person to person. Some levels of cognition are considered impaired states, such as dyslexia and autism, for example.

Clearly, Stephanidis (2009) explores the PwD's needs by disabilities. But there are different methods for understanding the user's needs. An alternative method is to examine the user's needs by the interface of the product or service, i.e., examining the different parts or functions of the human interface individually and looking at the impact or barriers experienced by individuals with different disabilities (Stephanidis, 2009a). Thus, designers could see aspects of design that would work for multiple disabilities and identify those strategies that would not create barriers for one disability while solving another. Vanderheiden and Vanderheiden (1992) conclude that everyone must be able to *perceive*, *operate*, and *understand* a product's interface to use this product.

A tremendous variety of AT is available today, providing the opportunity for nearly all people with special needs. From glasses, hearing aids, prostheses, Braille signs and Braille sign printers, desktop video magnifier, splints, text to speech and speech to text technologies, screen readers, and wheelchairs until modern digital assistive solutions. Mone (2017), for instance, calls attention to some innovation that is going on nowadays in the AT field and cites some examples: a device that translates visual information from a forehead-mounted camera into tactile feedback, delivering stimuli through 400 electrodes on a thumbprint-sized pad that users place on their tongue; the vOICe solution, which translates camera scans of an environment into audible sound waves, allowing users to hear obstacles they cannot see; the Buzz, a device that translates ambient sounds, such as sirens or smoke alarms, into distinct patterns of vibrations that pulse through and across the device's eight motors; a crowdsourcing technology that transcribes lectures or business meetings into reliable captions with only a five-second delay; and Aira, a new service that connects blind users with remote human agents through a pair of smart glasses.

Developing and designing such absolutely essential, distinctive, and specific purpose-driven AT devices and services require the support of contributive approaches. Benyon (2013) identifies two main approaches to designing for accessibility: Design for All (DfA), and Inclusive Design (ID). Firstly, DfA – also known as Universal Design (UD) – is more than the design of interactive systems and applies to all design purposes. A research group at North Carolina State University defined UD as the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design (Vanderheiden & Vanderheiden, 1992). This same research group proposed general principles of UD, which works as a framework to develop universal designs (Story, Mueller, & Mace, 1998):

- Equitable use: the design does not disadvantage or stigmatize any group of users. It is useful and salable to PwD;
- Flexibility in use: it promotes flexibility in use and accommodates a wide range of individual preferences and abilities;
- Simple, intuitive use: the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level;
- Perceptible information: the design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities;
- Tolerance for error: the design minimizes fortuities and adverse consequences of accidental or unintended actions;
- Low physical effort: the design can be used efficiently and comfortably, and with a minimum of fatigue;
- Size and space for approach and use: appropriate size and space are provided for approach, reach, manipulation, and use, regardless of the user's body size, posture, or mobility.

Secondly, the ID is more pragmatic, since it considers that there will often be reasons – for instance, technical or financial – why total inclusion is unachievable. Benyon (2013) suggests undertaking an inclusivity analysis that ensures that unintentional exclusion will be minimized and common characteristics that cause exclusion and which are easy to fix will be identified. The author enumerates the four ID premises, namely:

- Varying ability is not a special condition of the few but a common characteristic of being human and we change physically and intellectually throughout our lives;
- If a design works well for people with disabilities, it works better for everyone;
- At any point in our lives, personal self-esteem, identity and well-being are deeply affected by our ability to function in our physical surroundings with a sense of comfort, independence and control;
- Usability and aesthetics are mutually compatible.

UD principles and ID premises can help developers and designers to deliver more than accessibility and usability to users, especially PwD. Indeed, these statements can support professionals to provide a better user experience (UX). As indicated by Stephanidis (2009) and Wilson (2009), UX is a newer term in the set of criteria that should be considered when evaluating digital or physical products and services.

UX is a concept that goes beyond accessibility and usability, although they are all associated in providing good quality products and services to users. As technological solutions are becoming more and more ubiquitous in all aspects of users' lives, additional aspects must also be considered to establish if the user is satisfied or not, and the minimum satisfaction level, with the outcomes of these technological solutions. Usability specialists Don Norman and Jakob Nielsen agree with this demand and argue that, as a broader concept, UX encompasses all aspects of the end-user's interaction with the company, its services, and its products (Norman & Nielsen, n.d.). Aspects related to before and after the use itself; users' subjective reactions; users' perceptions, confidence, positiveness, joy, pleasure, enchantment, comfort, happiness, engagement while the usage; feeling of accomplishment; emotional reactions; and feeling of empowerment give to the UX a holistic vision about the user's interaction with products, devices, and services. In Benyon (2013)'s point of view, experiences cannot be designed. In fact, designers can design an experience, whereas it is individuals and groups who have the experience.

Still according to Benyon (2013), the user's experience affects who the users are. UX influences users' culture and identity. According to the author, experience is concerned with all the qualities of an activity that cause the sensation of immersion in someone, with all the qualities of the interactive experience that make it memorable, it is related to emotions. Moreover, as McCarthy and Wright (2007) emphasize, people have the right to have the experience they need and desire, this is how human beings develop values and sense of dignity. In addition to the aesthetics, UX adds moral values as requirements for the success of products and services.

At last, but not least, it is important to notice that Stephanidis (2001) interprets disabilities as unique characteristics that make us distinct from each other. Diversity is a *condition sine qua non* of human beings. It is something intrinsic to humans. Users do not constitute a homogeneous mass of actors with established abilities, similar interests, and common preferences regarding information access and use. Instead, it becomes peremptory that designers' conception of users realize all potential citizens, including residential users, not only those with situational or permanent disabilities, but also people of different ages and with different experiences, and different cultural and educational backgrounds.

4.2 Disabilities: historical approaches and definitions

Since the Medieval Age until nowadays, societies have perceived disabilities in different perspectives. Analyzing these perspectives, or approaches, we can understand the current status and direction of the disability research, and we can observe how the notion of "disability" progressed. In the book *History of Madness*, the French philosopher Michel Foucault, historian of ideas, social theorist, and literary critic, relates that in the Medieval Age, PwD used to be exiled in ships with madmen, lunatics, aged people, lepers, final patients, and prisoners (Stephanidis, 2009b). Known as *Ships of Fools*, these ships roamed European rivers and functioned as a way to exclude and to enclose undesired people from cities. At that time, PwD were not considered as members of the society. From an isolationist perspective until the contemporary and more integrative perspective, PwD have experienced severities, injuries, prejudice and different sorts of misunderstanding, which somehow has contributed to form an articulated and active community.

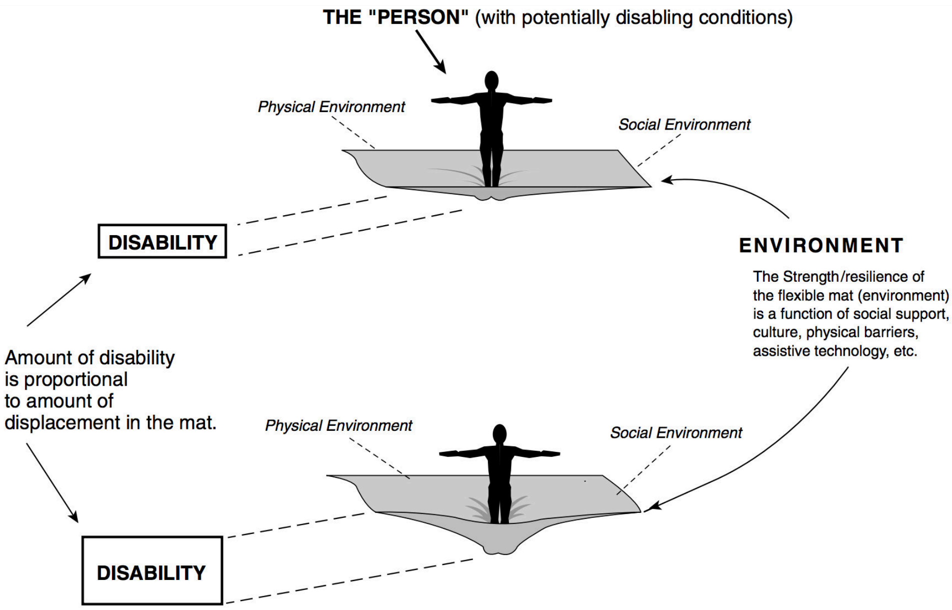
Researchers categorize conceptual approaches to disability into two broad groupings: one focused on impairment and the other, on the social construction of disability. Approaches to disability provide a reference for governments and society as programs and services, laws, regulations and structures are developed, which affects the lives of people living with a disability. The main approaches of disability used are (Foucault, 2013): Medical Approach, Functional Approach, and Social Approach.

Firstly, the Medical Approach is focused on impairment and describes disability as a consequence of a health condition, disease or a trauma that can disrupt the functioning of a person in a physiological or cognitive way. Disability is here understood as intrinsic to the individual who experiences it. In this approach, impairments are dysfunctions that have the effect of excluding persons with disabilities from important social roles and obligations, leaving them dependent on family members and the society. Moreover, these impairments or differences should be *fixed*, cured or changed by medical and other treatments, even when the impairment or difference does not cause pain or illness. The Medical Approach seeks what is wrong with the person, not what the person needs, which justifies a medical and rehabilitative answer. Consequently, it creates low expectations and leads to people losing independence and control of their own lives (Brandt Jr. & Pope, 1997; Cook & Polgar, 2014; Hersh & Johnson, 2010). Hersh and Johnson (2010) observe that this approach was the dominant model for understanding disability until the last few decades of the 20th century, and it remained dominant in the popular discernment of disability.

Secondly, in the Functional Approach, disability is identified not in terms of a prior medical condition, but by considering the functional limitations caused by impairments. For example, a person may have an underlying medical condition of diabetes. Thus, as this medical condition has no impact on the person's functional activities, there is no disability. However, if the diabetes causes the deteriorating eyesight, which limits the individual's ability to access transportation or perform his or her job functions, these functional limitations result in a disability. Functional limitations are associated with the person's ability to appropriately engage in key social roles, such as employment or caring for family members (Brandt Jr. & Pope, 1997; Hersh & Johnson, 2010).

Lastly, under the Social Approach, a person with a mobility impairment is not prevented from fully participating in society by the impairment, but by the failure of policy makers, planners and builders to take into account the existence of persons with mobility impairments and to create accessible transportation, buildings and services. According to the Social Approach, PwD are not excluded from employment so much by their medical condition as by the fears, myths and lack of information that lead potential employers to close their minds against their applications (Cook & Polgar, 2014; Hersh & Johnson, 2010). From this perspective, disability is less an individual issue than it is a societal one; a person's activities are limited not by the impairment or condition but by the environment and barriers that are consequences of a lack of social organization. As shown in Figure 17, considering disability as a displacement of the environment (floor mat), the amount of disability that a person experiences is a function of the interaction between the person and the environment. Social Approach states that it is the environment, and how the environment interacts with people, that must be fixed and enhanced in order to provide quality of life and mitigate exclusion. This perspective has had a profound impact on the disability theory and public policy over the past thirty years, and is now the dominant approach among researchers and activists (Brandt Jr. & Pope, 1997).

Figure 17 – Influence of the environment in the amount of disability experienced by someone.



Source: (Brandt Jr. & Pope, 1997)

Furthermore, the Social Approach considers that disability is best addressed by a deliberate and determined effort to remove the socially constructed barriers that disable individuals, to develop a society that is inclusive and respectful of persons across a wide spectrum of differences, and to take into account the human diversity. Technology developed in the Social Approach is typically paid by the individual with the disability or it is free, if mandated by law. Closed captioned television is an example of free technology mandated by law (Ladner, 2011).

On the other hand, it is important to mention the antithesis of the approaches to disability, known as ableism. Ableism is an approach that captures the idea that able-bodiedness is considered *normal* and most valued in society. An ableist approach helps explain why and how some people whose bodies are different from this norm are excluded. Ideas of ableism and its link to the classification of ability and disability emerged in North America, in particular, from disability activists in thinking through their everyday experiences of exclusion (Loja, Costa, Hughes, & Menezes, 2013). Campbell (2009) helped to articulate ableism, conceptualizing, defining and describing everyday forms of disability exclusion due to processes of ableism. In particular, ableism denotes the ways in which particular abilities such as independence, competence and productivity are hyper-valued by society, which, as a consequence, results in the devaluation of individuals who are assumed not to have these abilities.

4.3 Laws, policies, technical standards, and guidelines

Although nowadays the contemporary society is more reasonable relating to the accessibility cause, it has not been long since disability was seen as a synonym of sickness and PwD should be cured, as discussed in the previous section. Unfortunately, the current understanding of disability in our society is not the result of unselfish concerns for the welfare minority groups. Successful accessibility achievements and initiatives – and lately, the accessibility to digital artifacts – happened thanks to specific laws, policies, technical standards, and guidelines, among other resources (Lazar, Goldstein, & Taylor, 2015). After a law has completed the legislative process, it is put into effect as part of the legislation in force within a country or region. Policies outline the goal of a government ministry or agency, as well as the methods and principles to achieve those goals. Policies are not laws, but they can lead to the development of laws. Technical standards are consensus, an international understanding, which helps developers to ensure that anyone can benefit from their products and services. Guidelines are technical standards that cover a wide range of recommendations for making an action; they are considered best practices, although they are not mandatory and not testable – however they provide the framework and general objectives to help designers to understand the success criteria and better implement the techniques (Lazar et al., 2015; World Wide Web Consortium, 2016). Kim (2015) explains that there are two categories of guidelines: (a) domain specific – i.e, specific to user, platform, etc.; and (b) of general HCI design. The author accentuates that some guidelines can be relevant and common across different categories and cites the example of guidelines for e-commerce application, which should also address different general HCI design issues, such as display layout, how to solicit input, how to promote vendor-specific styles, and how to identify a particular user group.

In spite of the obtained advancements, and social and ethical motivations for more inclusive design practices, the pace of the industry has been slow to adopt them.

Keates et al. (2013) analyze that accessibility laws, policies, technical standards, and guidelines would avoid unnecessary exclusion, since the excluding barriers would be easily identified, and suggest some reasons to explain why the industry is so slow in adopting inclusive design practices: (a) lack of awareness of the issue; (b) lack of motivation for tackling it; and (c) lack of methods for tackling it.

Countries around the world use a variety of approaches to encourage accessibility, from guidance and voluntary compliance with standards to regulatory enforcement with fines, in order to increase, extend, and guarantee the rights of PwD. As mentioned previously in the section 4.1, United Nations Convention on the Rights of Persons with Disabilities makes a strong declaration of the rights of persons with disabilities to have equal access to digital information. The CRPD was adopted on December 13th, 2006, opened for signature on March 30th, 2007, and entered into force on May 3rd, 2008. It is considered the first comprehensive human rights treaty of the 21st century. It takes to a new height the movement from viewing persons with disabilities as “objects” of charity, medical treatment and social protection towards viewing PwD as “subjects” with rights, who are capable of claiming those rights and making decisions for their lives based on their free and informed consent, as well as capable of being active members of society. It adopts a broad categorization of persons with disabilities and reaffirms that all persons with all types of disabilities must enjoy all human rights and fundamental freedoms. The Convention is intended to be an instrument of human rights with an explicit, social development dimension. Countries that signed the treaty engaged to (United Nations, 2006):

- “Enable persons with disabilities to live independently and participate fully in all aspects of life” – Article 9;
- “The liberty of movement” – Article 18;
- “Living independently and being included in the community” – Article 19;
- “Personal mobility” – Article 20;
- “Education” – Article 24;
- “Health” – Article 25;
- “Work and employment” – Article 27;
- “Participation in political and public life” – Article 29;

- “Participation in cultural life, recreation, leisure and sport” – Article 30;

The United States of America has approved several laws that have promoted to PwD equal access to opportunities in different domains and aspects of life. Section 504 of the 1973 Rehabilitation Act was the first disability civil rights law to be sanctioned in the United States. It prohibits discrimination against PwD in programs that receive federal financial assistance. Moreover, Section 504 works together with two other legal initiatives – the Americans with Disabilities Act (ADA) and Individuals with Disabilities Education Act (IDEA) – to protect children and adults with disabilities from exclusion, and unequal treatment in schools, jobs and the community solely by reason of his or her disability. Section 508 of the Rehabilitation Act, as amended by the Workforce Investment Act of 1998, requires federal agencies to develop, procure, maintain and use ICT that is accessible to people with disabilities, regardless of whether or not they work for the federal government. For instance, Section 508 requires federal agencies to make their ICT such as technology, on-line training and websites accessible to everyone. This means that federal employees with disabilities are able to do their work on the accessible computers, phones and equipment in their offices, take on-line training or access the agency’s internal website to locate information. It is important to deem Section 508 in the context of other laws related to federal disability policy, and also part of the Rehabilitation Act of 1973. In addition to Section 504, Sections 501 and 505 prohibit federal employers from discriminating against qualified individuals with disabilities; Section 503 prohibits employment discrimination based on disability by federal contractors or subcontractors. (Brandt Jr. & Pope, 1997; United States of Amercia, 1998; United States of America, 1973).

The Americans with Disabilities Act of 1990 reinforces the previous laws and prohibits private and public employers from discriminating against qualified individuals with disabilities in job application procedures, hiring, firing, and other terms, conditions, and privileges of employment. The ADA covers employers with 15 or more employees and recognizes the governments as responsible for removing the social barriers to the full participation and integration of persons with disabilities on a basis of equality. According to ADA, employers should perform some actions to adapt their structure and provide reasonable accommodations, such as making existing facilities used by employees readily accessible to and usable by PwD, and acquiring or modifying equipment or devices, adjusting or modifying examinations, training materials, or policies, and providing qualified readers or interpreters. In September 2010, the Department of Justice (DOJ) published the ADA Standards for Accessible Design, which states that all electronic and information technology must be accessible to people with disabilities (Brandt Jr. & Pope, 1997; United States of America, 2017).

This set of legal obligations, among other rules and judicial principles, has improved the conditions of American citizens that have disabilities, but has also influenced other countries to establish their own federal statutes concerning the rights of PwD. In the case of Brazil, for example, they incorporated the CRPD into the national set of laws with a constitutional status on March 30th, 2007 (United Nations, 2012b). The Brazilian Government created the National Secretariat for the Promotion of the Rights of People with Disabilities (SNPD, in portuguese), responsible for the implementation of public policies concerning PwD. In order to promote the integration of PwD in the society, some laws and public actions have fostered the recruitment of PwD. As an example of these measures, to motivate the employability of PwD, the Law 8.213/91, article 93, establishes that companies with one hundred or more employees shall offer between 2% and 5% of their jobs to PwD and/or persons rehabilitated by Social Security (Brasil, 1991, p. 213). On the other hand, to improve the education and professional formation of PwD, the Law 12.711/2012 sets up at least 50% quota of federal universities student positions for minorities – PwD, black people, yellow people, and indian native people – distributed according to the proportion of these groups in the total population of each region (Brasil, 2012). In addition, the Decree 5.296/2004 allowed a substantial progress and great impact on the urban mobility and accessibility program – Accessible Brazil and promoting this program into a national accessibility policy. The Decree provides a basis for an "accessible city" through the adaptation of public sidewalks and roads, traffic lights, rooms, furniture, recreational and leisure spaces, transportation, public buildings, including educational establishments, and other individual and collective use facilities (Boareto, 2007). The analysis of the Decree 5.296 is important to the context of this thesis once it defines accessibility and the extensive understanding of the provision of accessibility in the urban space. Firstly, the Decree details accessibility as a condition for the use, with security and autonomy – independently or assisted – of spaces, urban equipment, buildings, transport services and devices, systems and means of communication and information, by PwD or people with reduced mobility. Secondly, the barrier to be overcame by accessibility actions comprise not only urbanistic barriers, buildings barriers, transportation barriers, but also barriers related to ICT. This means that any obstacle or impediment that makes it difficult or impossible to express or receive messages over media, devices or communication systems, whether mass or not, as well as those media that interfere or prevent access to information (Brasil, 2004).

In reality, the situation of PwD in Brazil is far from a comfortable position and need more attention and development. According to the 2010 Population Census, the country has 45.6 million people having at least one type of disability, whether visual, hearing, motor or mental/intellectual. Although they represent 23.9% of the Brazilian population in 2010, these people do not live in an adapted society. Most municipalities do not promote accessibility policies, such as leisure for people with disabilities (78%), accessible tourism (96.4%) and generation of work and income, or inclusion in the labor market (72.6%) (IBGE, 2012).

Differently from this situation, in France, the welfare approach was adopted, where the government is responsible for removing the social barriers to the full participation and integration of PwD on a basis of equality, using the human rights approach; it is centered on the persons and on the consequences of their impairments in the access to an ordinary environment (Lazar et al., 2015). The first main French law related to PwD, Law 75-534, was regulated on June 30th, 1975, with a major amendment to the Labor Code in 1987. This law establishes national obligation towards handicapped persons and relies on solidarism to justify and organize the intervention of the government on the identified PwD's problems and situations to which no regular institutional response is provided (France, 1975). Calvez (2010) analyzes that the 1975 law has been largely criticized on political grounds because it rests on an extension of the Medical Approach to the social realm, which contradicts the principle of equality of chances, put these people in a bureaucratic dependency and opposes their control over their own lives. France also signed the CRPD on March 30th, 2007 (United Nations, 2012b). However, in order (1) to face the criticism towards the Law 75-534, (2) to be in accordance with the obligations of the European directives, and (3) to follow the development towards the Social Approach, France approved the Law 2005-102 of February 11th, 2005, “on rights and equality of chances, participation and citizenship of disabled persons” (France, 2005). According to Calvez (2010), this law constitutes the new reference frame for disability policies, underlying the rights of PwD to general resources, employment, education, citizenship, and compensating the consequences of the disability. The Law 2005-102 established in France a quota model, which required employers with over twenty employees to have six percent of PwD in their workforce and they also must report to the government, showing these requirements are being fulfilled.

Other countries – such as Ireland, Germany, Italy, and Japan, among others – have used a variety of approaches to guide or to enforce the improvement of the disability issue. Lazar et al. (2015) conclude that no country can yet claim a full success in addressing the access and integration of PwD to the society. Moreover, due to the differences in legal tradition and culture, there is no indication that the good results achieved in a country will work in other countries as well.

Now, analyzing technical standards, these documents support developers, designers, and manufacturers to deliver products and services with an appropriate level of quality to users. Credible institutions made the standards and guidelines they publish become widely accepted, influencing even laws and policies. As in the case of the World Wide Web Consortium (W3C), which is the main standardization organization for the World Wide Web, and consists of an international consortium of almost 400 members, among companies, government agencies and independent organizations to establish standards for the creation and the interpretation of content for the Web. In 1997, seeking to improve the accessibility of the Web, the W3C launched the Web Accessibility Initiative (WAI), which is an endeavor compound of several working groups and interest groups dedicated to developing guidelines, technical reports, educational material, and other documents specifically to the several aspects of web accessibility, including web content, web browsers and media players, authoring tools, and evaluation tools (Preece et al., 2015; Sears & Jacko, 2009; W3C Web Accessibility, 2016).

Lazar et al. (2015) clarifies that the WAI working groups are responsible, among other actions, for developing the Web Content Accessibility Guidelines (WCAG), the most commonly used and internationally accepted web accessibility standard. The most recent version, 2.0[23], was launched in December 2008. WCAG has its importance based in different reasons. Firstly, it is a standard that had the participation of public actors and several stakeholders at every stage. Secondly, the WCAG's underlying principles are simple: mainly, the web content is required to be perceivable, operable, understandable, and robust (POUR) (Cook & Polgar, 2014; World Wide Web Consortium, 2008):

- Perceivable - relates to how available the content is to a given user – for instance, is an audio content available to deaf users through captions? Is the content adaptable and distinguishable?
- Operable - refers to the users' ability to interact with the content – can users make use of a keyboard or is a mouse necessary? Have the users enough time to read and use the content?
- Understandable - is about how the user processes different contents, and what the cognitive load is – is navigation consistent? Is the content readable and predictable?
- Robust - relates to the ability of the content to work on, as much as it is possible, in the past, present, and future technologies – is the content compatible with current and future AT?

For each guideline, there are testable success criteria, which are at three levels: A, AA, and AAA. The success criteria are digitally testable, as well as easily verified with usability testing by an accessibility technology user.

Although WCAG was elaborated considering the accessibility of the web content as its primarily goal, Lazar et al. (2015) emphasize that even content and applications not web-based can still benefit from applying some aspects of the WCAG standard. In 2013, the W3C published the document "Guidance on Applying WCAG 2.0 to Non-Web Information and Communications Technologies" (World Wide Web Consortium, 2013), which provided informative guidance, meaning that it is not a normative and it does not set requirements to the interpretation and application of the WCAG to non-web ICT. This document discusses how the criteria

[23] On January 30th, 2018, the WCAG version 2.1 was published as a Candidate Recommendation, indicating that the WAI working group believes it has addressed sufficient substantive issues and that the document is ready for trial implementations. During the Candidate Recommendation period, the Working Group will conduct implementation testing by testing Web sites in conformance with the WCAG 2.1 (World Wide Web Consortium, 2018).

of the WCAG 2.0, in accordance with its principles and guidelines, are applicable to non-web Information and ICT, such as standalone and wearable applications, entertainment consoles, mobile apps and other embedded software.

Another aspect that W3C and its working groups have addressed and developed is “Mobile accessibility”, with refers to the interaction between PwD and mobile phones, or still mobile devices - such as phones and tablets, digital TVs, wearables, devices in car, dashboards and airplane seat backs, devices in household appliances and other IoT devices, among others (World Wide Web Consortium, 2017). W3C working groups have made efforts to harmonize the WAI’s accessibility standards and mobile accessibility issues. As a result, the recommendation document “Mobile Web Application Best Practices” takes into consideration that the user can be a PwD and the mobile application must be prepared to handle the specificities of this user (World Wide Web Consortium, 2010). However, the most valuable W3C contribution to make advance in the mobile accessibility so far is the publication, in February of 2015, of the document “Mobile Accessibility: How WCAG 2.0 and Other W3C/WAI Guidelines Apply to Mobile”, describing how the WCAG and its principles, guidelines, and success criteria could be applied to mobile web content, mobile web apps, native apps, and hybrid apps using web components inside native apps (World Wide Web Consortium, 2015).

Laws, policies, technical standards, and guidelines concerning accessibility only do not necessarily yield ideal usability for the consumer. But they are essential to (1) underline to producers and professionals the particular needs of PwD; (2) signalize how to address users’ needs, which consequently can enhance the quality of products and services, and improve the user experience of PwD; (3) provide the best evidences, standards, and experts’ contribution available; (4) reduce the development time – considering that designers and developers are used to these documents; and (5) contribute to the professional formation of designers and developers (Ghaoui, 2005; Preece et al., 2015; Sears & Jacko, 2009).

In the end, all these actions and their results contribute to make AT more popular: AT is becoming more present in the urban landscape in a wider number of cities; PwD are benefited of advanced and digital AT allowing them to get involved in a broaden range of social and professional activities; companies, developers and designers have the encouragement to adapt their existent products and services or, still, to propose innovative AT solutions.

4.4 Digital AT in the urban space: related work

As more people are living in larger cities, urban problems are noticeable, as well as rapid and effective solutions are required (United Nations, 2012a). This scenery becomes even more complicated to PwD due to their special needs and to the fact that while getting bigger and more complex, cities have less likelihood to attend the population's heterogeneity.

In the last years, industry and academy have engaged in proposing and developing solutions to make the urban space smarter and to ensure the inclusion of the broadest possible group of citizens. Terms as accessibility, inclusion, assistive technology, and their variations have been found increasingly close to terms such as Smart Cities (SC), Urban Informatics, and Urban Technologies. Microsoft, for instance, in June 2016 officially started to support the Smart Cities for All (SC4A) initiative[24], a partnership between the Global Initiative for Inclusive Information and Communication Technologies (G3ict)[25] and World ENABLED[26]. SC4A aims to increase the awareness about the role that accessible technology must play in the planning, deployment, and functioning of SC and how they can better engage people with disabilities and aging communities in those processes. In 2016, G3ict launched a survey to assess ICT accessibility in SC around the world. Over 250 experts and SC program managers were surveyed and interviewed, with around 60% claiming that smart cities were failing with people with disabilities. Only 18% of the respondents

[24] http://smartcities4all.org/

[25] G3ict is an advocacy initiative launched in December 2006 by the United Nations Global Alliance for ICT and Development, in cooperation with the Secretariat for the Convention on the Rights of Persons with Disabilities at the United Nations Department of Economic and Social Affairs. Its mission is to facilitate and support the implementation of the dispositions of the CRPD on the accessibility of Information Communication Technologies (ICTs) and assistive technologies. G3ict is a nonprofit organization and relies on an international network of ICT accessibility experts to develop and promote good practices, technical resources and benchmarks for ICT accessibility advocates around the world (G3ict, 2016).

[26] World ENABLED is an educational non-profit organization that promotes the rights and dignities of persons with disabilities. Its fieldwork and research initiatives promote an inclusive human and civil rights approach to disability programs and policies (World ENABLED, n.d.).

knew of a smart city that used ICT accessibility standards (Smart Cities for All, 2016).

Focused in governmental and theoretical aspects, SC4A launched the Smart Cities for All Toolkit, a set of four resources to support a range of organizations, as well as private and public stakeholders, to assure an accessibility vision to cities (Smart Cities for All, 2017). They are:

- Smart Cities for All – Guide to Implementing Priority ICT Accessibility Standards: provides an inventory of three key standards that define ICT accessibility criteria – the European standard ETSI EN 301 549, which defines a set of functional accessibility requirements that can be applied to a broad range of ICT products and services; the Section 508 of the Rehabilitation Act; and the WCAG 2.0. In addition, this document presents a step-by-step checklist of actions that leaders can take to ensure their city is aware of these standards;
- Smart Cities for All – Guide to Adopting an ICT Accessibility Procurement Policy: helps cities to adopt a policy that requires any ICT purchase to be accessible to persons with disabilities and older persons;
- Smart Cities for All – Database of Solutions: tool that is being designed to showcase existing products and solutions that can be deployed by Smart Cities to positively impact citizens in critical areas, such as independent living, public safety, transportation, among others;
- Smart Cities for All – Communicating the Case for Stronger Commitment to Digital Inclusion in Cities: helps to effectively communicate the advantages of incorporating ICT accessibility, since one of the biggest challenges to create more inclusive smart cities is raising awareness of disability and ICT accessibility;
- European standard, ETSI EN 301 549: defines a set of functional accessibility requirements that can be applied to a broad range of ICT products and services.

AT&T Corporation, one of the world's largest telecommunications company, is also proposing SC solutions and builds its concepts of SC as an “inclusive and prosperous city" (AT&T, 2018). The company offers the AT&T Smart Cities Structure Monitoring, a solution that distribute sensors in the city landscape to monitor structural factors remotely. Based on the data collected, the sensors can trigger preventive actions and send email alerts to report the occurrence of emergency events. With this SC solution, AT&T seeks not only to benefit organizations and the community, but also to help improving safety and planning. The company explicitly elected the PwD and ageing people community as the core of its vision of an equitable and positive SC technology. In June 2017, AT&T in collaboration with G3ict, World ENABLED, and with Business for Social Responsibility (BSR)[27], launched a white paper entitled "Smart Cities for All: A Vision for an Inclusive, Accessible Urban Future", which emphasizes the potential of SC enabling technologies to benefit PwD and ageing people while building a more inclusive SC (Korngold, Lemos, & Rohwer, 2017). Although the white paper focuses on North America, it includes global examples and technologies, maps the opportunities for smart city technologies to benefit all communities, as well as the "keys to success" to ensure these technologies advance along five SC capabilities: Energy and utilities; Infrastructure; Transportation; Public Safety; and Citizen Engagement.

The white paper identifies four keys to success, and it is recommended to city authorities to ensure digital inclusion, namely:

- Design for Inclusion: according to the authors' believes, enhanced digital security and privacy protections would be a fundamental requirement as new technologies. Universal Design should be used against privacy abuses and to ensure that SC solutions are usable by all citizens;
- Engage Partners and Stakeholders: SC technologies must adopt a multi-stakeholder engagement process to ensure sustainable financing of these innovations and citizens' full participation in any projects;
- Promote Adoption of Technology: city officials must work to mitigate the digital divide that often prevents people who are aging or living with disabilities to access the full benefits of technology;

[27] BSR is a global nonprofit organization with a network of more than 250 companies' members and other partners. BSR develops sustainable business strategies and solutions through consulting, research, and cross-sector collaboration, aiming to build a just and sustainable world (BSR, 2018).

- Foster the Entrepreneur Ecosystem: many of the applications and solutions that will benefit these communities will arise from social entrepreneurs and innovators. Beyond enhancing the accessibility of city infrastructure and services, a key role for city government is to enable this social innovation to flourish and direct entrepreneurship to benefit these communities. Publicly funded incubators and open data portals are some of the many ways city governments can foster citizen solutions.

Notwithstanding, both Microsoft and AT&T SC proposals are industry-driven, meaning that they are built around the technologies and services provided by these companies: databases to Microsoft, telecommunications to AT&T, and consulting services to both companies. The narratives of both companies are marketing campaign-driven – expressions such as “success”, “positive outcomes”, and “advancing benefits”, among others, are very common in the companies’ solution reports – as well as a vague language lacking on clear implementation details.

On the other hand, in an academic perspective of treating accessibility in SC initiatives, industry and academy started to organize meetings, conferences, and summits as a way to disseminate the need of developing accessibility in the SC context. In March 2016, the Dutch foundation Waag Society – Institute for Art, Science and Technology – organized the webinar on Inclusive Smart Cities to discuss how to engage citizens through co-creation and co-design tools[28].

The European Community, for instance, sponsored in November 2016, in Brussels, Belgium, the conference “Inclusive Smart Cities: A European Manifesto on Citizen Engagement” putting together networks of regional and local authorities, civil society organizations, knowledgeable scholars, and industry representatives to cooperate and commit to the active involvement of citizens. The European Innovation Partnership on Smart Cities and Communities launched in this conference a manifesto on citizens’ engagement. It declares the commitment of signatories to create and foster accessible urban services for citizens, in order to improve the quality of life in cities and contribute to sustainable cities and a livable environment. In fact, to the European Manifest, the idea of inclusion is related to the empowerment of citizens trough their political involvement, engagement, and proposing actions to actively

[28] http://waag.org/en/event/citizen-focus-webinar-inclusive-smart-cities

involve citizens in urban innovation and decision-making processes when designing SC solutions (Kakderi, 2017).

In September 2012, the Inclusive Smart Cities Summit[29] happened in Washington, United States of America, aiming to bring together leaders from across the globe to discuss the future of SC and the need for inclusivity in innovation. This event was driven to big technology companies and did not have a clear statement about how to address accessibility and inclusion issues in the context of SC (Washington DC Economic Partnership, 2017).

The International Conference on Smart Homes and Health Telematics (ICOST) chose the conference theme as “Inclusive Smart Cities and e-Health” for two consecutive years, 2015 and 2016. The event calls research contributions from several areas, such as design and usability; assistive and sentient environments; human behavior and activities monitoring; and health IT and supportive technology (Geissbühler, Demongeot, Mokhtari, Abdulrazak, & Aloulou, 2015).

Discussing inclusiveness and urban technologies is the main objective of the Inclusive Smart Cities educational program of the Kies Op Maat Institute, in Almere, Holland. This one-semester program is designed around the idea of an inclusive city, which is a city where the processes of development take into consideration a wide variety of citizens and activities, specially focusing on an inclusive labor market (Kies op Maat, 2016).

Furthermore, academy and research groups have conducted studies combining accessibility and inclusiveness aspects to SC technology. The conquest of autonomy and independency is one of the motivating feelings of achievement for PwD and what have warranted the obtainment of rights for this community (World Health Organization, 2011). There is already a significant progress considering private and physical spaces (Federici & Scherer, 2012). On the other hand, public spaces still demand an increasing effort to bring more advancement. Unlike private spaces, public spaces are not-controlled environments, meaning that several people share the same space, where they can find noise, pollution, physical obstacles, and where changes can happen constantly and without previous notice. These characteristics make public spaces hostiles and unfriendly, even to people without

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[29] https://nvite.com/InclusiveSmartCities/

disabilities. Indeed, urban space has been adapted to support PwD to move around the city: elevators, ramps and tactile floors are examples of assistive technology available in the landscape of cities around the world. However, these achievements are not yet a consensus. Adapting the world to assist in PwD's needs have a high cost, especially if it involves constructions, such as breaking down or building walls or ramps, or if it requires to buy expensive equipment, such as elevators. Moreover, as the physical environment is in constant change, sometimes making a renovation can compromise the use of the assistive technology that used to be installed in a certain place. Or yet, renovation expenses can be much higher due to the pre-existence of assistive technology in this place. Unfortunately, these obstacles make it difficult to implement assistive technologies in public places, which sometimes leads to legal actions in order to make access to PwD a reality.

IoT has been conceived as an enabling technology to deal with the challenges of making a physical environment more accessible. One of the most important IoT's goals is the creation of smart environments, spaces and self-aware things for mobility, digital society and health applications, among other aspects (Vermesan & Friess, 2011). As confirmed in (Gutiérrez et al., 2013), "IoT can reduce the complexity of environments, transforming them into smart spaces".

Comparing with environmental adaptations that employ only physical solutions, adaptations that use a combination of physical and virtual solutions are more flexible, cheaper and require less human resources to be implemented. Concerning the context of Smart City initiatives, some studies have already discussed and proposed IoT solutions to accessibility issues, such as:

- Navigation and wayfinding (Ahmetovic, Gleason, Kitani, Takagi, & Asakawa, 2016; Alghamdi, van Schyndel, & Hamilton, 2014; Palazzi & Bujari, 2016; Rituerto, Fusco, & Coughlan, 2016; Wang et al., 2017);
- Data sharing and crowdsourcing (Prandi, 2014; Prandi, Mirri, & Salomoni, 2014);
- Spatial information organization (Tavares et al., 2016; Tavares, Barbosa, Costa, Yamin, & Real, 2012); and
- User interface adaptation ("Cloud4all," n.d.).

The Smart Station research project, proposed by Agostini et al. (2017), addresses a solution to the problem that blind people face when they try to take a bus: they need to rely on someone else's help to take the bus they are waiting for. The authors present a client-server architecture in which each bus and each bus station is equipped with a single-board microcontroller, such as Arduino; the single-board microcontroller also stores audio files for each bus line. When approaching a bus station, the bus sends to the bus station its ID and, automatically, the bus station plays loudly the audio file linked to the respective bus line. Thus, all blind people that are in the bus station will be able to identify the bus that is arriving.

Also focusing on helping blind people, Liu et al. (2015) proposed and implemented an integrated app called Voice Helper, which integrates open sources to provide readers for text messages, QR codes, OCR and navigation features, such as a digital map navigation reader. The system was developed for Android devices.

Smartphones are constantly referred as a key technology to support PwD in the urban space. It is the case of the NavCog study, which is a smartphone-based system that provides turn-by-turn navigation assistance based on accurate real-time localization over large spaces (Ahmetovic, Gleason, Ruan, et al., 2016). This digital AT is based on beacons[30] that, besides basic navigation capabilities, also inform the user about nearby points-of-interest (POI) and accessibility issues – for instance, the gap between trains and the platform, and stairs ahead.

Aiming to provide ubiquitous accessibility, the Hefestos Model offers context awareness, semantic representation, user profiles, and trail management in order to support accessibility for PwD and elderly people in various situations of their everyday life. This integrated model uses ontology to provide PwD and their families with contextual information. This ontology organizes the environment in three main classes: person, resource, and disability (Tavares et al., 2012). As a case study, the authors presented the Smart Wheelchair, which interacts through an embedded smartphone providing the user with context and accessibility-related information, as well as sending commands to the wheelchair, such as, go ahead, turn on the right, stop, and so on. The architectural components of their Smart Wheelchair are (Tavares

[30] Beacons are iBeacon protocol compatible hardware transmitters, a class of Bluetooth for low energy devices that broadcasts their identifier to nearby portable electronic devices. The technology enables smartphones, tablets, and other devices to perform actions when in close proximity to a beacon (Wikipedia, 2018).

et al., 2015): Hefestos Server (web services); Hefestos Wheelchair client (Android app); Hefestos Middleware (J2ME communication management module); Wheelchair embedded software (proprietary firmware).

An alternative approach to address accessibility issues in SC initiatives is provided by Aly et al. (2017) in their research article entitled “Towards Ubiquitous Accessibility Digital Maps for Smart Cities”. The authors proposed a technological solution based on ubiquitous accessibility digital-maps, where spaces of the indoor and the outdoor maps are automatically updated with the various accessibility features and marked with assessment of their accessibility levels for the different disability types, such as vision-impairment, wheel-chaired, sensory disorder, deafness, among others. In the authors’ opinion, although digital maps have become a part of our everyday life, available commercial and open-source digital maps have only limited accessibility information, if any. Thus, Aly et al. (2017) proposed a system based on the user’s sensor-rich mobile devices in a crowd-sourced manner, and also proposed a technological architecture that can infer the users’ different surrounding semantics and indicates the space’s accessibility level through different data collected by the sensors. All this information is used to automatically construct ubiquitous indoors and outdoors accessibility digital maps.

In a very similar way, except by the fact that the study is focused on the needs and requirements of people with movement disabilities in the urban space, the research article entitled “A Comprehensive System for Monitoring Urban Accessibility in Smart Cities” also explores automatic monitoring tools to dynamical discovers, assessing and classifying urban accessibility issues, and generating information related to the accessibility levels of urban environments (Mora, Gilart-Iglesias, Pérez-del Hoyo, & Andújar-Montoya, 2017). Based on the citizens’ traceability information, on RFID and GPS technology, and on Cloud Computing, the system is fed by the inference of the movement patterns for individuals, according to their degree of disability and by comparing the routes followed in each case to conclude, for instance, that PwD have to take different routes due to some obstacles, such as, stair, ramps, among others. Also, the system can be fed by reports of citizens regarding accessibility problems they found anywhere when they move around the city.

Also based on Cloud Computing and IoT devices – specifically distributed wearable devices in the form of Body Area Network – the study entitled “Health and Emergency-care Platform for the Elderly and Disabled People in the Smart City” proposed a platform aiming to monitor the health of elderly people and PwD, and to provide them with a service oriented emergency response in case of abnormal health conditions (Hussain, Wenbi, da Silva, Nadher, & Mudhish, 2015). Developed in a people-centric perspective, the system explores IoT capabilities to build an intelligent system with real-time monitoring and interaction for personalized healthcare of the elderly and PwD at their home.

As a step forward, Torre & Celik, 2015 proposed a content adaptation approach based on the Web of Things and adaptive web-systems, taking into consideration the users’ needs and preferences to provide customized content. Moreover, the authors indorsed annotating objects, making them available and linkable on the Web. However, the proposed solution is still delimited to private spaces and do not consider the broaden sphere of SC solutions and their problems – such as performance, privacy, network connection, among others. According to Torre and Celik (2015), the object’s content is fixed and it is the same for all users; the adaptation only works for the modality in which this content is offered to the user. In addition, this research did not consider the possibility of objects performing actions or services to users; neither how to address scalability and performance issues of the approach.

Table 3 summarizes the various initiatives and works discussed in this section according to the following aspects: theoretical/technological perspective, benefited users, domain, user interface, and enabling technologies. First, the proposals are either theoretical or technological. Second, most of the time the proposals are specific to a group of PwD, or to a few groups of PwD. Third, most of the cases are strict to a specific domain of application. Four, as the benefited group, or groups, of PwD is restricted, the user interface is in most of the cases determined and tailored for this group. Last, the enabling technologies of these works most of the time do not consider the increasingly number of information consumers in cities, the complexity of the urban environment, and the urban sprawl.

As it was observed, the previously mentioned studies addressed an abstract view of the solutions proposed to PwD in general. A more holistic and flexible approach to address accessibility issues in urban spaces is still lacking, as it is required in SC projects. Unfortunately, a proposal that provides a basis to the development of a variety of AT solutions to solve different SC domains problems is also lacking. SC enabling technologies still have to be explored, as in the case of smart objects, which can be employed to enhance the independency and autonomy of PwD in public spaces.

In the next chapter, we will present the Inclusive Smart Cities approach, a proposal that aims to fill these lacks.

Table 3 – Related works summary.

Initiative/ Research	Theoretical/ Technological perspective	Benefited users	Domain	User interface	Enabling technologies
Smart Cities for All (SC4A) *Microsoft, G3ict, World ENABLED*	Theoretical	PwD in general	Public administration	Does not apply	Does not apply
A Vision for an Inclusive, Accessible Urban Future *AT&T*	Theoretical	PwD in general	Public administration	Does not apply	Does not apply
Inclusive Smart Cities: A European Manifesto on Citizen Engagement *European Community*	Theoretical	PwD in general	Citizens' political engagement	Does not apply	Does not apply
Smart Station	Technological	Blind people	Transport/ Mobility	Audio	Embedded system in the bus and in the bus station; *ad hoc* communication
Voice Helper	Technological	Blind people	Urban navigation	Audio	QR Code; OCR; digital maps; smartphones
NavCog	Technological	Blind people	Urban navigation	Audio	Beacons; Digital maps; Smartphones
Hefestos Model	Technological	Blind, deaf and wheel-chaired people	Urban navigation	Adaptable	Ontology; Embedded software for general purpose and AT devices; Smartphones
Towards Ubiquitous Accessibility Digital Maps for Smart Cities	Technological	Blind, deaf and wheel-chaired people	Urban navigation	Do not mention	Digital maps; GPS; Smartphones
A Comprehensive System for Monitoring Urban Accessibility in Smart Cities	Technological	People with movement disabilities	Urban navigation/ Mobility	Textual and pictorial	RFID; Digital maps; Bluetooth; GPS; Cloud Computing
Health and Emergency-care Platform for the Elderly and Disabled People in the Smart City	Technological	PwD and elderly	Health	Textual and pictorial	Sensors (Body Area Network); Single-board microcontrollers; Cloud Computing
User-Adapted Web of Things for Accessibility	Technological	Blind, deaf and wheel-chaired people	General purpose	Adaptable	Semantics; Object annotation; Web services

5

The experience of PwD in urban spaces

As discussed in Chapter 4, over the last decades, PwD have achieved the recognition of their rights, which allowed them, as any other citizen, to act actively in different sectors of the contemporary societies, such as in education, workforce, leisure, lifestyle, commerce, politics, among others. While improvements have been made in equipping cities with physical assistive technology, PwD have to face most of the time unfriendly and unfavorable urban spaces to seize these rights, as verified in Chapter 2.

Alternatively, as examined in Chapter 3, technology is in the center of major changes in the way people experience the cities, how local authorities are providing citizens with location-based services and information, and how inhabitants interact with each other and with urban facilities. SC solutions promise to employ outstanding technological concepts to improve the quality of life of citizens and it has already been achieved in the case of the invaluable use of digital maps to navigate in big cities.

However, even considering the utopian scenario where all the problems SC pledge to address are solved – pollution, safety, transportation, health care, public safety, traffic control, air pollution, waste management, energy, emergency management, among others – most of the problems associated with PwD, as pointed out in Chapter 2, would have no reliable progress, as they still need the help of another person to identify and decrypt information that is commonly present in urban spaces and that are not in a intelligible format (and even that are not perceivable by everyone). This is one of the most important reasons to propose a new and inclusive branch for the SC vision: including in the list of problems to be addressed by SC initiatives the existing problems related to accessibility in contemporary cities, which will give a more realistic, renewed, and up-to-date outlook to Smart Cities. Still, accessibility issues may mean a more humanistic, citizen-centered, and positive change-driven perspective to SC projects.

Aiming to provide a better experience for PwD in urban spaces, we adopted a two-steps approach:

1. Identifying the problems and obstacles that PwD face when they are moving out in the city, the strategy they use to solve these problems as well as understanding how public authorities address the demands of PwD; and
2. Proposing a set of theoretical and technological tools to support public agents, entrepreneurs, developers and designers to conceive and implement digital accessible urban solutions.

This choice reflects our belief that, to offer a better urban experience to PwD, we need to first look the bad and good situations that PwD go through in their daily routine. Secondly, public agents and professionals involved in such endeavor must be supplied with a set of resources that will help them with the initial steps, avoiding waste of time, and that will guide them while designing digital accessible urban solutions, what can improve the quality of the final products. As discussed in Chapter 3, developing SC solutions *per si* is already a multidisciplinary task. Adding accessibility aspects and practitioners to this context makes it still more complex: public agents normally do not master technological issues; accessibility experts generally are not skilled in policy-making process; developers usually do not rule the accessibility subject. Hence, a way to boost the emergence of digital accessible urban solutions is furnishing these multidisciplinary teams with instruments able to help them (1) to manage the chaos while supplying them with principles and guidelines, and (2) to reinforce the communication process between the teams' members, breaking down the silos.

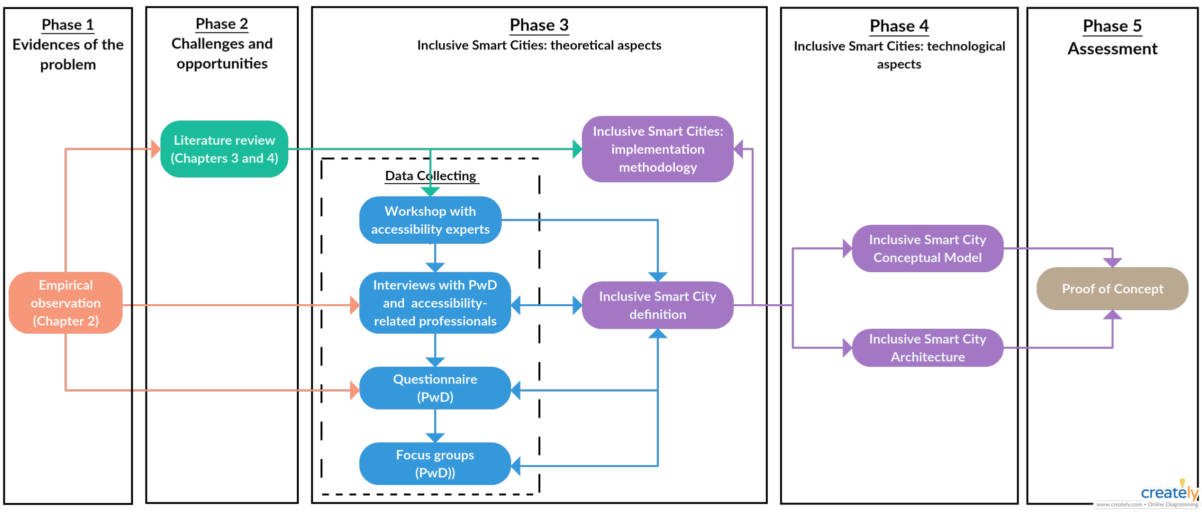
This chapter is dedicated to the first step of our approach: understanding how PwD experience the city. With the inspiration and a broaden understanding gathered in Chapters 2, 3, and 4, we progress towards the main contribution of this thesis: **The Inclusive Smart City (ISC).**

5.1 Methodology

This study employed a mixed-methods approach, specifically a sequential method beginning with a workshop with accessibility experts to understand the political context and capture how the policymaking process works in this area.

The knowledge acquired in the literature review gave us the basis and the vocabulary to go through the next phases proposed in the Methodology section of Chapter 1, namely, the development of theoretical and technological aspects of the Inclusive Smart Cities. Phase 3 starts with the design of a multiple method approach for data collecting. The multiple method approach employs workshops, interviews, questionnaire, focus group, and Delphi method to establish a direct contact with PwD and the different professionals that are involved in the accessibility field, leading us to explore the needs, thinking, assumptions, attitudes, and perceptions related to PwD in urban spaces. Figure 18 provides further details on the phases of this project, the research methods employed and how they are combined in order to achieve the goals and contributions of this thesis.

Figure 18 – Detailed research methodology.



The methodology and ethical aspects of the data-collecting activities were submitted, reviewed, and approved by the Research Ethics Committee of the Federal University of Recôncavo - State of Bahia, Brazil, on 28 November 2015, number 2.402.828. Table 4 shows when the methods were performed and how long it took to be done.

Table 4 – Profiles of the accessibility expert workshop's participants.

Methods	Start date	End date
Workshops with accessibility experts	February'2016	April'2016
Delphi method	May'2016	May'2016
Interviews with PwD and accessibility-related professionals	June'2016	September'2016
Questionnaire	January'2017	July'2017
Focus groups	August'2017	September'2017

All the collected data – audio, text and notes – were transcribed, revised, and then analyzed using the freeware Aquad[31]. In order to perform the analysis of the set of collected data, we applied the Qualitative Content Analysis (QCA) method, a careful, detailed and systematic examination and interpretation of a material corpus to identify patterns, themes, biases, and meanings (Neuendorf, 2016). The QCA comprises the following stages for the data analysis procedure (Bengtsson, 2016):

- Decontextualization: the researcher must familiarize him or herself with the data, and he/she has to read through the transcribed text to obtain the sense of the whole, before it can be broken down into smaller meaning units;
- Categorization: before the researcher begins to create categories, extended meaning units must be condensed. The depth of the meaning units determines the level at which the analysis can be performed. This process of condensation is often needed when data are based on interviews. To extract the sense of the data, the coded material can be divided into domains, such as broad groups based on different subjects of the study;
- Compilation: once the categories are established, the analysis and writing up process begin. For each category or theme, the researcher chooses appropriate meaning units presented in the running text as quotations.

As the data collection and data analysis activities were being performed for each experiment, the contributions of the thesis could be seen – ISC definition, requirements, conceptual model, implementation methodology, and architecture – and the next data collection activities could be carried out. In an iterative and incremental way, these

[31] https://www.predictiveanalyticstoday.com/aquad/

contributions were updated and, at the same time, new directions and objectives of the next data collection activities were defined.

5.2 Experiments' design and results

In this section we provide details concerning the data collection experiments design as well as the results, which are analyzed in Section 5.3.

5.2.1 Workshops with accessibility experts

We conducted two workshops of three-and-a-half-hour, and a meeting with four public agents who work as accessibility specialists for the Secretariat of the Rights of PwD in the city of Barueri, in the State of São Paulo, Brazil. During this experiment, as data collecting techniques, we recorded the audio of the meeting, took pictures and handwritten notes. Table 4 summarizes the profiles of the workshops' participants.

Table 5 – Profiles of the accessibility expert workshops' participants.

	Gender	**Age**	**Years working with PwD**	**Educational formation**	**Current job position**
W-P1	Female	52	17	Pedagogy	Accessibility consultant
W-P2	Female	55	13	Social worker	Accessibility consultant
W-P3	Male	49	6	Manager	Accessibility consultant
W-P4	Female	51	12	Psychology	Accessibility consultant

First, as shown in Figure 19, participants used post-it sticks in a blank wall to define the set of public and private stakeholders, the decision path, and the local departments that involved accessibility policy statements, and the adoption of urban assistive technology in the municipality. Second, we showed the participants two short movies[32,33] related to the definition and technological solutions of Smart Cities to motivate the discussion on how to embrace the accessibility cause in the agenda of SC projects.

[32] https://www.youtube.com/watch?v=5KDhl1K3c5Q
[33] https://www.youtube.com/watch?v=5TJmTyofYbc

Figure 19 – Workshop with accessibility experts.

According to workshop participants, the role of the government in implementing public policies and accessibility plans is fundamental in order to facilitate PwD's daily routine and to guarantee their rights. Specifically in the PwD's communities, some universal rights – considered as granted to all citizens – must be ratified, i.e., confirmed again. For instance, the current Brazilian Constitution ensures to all citizens the right to use public schools and public hospitals, however, there are some public schools and hospitals that refuse to accept PwD as users, arguing that they do not have adapted physical structure or professionally trained staff to take care of citizens with disabilities. Most of the time, these policies concerning accessibility are issued only from the demands of the PwD's community and from social pressure. As local authorities have a variety of requests and socio-political-economic challenges to deal with, PwD need to be involved and participate in the policymaking process, making clear what their needs and complaints are. The problem is that PwD are traditionally so isolated in the political sphere and so far from the policymaking discussion, that even considering specifically accessibility policies, most of times these policies do not reflect the real demands of the PwD community as a whole. Participants emphasized that PwD were so used to having nothing from local authorities that many of them still have no idea of their rights.

Moreover, participants emphasized that this lack of a strong feeling of belonging to a community produces in each citizen with disability the sense of need to fight *per si* and to solve his or her own and personal needs. However, most of the times, solving someone's individual problem can lead to the solution of a higher number of problems of an entire community of PwD.

Participants also mentioned that PwD have been invisible citizens for centuries, which explains the reasons why local authorities ignore PwD's rights and claims, and clarifies why we can feel the anger, revolt, and violence of their speech when they are asked to speak. Aiming to establish a dialogue channel with citizens with disabilities, local authorities should create and strengthen official forums and agencies, which would be able to mediate this dialogue by giving adequate attention to the PwD's demands and sensitizing policymakers to the fact that PwD are citizens as all other citizens are as well. Recognizing themselves in these accessibility forums and agencies would engage PwD as an organized community of citizens which may require changes related to the provision of their rights and monitor the continuity of rights already implemented.

Thus, the group of participants collaboratively elaborated the idea of a Smart City that would consider citizens with disabilities as potential users. This initiative would leverage public policies, technologies, and PwD's demands. According to the participants, there would not be a Smart City adapted to citizens with disabilities only. Since the beginning, SC initiatives would consider all city citizens. SC initiatives would empower PwD by providing them with useful information, thereby reducing the emotional cost these citizens have when they need to move around – they are often frustrated and stressed because they are prevented from having leisure, and their access to various urban facilities is usually difficult. The key elements that must be considered in such ecosystem to interact with citizens with disabilities would be:

- Civil society: ordinary citizens, PwD, PwD's relatives – especially feminine roles, such as mother, wife, aunt, among others;
- Government: local authorities, local agencies, social assistance and accessibility departments;
- Business: local stores and other local business, product and service providers; accessibility-related professionals, technology providers, assistive technology providers;
- Research and development: universities, research groups, innovation organizations.

The workshops with accessibility experts allowed: i) to determine the first main concepts that supported the definition of Inclusive Smart Cities; ii) to elaborate a preliminary list of stakeholders; iii) to draft an initial proposal for the political structure of an ISC; and iv) to outline the first version of the ISC implementation methodology.

In addition, we have three other contributions as outcomes of the workshops with accessibility specialists: (1) the initial list of requirements to be observed in ISC initiatives; (2) the ISC Business Model; and (3) the identification of the main ISC stakeholders. These contributions have allowed us to advance to the development of the theoretical aspects of the Inclusive Smart City.

5.2.2 Delphi method

Some of the results produced during the workshops with accessibility experts – specifically the list of stakeholders, the political structure, and the implementation methodology of the ISC – are valuable but also limited to the personal experience of each expert and to the context of the municipality in which the group of experts worked together. In addition, a definite evaluation of these elements in our proposal would require real implementation by local governments and long-term monitoring, which depends on political will and influence. Aware of these constraints and limitations, we invited 11 experts to evaluate our initial proposals and their potentials using an anonymous Delphi method. The Delphi method study consists in recruiting experts on a topic and sending them some statements that they should analyze and answer some questions; the experts' answers are compiled into a new document and sent back to the same experts; after evaluating the compiled document, the group members have the opportunity to review their previous responses; the method proceeds until the group of experts converges to a consensus answer to each question submitted (S. R. Brady, 2015).

We have sent the message available in Appendix A to 32 experts recruited from our personal contact lists and from the recommendation of the Secretariat of Rights of the PwD of the Barueri municipality. Responding to our call, 11 experts accepted to participate in our study – 3 of them working in the process of formulating accessibility policies in distinct municipalities in the state of São Paulo, Brazil; 2 others working as policy makers in other public policy domains in distinct municipalities in the state of São Paulo, Brazil; 3 participants are entrepreneurs in the assistive technology industry; and 3 participants are university researchers in the area of innovation and public policies.

In this group, consensus was reached with three rounds and this manifests a more consistent definition of an ISC, its political structure and implantation, and operation methodology. Participants in the Delphi method study emphasized the importance of creating, at the core of the local political structure, a layer responsible for meeting users' demands and for leading the ISC implementation and operation methodology. According to the participants, the engagement of PwD in the ISC administration is crucial, reinforcing the idea of having an ISC created by and for citizens. The participation of PwD in such administration should be achieved through their contributions in open plenary sessions, debates and other participatory events. Participants emphasized the role of private companies as key players in the ISC ecosystem. Furthermore, participants highlighted the importance of including the definition of metrics and evaluation indicators in the early stages of the implementation and operation methodology. They also suggested the inclusion of a maintenance time in the implementation and operation methodology, in which the solutions developed would be adapted according to changes or to correct encountered errors.

The main contributions of this activity were: (1) an evaluation of the proposals related to the theoretical aspects of the ISC, i.e., definition, stakeholders, political structure, and implementation methodology; and (2) bringing some valuable elements, such as the importance of establishing metrics in the early stages of the implementation and operation methodology. These contributions allowed us to refine the theoretical aspects of the ISC, taking advantage of the variety of participants' backgrounds, and exploring the specificities and particularities of the cities where they perform their daily activities.

5.2.3 Interviews with PwD and accessibility-related professionals

Between February and May 2015, 15 semi-structured in-depth interviews were conducted with PwD – 3 blind people, 2 deaf people, and 2 wheel-chaired people –, as well as with professionals that work with PwD – 3 subway assistants, 1 psychologist, and 1 sign language interpreter. The main goal of this activity was to be in contact with PwD, to know their specific needs concerning urban spaces, and to perceive how they experience the city – their perception and difficulties – and familiarity with technology.

Respondents were allowed to develop ideas, but the following questions conducted the conversations:

- What are the main concerns PwD have when they are in public spaces?
- What kind of strategies PwD should use to navigate safely in urban spaces?
- What kind of technology PwD use to navigate in urban spaces?
- What kind of activities PwD are most of the times denied of doing in cities (and they would like to do)?

The audio recordings of the interviews were transcribed and also submitted to the QCA procedure.

Respondents conveyed ambivalent feelings related to their experience in urban spaces. They expect to benefit from the services and advantages offered by cities to their citizens, but they feel they are prohibited from taking advantage of their rights. As a 30-years-old sign language interpreter female observed, "*in the end, people with disabilities have the feeling that they are always the ones who must adapt to the city; the city never adapts to them*".

The city reveals itself to PwD as a series of problems – uneven sidewalks, potholes, debris in the streets – and there are even some solutions that become problems later, as in the case of some Brazilian cities, where tactile floors guide to nowhere and acoustic traffic signals do not work properly. Technologies and digital services, such as smartphones, instant message services, GPS, and voice and video calls, are some of their allies in addition to some strategies, such as leaving home much earlier than other people would do and memorizing the sequence and the spatial arrangement of objects in the environment. According to a 56-year-old wheel-chaired female respondent, "*all of this preparation to face the unknown requires a huge mental effort and causes memory overload in PwD*". Other respondent, a 61-year-old blind female states, "*we end up developing memorizing skills because we are obligated to. We always have to create mental maps of spaces and neighborhoods. We must keep in mind the route we have to do. Even before training with the cane, we must develop the spatial orientation aiming to move around alone*". When they must go to a place where they have never been before, PwD feel anxious and distressed.

This whole process of seeking information, taking the wrong way – having to go back to continue searching for the right path – and looking for someone's help, causes a waste of time and undesirable consequences. As a 31-year-old blind female observed, "*if you are late, your boss is not interested on the reasons why you arrived late*". Participants mentioned they have already waited 20, 30, 45 minutes, sometimes exposing themselves to danger while looking for altruistic people to help them, at the risk of being approached by maleficent people. Even though, PwD rely on the information given by other (sometimes, unknown) people. Even when using assistive technology available in the city, as it is the case of tactile floors, when PwD find a signal of imminent obstacle, they must find someone to explain what kind of obstacle the tactile floor is referring to. Participants expressed disappointment about losing their independence and autonomy in urban spaces. In order to mitigate this dependency, PwD use permanent urban facilities – such as hospitals, policy stations, hotels, and newsstands – as landmarks to help them move around the city.

The interaction with people without disabilities in urban spaces is remarked as a source of trouble to PwD. Because of the barriers to communicate with other people in the city, a 26-year-old deaf man said: "*sometimes I feel I am the only deaf person in the universe*". Participants reported that it is common to find public agents who are impolite, impatient, and who complain about having to assist PwD to perform some tasks. In other words, if the environment were adapted to PwD, the next barrier would be to find someone with good will, empathy and accurate information to help them. In some cases, PwD were in a dangerous situation – falling in a sewer hole, falling while crossing a busy avenue, being lost – and people that were around did not help them, or the few people that help them ended up giving incorrect information. Specifically in the case of deaf people, who are not able to perceive the intensity, direction and source of acoustic elements, they are vulnerable to situations where people do not know they are interacting with someone that cannot hear, such as, police approaches or robbery [34,35]. According to the participants, it is not an easy task to find public agents and professionals who are properly trained in accessibility and with whom PwD can interact.

On the other hand, public agents observed that assisting PwD is just one among the all activities for which they are responsible. According to these agents, it would be interesting to be supported by technology to be aware that someone needs help. They also reported that using such a tool would not overburden their work.

Finally, participants listed some privileges that they are not allowed to do, some activities they have difficulties in doing or places they have difficulties in going in urban spaces: visiting large areas, such as parks and urban forests; walking quietly on the streets; discovering where is the buildings' main entrance; taking a bus; getting off the bus in the correct bus stop; going to crowded places, such as music concerts; practicing sports; going shopping; and, going to the movies – according to a 28-year-old signal language interpreter female: even when PwD overcome a barrier, other problems arise, as is the case, for instance, of going to the movies, "*if the movie is subtitled, it will be a nightmare to interact with the ticket seller in order to buy the ticket, because he or she probably do not know how to use sign language*".

The main contributions of this activity were: (1) the basis for elaborating a broaden study – the questionnaire; (2) the strategies and technologies PwD use to navigate in urban spaces; (3) the obstacles they face in the city and the situations in which they can not act in an independent and autonomous manner; and (4) PwD's first impressions of how a Smart City initiative would be, also concerning accessibility issues. These contributions allowed us to move forward on the conceptualization of Inclusive Smart Cities, and the features that this idea should provide to a wide range of citizens.

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[34] Deaf boy tries to communicate in sign language (Libras) with a robber: https://g1.globo.com/df/distrito-federal/noticia/menino-surdo-e-mudo-tenta-se-comunicar-em-libras-com-assaltante-no-df-veja-video.ghtml

[35] Deaf teenager killed during a robbery: http://www.jornaldaparaiba.com.br/vida_urbana/adolescente-surdo-e-morto-durante-assalto-a-bar-em-pedras-de-fogo.html

5.2.4 Questionnaire

In order to reach a wider number of PwD, which would reflect in considering different contexts, cities and backgrounds, we developed an online survey in the form of a questionnaire. This research instrument mainly aimed to anonymously identify problems and barriers that PwD face when they are in public spaces, the strategies they use to solve these problems, what are their feelings concerning urban assistive technologies, and how they are willing to adopt digital technologies.

The questionnaire development was carried out in two steps. In the first step, a preliminary version was created as a pilot study. In the second step, an improved version was developed, considering the issues pointed out by the subjects in the pilot study. Five individuals took part in the pilot study and, after some adjustments, a questionnaire was published in a web service. We sent messages with the questionnaire hyperlink to mailing lists, specific discussion groups, and social media networks that had PwD as members or that was related to accessibility issues inviting participants. The average time to fill out the questionnaire was about 15 minutes.

As can be seen in Appendix B, the questionnaire has 28 questions and is divided into five parts:

1. Ethics statements: informs the respondent about the privacy and confidentiality aspects of the study;
2. Question 1 to Question 6: asks about demographic data of the respondent;
3. Question 7 to Question 11: asks about the respondent's familiarity with the Internet and mobile devices;
4. Question 12 to Question 22: asks about the respondent's experience in urban spaces;
5. Question 23 to Question 28: asks about the respondent's implicitly or explicitly perception of SC projects.

Respondents were invited to anonymously answer different kinds of questions: open, scenario-based, multi-options, and Likert Scale style. Moreover, the web-based questionnaire was provided in English, Portuguese, and French. The questionnaire was available online to respondents from January to July 2017. Respondents were invited, without financial incentives, through social networks, Special Interest Groups (SIG) in accessibility or in related subjects, and online advertisement. The participants' inclusion criteria were: (1) be a PwD, specifically, motor/mobility, visual, auditory or any combination of the previous disabilities, i.e., multiple disabilities; and (2) older than 18 years.

We obtained 186 participant responses – 91 in Portuguese, 84 in French, and 11 in English. In order to guarantee the validity of the responses, we examined and cleansed the data verifying the conformance with the inclusion criteria, resulting in the exclusion of 115 participants who did not meet one or more of these criteria. As Table 6 shows, after dropping out the excluded responses, the final dataset amounted to a sample size of 71 usable responses.

Table 6 – Responses to the online survey.

Language	Total responses	Excluded responses	Valid responses
Portuguese	91	36	55
French	84	77	7
English	11	2	9
Total	**186**	**115**	**71**

All data collected in this study were first translated into English before being submitted to the QCA method. Once the question about which disability the respondent had was open, we had to transform the collected data into a well-defined and standardized form. Therefore, we summarized the original data (terms inside brackets) into four main categories, as follows:

- Auditory (auditory, deaf);
- Motor/Mobility (physical, motor, wheel chaired, tetraplegia, paraplegia, amputation, dwarfism, Myalgic Encephalopathy, Chronic Fatigue Syndrome, monoparesthesia, spinal cord injury);
- Multiple disabilities (epilepsy and Ehlers Danlos Syndrome; Physical and auditory; Complex Regional Pain Syndrome, Intractable Chronic Migraine, Mew Daily Headache Syndrome, Postural Orthostatic Tachycardia Syndrome, Ehlers Danlos Syndrome, and hypermobility type; Peripheral Neuropathy, chronic pain, and spina bifida occulta);
- Visual (visual, total blindness, low vision, blind).

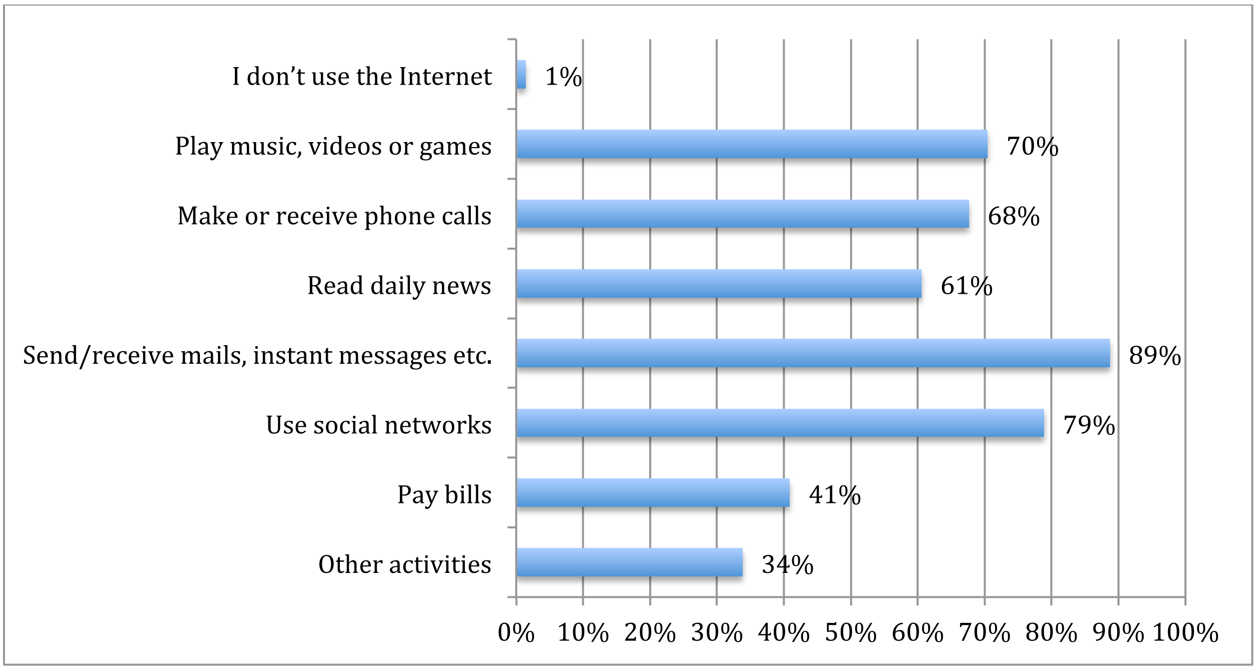
The majority of the respondents were between 18 and 44 years of age – therefore, a sample characterized by young adult and adult individuals (33.8% each). Most of them were male (56.3%), while 38.0% were female. Still concerning the variable Gender, the alternative "other" was assigned by 5.7% of the sample, referring to non-binary, genderfluid, gendervague, genderqueer, and demigirl conditions. In despite of our efforts to distribute the participants among the predefined set of disabilities in the inclusion criteria, the most predominant disabilities were Visual (45.1%), followed by Motor/Mobility (42.2%). The countries with more responses were Brazil (76.0%), followed by France and United States (9.9% each), and finally Canada, Switzerland, and Germany (1.4% each). Further descriptive information is provided in Table 7, and more details can be found in Appendix C.

Table 7 – Descriptive Information on Demographics variables.

Variables	Frequency (N=71)	Percentages
Age		
18-29	24	33.8%
30-44	24	33.8%
45-64	18	25.3%
>64	5	7.1%
Gender		
Male	40	56.3%
Female	27	38.0%
Other	4	5.7%
Disability		
Auditory	4	5.7%
Motor/Mobility	30	42.2%
Multiple disabilities	5	7.0%
Visual	32	45.1%
Country		
Brazil	54	76.0%
Canada	1	1.4%
France	7	9.9%
Switzerland	1	1.4%
Germany	1	1.4%
United States	7	9.9%

A multiple-choice question was asked about how they most often use the Internet on mobile devices – such as smartphones and tablets. Most of the respondents said that the main activity performed is sending and/or receiving e-mails, SMS and WhatsApp messages (89%), followed by using social networks (79%), playing music, videos or games (70%), making or receiving phone calls (68%), reading daily news (61%), and paying bills (41%), as may be observed in Figure 20. All these values were calculated considering the entire sample. An amount of 34% of the respondents also chose the option "other activities" and detailed them as seeking for job opportunities, health research, education, getting traffic information, web browsing, shopping, getting a cab, GPS navigation, and work related activities.

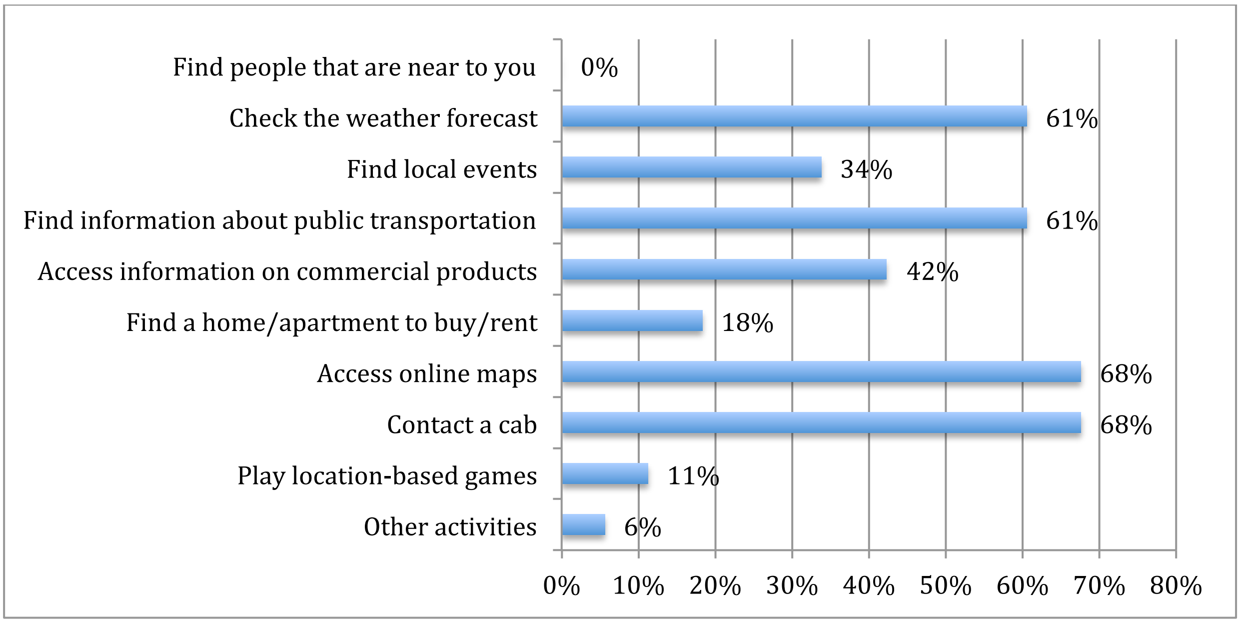
Figure 20 – Internet usage on mobile devices.



When asked about the mobile Internet usage frequency, 22.5% of the sample reported using it from one to five times a day, whereas the majority of 69% reported using it more than five times a day. The lowest indication number, 8.5% of the sample, indicated they did not have any mobile devices, but they connected to the Internet using other equipment. Specifically about the use of Internet when they are outside or in public spaces, 74.6% of the respondents confirmed that they do connect to the Internet in such situations, while 25.4% answered they do not connect to the Internet in public spaces. Invited to name the activities they usually do when they are connected to the Internet outside private places, respondents specified they: access social media and instant messaging apps, get a cab, play games, get traffic information, use GPS navigation, access mobile banking, share pictures, read daily news, watch movies, make phone and video calls, read and send e-mails, and listen to music.

Next, in a multiple-choice question, we presented to respondents a set of activates and asked them which ones they would perform outside of his/her private places – such as, home and office – based on the GPS current position. As Figure 21 depicts, accessing online maps and contacting a cab were extensively chosen by 68% of the sample, followed by checking the weather forecast and finding information about public transportation (61% each). The "other activities" option was chosen by 6% of respondents, who described the following extra activities: access search engines, connect to location-based educational software, obtain indoor information when he/she is in a shopping mall, and use Ariadna[36].

Figure 21 – Activities performed based on GPS position.



Aiming at exploring which problems PwD face in urban spaces as well as the strategies they adopt to solve these problems, we idealized a situation descripted as a scenario. Jacko (2012) argues that using scenarios creates a situation in which the user can experience what he/she would need and feel like in a realistic context. The scenario we generated was: "*You have an extremely important appointment in a neighborhood where you have never been before and you aren't familiar with the area*".

Firstly, in an open question, respondents were asked "*how would you get information about the neighborhood and how would you arrive at the meeting on time?*". 53.5% stated they would use GPS-based mapping and routing applications – namely, Google Maps, CityMapper, and Waze. Even considering only people with visual disability, 40% of the

[36] Ariadna is a mobile navigation system for visually impaired and blind people.

respondents answered they would use GPS-based solutions in order get in the meeting on time. Other alternatives cited were: call a cab; ask for help from parents and friends; search the weather forecast; access applications that provides panoramic views along the streets, such as Google Street View; call to public agencies, city hall or public transportation companies in order to discover if the route is accessible; and use instant messaging apps.

Secondly, still working with an open question, we asked "*what kind of information about the neighborhood would be useful to know before leaving your home to go to the meeting?*". The majority, 67%, informed that transport-related information would be valuable: public transportation availability and schedule; distances; routing and description of the entire route; and traffic conditions. The respondents also pointed out other types of information that they think would be valuable:

- The neighborhood accessibility level: the existence of accessible facilities – such as adapted sidewalks and crossings, tactile floors, lifts, escalators, bus stops and subway stations – and their condition of operation;
- Landmarks: ideally those that remain for a long period of time and are widely known, such as hospitals, drugstores, public agencies, gas stations, bus stops, subway stations, city monuments or statues;
- Safe and security issues: if the neighborhood is dangerous or not;
- Weather forecast; and
- How crowded and busy is the neighborhood.

According to the responses to this question, landmarks stand out as a support instrument in which people with disabilities rely on. One of the respondents, a young adult man with visual disability, stated that since "*people usually give wrong information*". Because of this fact, he has established a strategy of combining the use of a GPS-based app and landmarks to locate precisely where he wants to go.

Thirdly, we questioned them about the types of problems respondents could face on the way to the appointment's place. 54.5% indicated that transportation problems would be more likely to happen, such as: public transportation delays; traffic jams; traffic collisions; missing a bus/train or a connection; public transportation no-show; street demonstrations; and public transportation emergency or mechanical failures. Moreover, respondents informed that getting lost would also be a problem. This could happen in the case of losing the mobile network connection and the access to GPS-based apps, for instance, or in case of malfunction of these apps, which could lead the user to a complete undesirable destination or to dead-end streets. Respondents also expressed that lack of accessibility would be a significant problem in the proposed situation, once they could find: complete lack of accessibility, such as not having adapted public transport or ramps, or having lots of stairs, sidewalks under constructions or streets in maintenance; not accessible buildings; narrow and heavy doors; inaccessible traffic lights; large open areas to cross, such as parks and squares; and difficulty finding the exact entrance, for example, crossing large company areas to get to the main entrance. Other concerns evidenced by the respondents were: being robbed; depending on finding "good hearted people" to get help; and lack of public transportation seats which according to a young adult woman with multiple disabilities, "*usually results in me sitting on the subway floor, and believe me that's the last thing you ever want to do ever*". It is important to notice that some support tools can also cause problems for PwD, such as GPS-based apps. Despite providing a considerable aid to users in urban navigation, these tools have as limitation "*the inability to identify pedestrian paths of travel, for example, determining which side of the street has a sidewalk*", according to an adult respondent with visual impairment, and age between 45 and 64 years old.

The respondents were then asked to provide more details about what would help them solve the problems they might have in public spaces. Therefore, we grouped respondents' suggestions into five main categories of plausible solutions ordered here according to the number of suggestions of each category:

- <u>Technology</u>: improvements on GPS-based apps and mobile networks, especially providing alternative routes, giving information regarding sidewalks, paths, and anticipating obstacles and barriers on the route; more detailed navigation maps; audible information on buses and subways; novel navigation technologies that would work even offline;
- <u>Information resources</u>: respondents emphasized the importance of having real-time information to find a solution for their problems in public spaces. They enumerated the need for information describing what is happening on the route, such as obstacles and barriers, traffic, and if there is availability of accessible facilities. In addition, respondents highlighted that signalizing landmarks – such as bakeries, drugstores, bars/restaurants, city hall, among others – would improve their orientation and navigation in urban spaces;

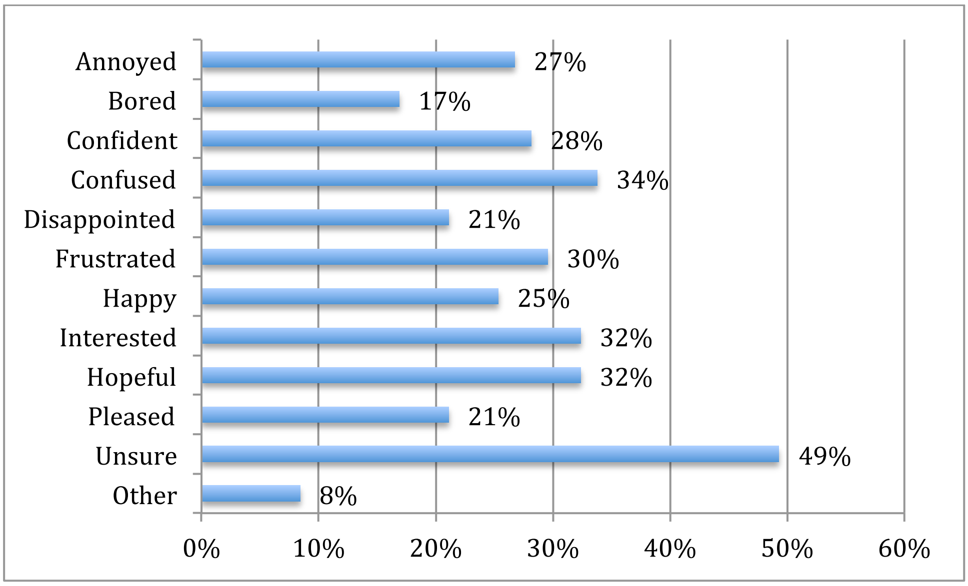
- Governmental actions: some of the respondents recognize that some actions to solve their problems should be ruled by government authorities, for example: to improve the quality of public transportation services and to adapt them according to accessibility requirements; adapt public services concerning accessibility issues; create and improve regulatory laws relating to mobility policy, accessibility facilities, private services; reinforce good urban signage to help identify the citizen's current position; and provide alert messages about unexpected disruption of services, as well as warn citizens about accessibility facilities that are malfunctioning;
- Human assistance: human aid has also been reminded as a crucial factor in helping PwD find a solution if they have any problems in the suggested scenario, especially local residents who should be able to provide accurate information about the neighborhood. However, respondents pointed out that the human relationship with PwD and that a change of attitude should be the subject of workshops, talks and lectures for ordinary citizens in order to change their, sometimes, poor behavior towards PwD. In other words, sympathy and empathy would make a difference in a problematic situation involving a disabled person in public spaces. According to an adult respondent with motor/mobility disability and age between 30 to 44 years old, in cities, "*people are always in a hurry and don't want to 'waist' their time with anybody that needs some help*". Moreover, in many situations, people give wrong information or wrong directions;
- Personal attitude: finally, respondents admitted that part of the solution to possible problems that may occur in the suggested scenario depends on their own behavior, personal disposition and ability to prepare themselves in advance. Among the answers, they said they could leave home earlier to avoid pitfalls and look for shortcuts. Exemplifying some of their personal strategies adopted, a non-binary young adult respondent said "*I would look up the information the night before on Google Maps and write it out for myself in my calendar and then, the day I had to of follow these directions, I would also use Google Maps with the GPS turned on. I'd also leave a ridiculous amount of extra time just in case*".

The next question – "*how do you usually solve unexpected problems that happen in public spaces?"* – allows us to unveil some of the strategies adopted by PwD to deal with unforeseen situations that occur in public spaces. Most of respondents, 43.2%, said they ask for help to get more information, sometimes to unknown people, and they attempt to talk to people that are close to or around them before trying to figure it out on their own. Depending on the problem, some PwD prefer looking for the responsible, demanding improvements to the public authorities or trying to get accurate orientation in prefectures, subway stations, local agencies or police stations. Counting 29.3% of the respondents, we grouped answers that we identify as unconventional/atypical strategies: "*with politeness*"; "*insisting*"; "*with common sense*"; *"I try to do the best possible*"; "*I find a way*"; "*At the time of the event, I'll see what I can do*"; "*I try to keep myself safe*"; "*I turn around, which increases the transport time*"; "*Most of the time there is no way to solve it*"; "*I throw my hands up in the air, sit down on the subway station floor or lean on a pillar, watch my pain levels increase as I become lightheaded, and I curse the public transportation company*"; "*I use my creativity*"; "*I yell at them*"; and "*Freaking out*". Furthermore, 15.5% of respondents mentioned that they keep calm and patiently wait for help and for the problem solution – a blind man aged 45-64 remarks "*I stop and wait for someone to come and ask me if I need help*", which usually does not happen fast, or simple does not happen; and he continues, "*Once, on the bus, I asked for help to a person, but this person got off the bus earlier and did not let me know that he was leaving before my destination*". Still, respondents said that they try to anticipate unexpected events – "*I always have a Plan B*" – and try to adapt themselves when such events happen – a blind women aged 45-64 said that she "*plans to arrive in advance to be able to solve unexpected problems, and take a taxi*". Finally, 12.0% of respondents mentioned that they use their phone to call a relative/friend.

The next question explored the strategies that PwD employ to discover if a place where they have arrived by the very first time provides assistive technology – such as Braille signs, accessibility ramps, elevator, etc. – and, in case of existing, how they can find those accessibility features. An amount of 61 respondents answered this open question – 28 with visual disabilities, 24 with motor disabilities, 5 with multiple disabilities, and 5 with auditory disabilities. Most of them indicated assuming a multi-strategy approach; however, 71% of the respondents signed that most of the times the prevailing strategy they adopt is endeavoring to find someone to ask for help – corresponding to 100% of respondents with auditory disabilities, 89% with visual disabilities, 54% with motor disabilities, and 40% with multiple disabilities. Ordinary employees or the one in charge of the place, local agencies' servants, receptionists, volunteers, passersby, and unknown people are some of the sources of information for PwD in public spaces. Sometimes, relying on someone else is the only option PwD have – as a blind man aged 45 to 64 states: "*I need someone to notify me of the existence of Braille at a bus stop. It does not matter if there is Braille signs at the bus stop if I do not know where it is located; and a bus stop may have a large surface to touch when I am trying to find Braille signs by myself*". Even though trying to find someone to get some information about available assistive technology is a common alternative, it can conflict with the sense of independence, which is so precious to PwD. For instance, a wheelchaired female aged 45 to 64 outlined that first, she prefers to observe around and ask for help the least possible. 16% of the total amount of respondents chose asking in advance, searching on the Internet, call to the place or even use maps – specially sightseeing people. Finally, 13% of the total amount of respondents revealed that they pay attention to signs indicating the existence of assistive technology around of them.

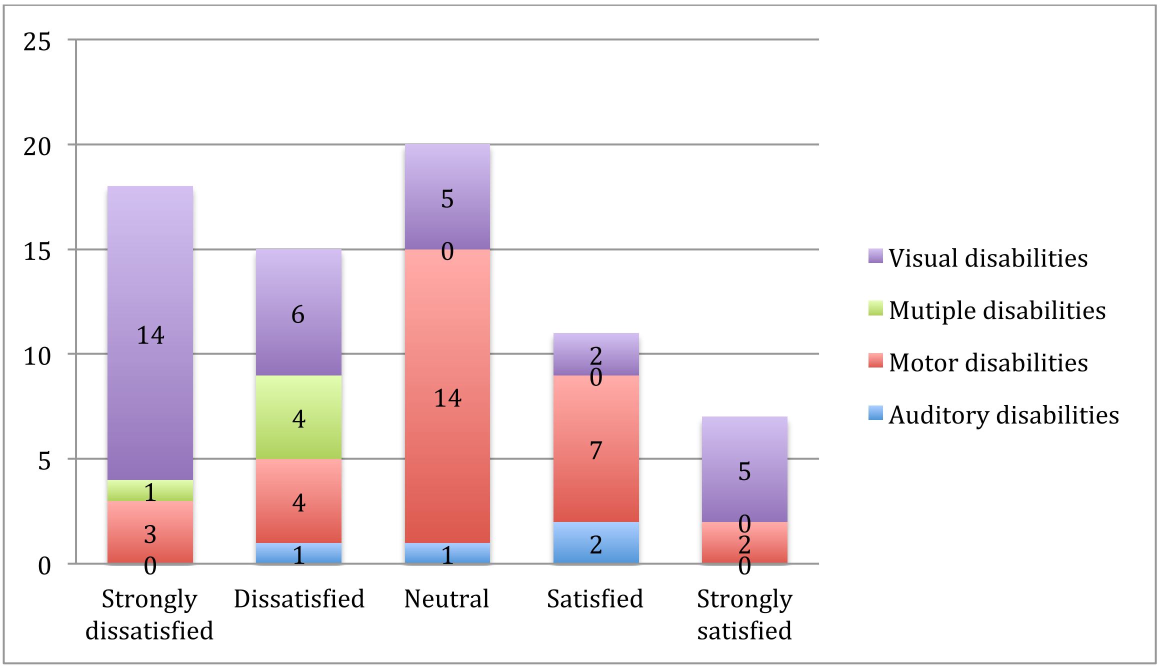
Next, we conceived a question to explore the emotional reactions of respondents when they are in public spaces with the purpose of evaluating their experience when they are moving around the city. We selected the Emotion Words Prompt List (EWPL) tool to bring out the good and bad feelings the respondents had concerning public spaces. The EWPL is a general-purpose instrument to measure the overall user experience of products and services that consists of the following 11 emotional words (Petrie & Precious, 2010): annoyed, bored, confident, confused, disappointed, frustrated, happy, interested, hopeful, pleased, and unsure. Respondents were allowed to choose all the answers that would apply. In order to map eventual new feelings that are specific to the urban experience, we added the "other" alternative and asked the respondents that checked this alternative to describe it. As Figure 22 depicts, the EWPL words can be ranked according to the most frequent respondents' choices as follow: unsure (49%); confused (34%); interested and hopeful are in the same position (32%); frustrated (30%); confident (28%); annoyed (27%); happy (25%); pleased (21%); bored (17%). In addition, 8% of respondents checked the "other" alternative, where they included the word "*safe*". Respondents also took advantage of the opportunity of adding comments to explain their feelings: "*Sometimes I feel frustrated and angry about people's careless when parking on sidewalks, placing things in the middle of the sidewalks and always saying 'only for a minute', and people not sticking to regulations about public spaces*"; "*It is difficult to answer this via a checklist. The most complicated barriers I encounter usually* *involve meddlesome sighted people who do not like to take 'no' for an answer*". Moreover, respondents outlined that the city corresponds to a very diverse context and that the urban experience is composed of a mixture of feelings, which may vary according to the day or a specific situation, as if it were a free or paying entrance place – for instance: "*Depending on the day, the right moment, and the place where I am, I would check all the alternatives*"; "*All depends on the situation. People often do not understand our condition and they make fun of it, but there are smart and respectable people*".

Figure 22 – Emotional reactions when respondents are in public spaces.



The focus of the next question was the general assessment that respondents gave to assistive technologies provided in public areas by their cities. We designed a 5-point Likert-type question, from 1 (strongly dissatisfied) to 5 (strongly satisfied). As can be seen in Figure 23, most answers remark the disapproval of assistive technology in urban spaces, 33 respondents – "strongly dissatisfied" (18), and "dissatisfied" (15); while 18 respondents approve the accessibility facilities of their cities – "satisfied" (11), and "strongly satisfied" (7). Furthermore, 20 respondents have chosen the "neutral" alternative.

Figure 23 – Overall evaluation of assistive technology provided by cities in public spaces.



In order to better explore and understand the distribution of values found with the previous question, we proposed, then, an open question asking respondents to justify the reasons of their overall evaluation of assistive technology in public spaces. This question has proved to be particularly important specially to understand the good and bad remarks, as well as the motivation of such high score of respondents that have chosen the neutral alternative. We had 52 answers to this question. Respondents that graded themselves with "strongly dissatisfied" and "dissatisfied" with the urban assistive facilities in their cities listed several problems related to accessibility: pothole on the sidewalks; streets in an extremely bad condition; restaurants, local agencies, churches, and stores with several architectural barriers; spotty accesses; tree roots on the sidewalks; lack of indoor orientation in shopping malls and supermarkets; "*elevators are often out of order and/or filled with urine and there aren't elevators at most stations*"; among others. Also, several respondents reported that accessibility is not a priority to the local authorities of their cities ("*lack of commitment of local authorities and public agents*"), which causes a complete absence of basic and simple assistive technologies. And even when these AT are provided, they are not well executed ("*improper installation of curb, lack of accessible traffic signals for deaf individuals, poorly designed intersections, lack of compliance with snow cleaning on the streets…*"; "*even tactile floors may have obstacles, such as payphones and poles*" "*depending on where the tactile floor is installed, it is more harmful than helpful*". Moreover, respondents reported the absence of accessibility-related skills, the lack of empathy and positive attitude of public agents and of the population in general ("*unqualified public agents concerning accessibility issues*"); lack of informational campaigns and advertisements; lack of awareness towards PwD; lack of good manners and politeness concerning PwD. Some of the respondents that have chosen the "neutral" alternative justified their choice because they are not users of such urban assistive features. Other respondents elucidated that some improvements have been done in the urban accessibility field, but they also underline that there is still a lot of work to do ("*better than it was, needs a lot more work*"; "(…) *employing digital technologies*"). Nevertheless, they stood up for the expansion of good accessibility initiatives to a broaden urban area ("*I chose 'neutral' because I use the subway a lot and it is very accessible, but the city as a whole has few accessible technologies; it could have more, because nowadays there are only accessible things in very specific places*"). On the other hand, respondents that signalized themselves as "satisfied" and "strongly satisfied" (mostly people with motor disabilities and people with auditory disabilities), argued that urban AT are good where they frequently go and that these AT do not affect them negatively. They recognize that there are several positive improvements and instructions to PwD in urban spaces, but they also emphasize that it could be better.

The next aspect we have explored with the questionnaire was emergency or embarrassing situations PwD had experienced in public spaces – such as getting lost or needing to go to the restroom – and how these citizens dealt with such situations. A total of 55 respondents answered this question – 42 for "Yes", and 13 for "No". Getting lost and needing to go to the restroom is quite common, as respondents confirmed, and most of the time they seek information with another person, sometimes an unknown person ("*I try to wait for someone to come and then I ask for help*"); they also use mobile technology – such as GPS-based apps and ridesharing apps – and ask for help in distinct urban landmarks, such as gas stations. Several obstacles and strategies were mentioned by respondents when they need to go to the restroom: "*most downtown restaurants in the city where I live do not have adequate toilets*"; "*I needed a bathroom and they were all behind pay walls*"; "*I usually go to the bathroom, but I always ask someone to help me get to the bathroom*"; "*I often need to go to the bathroom in public spaces and often find a Starbucks and use the bathroom*"; "*I just duck into whatever hotel is nearby*"; "*I had to go to the bathroom and there was no toilet paper*"; "*I have ulcerative colitis and once had to find a relatively unoccupied area to poop in a box I could throw away later because no bathroom was currently available*"; "*Once I was at the* *mall and I felt like urinating, but the restroom was very far away. So, I decided to go to my car and I urinated in a container that I use for emergencies, but after I did it I did not go back to the mall and I left. It is sad because if there were no locomotion problems there, I would have stayed longer*". In addition, as already mentioned in previous questions, PwD declared that they try to anticipate possible difficulties before getting out of their homes: "*Regarding restrooms, I do my best to avoid this by taking care of business prior to departure*".

PwD also reported that they are exposed to dangerous situations in public spaces, such as falling into a hole in a busy street; difficulty opening revolving doors, heavy doors and doors that only open with the use of an access badge; tripping or slipping across a bridge or sidewalk; arrive at a bus stop and have no one to give information; fall of the wheelchair; "*Stepping in the mud, almost being run over, wondering what the bus is and people do not answer you, hitting an iron in the middle of the sidewalk (...)*"; "*I try to avoid big concerts or super crowded places (...)*"; "*Once I lost my cane, because a car passed over it and passers-by kicked it off. Another time, I was at the bus stop and asked someone to help me, but that person left and forgot me. That's why my strategy now is to ask for help for several people*"; "*It is distressing for me when there is a problem on the subway or the bus and they warn people by audio that everyone should leave, but I cannot hear it.*"; "*The lifts of the buses are terrible, unstable and who uses them do not feel safe.*"; and, "*I always bump into glass doors*". Once again, personal attitude and lack of empathy were listed as embarrassing situations that PwD face in urban spaces: "*Shopping mall assistants are not prepared to assist deaf or hearing impaired people; they are not aware that not everyone has a perfect hearing. I have rarely found understanding, comprehensive, and patient attendants. Sometimes, the only solution is to give up. And I know most of the times it is not their fault, because they were not prepared to deal with this kind of situation.*".

We asked the participants to bring up situations that happen in urban spaces that are impossible to them to do by themselves, in which they mandatorily need someone's assistance. A number of 45 respondents of the initial sample answered this question. We related these answers to the following three groups of situations:

- Transportation: taking a bus or a subway line is the most cited situation among the given answers, as well as other related problems derived from them (finding bus stops and subway stations; "*There are some train platforms that do not have elevators yet and take a considerable effort on my part to get to*"; "*Shifting from a subway to a train is also something that is wise to do* *with the help of another person so you do not get lost on the platforms*"; "*getting in and off a bus or a subway/train when it is crowded*"; "*getting off the bus stop*"; and "*waiting for buses is the toughest situation*");

- Traffic and walking: crossing streets (specially crowded ways and intense-traffic avenues); walking on streets and sidewalks; "*Get home after a night out"; "Going to the outer boroughs";* "*walking in the crowd*"; "*sidewalks too high or too narrow"*; "*finding a specific location or a building by its given number in a street*"; "to go *up and down the stairs*"; and "*There are areas, including the transit system administrative offices, which lack access via public transit. They are located out on a highway, making walking risky*";
- Commercial, social and leisure activities: some respondents have stated that it is impossible for them to go to malls and supermarkets, as well as shopping ("*Getting stuff off high shelves in stores. Otherwise, if I can't use it I won't spend my money there, I go someplace else*"), and using ATM machines. Others mentioned that it is impossible to go to music concerts and even communicate with public agents through armored windows in public departments or even in lottery stores and subway stations. Respondents also remarked they can not enjoy leisure activities by themselves, such as visiting city parks, going to the movies, riding a bike, going to the beach ("*I suffer a lot because I don't like to be observed*"), practicing sports, going to the mountains, cooking, ordering some pizza, visiting historical places, museums, restaurants, bars, and Carnival parties.

We started the fifth and final part of the questionnaire investigating the meaning of "quality of life" for the respondents in the context of urban spaces. As discussed in the Section 3.5, this is usually found in SC definitions and it is a Marketing appealing term connected to the benefits brought by SC technologies. 59 respondents answered this question. The first aspect remarked among the answers, which is justified by the target of our study, was that quality of life in a city is related to provide and to ensure urban assistive technology and accessibility to every citizen ("*Universal design for everyone, not only for PwD*"; "*High-quality urban facilities, essential public services near your home, accessibility and the right to come and go, and well-organized public spaces*"). Moreover, respondents associated quality of life with social equality in terms of full participation and engagement, as well as with performing ordinary activities ("*A priori, to have the same opportunities and possibilities as other individuals have. Not only to have access to study, care, work, transportation, but also go shopping, visiting friends and family, finding people to talk to (...)*"; "*Ability to safely perform activities of daily living and engage in community activities without expending inordinate energy*"; "*The ability to engage in day-to-day activities within the community in the same way as my sighted peers*"; "*Being able to manage life alone, e.g. going shopping, taking advantage of other services, solving public administration issues, going to bars and restaurants, participating in cultural events - concerts, theatre, cinema, etc.*"). Yet, respondents highlighted that their quality of life is being assisted in case of trouble or difficult situations, and also if they need help; however, the greatest achievement to them would be "*to make everything I want and I need without anyone's help*", in an independent and autonomous way ("*Quality of life is an exercise of independency and autonomy, which is the effective appropriation of the right to come and go*"). Another dimension of quality of life indicated by the respondents was the ability to easily organize *and plan their daily activities without wasting time ("Less stress and less wasted time in locomotion";"The ability to spend my day with ease").*

Other aspects emerged from the answers emphasizing traditional public services:

- <u>Urban infrastructure:</u> a city having nice sidewalks; well paved streets; a well signalized city; having visual stop announcers on the bus; a safe neighborhood, having grocery stores within a 5-10-minute walk; having restaurants within walking distance; with curbs; adapted restrooms; adapted suit dressers in stores; with lifters working at bus terminals; with elevators in buses functioning properly; with a high-quality transportation network;
- <u>Health:</u> high quality health facilities;
- <u>Education:</u> high quality educational facilities;
- <u>Environment and sustainability:</u> a clean city, with clean air, less pollution and with green areas;
- <u>Safe and security:</u> moving around the city safely; and,
- <u>Leisure activities</u>.

Two different elements were pointed out as significant to a city to provide quality of life to its inhabitants. On the one hand, human attitudes have emerged as an element that can make a difference in relation to the good urban experience: well-educated and polite people to assist and deal with PwD, and people able to respect PwD as human beings. On the other hand, a respondent stated that having money is a determining factor in having a good quality of life in cities, because it is the key for them to have access to places that invest and care about accessibility.

Thus, we asked a question to examine whether the respondents were aware of the progress that other cities have made concerning the use of urban assistive technology and/or what innovations in this field that they would like to have in their own city. A total of 55 respondents answered the question – 59.2% said "No", while 40.8% said "Yes". Among the answers, some made reference to AT that are already common in big cities: audible traffic lights, i.e. traffic lights with beeping audible signals; tactile floor tiles; audible pedestrian signals; and bus lifts and ramps ("*without the assistance of bus drivers and bus ticket collectors*"). Other answers were more related to up-to-date technologies:

- Personal indoor and outdoor electronic navigation tools ("*which informs where stores and restrooms are when I'm in a shopping mall or at an airport, for example*"; "*in a nearby city, they installed an indoor navigation system inside a building (public administration), they developed a special navigation system for the blind with a 4 cm accuracy, thus one can move around completely alone in the whole city"*);
- Communication and interaction tools: respondents observed that innovative communication and interaction tools would improve their perception of the public and commercial services provided in their cities ("*Cabs and banks in London, UK, all have hearing loops. Stops announced visually on every bus in London & on every bus, S-bahn, U-bahn, and tram in Berlin. In DC not all the buses have working LED announcers - or working talking announcers. I also rely on listening to the stop announcers to know when to get off the bus, especially at night, and the blind rely on that a lot more than I do"; and "One good example would be technology at bus stops that provides arrival of buses and trains in real time").*

Moreover, a resident remarked that social achievements could also be understood as an innovation and should be imitated as a good example by other cities: "*I've heard that in big cities like São Paulo and Rio de Janeiro, big companies hire people with disabilities and they* *have labor rights and good wages too, very different from where I live, because normally the policy is to earn only a minimum wage".*

Thus, we encouraged respondents to reason on the ways their cities could be more efficient helping them and other PwD to perform their daily activities in urban areas. A total of 54 respondents answered these questions. Firstly, 54% of these 54 respondents pointed out the need to have adapted environments in the cities and demanded improvements in accessibility related to urban physical infrastructures and public services, such as: proper sidewalks; lifts; curbs and ramps; traffic lights with audible beeps; tactile floor tiles; audiovisual information on buses (announcing the next stops) and at bus stops (announcing the buses at that bus stop and at what time the next bus will arrive); smarter traffic light systems that allow PwD to cross the streets safely; and accessibility to public transport. Secondly, 20.4% of the 54 respondents declared that investing in the human aspect of the city would help them cope with their daily activities in urban areas: better human relationships; more empathy between people; the development of social interactions between people with and without disabilities; educational campaigns promoting respect for PwD and their needs; improving the awareness and communication of the inhabitants; inclusion of PwD in the labor force; making public agents more engaged with the accessibility cause; encouraging volunteers to assist PwD in their neighborhood; creating awareness campaigns on the rights of PwD, having more people ready to help PwD; and humanizing the city. Thirdly, 16.6% of the respondents suggested that local authorities' commitment and the development of public policies and regulations related to accessibility issues would help them to perform their daily activities in cities: cooperation between local agencies, associations and PwD groups; "*Better mapping and identification of accessibility";* "*Considering laws and regulations, local authorities should consult PwD when constructing new areas*"; "*Local authorities should do what is required by the existing laws*"; "*This would be welcoming us into decision making. Right now, the city often takes an action without investing the impact upon disabled people. The outcome has been dangerous modifications to intersections and other similar problems*"; "*investing in an accessibility plan for all*"; "*Putting in wheelchairs during a half-day long the mayor, the elected officials, the technical service board, living as I live… I'm sure that everything will be fine later"*; "*The local city hall could finance the adaptation of access ramps for cabs and building*". Finally, 7% said they did not know how to answer the question.

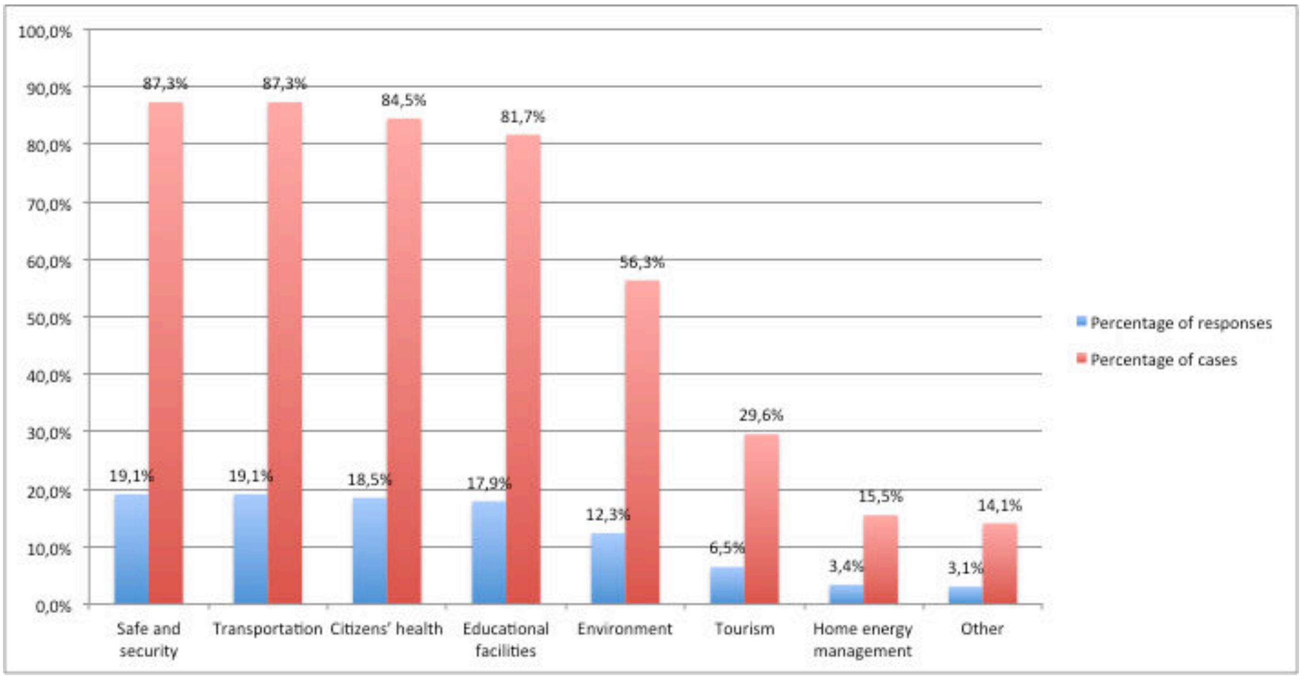
In the last question of the survey, we examined how PwD evaluate the goals and benefits promised by SC initiatives, which were established by Khatoun and Zeadally (2016), in order of importance. We asked respondents to choose from a list of goals all the alternatives they considered to be priorities for local governments. Table 8 summarizes the answers to this question, and they are ranked according to the order Khatoun and Zeadally (2016) present the goals and benefits of SC initiatives: the second column indicates the number of unique responses for each benefit; the third column indicates the percentage of responses, i.e., the percentage of each response of the total responses (324) of the dataset; and, the forth column indicates the percentage of each response considering the number of respondents who answered this question (71).

Table 8 – Respondents evaluation of the goals and benefits promised by SC initiatives.

	Responses		
SC goals and benefits	**N**	**Percent**	**Percent of cases**
Safe and security	62	19,1%	87,3%
Environment	40	12,3%	56,3%
Transportation	62	18,5%	87,3%
Home energy management	11	3,4%	15,5%
Educational facilities	58	17,9%	81,7%
Tourism	21	6,5%	29,6%
Citizens' health	60	19,1%	84,5%
Other	10	3,2%	14,1%
Total	324	100%	456,30%

As Figure 24 depicts, respondents ranked Safe and security, Transportation, Citizens' health, and Educational facilities as the most important benefits of SC initiatives in their opinion. The environmental cause appears as the next item in the ranking, while Tourism, Home energy management, and Other are ranked in minor positions.

Figure 24 – SC benefits ranking according to respondents.



Thus, we asked respondents who chose the "Other" alternative to explain their choice. A total of 30 respondents answered this question. The most representative number of suggestions, 30%, considers that "Accessibility" and compliance with accessibility laws and regulations – such as ADA, IDEA, and Section 504 – should also be listed among the goals and benefits of SC initiatives. In addition, 23.5% of respondents cited "Urban mobility", supposedly different from Transportation, which was listed among the goals and benefits of SC initiatives, once urban mobility usually includes accessibility concerns. "Leisure, sports, culture, and social life" was reminded by 18% of the respondents. Another 18% observed that SC initiatives would also influence and maintain a humanistic approach among their goals: respect for minorities; combat racism, sexism, homophobia, etc.; and support parents and children with disabilities to deal with their needs. Finally, 10.5% of respondents said they would include "Job" in the list of goals and benefits of SC initiatives.

The quantity and diversity of respondents to the questionnaire allowed to: (1) broaden our understand on how PwD experience the cities through the problems and barriers they face, and the strategies they use; (2) understand how PwD use technologies in general and when they are in the context of urban activities; and (3) PwD's concerns on Smart Cities' priorities. These achievements enriched our definition of Inclusive Smart Cities, and indicated some indications, or design principles, to be considered when conceiving ISC solutions.

5.2.5 Focus group

After analyzing the data collected with the questionnaire, some questions remained open. We conducted two semi-structure focus group discussions with PwD in order to clarify these questions, propose other urban sceneries to PwD, and confirm the results of the questionnaire experiment. Six blind people composed the first group, while four deaf people composed the second group. The participants were between 23 and 45 years old. The meetings took place in Barueri (Brazil) and Paris (France). Participants were primarily recruited by an indication of the Secretariat of the Rights of the PwD of the Barueri municipality, as well as through the members of the Accessibility Work Group – a group of researchers, students, entrepreneurs, and local authorities concerned with and/or engaged in the accessibility cause – at Université Paris-Saclay. The audio recordings of the focus group sessions were transcribed and submitted to the QCA procedure.

Each focus group session lasted from 60 to 90 minutes. During the focus groups, participants were invited to discuss their problems in urban areas, their views and use of information and communication technologies, about their impressions of urban accessibility.

With the focus groups, we had the opportunity to examine more deeply some of the problems PwD experience in urban spaces. The lack of accessibility and adaptations in the city is not an isolated problem. A 31-years-old deaf man remembered that as a child he had a "*teacher who forced deaf students to repeat the year, claiming that they were not able to learn. Obviously that problem was not the students themselves, but the teacher who was not able to communicate with his pupils*". Even demonstrating frustration and indignation about the problems that they commonly have in urban spaces, some participants seemed open to learning and having a positive attitude. A 26-years-old blind man stated, "*As far as getting lost, yes, I see this as a part of knowing an area, rather than a frightening event*".

In addition, participants discussed how they can compensate for the human senses or abilities they do not have. A 30-year-old deaf female said, "*Deaf people are extremely visual, what make us try to capture with our eyes everything that is happening around us*". Events in urban spaces happen all together and at the same time, and they end up disputing PwD's focus and attention. A 34-year-old deaf man stated, "*In urban spaces, deaf people need to pay attention and visually estimate the speed and distance of the cars that are approaching*". Moreover, a 29-year-old blind female stated, "*It is horrible to have to decipher the grooves of the tactile floor while there are several pedestrians coming in all directions*".

Many participants expressed critical reflections regarding their participation in the policy-making process and the importance of giving their opinion to support local authorities in making decisions on accessibility issues and improvements, as well as participating in the adoption of assistive technology in urban spaces. For example, a 45-year-old blind man stated, "*We recognize that there are many improvements made in urban accessibility, but many projects remain only on paper. Local authorities comply only with the minimum stipulated in the laws and regulations, and they do not go beyond it. For instance, some buses that are adapted with lifts for boarding wheelchairs have very tight seats available to PwD. They think that just because we have a 'free pass' and do not pay for transportation tickets we do not deserve comfort*". According to the participants, most of the time urban planners, engineers, and authorities do not worry about accessibility, for example, when accessibility is not considered when choosing urban structure, as it is the case of revolving doors and glass walls, which hamper PwD to access some buildings.

The main contributions of this activity were: (1) to clarify some open questions and confirm the results of the previous data collecting activities; and (2) some design principles related to the impact of adding new assistive technologies to an individual who most often already uses some other assistive technology.

5.3 Analysis

Our study demonstrates PwD's dissatisfaction concerning the conditions offered to them to move around the cities and to use urban facilities – such as transportation, public services, leisure, among others. We observed that PwD evaluate their urban experiences based on the independency and autonomy level they have in urban spaces. Analyzing the results of the experiments we have conducted, we list the elements that can influence the urban experience of PwD.

First, local authorities play an essential role in recognizing PwD's demands and considering these requests as important as other citizen's requests. In the context of a city, several improvements related to urban accessibility depend on the creation of laws and regulations, which are activities run by city governments. PwD want to be heard and they want to participate in the urban accessibility policy-making process. Local authorities should develop means to engage PwD in the political process, which would make them proactive citizens. After all, as Lefebvre advocated in 1974, the right to the city refers not only to the use of urban services and to take advantage of the benefits that the city is able to provide, but also to the right to participate in making the urban space better, to be productive in such space, and to build your own identity and feeling of belonging. For society as a whole, this assertion is not a novelty; however, for PwD this scenario is far from being a reality.

In addition, we connected a list of problems that PwD face in urban spaces to the lack of properly adapted information, considering everyone's abilities. In fact, as noticed in Chapter 2, cities mainly use visual and auditory modalities to inform, signalize, and warn citizens. According to the participants of our study, the lack of adequate access to such information causes in PwD: dependence on another person's help, anxiety, frustration, waste of time, and it can expose them to dangerous situation. To shorten the impacts of the lack of adapted information, PwD must develop particular strategies, such as improving their memory abilities, and building spatial maps. On the contrary, according to Lange and Waal (2013), who investigated the benefits of locative media, the existence of locative adapted information can help PwD to perform their daily urban activities more efficiently. PwD do not benefit from the guidance and signaling systems that cities provide to their inhabitants, aiming to make urban life more harmonious and productive. If the presence of such orientation systems helps citizens to perform their activities more efficiently, their absence or its inaccessibility prevent PwD from doing simple and ordinary things, such as going to parks, taking a bus, and going shopping. Our study outlines that the Universal Design principles, already indicated for physical components of urban planning projects (Burton & Mitchell, 2006; Gray, Zimmerman, & Rimmer, 2012), should also be applied to information and digital services available to citizens in urban spaces, which means that such resources should be delivered in an understandable format and according to the greatest number of abilities that citizens may have.

Moreover, PwD mentioned that existing digital technologies and services conceived for urban spaces should be adapted to users with special needs. This specific aspect of the results confirms what Field et al. (2007) call *mainstreaming disabilities*, which shows the need to disseminate Universal Design principles to any service or technological solution for general use, and not just for the use of people with disabilities, which would break the traditional barriers that isolates PwD as a "special" group of users in schools, sport clubs, transports, among others. As demonstrated in our study, PwD are regular users of digital technologies and most of them access the Internet and mobile applications, regardless of their special needs. Such information indicates that PwD would adopt most of the digital services proposed by SC initiatives, if such services were adapted for users with special needs. Our study may add new concepts to previous research by extending the need to integrate existing disabilities to SC solutions, including GPS-like systems, mapping applications, and technology solutions that would facilitate navigation in urban spaces.

Next, the interaction with other human beings in urban spaces is the reason for conflicting feelings in PwD. PwD understand that public agents, such as police officers and subway attendants, would be ready to help citizens with special needs, and they often help them. However, other times this help may seem like a punishment, once it takes a long time to arrive or is accompanied by complaints and bad words from public agents. The attitudes of citizens without disabilities towards PwD are no different compared to public agents. In our study, we observed that in urban spaces, in most occasions, people did not care if someone with disability needs help or not, even in dangerous situations. Comparing our findings with those of Bigby and Wiesel (2015), who studied negative community attitudes toward people with intellectual disabilities, and those of Bredewold et al. (2016), one of the reasons for such distancing is that staff and regular citizens are afraid of over-commitment. People understand that PwD do not know when it is time to move on, which according to Bredewold et al. (2016), suggests that interactions with other people in urban spaces are similar to negotiations, where PwD must follow some coexistence rules and demonstrate patience in order to be successful. In our study, we have broadened the range of disability categories, but the community's lack of attitudes towards PwD remains significant and may justify the importance that PwD give to the sense of independency and autonomy, especially in urban areas. Furthermore, as Fincher and Iveson (2008) argue, contacts between different groups of citizens in a modern urban environment can lead to moments of sociability, where people acknowledge each other's existence and feel recognized.

This combination of human interaction, PwD, and the community naturally lead us to the Human-Computer Interaction field, which has proposed theories and developed studies related to some of the challenges encountered in contemporary urban spaces, such as engaging citizens in community issues and motivating inclusion. One of these studies is known as Citizen Science, developed by Preece (2016), who proposed design principles and tools to engage citizens in collecting and sharing data, aiming to "amplify society's well-being globally as well as locally", specially in the sustainability cause. Citizen Science proposes a paradigm that shifts the individual perspective to the community perspective. However, Preece's work is concerned to the environmental sustainability, while our study is concerned with social sustainability, as defined by Vallance et al. (2011) as the preservation and maintenance of human social interactions in relation to the principles of democracy and equity. We believe that the combination of Preece's Citizen Science with social sustainability can greatly contribute to the involvement of PwD in their community, and it can engage citizens in discussions and decisions that may interest them and that are related to their rights and concerns, as well as improve the interaction between PwD and other people in urban spaces.

Finally, hindering PwD access to SC solutions motivates the digital divide, at least when it comes to digital solutions that have already positively changed the lives of common citizens. Digital divide induces social divide. As Langdon et al. (2014) argue, access to urban digital assistive technologies is especially critical for PwD who already face considerable obstacles regarding social and economic participation. Our findings in this research reinforce that PwD are not content to continue being banned to the periphery of society, and it points out that technology can play an important role in putting PwD as beneficiaries of recent urban changes.

5.4 Chapter summary

In this chapter, we presented and analyzed the use of technologies, interaction habits, stories, and problems that PwD have when they are in urban spaces. The multi-instrument approach has enabled us to produce a broader picture of these issues, covering not only the PwD's perspective, but also other stakeholders engaged in the accessibility domain. Moreover, we showed that the different perspectives of the participants of our study converge to the following points: the lack of consideration concerning PwD's demands and rights related to public spaces, and the need for independence and autonomy to perform some tasks in urban spaces.

The testimonials presented in this chapter encourage the development of technological solutions that are more oriented to society and less oriented towards technology and entrepreneurship. In the case of SC initiatives, for instance, instead of focusing primarily on visionary scenarios, practitioners and researchers should focus on real problems of real citizens, including PwD, which are the core of our proposal, and which we will discuss in the next chapter.

6

Inclusive Smart Cities: theory and tools

As discussed in Chapter 4, over the last decades PwD have achieved the recognition of their rights, which allowed them, as any other citizen, to act actively in different sectors of contemporary societies, such as education, workforce, leisure, lifestyle, commerce, politics, among others. While improvements have been made to equip the city with physical assistive technology, PwD often have to face unfriendly and unfavorable urban spaces to seize these rights, as verified in Chapter 2.

Alternatively, as examined in Chapter 3, technology is at the center of major changes, especially in how people experience cities, how local authorities are providing citizens with location-based services and information, how inhabitants interact with each other, and how they interact with urban appliances. SC solutions promise to employ outstanding technological concepts to improve citizens' quality of life and this has already been achieved, as in the case of the invaluable use of digital maps to navigate large cities.

However, even considering the utopian scenario where all the problems that SC initiatives pledge to address are solved – pollution, safety, transportation, health care, public safety, traffic control, air pollution, emergency management, among others – most of the problems associated to PwD, and pointed out in Chapter 2, would have no reliable progress. As Chapter 5 presents, PwD still rely on the help of others to obtain information, which most of the time is already available in public spaces, but is not adapted according to the needs and abilities of every citizen. PWD refuse to accept the precarious situation of accessibility in the cities where they live. However, despite all the difficulties, they are open to learning and employing technologies to help them deal with urban problems and remain persistent using a set of strategies to overcome the obstacles that urban spaces impose on them.

In this chapter, we address the second step of our approach: *proposing a set of theoretical and technological tools to support public agents, entrepreneurs, developers and designers, as well as researchers to conceive and implement digital accessible urban solutions.*

Based on a meta-analysis of the experiments' results reported in Chapter 5 and on the literature review (Chapters 3 and 4), in the next sections, we describe the theoretical and technological foundations of our proposal: the Inclusive Smart City (ISC). The theoretical aspects of the ISC are: definition, requirements, design principles, implementation methodology, and business model; while the technological aspects are: conceptual model and architecture.

6.1 Definition

Inclusive Intelligent City is a set of pervasive and digital urban assistive technologies, suggested and/or adopted by government authorities and civil society to assist PwD in the cities, allowing those citizens to move around independently and perform their daily activities autonomously, resulting in a better user experience in urban spaces. ISC solutions use technology to provide PwD with (1) supplementary forms of interacting with cities, as well as (2) additional alternatives to support PwD to perform their activities in urban spaces efficiently. ISC is an integrated effort to counterbalance environmental deficiencies in communication and interaction with PwD.

Primarily, ISC initiatives seek to strengthen the social aspects of Smart Cities, as these initiatives are capable of enabling the inclusion of a wider range of citizens as beneficiaries of innovative urban technologies and services. As with other SC branches, which reformulate the initial SC vision while enclosing specific aspects of the contemporary society (as it is the case of Resilient Smart Cities, and Green Smart Cities discussed in Section 3.6), ISC updates the traditional SC idea, including accessibility issues and PwD's needs as part of the SC agenda.

Examining the results of our study, which are presented in Chapter 5, we interpret and summarize the following characteristics that cities would provide in order to improve PwD's experience in urban space:

- Adapt information and digital services available in urban spaces, making them suitable to different formats;
- Adjust urban technologies and mobility solutions in accordance with different people's abilities;
- Retrofit traditional assistive technologies with new features;
- Support the navigation/exploration of the urban landscape;
- Identify and describe objects and locations;
- Help PwD find urban facilities and appliances;
- Anticipate unexpected events and/or dangerous situations;
- Make it easier to find people who are willing to help;
- Provide efficient communication channels to allow the interaction between PwD and local authorities/public agents.

PwD are becoming protagonists of their own history in several fields. The education, work, and leisure sectors, for example, having undertaken efforts and developed technologies to ensure that PwD have the benefit of performing their tasks by themselves. This demand also concerns the urban space. As a contribution, the ISC vision allows to add some functionalities in the initial SC concept, which can increase the efficiency of the urban technology to improve the quality of life of a greater number of citizens. As Figure 25 portrays, the accessibility layer provided by ISC's vision is the interface between a diverse group of citizens and SC services, which have increasingly been described as absolutely necessary tools to live and to have a productive interaction in contemporary urban environments.

Figure 25 – Inclusive Smart City vision.

Consistent with SC's foundations of employing technology to improve inhabitants' quality of life, ISC associates the SC enabling technologies – namely, Ubiquitous Computing, Internet of Things, and Cloud Computing – with the goal of providing digital assistive technologies for an entire city to interact with different urban objects in a distributed technological infrastructure. In this context, ISC means equipping the city to offer new alternatives and innovative solutions that could improve PwD's experience in urban spaces. Regarding the improvement of accessibility aspects in urban spaces, IoT can play a strategic role, offering new solutions to problems that PwD affirm they have in urban spaces. These smart things can act as reference points by providing navigation and guidance information. IoT components could help PwD to participate in the urban dynamics, making these citizens not only feel part of the urban scene, but also feel that the city belongs to them – that they have the right to the city, in Lefebvre's words, as discussed in Section 5.3. A practical example of this is that smart things are able to identify urban objects, enabling these objects to interact with devices used by users with disabilities, delivering locative, appropriate, and adapted information to PwD. The network of smart things available in contemporary cities can provide PwD with supplementary aid in urban spaces. This aspect of the ISC confirms

Latour's vision of contemporary societies, for whom we live in a connected society, which is formed by active human and non-human, as previously discussed in Section 3.2.1. ISC vision emphasizes that these relationships are nonhierarchical, since both humans and non-humans are able to monitor what is happening around them, access communication networks to seek information that is not available locally, and process their own demands, including human beings' and other objects' demands. For example, from the ISC perspective, urban objects are inclusive smart things that can act as reference points by providing navigation and guidance information to PwD, imitating people without disabilities or even offering more detailed information and new functionalities that living people would not be able to do.

ISC initiatives are citizen-centered, i.e., the focus of these initiatives is the person and his/her abilities rather than his/her disabilities. This explains the need to provide accessible information, integrating them into digital services that are already available in urban spaces in different formats, such as audio, animation, plain text, image, among others. The citizen with disabilities will be more likely to find a suitable format that is adapted and understandable with the sensory abilities he/she has. Furthermore, as our study results show, mobility applications and other GPS-like systems developed as part of SC initiatives are not capable of interacting effectively with PwD. We need to integrate accessibility in the field of SC solutions, considering accessibility issues and making Universal Design principles part of the process of developing any digital urban technology since the very beginning of the development process. In the new ISC perspective, the difference, or disabilities, must be seen as a source of innovation rather than a problem.

The data collected in our study indicate that physical assistive technologies *per se* are not sufficient to guarantee urban accessibility. PwD questioned the usefulness of some assistive technologies available in urban spaces. Equipment that is sometimes required by regulation and is designed to help PwD is often underutilized. This can happen because the equipment, for example, is not properly installed (such as tactile floors that end up abruptly in front of a wall), because it is not easily found in the environment where they are installed (such as Braille tags), or because PwD are not trained to interact correctly with them (such as audible traffic lights). Participants of our study pointed out the lack of digital assistive technologies in urban spaces. We need a digital (and informative) urban layer on the existing physical urban layer. Hence, another feature of ISC's initiatives is to retrofit traditional urban assistive technologies, transforming them into smart objects, as presented in Section 3.2.1. Cities already have a network of traditional urban assistive technologies, whose conceptual model and functioning are already well known. Such urban assistive technology cannot be discarded. On the contrary, this infrastructure must be equipped with digital resources and devices, aiming to provide PwD with new functionalities, such as tactile floors that would be equipped with sensors capable of providing the blinds with additional audio information about the environment around of him/her.

Another demand raised by our study's participants is the need explore the city and navigate safely in the urban landscape to go from point A to point B, while receiving *in situ* environmental *stimuli*. These orientations and impressions may allow PwD to create with their abilities their own understanding of how the city is organized. As showed in Chapter 2 and confirmed by our findings in Chapter 5, relevant information that is available in urban spaces is not accessible to PwD, which results in the construction of a fragmented or incomplete idea of how the city presents itself to the inhabitants. The lack of such information makes PwD insecure to navigate in urban spaces or to simply explore what cities have to offer. ISC initiatives aim to bring confidence to PwD to be in the urban space using information, appliances, landmarks, clues, and other urban objects in their favor, enabling the appropriation of the urban space by PwD. Those people demand solutions to practice their citizenship in relation to the urban environment.

Another feature of ISC initiatives is to minimize the cognitive load PwD have before and after undertaking activities in urban spaces, trying to predict and be prepared for any unforeseen circumstances. ISC solutions can continually check what PwD are doing and what they will do in order to warn them (in advance and in a format appropriate to each one's abilities) about the obstacles that users might face in their route, or to alert them about dangerous situations that may occur. PwD require technological solutions that can provide real-time and adapted information about what is happening in the urban area where they are or where they want to go.

ISC's next challenge is to facilitate the interaction and communication between PwD with other PwD, with people without disabilities to help them when they need, and with local authorities. If the intelligent environment is able to identify where the PwD is, or near which objects he/she is, this environment can notify public agents or even volunteers that someone needs help in a precise location, preventing PwD from waiting minutes to have their situation resolved. As a strategy, ISC initiatives can employ social network-based solutions to identify people willing to help PwD in a neighborhood, in specific locations or in larger urban areas. This solution would prevent PwD from approaching people who are not able to help them, especially from bad-mannered and rude people. A community of volunteers would form such social network-based solutions and public agents who want to assist people in need, who know the location or even are close to the person in difficulty, so they could help him/her navigate new environments, for example. The generation of effective human interactions can improve PwD's urban experience, as it will reduce wasted time, stress, anxiety, and unpleasant situations.

Especially in the case of local authorities, they do not have a direct channel to contact PwD, for instance, to inform about new rights and opportunities and that PwD might be beneficiaries. Public authorities could use location-based media to provide PwD with an alternative to contact this population by providing personalized content at the right moment and where the citizen would need it. For example, an 18-year-old blind woman could be informed about a vaccination campaign for young women just as she walks past a hospital, or a 25-year-old wheel-chaired man who is informed about a job opportunity suitable to his professional formation and to his abilities when he passes in front of a commercial center. Local authorities can take advantage of the ISC network, sensors, and data collected to analyze the profile of citizens with disabilities, mining their behavior and discovering what kind of services they need, and where and how to provide them. Furthermore, PwD could actively play their role as citizens, reporting to local authorities about the problems they have in a particular location, monitoring and demanding a solution. As PwD have stated in our study, they are aware that local authorities are not concerned with ensuring the implementation of solutions to their demands. Giving PwD a chance to express themselves about the conditions of urban places and facilities is the way ISC empowers PwD as citizens to manifest the city they want and involve them in the construction of a public and democratic space.

Although ISC is geared towards meeting PwD's demands related to accessibility issues in urban spaces, the term "inclusive" encompasses a broader audience that can benefit from the advances that ISC initiatives can bring. Aged people, pregnant women, refugees, tourists, and illiterate people are some of the social groups that somehow have trouble understanding the urban signaling code and moving around the cities. It would be useful to offer these people information about what is happening in urban spaces in an appropriate format considering their abilities. In fact, ISC solutions can be useful for all inhabitants of a city as they offer alternative ways of interacting with the city. Thus, citizens without disabilities that are new to a neighborhood may enjoy the option of navigating in that area, receiving annotated information about urban objects, stores and other amenities that are available along the streets. The term "accessibility" is more related to disabilities, while the term "inclusion" is more related to the need to consider the plurality of social groups we can find in a city. Furthermore, the term "inclusive" integrates aspects of social inclusion and citizenship, since it is related to guaranteeing access to services to the widest range of users possible and to the right they have to interact with their cities in an effective way.

6.2 ISC requirements

The goals of improving the experience of PwD in urban spaces and promoting a wider social inclusion of those people are ambitious challenges. In order to achieve these objectives, in this section we propose a list of requirements that ISC initiatives must have and satisfy grouped in two distinct categories: governance and technological infrastructure. Governance requirements are high-level objectives and describe the problems that the city should solve concerning PwD's demands, while technological infrastructure requirements define the characteristics that the technological layer must seek to provide a valuable ISC. Such requirements are key aspects that can be used as inputs in the process of implementing an Inclusive Smart City and should guide the development of digital urban assistive technologies or even the process of selecting technologies to be used.

We came up with the following list of ISC requirements reinterpreting SC requirements, as discussed in Section 3.1, using the results of our study and the definition of ISC:

- Governance requirements:
    - **Promoting collaboration between citizens, government, entrepreneurs, and researchers**: ISC initiatives must align civil society, public agencies, private companies, and universities in order to define PwD's demands, develop innovative solutions, and continuously increase the value of the solutions deployed;
    - **Implementing legislation, regulations, and standards related to urban digital assistive technologies:** as it occurs with other assistive technologies and as observed in Section 4.3, government plays a fundamental role in popularizing and accepting ISC solutions by

creating specific regulations and defining standards related to digital urban accessibility;

- **Fostering the digitalization and adaptation of urban information and services, as well as connecting them to urban objects and points of interest in the urban environment:** in the context of ISC, the location and identification of objects is responsible for providing adapted locative content to PwD, thus, the more services and information available /associated to the objects, the greater experience they can offer to citizens with disabilities. Maintaining such data repositories is not a trivial task, therefore, local authorities should motivate public agents and ordinary citizens to create and update annotated information of objects and places in urban spaces;
- **Developing communication channels to stimulate the participation of PwD in the policymaking process and in the local government decision**: one of the historical demands of PwD is to participate in the conception, development, and evaluation of the solutions that are provided to them. The establishment of effective communication channels between local authorities and PwD can support a productive participation, for example, in identifying malfunctioning of objects and urban amenities, as well as assessing whether the services provided to citizens with disabilities are in conformity with their abilities.

- Technological infrastructure requirements:
  - **Object availability:** relevant objects in the urban landscape must be available for PwD and must be able to interact with PwD's interactive devices, aiming to provide locative information and services;
  - **Multi-format content:** content provided by objects and locations in an ISC must be suitable according to citizens' abilities and preferences;
  - **User experience:** cities are already complex environments, so ISC technologies must be easy to use and learn, and must provide high quality user experience. Usability and a good user interface can play an essential role in improving the citizens' quality of life by

influencing how citizens interact with ISC technologies, i.e., they can determine whether citizens have good experiences or not;

- **Heterogeneity and Interoperability:** ISC must support the ability to connect heterogeneous objects to the network infrastructure and allow them to perform their tasks regardless of their origin, the computational resources they have, and interaction modalities they provide to users. More than connecting distinct objects to the network, ISC requires objects to communicate with each other and exchange information easily;
- **Scalability and Flexibility:** ISC must be designed taking into account the constant changes of urban spaces, the increase of computational resources consumption, as well as the modification of previous users' requests or, in addition, the emergence of new demands;
- **Open data:** the annotated information related to objects in an ISC should be available in open and accessible repositories. These repositories would provide data definitions that would provide a standardized way for developers to use and reuse objects' data to increase the number of new and innovative solutions;
- **Availability:** as the information and services that ISC provides to PwD directly influence their autonomy and independence in urban spaces, such data should be as accessible as possible to users. ISC should define strategies for data replication and distributed processing to guarantee that PwD have a certain level of independence, even in unforeseen situations, such as poor connection to the network or remote server out of service.
- **Privacy protection and Security:** PwD are sensitive to privacy and security issues, especially because they are constantly seeking for someone else's help, and most of the time they do not know these people. Blind people do not feel confident in interacting with digital devices when they are in public spaces because they cannot be sure if there is someone close to them, observing quietly and secretly their personal information. In addition, ISC is able to keep track of all the objects that a person interacts with along the way. With this information, some systems can discover the user's behavior, his/her

routine, where he/she usually goes, how much time he/she spends in each location, among others. ISC initiatives must be transparent to citizens about what kind of information they collect and what they use it for. Citizens should be able to define what types of information that can be collected and access the information that has been collected.

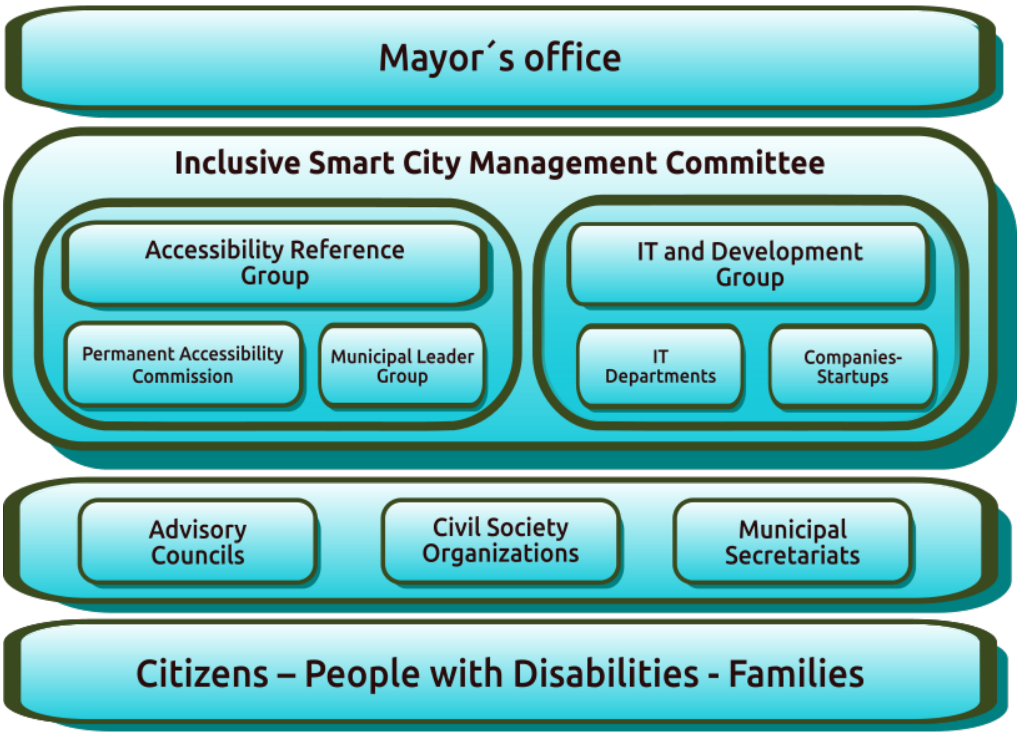
These requirements can help authorities and professionals understand problems related to digital accessibility in urban spaces, clarify the domain's context of urban digital assistive technologies, and anticipate problems in process of developing ISC technological solutions. Considering this list of requirements as a benchmark when developing a specific ISC vision can alert authorities and professionals to the importance of recognizing the diversity of citizens and can benefit as many citizens as possible, as well as mainstreaming digital solutions to solve citizens' barriers in urban environments. The definition of political requirements contributed to the conception of the Business Plan and to the proposal of an Implementation Methodology for the ISC; while the Technological Infrastructure requirements allowed us to identify key elements of the ISC's Conceptual Model and Architecture.

6.3 Political Structure and Implementation/Operation Methodology

Accessibility regulation can be defined in different spheres, such as national and regional, but the implementation, or the inapplicability, of such acts takes place in the city, where citizens live. In addition, we must consider that an ISC covers a public territory under local government control. Therefore, having the local government as an upholder is a crucial factor in the success of ISC initiatives. In this section, we will cover the managerial aspects of the ISC. Based on a meta-analysis of the results obtained in the study we have presented in Chapter 5, especially based on the results of the Workshop with Accessibility-related experts, on the answers provided by the Delphi method, and on the ISC Government requirements, we will describe how local authorities can integrate institutions and other actors around answering to PwD's demands and how these groups interact with each other to create and maintain measures that may result in a better urban experience for PwD.

The basis of the ISC's political structure is the city's inhabitants, as depicted in Figure 26. Ordinary citizens, PwD, and their families report the problems they face as they move around the city, their needs, and their evaluation about ISC actions led by the local government. Citizens maintain direct contact with Advisory Councils, the Organized Society and Municipal Secretariats, which are responsible for gathering citizens' demands or even describing citizens' needs. Advisory Councils are commonly assemblies for consultation, advice or discussion on a variety of subjects that interest the municipality, such as education, health, public security, accessibility, among others. Civil Society Organizations are institutions founded by citizens that are not part of the government, although they are involved in areas of social educational, health care, human rights, environmental, and others. As an example, we can mention Nongovernmental Organizations (NGOs), which provide services and benefits to their members and, most of the time, are non-profit institutions. Next, Municipal Secretariats are responsible for formulating and implementing public local policies in different areas, such as culture, finances, education, health, accessibility and others. Together, these entities are responsible for the interface between citizens and the Inclusive Smart City Management Committee, the central layer of the ISC political structure.

Figure 26 – Political structure for an ISC.



The ISC Management Committee is an executive division of the local government whose main objectives are: (a) to lead the actions in order to meet the citizens' demands related to urban accessibility problems; (b) maintain a multi-agent board around the policy implementation process – elaborating, executing and following up digital urban accessibility policies; and (c) intercede with other organizations and local authorities on the improvements of digital urban assistive technologies in the municipality. This Management Committee is composed of agents representing the civil society, including PwD, local government branches – executive, legislative, and judicial, each municipal secretariat, and the entrepreneurial sector. On one hand, this composition facilitates the Management Committee to establish effective mechanisms to be closer to citizens and to be permanently attentive to the opportunities to remove urban accessibility barriers, which, consequently, can lead to a better understanding of what needs to be improved regarding urban accessibility. On the other hand, this Committee has the opportunity to work as an influential group, disseminating ISC culture to several sectors of society and to various levels of local political organization. In order to achieve its objectives, ISC Management Committee should collectively create and guide the local government regarding policies, as well as make decisions related to the implementation of the ISC solutions.

There are two groups that support the ISC Management Committee to accomplish its activities: the Accessibility Reference Group, which is responsible for advising the Management Committee on the accessibility regulation and standardization; and the IT and Development Group, responsible for putting into practice, i.e., developing technological solutions and innovative services, which are the actions defined by the Management Committee. The Accessibility Reference Group consists of (1) the Permanent Accessibility Commission, which plays the role of creating the ISC regulation, observing the compliance of the local accessibility regulation with laws and standards of regional and national governmental levels, and gathering distinct standards for both accessibility and urban environments; and (2) the Municipal Leader Group, responsible for monitoring the adherence of public and private places to the laws and standards defined by the Accessibility Reference Group.

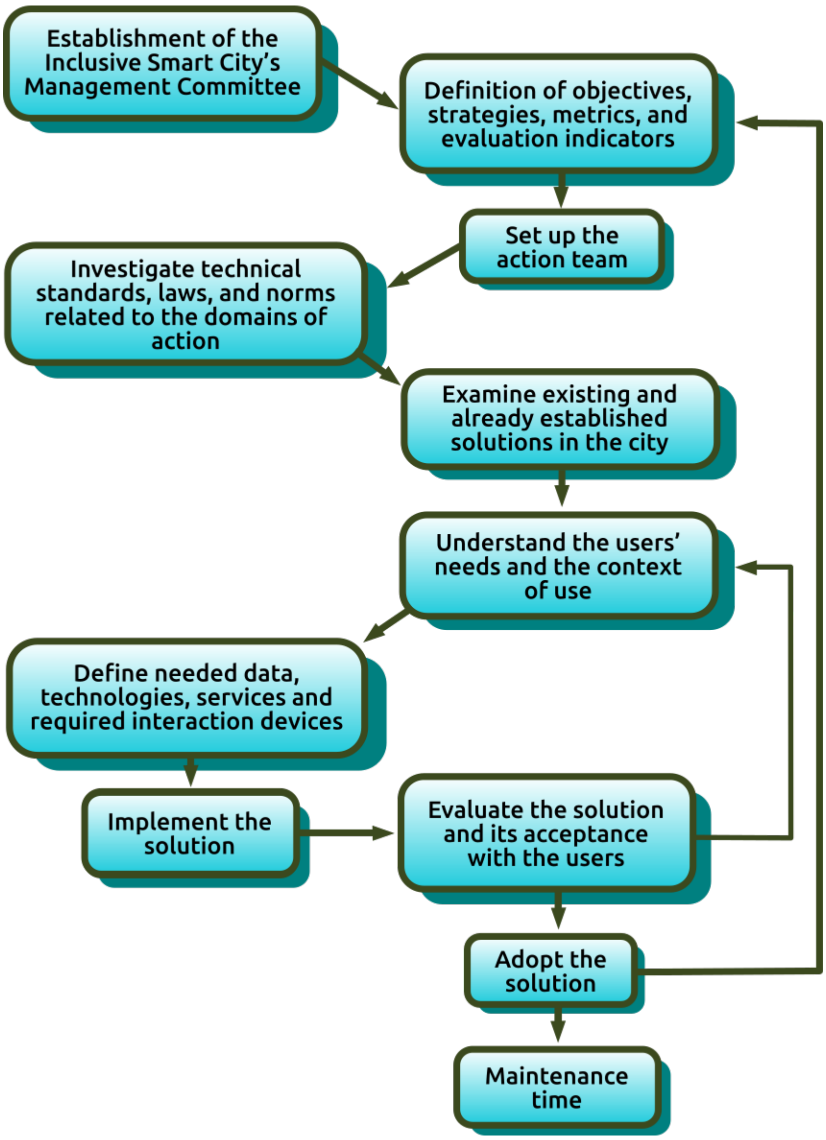
Responsible for providing technological support to the Management Committee, the IT and Development Group is composed of the IT Departments of the different governmental institutions, and Private Companies and Start-ups. Both components should adopt a strategy based on collaboration and cooperation, mainly because this is a multidisciplinary group of experts responsible for processing and reasoning in massive amounts of diverse data, dealing with heterogeneous formats, specifying telecommunication and network technologies, and designing novel user interfaces and interaction models. Governmental IT Departments should keep sensitive citizens' data under their responsibility, but most of the time they are already overwhelmed with the demands of their own institutions. On the other hand, Private Companies and Start-ups are more agile in the development of innovative technologies, more experienced in the development of technological solutions for complex contexts, and more adapted to development processes of modern technologies.

Finally, at the top of the political structure, the Mayor’s Office is responsible for evaluating, endorsing and sponsoring the acts and decisions of the ISC Management Committee.

We advocate that the ISC Management Committee should adopt a long-term acting plan and, ideally, should be an independent layer in the local political structure, protected from political disputes, party influences, and seasonal changes in the local political power. Therefore, ensuring an appropriate level of autonomy to the ISC Management Committee is another key challenge for ISC initiatives. The engagement of civil society is even more relevant in such situation. Citizens should advocate that the activities performed by the ISC Management Committee must be permanent, continuous, and directly committed to civil society rather than political influences.

In addition, we provide a roadmap or a methodology for implementing and operating an Inclusive Smart City. This process begins with the creation of the ISC Management Committee, and the institution and organization of the Committee supporting groups, as Figure 27 portrays. Thus, the Committee defines the ISC’s vision for the municipality, its priorities, strategies, and goals. The next step triggers an iterative loop of actions related to the solution of urban accessibility problems and the development of digital urban assistive technologies. Such actions can even be performed in parallel. Running on a different thread, each action can end the development of one or more technological solutions, and begins with the creation of a team of professionals whose expertise is required to run the action. Next, as in a benchmarking process, each expert investigates the existence of any prior document or previous related experience that could contribute or accelerate the activities performed by the team. In this step, the experts learn from the previous successes and mistakes. Furthermore, experts must also explore in the city about the existence of similar solutions or even solutions in other domains, which could inspire them or provide design insights, obstacles, citizen engagement strategies, among others. In the next step, experts map and understand the user's real needs and the context of use. Thus, the team must define the resources required by the action: set of data, technologies, services, and interactive devices. The experts then assemble all the resources and parts of the solution and install them in the places for which they were designed. After that, real users evaluate the solution and its use. While it is not yet approved, experts must return iteratively to the step of understanding the users' real needs in order to redefine, readapt, and evaluate new solutions. When users approve the solution, the results and the experience obtained in the development process must feedback the general ISC aims, and the Management Committee can re-evaluate the priorities and strategies of the ISC initiative. Furthermore, the technological solution and its use must be monitored periodically, aiming to correct, adapt or extend existing functionalities.

Figure 27 – ISC implementation/operation methodology.



We understand that many issues in the implementation and operation of an ISC depend on the context, i.e., the size of the city, how many inhabitants it has, the political orientation of politicians in power, local cultural aspects, etc. However, in this section we discussed a flexible vision for the political structure, and the implementation and operation methodology of an ISC, which are suitable to different styles of cities and adaptable according to the structure and resources they have at their disposal. Our proposals have the potential to bring together the key elements of the administration of an ISC: citizens, government, companies, universities and research groups. In the next section, we will discuss how the elements of the ISC ecosystem can interact with one other in the production and consumption of digital urban assistive technologies in a sustainable way.

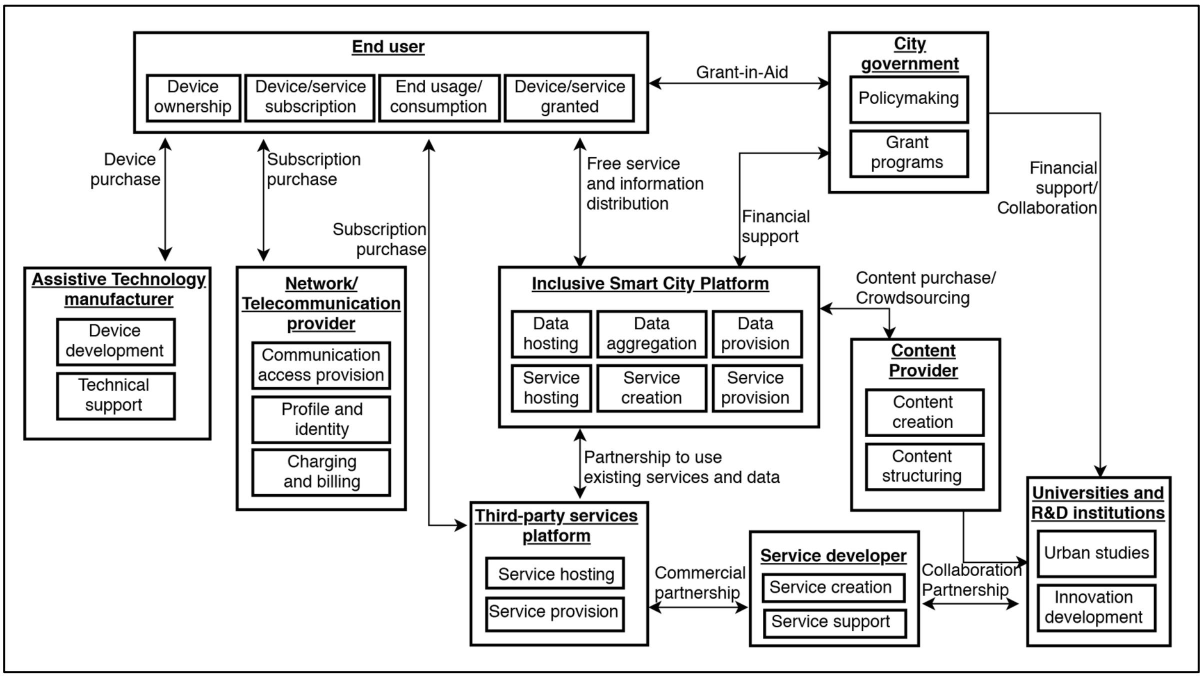
6.4 ISC Business model

We have underlined in the previous sections the importance of a partnership with the government for ISC initiatives. However, relying predominantly on the sponsorship from local authorities is not a good strategy. Instead, ISC can profit from the promising business models built on the Smart Cities ecosystem, where multiple agents and innovative services are combined, resulting in new possibilities for producing, consuming, and exchanging information and digital services – as discussed in Section 3.4.

The ISC vision provides some elements that can be explored in order to enhance SC's business model. The development of innovative digital urban assistive technology, the demand for registering and keeping inclusive smart objects up-to-date, and the involvement of PwD in paid and unpaid operations are new possibilities and opportunities to be considered in a perspective where the government financial resources is not the only source of investment. If the government is unable to provide PwD a wide range of ISC services, it may alternatively establish partnerships with private companies to provide citizens with more quality services. In this business model, the government may propose partial or full payment or it may give citizens the alternative of paying for more sophisticated services. Again, the particularities of the city, the general orientation of the local government, and the strength of local companies determine the constraints and ability to add value to services and interactions among ISC agents.

We propose a "social" business model for the ISC based on the perspective of providing adapted content in urban spaces. In this social business model, commercial transactions are allowed, but unpaid interactions are also supported, such as crowdsourcing, locative social networking, volunteers, and engaged actions, etc. As illustrated in Figure 28, in ISC's business model, the ISC Platform provides end-users with data and services related to urban places and spaces. End-users – PwD, PwD's relatives, and ordinary citizens – have free access to ISC Platform data and services, which can be done using assistive technologies or other mobile communication devices. AT manufacturers are companies that can both explore the conception of innovative interactive devices and provide technical support services. Network and Telecommunications providers are responsible for giving access to end-users to connect to the ISC Platform. In addition, third-party services platforms can provide end-user with paid data and services with more benefits, which means that they can, for example, clean and structure the raw data available on the ISC Platform to provide more valuable information to end-users. Third-party service platforms can establish commercial partnerships and collaborate with third-party service platforms aiming with the goal of providing services that are even more sophisticated. Next, Content providers are organizations or individuals responsible for feeding the ISC Platform with data on places and urban spaces. Small and medium enterprises – such as graphic design companies, multimedia producers, information curators, text editors, and publishers – can explore the content creation sector in the generation of information that will be delivered in urban spaces in various formats. Different entities and individuals - such as Geographic Information System companies, shop owners, public agents, taxi drivers, PwD, and any other citizen - may charge for the service of registering and/or updating information about some urban or local facility, or may simply participate in a voluntary crowdsourcing action - as is the case with annotated crowdsourcing maps. Besides creating content, Content Providers also offer the service of structuring, categorizing, and organizing the urban information, which is an essential task due to the complexity and ambiguity of such information.

Figure 28 – ISC business model.



The City government acts as a financial support for the operation of the ISC Platform, distributing or subsiding assistive technology to end-users, and guaranteeing that they can connect at least to the elementary set of data and services available on the ISC Platform, which maintains the initial operation of the entire ecosystem while other types of relationships between the business model actors are consolidated. On the other hand, the City government reinforces its role of balancing the interests of all entities that are present in the ISC's business model through the policymaking activities.

Universities and R&D (Research and Development) institutions, with studies and research on various urban issues, can collaborate with local governments by establishing cooperation in exchange for financial support or other types of investments. In addition, businesses can benefit from the experience found in these institutions through public-private partnerships to create innovative products and services.

Social challenges, as it is the case of urban accessibility, need creative solutions that do not burden the local government. The ISC business model describes the rationale of how local governments and stakeholders involved with urban accessibility can create, deliver, and capture value in economic, social, cultural, or other contexts. Digital urban assistive technologies can allow PwD to actively participate in the annotated environment, which creates public value in the marketplace of services provided by the City government and local companies. Value can be added to information and services, making them available in different formats, sharing annotated information, exploring different ways of sensing and interacting with them, developing innovative devices for interacting with information and services in urban spaces, and designing innovative services capable of engaging end-user as information producers and consumers.

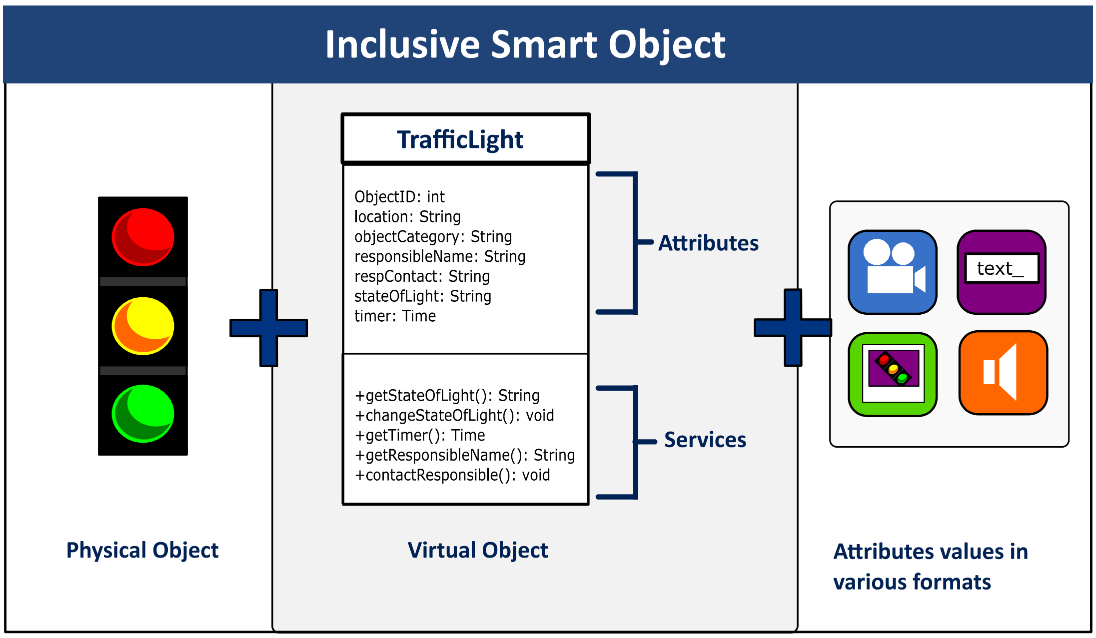
In summary, the business model we propose to ISC is based on the creation, collaboration, and sharing of annotated and accessible information related to places and objects organized in urban space, which can enable economic, social and political participation of a wide range of citizens, including PwD. The involvement of civil society, local government, companies, and universities in uncovering problems and searching for innovative solutions is decisive to keep this ecosystem active. The combination of the agents and services described in the ISC business model can provide PwD with new ways to navigate and explore urban spaces, which is the subject of the next section.

6.5 Conceptual model

After the theoretical discussion about the ISC in the previous sections, the next step is to describe how to combine technologies to support the ISC's features and to introduce a concrete representation of an Inclusive Smart City, how it is organized and how it operates. We assume that cities are diverse and that urban spaces should reflect such plurality of citizens. Instead of isolating PwD, denying or hindering their presence in public spaces, cities should embrace them. We advocate that if we want to make PwD visible in the city and be part of the urban environment, we must propose an alternative representation of urban spaces. In fact, a complementary representation would be appropriate, since we do not discard the existing environment, we retrofit it.

According to ISC's vision, and consistent with the idea of smart objects discussed in Section 3.2.1, the objects and facilities existing in urban spaces – such as buildings, bus stops, traffic lights, trees, traffic signs, street blocks, among others – can be equipped with computational resources – processing and memory –, which make them identifiable. Thus, these physical objects are connected to a digital counterpart, which is a virtual representation of the physical object. Differently from the Smart City vision, in ISC solutions, the annotated objects available in cities, i.e., the information that is annotated in such objects, must be accessible to a broader variety of citizens. It is important to note that in ISC every virtual object has two basic features: attributes and services. Attributes characterize the physical object of another and determine the state, appearance, or other qualities of that object. On the other hand, services refer to functionalities provided by the object, for instance, activities that it can do or operations that can be executed with a specific purpose. In addition, the virtual object maintains the information related to the physical object, i.e., the attributes in different formats. As Figure 29 depicts, we define an inclusive smart object as the combination of a physical object, its virtual counterpart – with attributes and services – and the values of each attribute in different formats, such as audio, text, and animation. Providing physical object information in various formats is what makes inclusive smart objects accessible. Besides being more accessible, maintenance operations of inclusive smart objects are faster, cheaper and less laborious than making adjustments to ordinary physical objects, once in inclusive smart objects these operations are performed in the virtual representation and made available to users without any physic intervention.

Figure 29 – Inclusive smart objects.



The attributes of the virtual object are modeled as (1) general attributes, a set of core attributes that each Inclusive Thing must provide to users; and (2) specific attributes, a flexible set of attributes that depends on the domain and scope of the application, and on the semantics of the object. Specifically, the general attributes are:

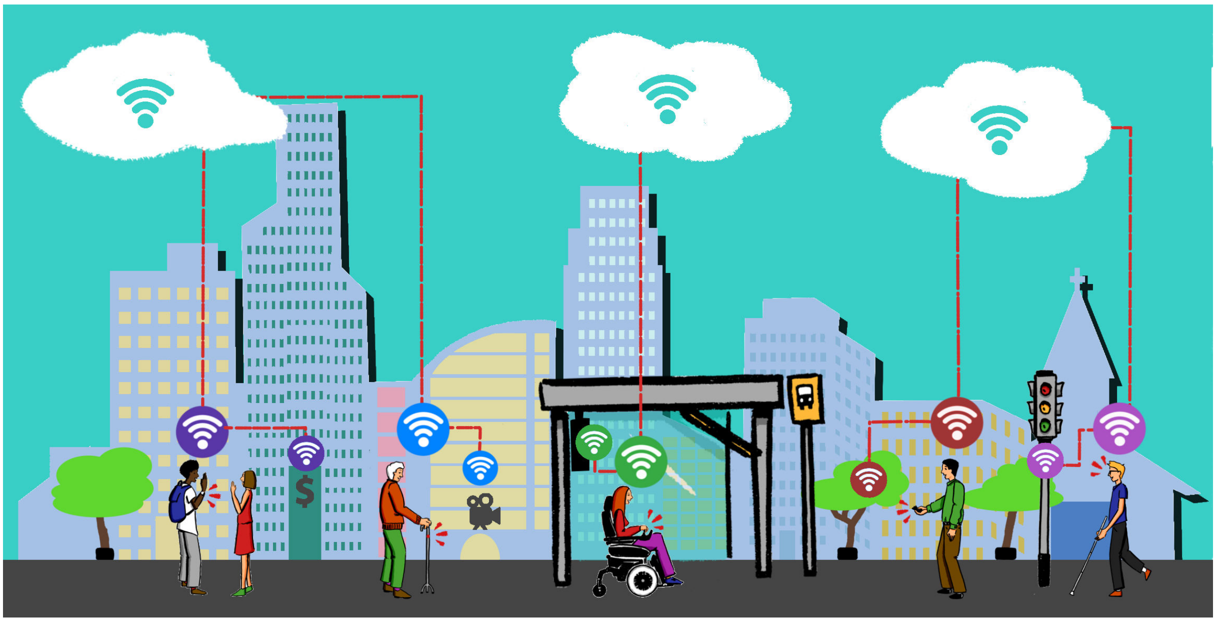
- ObjectID: link between the physical object and the virtual object;

- Class: defines the object as a member of a category of objects;
- Location: physical position of the object;
- Description: descriptive representation of the object, external and internal characterization, its operation, restrictions of use, and other information;
- Responsible: the person responsible for the object's availability;
- Responsible e-mail: the e-mail address of the object's responsible;
- Responsible telephone: the telephone number of the object's responsible;
- Status: identifies the operating status of the object – available, in maintenance, paused, unavailable;
- Display: describes the message that is shown on the object;
- Message: general information, warnings or other types of messages that can be delivered to users who are close to the object;
- Users' reviews: comments or reviews left by other users regarding the object or use of the object.

There is a very similar arrangement for the services provided by Inclusive Smart Objects: (1) general services, which are defined for each Inclusive Smart Object, and (2) specific services, which depend on the behavior of each physical object. There are five general services: retrieve general attributes, call the responsible, send email to the responsible, read reviews, and create a review.

In order to show how users and smart objects behave and interact with each other in ISC, we introduce the ISC Conceptual Model, in which users, especially PwD, use interactive devices to interact actively or passively with inclusive smart objects found in the surroundings, as Figure 30 depicts. In an ISC, while users are moving around cities, they can interact with inclusive smart objects that are noticeable, available, or accessible in urban spaces. Users and inclusive smart objects can exchange information by setting up an interactive dialog that can be started by the user who needs some aid or assistance in performing a specific activity – such as discovering where the nearest restroom is and how to get there, or informing the subway station staff that he or she is at the entrance of the station and needs guidance to reach the train platform.

Figure 30 – Elements of the ISC conceptual model.

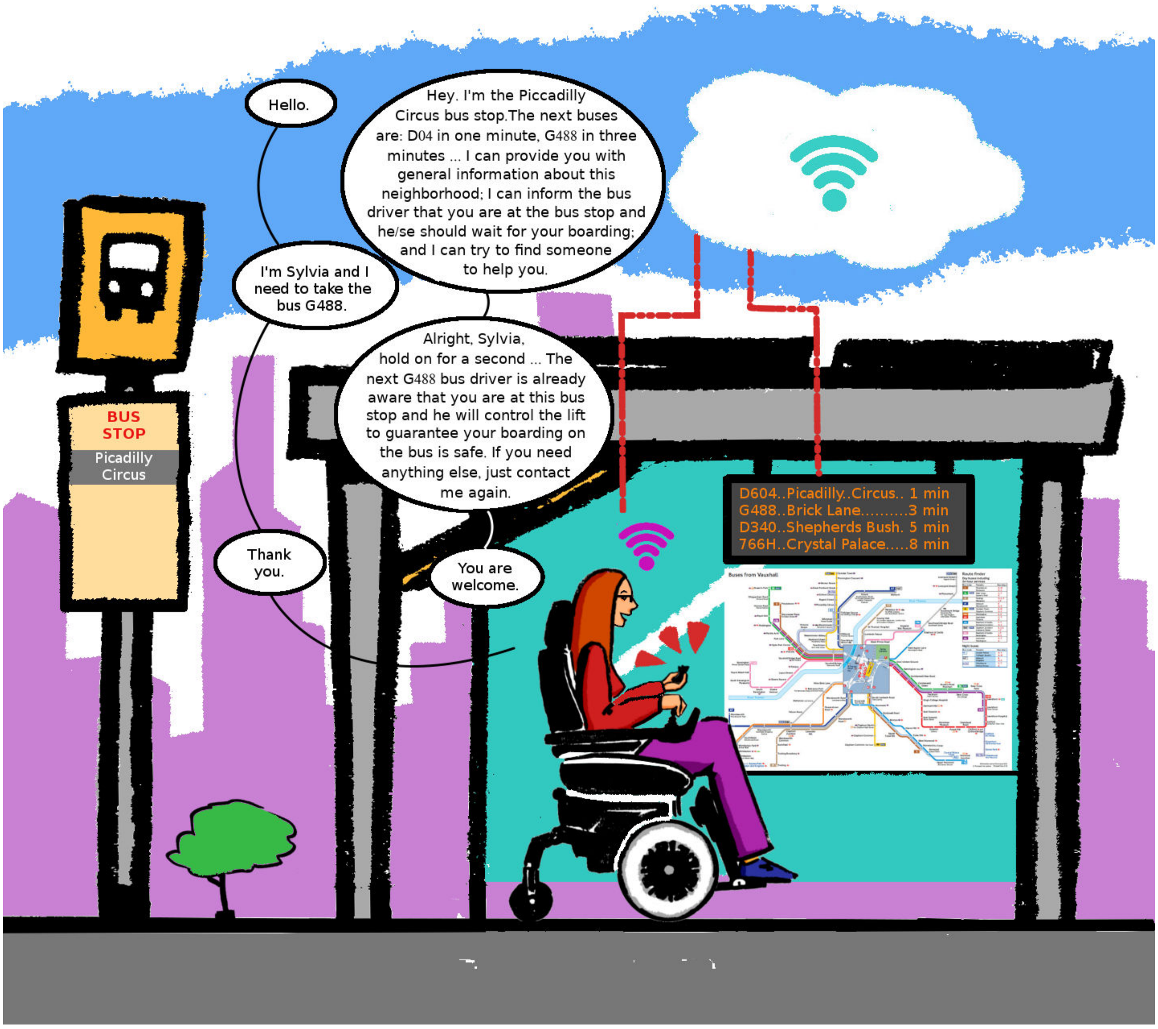


Moreover, based on the identification of users and their location, ISC can proactively alert users about information and services that are available to them where they are or even broadcast an emergency message, for example. It is important to anticipate PwD's needs and make their routine in urban spaces more productive and easier, but it is also valuable to give them control over the dialogue with the urban environment, as Figure 31 shows.

Inclusive smart objects can act as additional urban landmarks and sources of information and services for PwD. In the context of an ISC, traffic lights can inform a user who is next to it which color is currently being displayed (green, yellow or red), the street name the user is in, how long he or she has to cross the street, or yet, how long the signal will be closed to the cars and remain open, so the citizen can cross the street. In addition, the citizen can activate the traffic light using some digital service, inform that he or she is near it and wants to cross the street – simulating what is already being done in some places by activating the traffic light button –, which results in the interruption of car traffic and allows the citizen to cross the street safely. Moreover, for instance, if the person accidentally falls or suffers another type of incident, he or she can digitally trigger the traffic light again, preventing it from opening to cars and avoiding these cars from advancing on the injured citizen. In this specific case, the citizen can still request the traffic light to call the nearest emergency service to help him or she.

As urban landmarks, the inclusive smart objects can orientate PwD when navigating in urban spaces, helping them build a richer representation of the urban environment. Since locative information is provided in a way that PwD is able to comprehend, it can associate significance to places that were previously empty or meaningless spaces and to objects that were not known to PwD.

Figure 31 – Elements of the ISC conceptual model.



Furthermore, the ISC vision allows PwD to associate information to an urban location or object, annotating complementary information, reporting problems and leaving their impressions using the object itself as media. This accessible locative media can assist other citizens who will interact with the object in the future or can help local authorities deal with any problematic situation that may arise. PwD can also explore other location-driven functionalities, such as sharing with relatives and friends the object's location that he or she is close to, sharing with the general public their location to get assistance, or sending a friend a place with a cultural a recommendation or a sales opportunity.

This conceptual model supports not only community-driven interaction, such as locative announcements and newsboards provided to neighborhood residents, business offers broadcasted to passers-by in a specific area of the city, and public health campaign targeting blind people. It also supports personalized and individualized interaction, as in the case of a building that discovers that a particular user is deaf and signals to him or her which stores have sign language interpreters capable of communicating with him or her. Other interaction models can be explored using the conceptual model we propose:

- Users can send information about objects and share contextual information with other users;
- Users can set up triggers that perform some action or warn other users about some atypical situations, such as alerting when they are near dangerous areas, preventing users from entering into dead-ends, or just informing users when they are near free toilets or even when it is going to rain, among others;
- Users can leave messages on objects, leaving additional information to other users that may pass near that object in the future, or even alerting local authorities about improvements that need to be made in that area. In this case, users can actively engage in annotating what happens in the city and participating as citizens for the improvement of urban environments.

Having this conceptual model in mind, developers and designers are able to straighten out their thinking before beginning to conceive urban assistive technologies in which PwD can be more independent and autonomous. Smart objects act as landmarks, providing users with personalized location-based information and services. Indeed, the use of IoT, wearable technologies, and accessible locative media can make the physical world perceivable and navigable according to everyone's abilities. Providing accessible and richer information about how the environment around the user can improve and enhance the experience PwD have in urban spaces, and make these places more stimulating, enjoyable, and exciting.

6.6 Design principles

The knowledge gained from the questionnaire, the interviews, and the Focus Group sessions allowed us to identify some design considerations and fundamentals that designers and developers of ISC solutions should considerer, as well as practices to avoid. As these design principles emerge from the testimonials of potential real users of ISC solutions, these principles can anticipate design problems and provide helpful cues and guidelines, which can accelerate the conception of urban digital assistive technologies. Hence, applying these design principles to ISC projects can increase the chances of meeting the expectations of a wider user group.

Principles of accessible design have already advanced in other digital domains with great benefits, such as the Web. Smart Cities initiatives should also move forward in this direction. We propose the following list of design principles as resources that facilitate the development of technological solutions committed to providing a better urban experience for PwD:

- **People and their abilities first, not technology:** understanding people's needs, their abilities, how and where they will use the technology must be the priority for designers and developers, rather than aesthetics. Professionals should put themselves in the PwD's shoes to empathically understand how they experience the city, what they want and what their motivations and goals are;
- **Alternative input/output mechanisms:** depending on the individual user abilities, interaction with some applications can be very difficult and require repeated operations, or require considerable physical and mental efforts to precisely enter or obtain the information. Designers should provide different and independent channels of sensory input/output – or interaction modalities – between users and ISC solutions. In addition, devices must be flexible and adjustable according to the user's physical characteristics, body shape, and range of motion;
- **Urban spaces are uncontrolled environments:** PwD and the technological objects they possess can be exposed to rains, dust, excessive brightness, noisy environments, and other unusual situations. Designers must foresee and reckon such circumstances, developing adequate protection to ensure that the technological solution works properly, even when environmental conditions are not perfect;

- **Do not rely solely on audio and visual information:** for people with multiple disabilities, only one information modality may not be enough to provide the content that the user needs to obtain. The same is true for blind users, who prefer to use voice user interfaces, but they may be in noisy environments; or deaf users, who prefers to use textual or video user interfaces, but they may be in places of excessive brightness. The difficulties encountered in these environments can be circumvented by combining the first interface the user prefers with other interface modalities, such as gesture, tangible, haptic, among others;
- **Avoid the Masking Phenomenon:** when a person is born without a certain sense or loses it throughout life, the human brain reorganizes itself by sending the energy and processing power that would be spent on that sense to other senses, improving them. Abilities associated with the "lost" sense are compensated by the abilities from other sense, or by the development of new abilities. As an example, blind people often have improved hearing and touching abilities, and can even use the "clicking" technique, in which they make clicking sounds and interpret the echo they hear to determine the environment around them. Digital urban assistive technologies cannot disrupt or interfere with the alternative abilities that PwD have developed. In the case of blind people, technological solutions cannot, for instance, over-ear headphones and gloves that entirely cover the hands and even the fingertips, which could mask or compromise, respectively, the hearing and touching abilities;
- **Simplicity of the user interface:** the city is a complex environment, integrating various urban functions and resources, as well as several subsystems and networks. ISC solutions cannot be a further obstacle, taking time and effort from users to understand them. Thus, the user interface must be simple, focusing on the essence of the problem and reducing the users' cognitive load. Designers and developers should only include elements necessary for the solution, eliminating elements that are not essential. For example, using cables to interconnect personal devices – such as in a Body Area Network – may disrupt and/or interrupt user movements and pace, interfere with the use of other assistive technologies, and possibly cause

incidents. In this case, Bluetooth network technology would facilitate user interface interactions;

- **Do not rely on remote access:** in some circumstances, PwD can only rely on ISC applications. If these applications require remote information and this information is not available, the correct operation of the application may be affected or interrupted. Network connections in urban spaces are unstable and users may lose their Internet connection or be in a shadow zone, i.e., an urban area where the network connection is intermittent or unavailable. Designers must predict critical situations and ensure that the user has not been left out. Some strategies that could be used to solve this problem are: downloading critical information in order to balance the use of remote and local data; providing remote connection to at least one object among all the objects that are in one place; and so on;
- **Keep users aware of the power status and computing resources of their personal devices:** context and location-based applications, such as ISC applications, are energy, memory and processing-consuming. Users should be informed of their devices' power status and computational resources so they can find a way to charge their devices, if necessary, or they can decide how to prioritize the various tasks they have to perform when they are in urban spaces. Failure to observe this principle may jeopardize the sense of independence, autonomy and security that ISC solutions can offer to PwD in urban spaces;
- **Consistency*:*** in ISC, one of the most challenging design principles is to keep the consistency between heterogeneous elements – for example, different inclusive smart objects created and maintained by diverse organizations, and distinct devices that provide various modalities of user interaction. Such a diverse environment can lead to cognitive overload. Designers and developers should create consistency in how ISC elements behave – such as inclusive smart objects and interaction modalities – so users could learn how new applications work faster, based on previous experiences, which can make the user experience more efficient.

The ISC professional team should consider these design principles as part of the project documentation from the stage of investigating technical standards, laws and norms to the implementation and operation methodology.

These design principles should not be analyzed and considered in isolation. On the contrary, they should be considered mutually, as they help one another. These design principles should be seen as a starting point to motivate further discussions on how to improve the quality of ISC projects by anticipating the frequent concerns that can arise when creating digital urban inclusive smart assistive technologies.

6.7 ISC system architecture

Once the requirements and the Conceptual Model have pointed out the main challenges of the ISC, and considering the findings obtained in the literature review that we conducted, the following aspects should be included to adequately address the accessibility of cities:

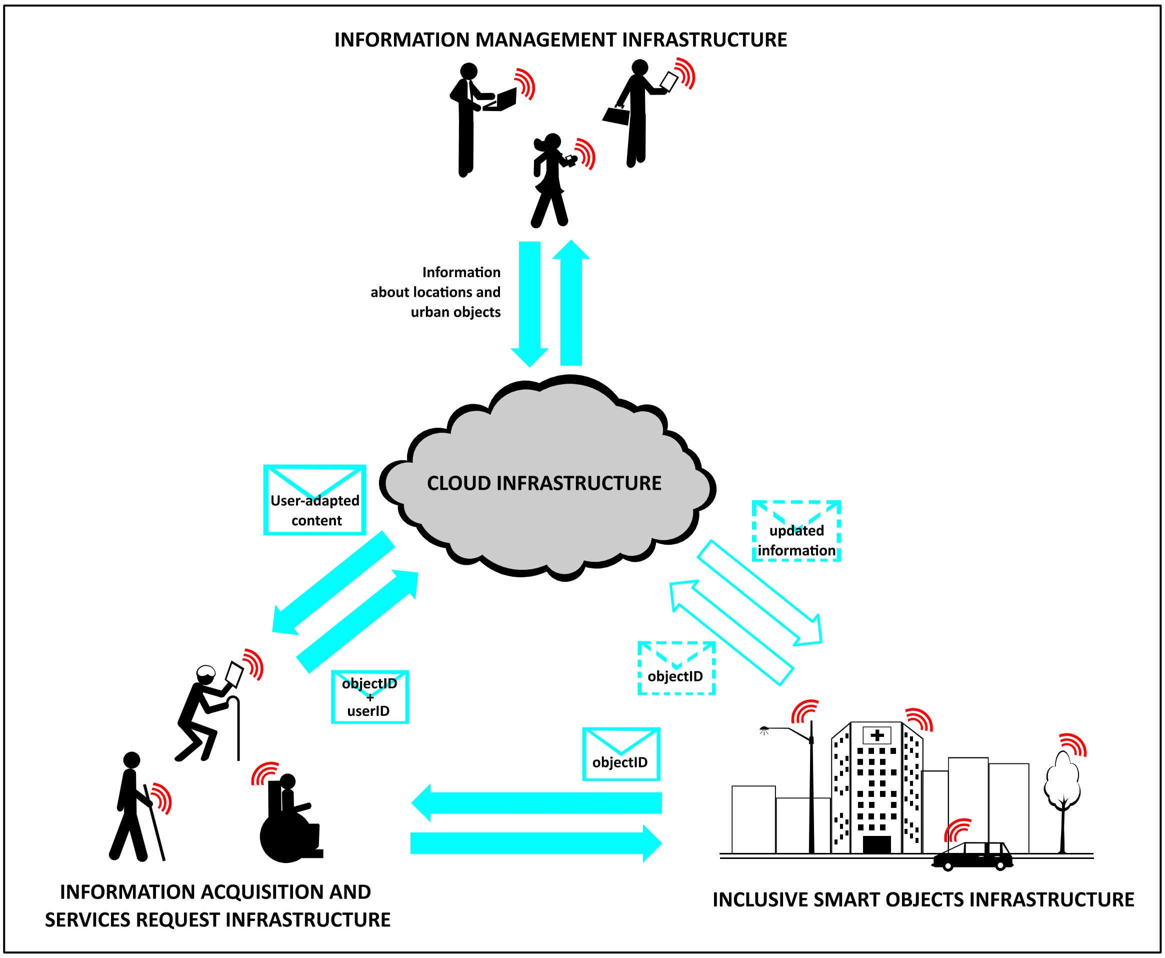
- Enabling interaction between inclusive smart objects and PwD in urban environments;
- Adapting the information that is available in urban spaces, making them also available and perceptible to PwD;
- Allowing PwD to request that inclusive smart objects perform tasks and services in urban spaces;
- Facilitating PwD to find help from others when they are in public places;
- Including citizen participation in the city development and government.

When perceived by PwD, inclusive smart objects can act as prominent urban landscape features that guide, orientate and help citizens with disabilities navigate in cities. Such accomplishment is achieved through the localization of objects that surround the user and through the adaptation of objects' information, which requires prior knowledge about the user's abilities and preferences. Managing objects' location and user identification allows the ISC to trigger services and perform tasks that can facilitate the daily routine of PwD in cities, such as, finding willing people or public agents to help when they need, or changing the light of an inclusive smart traffic signal in order to cross the street. In addition, making inclusive smart objects accessible to PwD enables these citizens to report problems related to urban facilities, require repairs, and monitor the solution work, which can result in the engagement of PwD as more active citizens.

The achievement of these aspects summarizes the desirable features of the ISC. As an approach to provide the features described in this section and characteristics outlined in the Conceptual Model, as well as a response to the ISC challenges, we propose a distributed architecture that takes advantage of the associations of digital assistive technologies and new ICT technologies in a context characterized by the deployment of a ubiquitous communication infrastructure in Smart Cities environments and their enabling technologies – Cloud Computing and Internet of Things, as discussed in Section 3.2.

In ISC, users and the urban environment establish a symbiotic interaction mediated by the technology that outfits both human and non-human agents. In order to effectively combine these agents, the ISC architecture is composed of four parts that contain the infrastructure components and provide the services: Information Management Infrastructure, Citizen Information Acquisition and Services Request Infrastructure, Inclusive Smart Objects Infrastructure, and Cloud Infrastructure. The basic schema of the architecture is shown in Figure 32. The Information Management infrastructure is responsible for providing tools with which local authorities, public agents, public and private intuitions, ordinary citizens and PwD will be able to register and maintain information related to inclusive smart objects, places, urban facilities, messages to be delivered to citizens, users' data and preferences, and all information necessary for the proper functioning of the ISC. Using these tools, information providers can register the inclusive smart objects' information in a variety of content formats – audio, video, text, image, and so on – which could allow the information to reach a more expressive number of citizens. For instance, using a Web-based user interface, shop owners can register information about promotions, or public agents can send messages to deaf people in a certain urban region. Moreover, non-disabled citizens can use a mobile application to report problems related to neighborhood violence, citizens can annotate information about the accessibility level of public building, and users in wheelchairs can report poor conditions of sidewalks on an avenue.

Figure 32 – Interactions between the components of the ISC system architecture.



The main purpose of the Information Acquisition and Services Request infrastructure is to discover the inclusive smart objects that surround the user when he or she walks through the city, obtain the inclusive smart objects' identification – when the user selects a specific inclusive smart object –, and search the Cloud infrastructure for further specific information and/or services. The user's location can be defined by GPS technology or when he or she identifies an inclusive smart object, which explicitly declares to the ISC platform the region where the user is. The technology components carried out by the user are: information input and output devices, and network connection. These components can be embedded in only one device, but they can also be distributed in a body sensor network, for instance. Information input and output devices should be tailored to the user's abilities and should able to register the user's input choices and deliver the information in different formats, such as audio, video, text, gestures, haptic, and other interaction modalities. Different technologies work in the task of identifying, selecting and communicating with inclusive smart objects: QR Code, RFID reader, NFC, Bluetooth, infrared, Wi-Fi networks, among others. Users' devices can connect to the network using Wi-Fi or mobile connections.

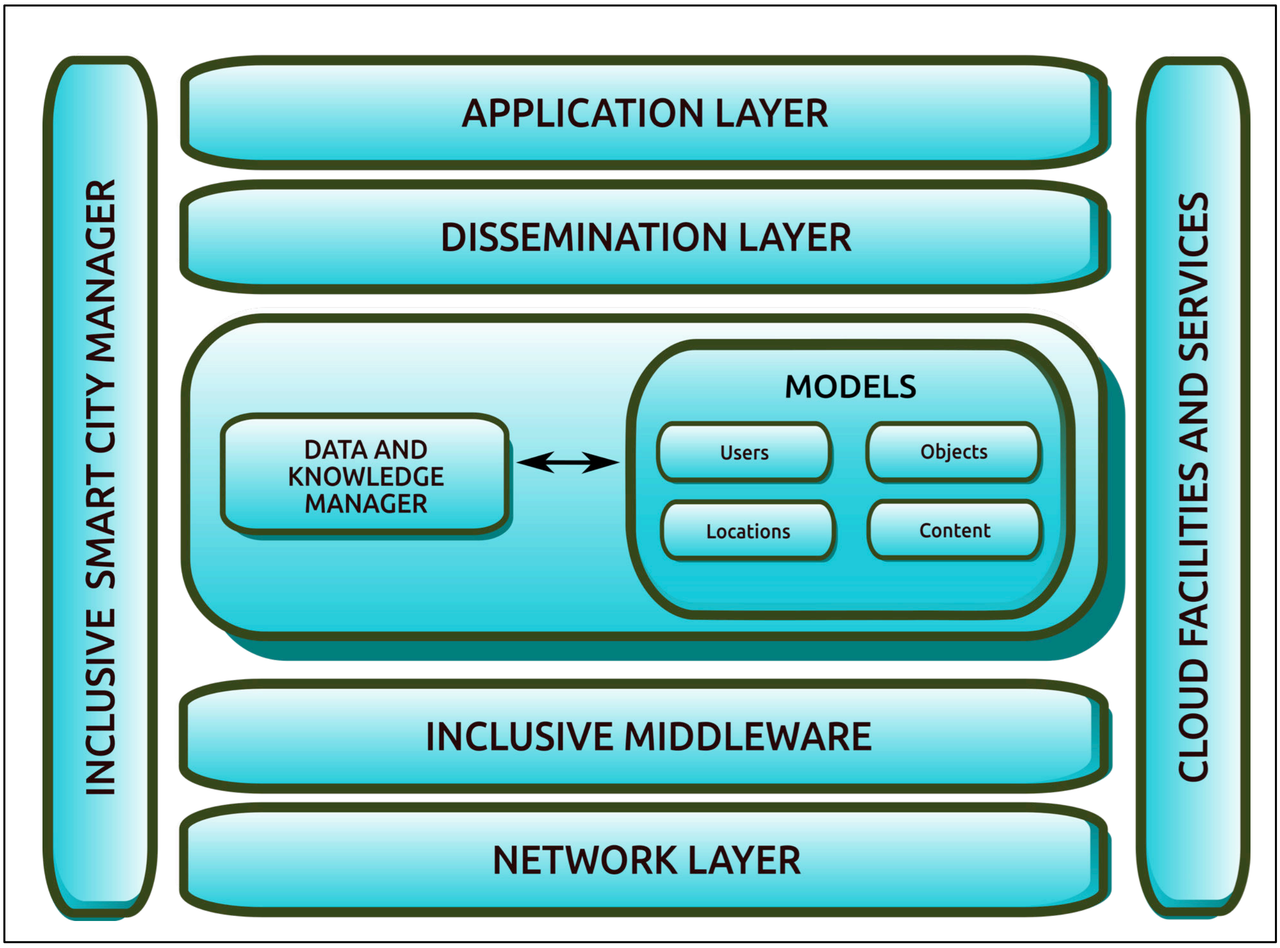
The Inclusive Smart Objects infrastructure contains the inclusive smart object available for interacting with PwD. To be discoverable, inclusive smart objects must use identification technologies, such wireless solutions. When selected, the inclusive smart object reveals some of its properties, such as location, category, and other attributes that will be discussed further in this section. When the user selects an object, he or she is able to receive information and services associated with the specific inclusive smart object, the location where the object is, or the category to which the object belongs. For instance, using the example presented in Figure 30, the user may receive information that is associated to: (1) that specific bus stop – i.e., related to bus stop identification; (2) all objects that are available in the same street or in the same neighborhood that the bus stop is; and (3) the same category of objects to which the bus stop belongs – i.e., street facilities, local public transport system, agglomeration of people, and so on. In this way, PwD can dialogue with urban objects.

Inclusive smart objects can locally keep some strategic and essential information to transmit to the users – such as their identification, location, description, category, and others. However, eventually, inclusive smart objects should be able to connect to the Cloud infrastructure to look for more detailed information, update local information, or even to perform user-requested services using a Wi-Fi, mobile, or cable connection. After discovering the object's identification, the user's device encapsulates the identification of the object with the user's own identification and sends it to the Cloud infrastructure, whose main purpose is to find out what information and services are available to that user in that particular location. Then, the user's device identifies which is the right content format to set up the required information, adapts it according to the user's abilities, and it also deals with other user requests. The user can navigate through the menu of options that is delivered to him or her to find information and/or to perform services, taking advantage of different interactive modalities, such as pointing devices, keyboard, touchscreen, voice and gesture, among others.

The Cloud Infrastructure is the centralized part of the ISC architecture, which is responsible for collecting all digital information in the ISC, processing users' requests and all problems, and also for adapting the information that should be delivered to the user in the correct content format. This infrastructure is implemented in the cloud to be easily accessed by stakeholders in various cities. The Cloud Infrastructure components take advantage of the cloud facilities and services already defined and provided by the Smart City infrastructure, such as security, authentication, privacy, elasticity, network access, among others, as discussed in Section 3.2.3. In addition, developers can use other more sophisticated resources – such as data mining and analysis, rich user interfaces, IoT device connection pools, among others – while using robust proprietary Cloud Computing tools or even open-source ones, as it is the case of the FIWARE platform. The Cloud infrastructure consists of seven main components: the Network layer, the Inclusive Manager, the Data and Knowledge Manager, the Dissemination layer, the Application layer, the Smart City facilities and services layer, and the Inclusive Smart City Manager. Aiming to foster the digital layer of the ISC, these components of the ISC architecture are combined with the components that are already described in the SC architecture, which are discussed in Section 3.3 and summarized in Figure 15.

The basic scheme of the Cloud infrastructure and its components is shown in Figure 33 and can be described as follows:

Figure 33 – Cloud infrastructure.



- **Network layer**: the bottom layer represents an abstraction of the network technologies used to connect the user's devices and the Cloud infrastructure. It can be a Wi-Fi or mobile network connection, for example, and its main goal is to enable user's demands to reach the Cloud infrastructure;
- **Inclusive Middleware**: responsible for receiving the users' demand that are sent to the ISC platform. This component initially verifies the conformity and feasibility of users' demands based on: (1) the user identification, as well as his or her preferences; (2) the identification of the inclusive smart object selected by the user, and (3) the type of demand – if it is a request for information or service, or if it is related to registering new information, for example. The Inclusive Middleware provides an input interface to standardize the received messages from different users' devices and sensor technologies in a homogeneous scheme that is understandable by the upper layers of the Cloud infrastructure. After the initial treatment, ISC Middleware stores the messages in a message queue, which is a persistent system that orchestrates the message routing to the appropriate top-layer component. ISC Middleware guarantees some ISC platform characteristics, such as scalability – serving a flexible number of users, users' interactive devices, and inclusive smart objects thanks to its input interface; interoperability – ISC Middleware must be based on technological solutions that allow data format transformation and protocol bridging, such as APIs, Service Oriented Architecture, and Web Services technologies; and availability – as this module is installed in the Cloud, if one node fails permanently, another node can replace it;
- **Data and Knowledge Manager**: based on the message received from the Inclusive Middleware, the Data and Knowledge manager identifies what type of action should be performed – (1) register new data, as well as update and delete existing data; (2) search and retrieve. For this reason, this module has access to models that persist information concerning users, including smart objects, locations and places, as well as messages exchanged between local authorities, public agents, and users. The actions of register, update and delete the data models, which can be specified and stored in different data formats such as XML documents, relational databases, NOSQL databases, plain text, among others. The Data and Knowledge manager is also responsible for tying an informational element – such as an attribute of an inclusive smart object or

content sent from a user to a local authority – to the different formats that this information could be represented. The search and retrieve action initially accesses the models trying to find out complementary content that should be delivered when the user profile and the inclusive smart object profile match one another. Thus, the Data and Knowledge manager set up a message with the information that should be delivered to the user and coded in the format that meets the user's abilities and preferences. Next, the Data and Knowledge manager forwards the message to the Dissemination layer;

- **Dissemination layer**: the main goal of this component is to format the messages independently of a target application or platform and organize the messages in clusters of services or applications designed to assist users in urban spaces – communication, wayfinding, navigation, social networking, among others. Focused on the semantics of the information it provides, the Dissemination layer is a container that facilitates applications from different platforms to use and share the users' processed demands. In other words, the Dissemination layer keeps the results processed by the lower layers as a showcase, where the user applications, which are in the upper layer, can supply themselves;
- **Application layer**: this module represents the user interface, which provides accessibility services to the key stakeholders: PwD, local authorities, and public service provider companies, such as transportation, emergencies, etc. This component is responsible for producing the result of processing the user's demand, according to the user's abilities and preferences, and the capabilities of the interactive device that the user utilize. Applications in this layer receive the platform-independent data from the Dissemination layer and apply their own style and presentation characteristics to provide a particular end-user experience. For instance, an application may receive a video with a warning message from the Dissemination layer and customize it by adding complementary information and links to other content before displaying it to desktop users; while another application decides to compress the same video aiming to reduce its size and make the video caption look bold before delivering it to mobile phone users.
- **Inclusive Smart City Manager**: centralizes ISC platform coordination by providing administrators, local authorities, policymakers and other

stakeholders with tools to configure services and resources provided by the ISC. Moreover, this layer monitors the usage of assistive technologies, the level of assistance provided in different urban areas, and other features. In summary, this component systematically tracks everything that is happening in the Cloud infrastructure, collecting information to provide strategic reports on the ISC operation and how to improve it;

- **Smart City facilities and services layer**: responsible for providing common and specialized services for all other layers of the Cloud infrastructure, such as authentication checking, security mechanisms, rich interfaces, data mining and analysis, data and media processing, data store, among others.

The ISC architecture enables the synergy between PwD and inclusive smart objects, so that PwD can access information and services associated with urban places and locations – where inclusive smart objects are – and to annotate data for the inclusive smart objects, participating in the dynamics of the city. We also propose the following approach to transform a regular urban space in an inclusive smart space:

1. Define the area where users will be able to receive user-adapted content;
2. Define the granularity, or level of details, that will be provided from the chosen area. For example, on an avenue, only the main description of the building can be provided, or in each building, all floors and interior rooms can also be detailed for the users;
3. Choose the existing eligible inclusive smart objects in the chosen area;
4. Physically identify objects with tags or sensors, and connect them to network infrastructures when necessary;
5. For each object:
   a) Define information/services;
   b) Add information/services to the object model;
   c) Test the connectivity.

Assuming that users and interaction devices have already been included in their respective models, this approach ensures the correct communication between PwD and inclusive smart objects.

6.8 Chapter summary

Essentially, the Inclusive Smart City proposes to broaden the Smart City vision to consider PwD as beneficiaries and potential users of urban technologies. To provide a better experience for PwD, cities should treat each individual differently, avoiding mass information and services, besides anticipating unexpected events and situations, as well as providing orientation and navigation in urban spaces. We believe that such challenges must be addressed by combining governmental and technological efforts.

In this chapter, we presented a set of tools to support local authorities, policymakers, designers, and developers to conceive and build ISC solutions. The definition of ISC determines the characteristics that this new vision must have and establishes points of convergence and divergence of ISC with the traditional SC and with other SC branches. Thus, we have provided a list of requirements that might anticipate some problems that are eligible to occur in ISC projects. Next, we discussed how local governments should adapt their political structure to include the urban accessibility cause at the center of municipal political issues, and provided a methodology for implementing and operating an ISC. The following tool presented was the business model in which users, businesses and local government could collaborate, produce and consume information, services and technology, creating a potentially sustainable environment. With the Conceptual Model, we considered how digital urban assistive technology could allow PwD to interact with other citizens and with other objects that could be found in urban spaces, aiming to solve the problems that PwD face when moving around cities. Subsequently, we provided a list of Design Principles that could facilitate the development of digital urban assistive technologies. Finally, we presented the ISC architecture, which provides the technological infrastructure that enables PwD, local authorities, citizens without disabilities, and inclusive smart objects to produce and share information related to the city and urban accessibility. All of these tools were conceived to provide PwD with a new way of experiencing the city.

In the next chapter, we will discuss a Proof-of-Concept (PoC) that we developed in order to investigate how PwD evaluate a digital urban assistive technology developed according to ISC's vision.

7

Evaluating the PwD user experience when using ISC technologies: the UrbanAssist application

Some of the resources discussed in Chapter 6, such as the Political Structure, Implementation/Operation Methodology, and Business Model are not simple to evaluate. An extensive assessment of these resources depends on the effective development of an Inclusive Smart City, which requires financial investment, time and political will. For this reason, we chose and applied the Delphi method with accessibility and policymaking experienced professionals who, based on their previous experiences in their areas of activity, refined our initial proposal, making it more suitable to the reality of cities and with greater potential to be useful resources to local authorities and business sectors.

However, the Conceptual Model, Design Principles, and system architecture can be submitted to real-world applications to verify their feasibility and how real users react when they use technological solutions that are tailored to their (specific) needs. The main goal of this chapter is to present the development of the UrbanAssist application, a Proof of Concept built according to the ISC's principles and that provides the features that the ISC should have, which are discussed in the Conceptual Model, Section 6.5. As Wikipedia describes, PoCs help technical teams explore emerging technologies and demonstrate that a product or solution is viable and has practical potential (Wikipedia, 2018). The UrbanAssist application allows us to verify the feasibility of implementing the ISC system architecture and to evaluate the user experience that PwD have when using digital urban assistive technologies that are in accordance with ISC's vision.

7.1 UrbanAssist application description

Our approach with the UrbanAssist application is to put into practice the design ideas behind the Conceptual Model and the System Architecture of the ISC. Analyzing the data collected from PwD, as discussed in Chapter 5, we identified that navigation and orientation guidance in urban spaces would be very useful and would positively influence the urban experience these users have. Following isolated actions of the ISC Implementation/Operation Methodology, we first investigated technical standards and norms for digital accessibility in urban spaces. Concerning this topic, our search did not match any results. Next, we searched for existing applications and services for annotating information about urban facilities. Among the solutions we have found, the Colab mobile application[37], a social network for civic engagement that connects local governments and citizens, and where citizens can indicate urban problems and ask local authorities to solve them. The Colab application gave us some design insights, although it does not address accessibility issues and does not support some users with disabilities, such as blind people.

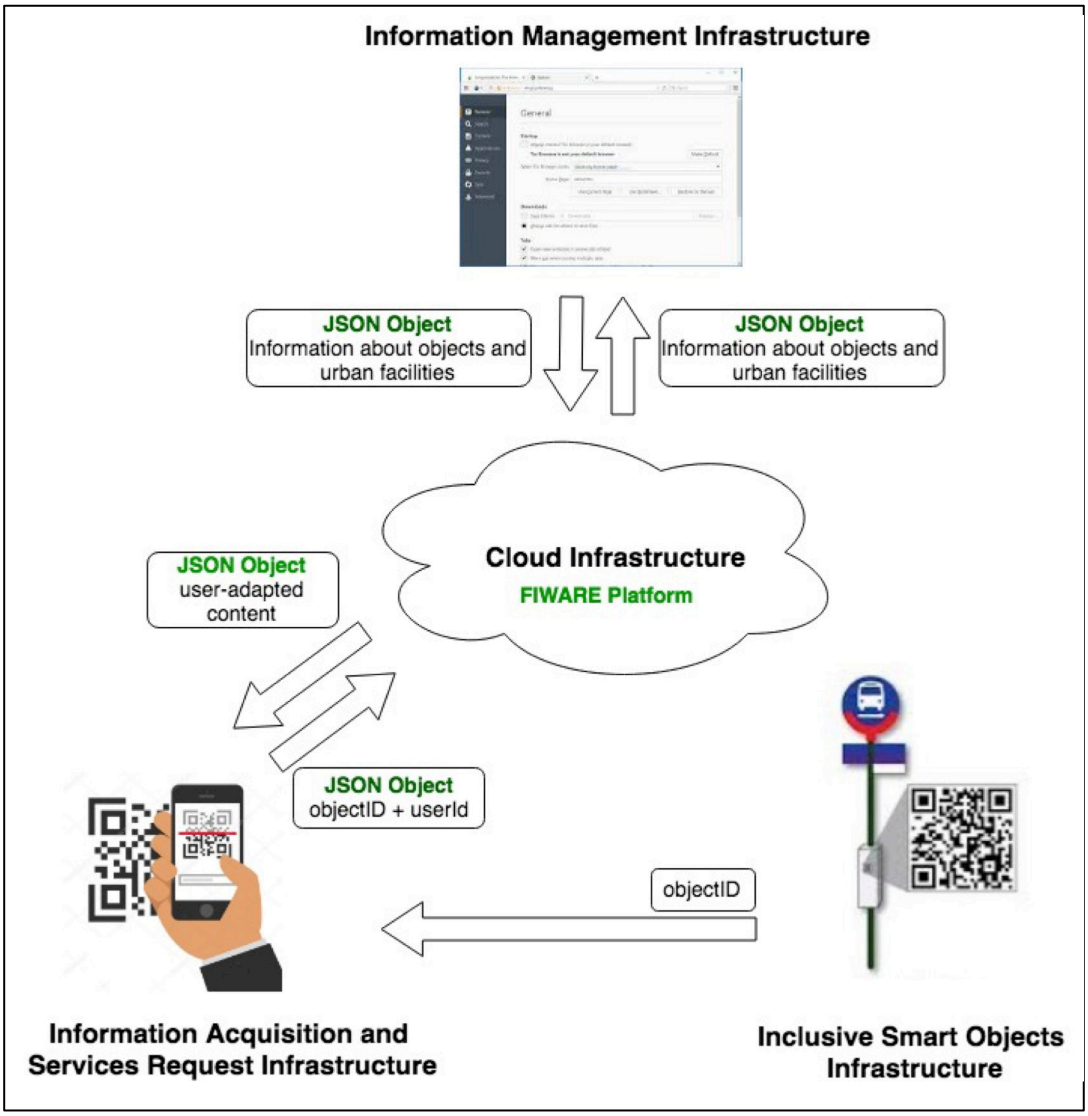
In order to understand the users' needs and the context of use, we interviewed three PwD – one blind, one deaf, and one wheelchaired – and two accessibility domain experts about the essential functionalities that the UrbanAssist application should offer. In our discussions, we inquired them about the benefits and challenges while moving around cities. Considering what we have learned from these interviews, the UrbanAssist application covers the following aspects:

- Enable PwD to explore the environment that surrounds them;
- Allow PwD to receive appropriately adapted content, according to their abilities;
- Allow PwD to get in touch with people who are nearby, if necessary.

First, we have considered the best configuration for the system architecture, bearing in mind that it should be a low-cost solution. In such a system architecture, once urban objects and facilities were identified and connected to their virtual counterparts, they would be able to provide user-adapted information for PwD and even trigger some tasks for them. Figure 34 shows the ISC system architecture we have modeled and the technologies we have combined to implement the UrbanAssist application.

[37] https://www.colab.re/

Figure 34 – The UrbanAssist System Architecture.

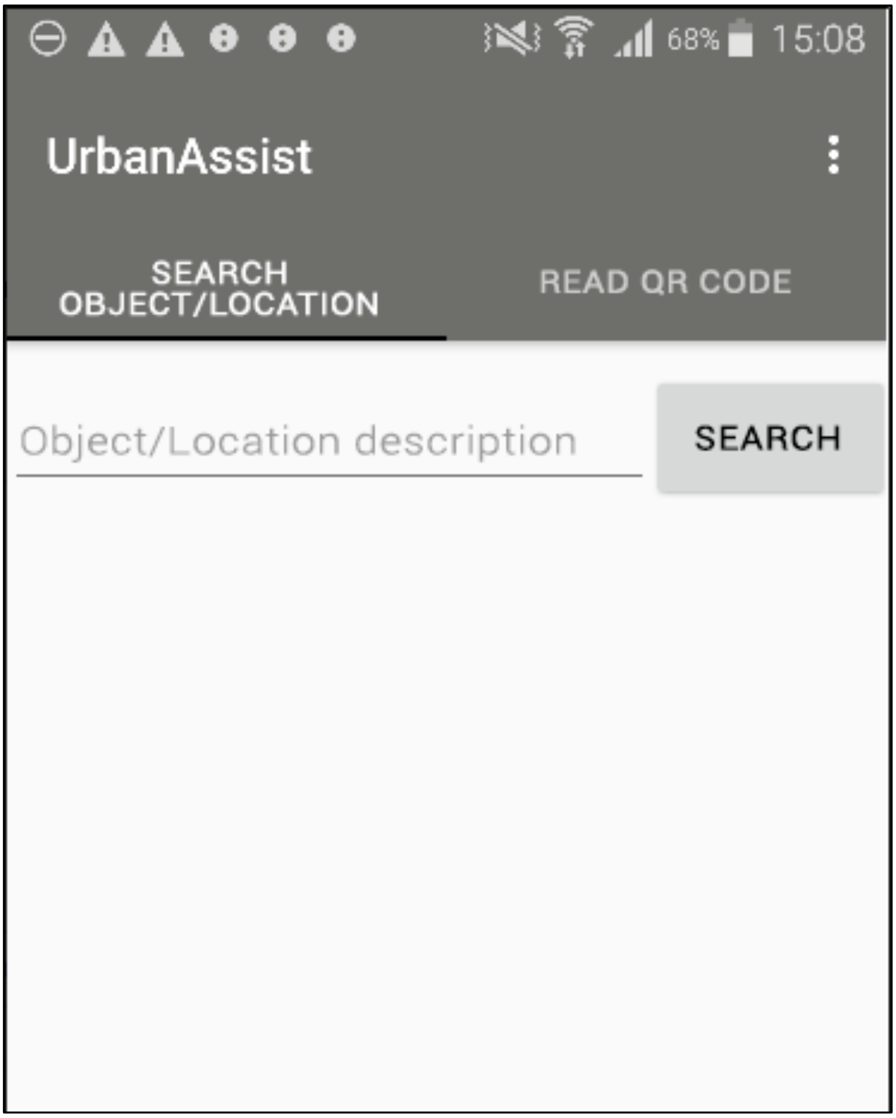


In order to meet the requirement to create a low-cost proof of concept, we have decided to use QR Codes to identify the objects that would be made available to users, which correspond to the Inclusive Smart Objects infrastructure in the ISC System Architecture. In addition to identifying the object, the QR code label is capable of containing a certain amount of information about the item to which it is attached. Typically, a smartphone is used as a QR code scanner, displaying the code and converting it into some useful forms – for instance, a URL to a website, preventing the user from typing it into a web browser. We believe that once the identification of objects with QR codes works, i.e., it works even with a relatively simple technology, other scenarios with more sophisticated technologies can be even more promising. Barcodes and QR codes have already been explored in commercial application and academic research addressing accessibility issues (Baker et al., 2016; Linnemeier, Lin, Laput,

& Vijjapurapu, 2012), including indoor and outdoor navigation and guidance to blind people (Alghamdi, van Schyndel, & Hamilton, 2014; Ko, 2013).

Representing the Information Acquisition and Services Request Infrastructure component of the ISC System Architecture, we have developed a mobile application in Android 4.0.3 Ice Cream Sandwich to provide accessibility services and functionalities for users of the UrbanAssist application. Figure 35 shows the home screen of the mobile application with the basic functionalities: Search Object/Location and Read QR Code tabs.

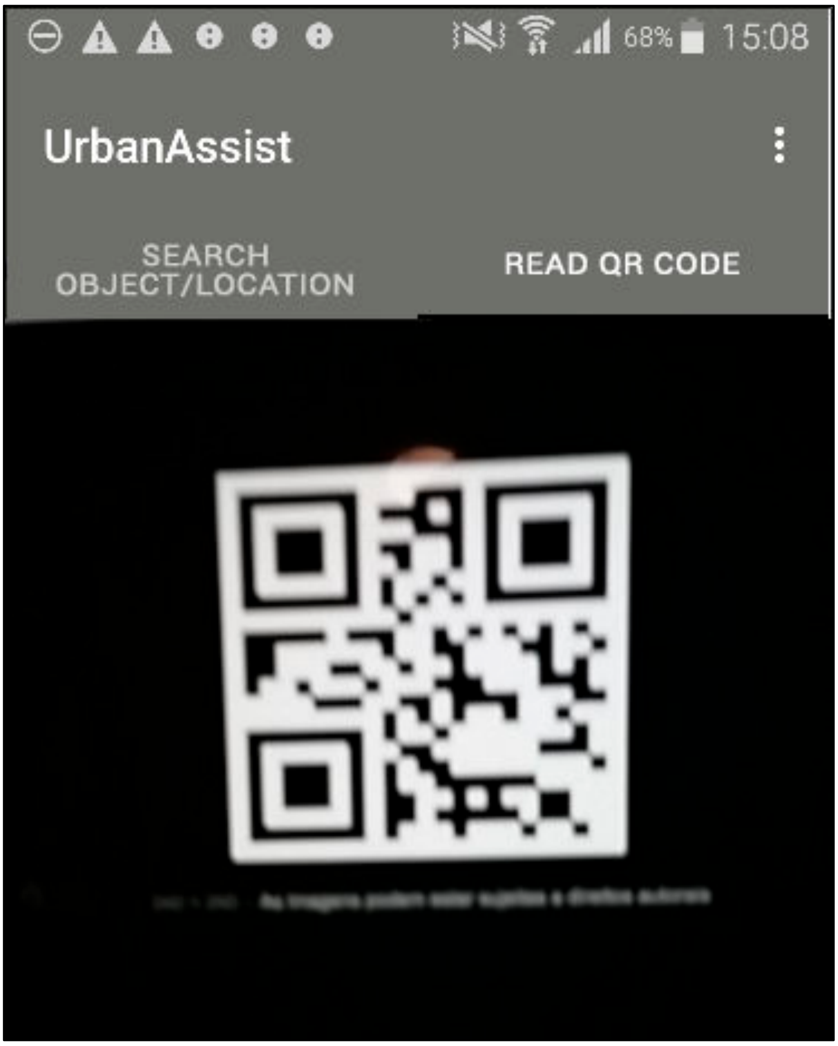
Figure 35 – Search Object/Location tab.



When the Search Object/Location tab is selected on the application’s home screen, the user is able to enter an object or location name in the text box and press the Search button, which will take him or her to the Search Results screen. After selecting an item from the available results, the user is redirected to the screen with the specific information of the selected object/location.

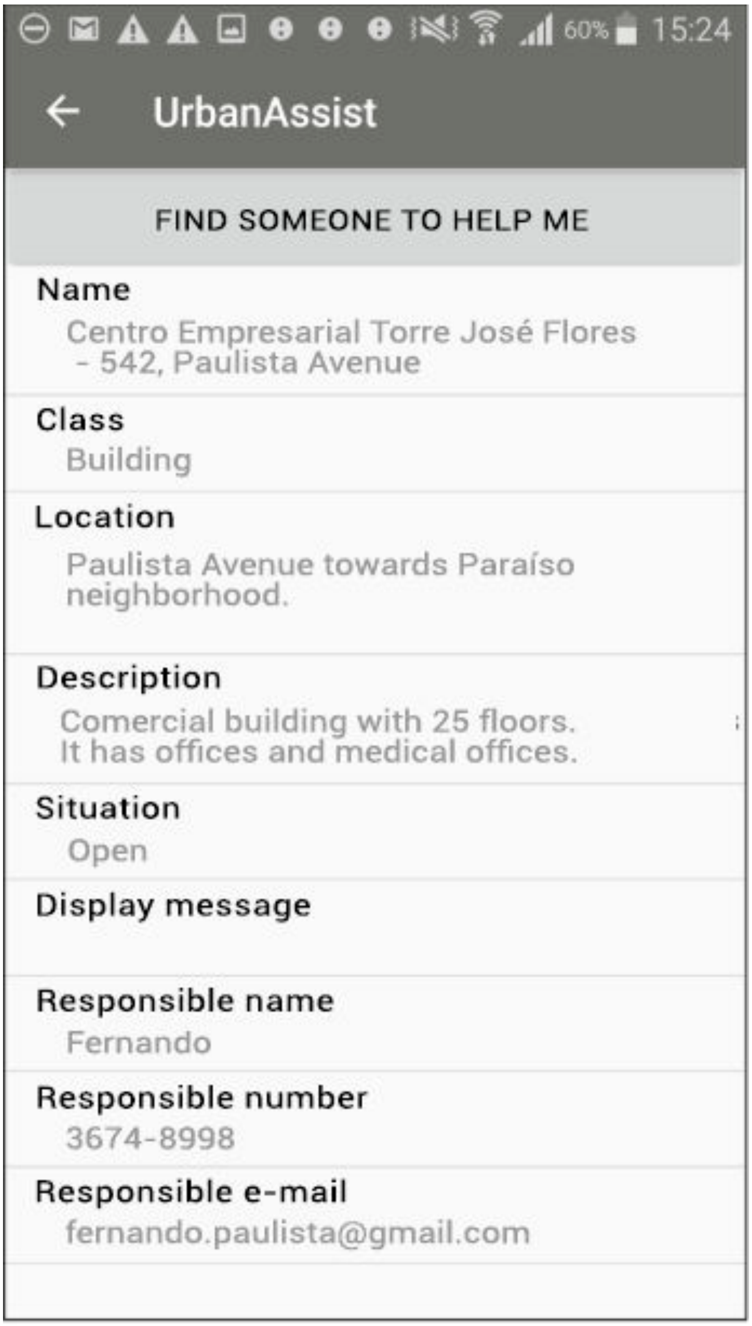
Another way to access object/location information and services is to select the Read QR Code tab on the home screen, as shown in Figure 36, and scan a QR code pointing the cell phone camera to it.

Figure 36 – Read QR Code tab.



The mobile application communicates with the Cloud Infrastructure by sending a message with the object and the user ID. If the user has the ability to read textual information, and if preferred, the mobile application will display the information and services related to the scanned object, as represented in Figure 37. As one can see, the “Find someone to help me” button represents a service provided by the selected object. The object information set is represented by Name, Class, Location, and so on. As expected, if the user can only understand messages in the form of animation, the search result for object or location will be displayed as videos, such as sign language videos, for instance.

Figure 37 – Object information and services tab.



We have chosen the FIWARE open source platform to act as the Cloud Infrastructure. We have set up the cloud environment with a virtual machine configured with Ubuntu 16.04, as the operating system; Apache Tomcat 9.0.10, as the service container; and

Java EE 9.0, as the software development kit for creating and maintaining servlets. Communication between the Cloud infrastructure and the other components of the UrbanAssist application's system architecture was designed according to the Service Oriented Architecture (SOA), which provides services that are obtained by inclusive objects already available on the web, such as web services. Web services are designed to support interoperable machine-to-machine communication over a network. We have developed web services as a form of servlets, which can be accessed by Java and non-Java applications. All communication between the Cloud infrastructure and the other components of the UrbanAssist application's system architecture is based on JavaScript Object Notation (JSON), which is a lightweight data-interchange format. In addition, models maintained by the Cloud infrastructure – information related to users, objects, locations, and general content – are structured using JSON, mainly because it is a text-only format, which causes it to be easily uploaded and downloaded to the Cloud Infrastructure, and also because it is a language-independent format.

In the Cloud infrastructure, messages in the form of JSON objects are received by Apache Tomcat, which redirects them to the *UrbanAssistMainController* class*,* a web service that represents the Inclusive Middleware of the ISC system architecture. The *UrbanAssistMainController* first stores the messages, then selects one by one to identify the type of request, and finally forwards it to the component of the layer above, which is the Data and Knowledge Manager. This layer consists of several specialized services that directly access the data from the UrbanAssist application stored in the Model component. Theses specialized services process the user's requests on different data processing tasks, such as retrieving data from a specific object or location (*GetObject*), including a new user (*IncludeUser*), and deleting data from a location (*DeleteLocation*). Other types of specific requests can also be processed, such as activating a connected device and requesting that it keep the automatic doors open or call the elevator, for example. After processing the user request, the web service forwards the JSON object with the results to the next layer, the Dissemination Layer, which is represented in the UrbanAssist application by the *DisseminationController* class, a web service that forwards the results processed by the specialized services to the user who made the request.

Finally, we have developed a web-based user interface to represent the Information Management Infrastructure, allowing the technical team to register information about objects, users, locations, messages to users, and the different formats that this information can have.

7.2 User study

Aiming to create a demonstration scenario to present the resources that ISC can provide to real users and get their impressions on the use of the facilities provided by the ISC, we have listed some representative urban routes that offered citizens several urban facilities in the state of São Paulo, Brazil. We have chosen a 200-meter circuit on Paulista Avenue, which is one of the most important avenues in the city and is a symbol of São Paulo's economic and political power center. The crowded Paulista Avenue can be considered as a city of its own, with 1.7 km and 800,000 commuters transiting there daily. This avenue offers citizens a variety of urban facilities – such as banks, financial and cultural institutions, hospitals, government agencies, schools and universities, shopping centers, signposts, traffic lights, residential buildings, bus stops, subway stations, among others. The circuit that we have chosen is very representative sample of the Paulista Avenue urban wealth, and, as can be seen in Figure 38, it provides users with a wide range of visual information.

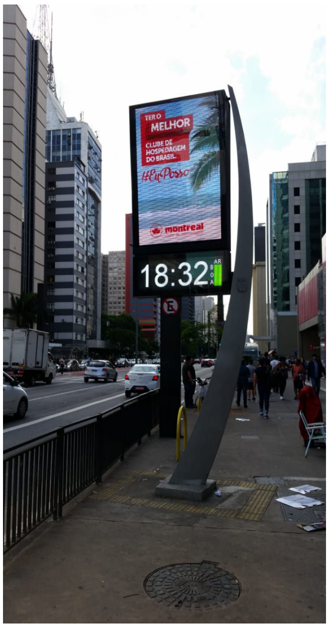
Unfortunately, we were unable to recruit participants who were already in the Paulista Avenue region. Thanks to an academic partnership with the Secretariat for the Promotion of the Rights of People with Disabilities of the Barueri municipality, we were able to recruit some of the users of the services offered by this Secretariat who were interested in participating in the study. In this specific study, the recruited people were residents of the municipality of Barueri. The Secretariat was in charge of transporting them to the Secretarat building where we decided to simulate the Paulista Avenue circuit so that the circuit could be tested by potencial users of the diferente ISC functionalities. We first mapped the objects and buildings in one block of the Paulista Avenue circuit. Next, we used the web-based user interface of the Information Management Infrastructure to create a digital version for each object by providing a set of information in portuguese – such as identification, location, services, contact, availability, and so on – in text, audio, and sign language videos formats. Then, we generated QR codes corresponding to each object ID and linked the QR code to the digital version of the object.

Figure 38 – General aspects of the chosen and real scenario for the user study.

(a) Subway station entrance

(b) Stores

(c) Music festival schedule parties totem



(d) Advertisement/Time/Temperature totem

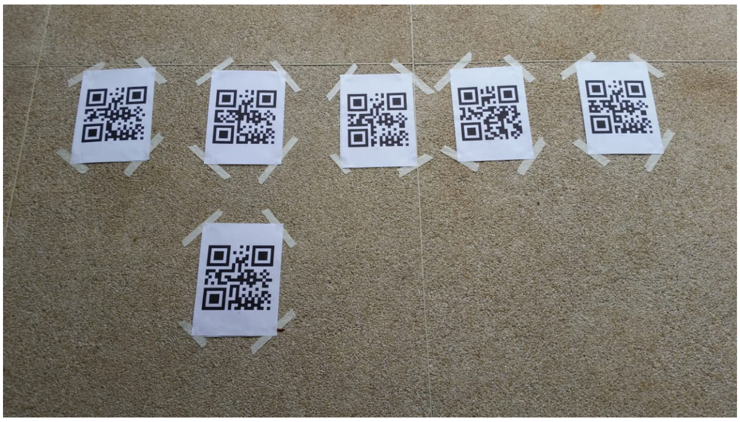
(e) Bus stop

(f) Tactile floor

Following the steps described previously, we took advantage of a tactile floor in the corridor of the Secretariat building as a reference to a tactile floor that really exists in the Paulista Avenue circuit we chose. We then distributed some printed QR codes near this tactile floor, see Figure 39, to sequentially represent the buildings and urban facilities that actually exist along the Paulista Avenue circuit.

Figure 39 – Simulated circuit.

(a) Overview of the simulated circuit.



(b) Demonstration of several stores on the ground floor of a building.

To avoid wasting time during the experiment, we created three different user profiles: one, able to access textual information; another, capable of accessing audio information; the following, capable of accessing sign language videos; and the latest profile, users who volunteer to help PwD in urban space if they need and ask using the UrbanAssist mobile application. We registered the two members of the professional team who conducted the experiment as volunteers. In addition to identifying the user location by proximity to the last object that was selected, UrbanAssist application also monitors, from time to time, the GPS location of the active users that are registered in the system. After receiving the PwD's request for help, UrbanAssist checks which volunteers are closest to the PwD and contacts them, providing the exact position of the person who requested assistance. The first volunteer who touches the "Accept" option on the mobile screen is selected to meet the PwD and help him/her.

We invited approximately 80 users of services offered by the Secretariat for the Promotion of the Rights of People with Disabilities of the Barueri municipality to participate in our study with no financial compensation. Only ten accepted the invitation: five men and five women, ages between 28 and 51 years (Mean: 39.4, SD: 7.9), six participants with visual disabilities (four blinds and two low vision), and four with mobility disabilities – three wheelchaired people, and one person with crutches. All the participants use mobile devices and use these devices to access the Internet. Among the participants, two (20%, men, ages 28 and 51 years old, motor disabilities) had already used QR codes or another barcode reading application. Table 9 provides more detailed information about the participants in the user study. P1, P2, P3, and P8 used the text-based user interface, while P4, P5, P6, P7, P9, and P10 chose the audio-based user interface.

Table 9 – User study: descriptive information on demographics variables.

Participant	Gender	Age	Disability
P1	Male	28	Mobility
P2	Male	51	Mobility
P3	Male	36	Mobility
P4	Female	37	Visual
P5	Male	33	Visual
P6	Female	30	Visual
P7	Female	50	Visual
P8	Female	44	Mobility
P9	Female	43	Visual
P10	Male	42	Visual

As a methodology for this study, we defined a Test Protocol (see Appendix D), which is composed of four parts:

1) Ethics statements: inform the respondent about the privacy and confidentiality aspects of the study;
2) Pre-test questionnaire: attests if the participant uses mobile devices, Internet on mobile devices, and QR code;
3) Training session: a 5-minute training showing the main functionalities of the mobile application;
4) Tasks: we asked the participants to

(a) Find out what is the name of the first block building;
(b) Find a restroom near him/her, practicing the search for generic facilities and receiving a list with several results;
(c) Navigate to the Venice Shopping building, practicing the search for a specific location and receiving the address and some information of this location; and
(d) Ask someone's help to solve a problem the user is experiencing.

5) Post-test questionnaire: administered at the end of the session to capture the impressions the participant had, whether positive or negative, while using the application to perform the tasks.

We installed the application we developed on a Galaxy S5 smartphone configured with 16 GB of internal memory, Android 4.4.2 operating system, and a 2.5 GHz Qualcomm Quad-core processor. Figure 40 depicts a user interacting with the UrbanAssist application to explore and navigate the simulated circuit.

Figure 40 – User interacting with the UrbanAssist application.

Qualitative data – in the form of pictures, audio recordings, and descriptive notes – were gathered to register PwD's comments as they explored and navigated the city. We also wrote down some insights and ideas related to the user interaction mechanisms that have arisen while the user study was being conducted.

7.3 Results

The participants' evaluation was significantly higher than chance (Mean: 9.65, SD: 0.65 – on a rating scale from 0 to 10). In addition, all participants positively evaluated the functionalities provided by the UrbanAssist application. One reason for such high evaluation was that the UrbanAssist application "*enhanced the sense of independence of PwD*" (P10) and "*this application works like a GPS*" (P4). Furthermore, participants appreciated the possibility of interacting with inclusive smart objects, because "*we are able to know what is happening around us, and if we are close to what we are looking for*", "*I can go to the supermarket or take the bus without asking for help*" (P7), and "*to get information without having to ask anything to anyone; sometimes people give wrong information*" (P1).

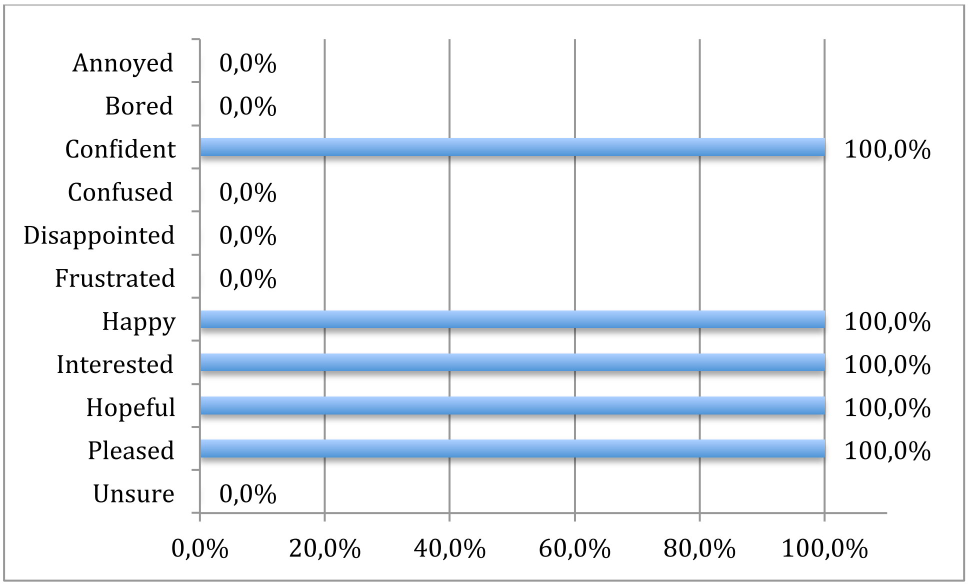
Participants mentioned that knowing in advance whether urban services and facilities are available or not is very important, once it prevents them from wasting their time and warns them to seek other means or alternatives. As P1 says, "*it is outrageous when you have to move to a certain location and find out that the elevator is broken only when you get there, which would hinder PwD from accessing higher floors*". According to P8, this application functionality helps PwD organize themselves, identifying if they need the company of a relative or friend to help them in situations they cannot solve on their own.

Participants appreciated the ability to use the UrbanAssist application to locate someone to assist them, and listed some situations where this functionality would be very useful: "*when I am alone*" (P3), "*when I get to an information desk and there is no one to assist me*" (P4), "*when I am at the bank and I need help from the staff to use an ATM*" (P5), "*when I am lost or I do not know where I am*" (P7).

We employed the Emotion Words Prompt List (EWPL), discussed in Section 5.2.4, to highlight participants' feelings and emotions when interacting with the UrbanAssist application. As Figure 41 portrays, all participants (100%) chose words related to good emotional feelings, stating that they were: confident, happy, interested, hopeful, and pleased.

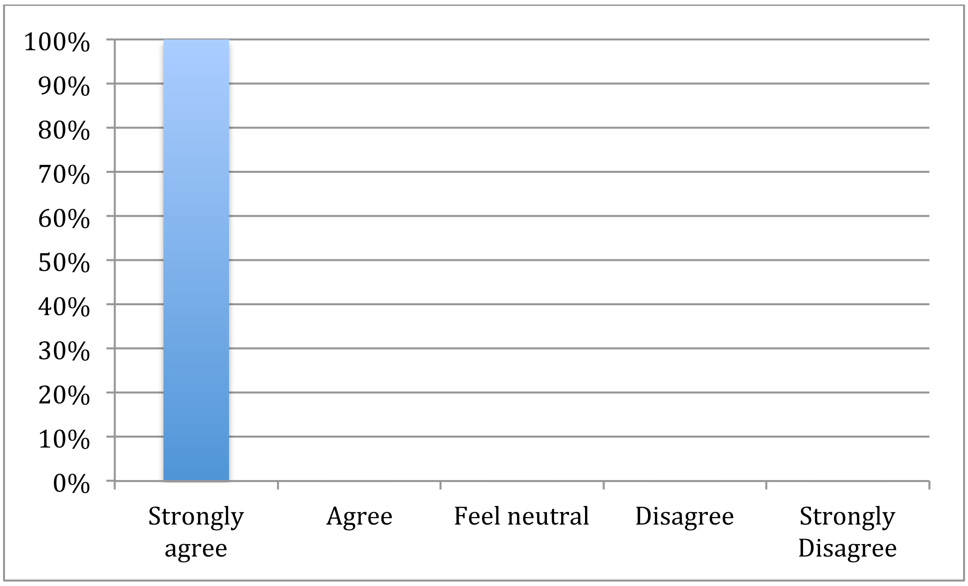
None of the participants chose words related to bad emotional feelings (annoyed, bored, confused, disappointed, frustrated or unsure).

Figure 41 – Participants' emotional reactions when interacting with the UrbanAssist application.



Consequently, in a 5-point Likert-type question, we asked participants to choose an alternative according to their agreement with the sentence "Assistive technologies that allow interacting with objects and things in urban space can increase the independence and autonomy of people with disabilities". As Figure 42 characterizes, all participants chose the "Strongly agree" alternative.

Figure 42 – Participants' conformity that applications as UrbanAssist can increase the independence of PwD.



Finally, we asked participants to point out some possible disadvantages or limitations of the UrbanAssist application. P3 and P6 have reported that some information or locations that users wish to obtain further details are not yet mapped, and that it is difficult to keep all urban objects and facilities registered and up-to-date in the system. P4 and P10 remembered that sometimes user can be left in the lurch because the application crashed, due to lack of signal or connection to a mobile network, or another problem related to the operation of the mobile device. According to P8, she would be in trouble if her cell phone were stolen, making her unable to use the application.

7.4 Analysis

We showed with our design and evaluation of the UrbanAssist application that the approach that we have developed, the ISC, can greatly improve the independence and autonomy of PwD in urban spaces. This was demonstrated when users positively evaluated the resources provided by the UrbanAssist application.

Although we could not count on hearing disabilities participants and although we have invited users who fit into this group and have prepared the UrbanAssist with sign language animations for all the information available in the application. In fact, 60% of our sample is formed by people with visual disabilities, considered the most dissatisfied group of disabled people with the assistive technologies available in cities (see Figure 23) and those most affected by the lack of access to the large number of visual information available in urban spaces (E. Brady, Morris, Zhong, White, & Bigham, 2013; Emiliani & Stephanidis, 2005). Therefore, if people with visual and mobility disabilities have positively assessed the UrbanAssist application, it is plausible that people with hearing disability would also do the same.

Another important aspect to highlight is that the older the users, the more challenges and difficulties they face when using Information and Communication Technologies in general, as they are more reluctant to accept and adopt new technologies (Chung, Park, Wang, Fulk, & McLaughlin, 2010; Ijsselsteijn, Nap, de Kort, & Poels, 2007; Lai & Li, 2005; Lu, Zhou, & Wang, 2009; Morris & Venkatesh, 2000; Renaud & van Biljon, 2008). 70% of participants are over 35 years old. Given that users in this age group have approved UrbanAssist, probably younger users will also positively evaluate this application.

As the results of our study reinforce, the process of designing and developing urban digital assistive technology should not be limited to technical issues and requirements only. It should also be considered that there is a considerable and relevant number of inclusive smart objects available in comprehensive urban areas, and that information about the inclusive smart objects must be maintained and guaranteed to remain up-to-date. In addition, there should be a concern with urban safety, analyzing where the user uses a cell phone and whether the location is safe or not.

The study performed had some limitations. It would be important to conduct larger samples studies with other groups of people with disabilities – or other potential users – to enable statistical testing. However, the present study has made valuable contributions to pointing out interesting discoveries and new avenues of research to investigate the user experience of digital urban assistive technologies.

7.5 Chapter summary

We have designed, developed, and evaluated the user experience of the UrbanAssist application, a digital urban assistive technology that combines Internet of Things and Cloud Computing to help PwD navigate in urban spaces and interact with objects that provide user-adapted content to them. With the development of this PoC, we have demonstrated the feasibility of ISC solutions. UrbanAssist application demonstrates that there is a new way to explore urban spaces and provided a promising and interactive environment that was appreciated by users. We hope our work will bring insights and motivate researchers and designers who want to create innovative experiences for PwD based on direct interaction with the city.

8

Conclusions

In Chapter 1, Introduction, we stated that our research question is "*How to support a better urban experience for people with disabilities?*", and our main hypothesis is that Smart City technologies can play a fundamental role as an approach to answer this question.

As results of an empiric observation, we presented in Chapter 2 how a city communicates with its inhabitants and how visual and auditory are the information available in urban centers to guide and assist citizen to navigate in the urban environment while performing their daily living activities. Such evidences indicate that people with disabilities are excluded from the communicational process that happens in cities, specifically in urban spaces.

In order to address Objective 1 – *Identify the challenges PwD face in urban spaces, as well as the opportunities SC technologies bring to inhabitants* – we first presented in Chapter 3 a literature review on the main topics related to SC and the potential of SC enabling technologies: Internet of Things, Ubiquitous Computing, and Cloud Computing. We also discussed the limitations and challenges of SC, particularly the need to shift from a technology-driven vision to a citizen-centric vision. In addition, we discussed the importance of strengthening the social perspective of SC initiatives. Chapter 4 presented the main concepts related to Accessibility, the different approaches to understanding and studying this subject, especially the Social Approach, which states that disability is not in the individual, but in society and the environment that does not provide the appropriate conditions for the individual to fully participate and be a citizen of social, professional, educational, recreational activities, and so on. Society and the environment need to be corrected and their disabilities compensated to include a significant portion of the population that is excluded from a range of activities when their abilities are not addressed in urban communication processes. In Chapter 4, we also presented the related works that we found in the literature. Most of these works are targeted to a specific disability, a specific group of users, or provide an interaction modality in their user interface.

In Chapter 5, we deepened the study that began with empirical observations (Chapter 2) and then conducted a study based on a multi-instrument approach, consisting of Workshop, Delphi method, interviews, and Focus Group with people with disabilities, accessibility experts, professionals that work with PwD, and policymakers. This study traced a multi-perspective overview in the process of creating public policies focused on accessibility, including the difficulties encountered by PwD in relation to urban spaces, how these difficulties are circumvented, and how PwD deal with unexpected problems that occur in urban spaces. We also verified the impressions that PwD have regarding the assistive technologies available in urban spaces, the emotional feelings that PwD have when they are in urban spaces, the situations in which they depend on the help them, and so on.

Chapter 6 presented the main contributions of this thesis. We began Chapter 6 addressing the Objective 2 – *Provide theoretical background to Inclusive Smart Cities* – while defining ISC as a set of pervasive and digital urban assistive technologies jointly adopted by local government and civil society to assist PwD and improve their independence and autonomy in urban spaces. We argued that ISC should adapt information and digital services available in public spaces, making them suitable to different formats; adjust urban technologies and mobility solutions according to different people's abilities; identify and describe objects and locations, among other features. We also provided a list of requirements that should be observed by the local government and professionals to understand the fundamental issues that must be addressed in ISC initiatives, which could anticipate potential problems and lead to a more successful ISC initiative. Still related to ISC governance and organization, we proposed a Political Structure and Implementation/Operation Methodology, as well as a Business Model. Theses three tools help to align political institutions, civil society, business, professional teams, universities, and R&D institutions in a sustainable manner, aiming at implementing and operating the ISC.

The second part of Chapter 6 addresses the Objective 3 – *Propose a set of technological tools to help designers and developers design Inclusive Smart Cities* –, presenting the Conceptual Model, a list of Design Principles, and the System Architecture that could be used as a reference model to Inclusive Smart Cities. The Conceptual Model envisions that PwD move around the city interacting with smart objects that provide user-adapted information and services – the inclusive smart objects. These inclusive smart objects (a) function as reference points for PwD, (b) can maintain interactive dialogs with PwD, where they provide information and services to PwD and send the requests and choices made by the user to be processed in the Cloud. The next tool, the Design Principles, guide designers and developers to focus on citizens and their abilities while conceiving ISC initiatives. We emphasized the importance of exploring alternative input/output mechanisms, that urban spaces are uncontrolled environments, and that designers and developers should seriously consider the urban context and the situations in which users will interact with the technological solutions available in ISC, that remote information should be balanced with local processing and avoid remote access, among other design principles. Finally, we discussed the ISC System Architecture, composed of the following components: Information Acquisition and Services Request Infrastructure (users and their interactive devices); Inclusive Smart Objects Infrastructure (inclusive smart objects and the environment); Information Management Infrastructure (module responsible for providing tools for registering and maintaining information in various content formats); and Cloud Infrastructure (stores information, processes users' requests, and provides services according to users' preferences and abilities).

In Chapter 7 we presented the PwD's evaluation of the user experience while using ISC technologies. We discussed the UrbanAssist application design, development, and evaluation processes, a digital urban assistive technology conceived as a Proof of Concept implemented according to the ISC vision, i.e., that allows PwD to interact with inclusive smart objects that are available in urban spaces and that provide user-adapted information and the possibility of performing actions, such as finding someone to help the user with disabilities when needed. Overall, participants felt they were able to navigate, explore the simulated circuit, interact with inclusive smart objects, and experience the functionalities and resources of the mobile application. Participants' responses showed that a digital urban assistive technology inspired by the ISC vision is capable of improving the independence and autonomy of PwD in urban spaces.

In this thesis, we discussed and argued the importance of bringing issues related to accessibility and PwD's rights to urban spaces to Smart Cities projects, making them Inclusive Smart Cities. An ISC is about offering alternatives to PwD. ISC's vision provides valuable insights into the design of digital urban assistive technologies. ISC proposals have the potential to positively impact the experiences that PwD have in urban spaces, such as (1) increasing the sense of autonomy of these people, while providing a greater sense of security when navigating in urban spaces, and knowing that (2) they will use mechanisms adapted to their abilities to explore the environment around them, finding objects, locations and points of reference, (3) they are not alone and can ask for help using digital technology solutions that will efficiently signal people who are near them and the authorities, (4) their time is being spent efficiently, (5) they can count on the help of sensors and devices that will help them in their daily activities in urban spaces without wasting their time or cognitive load, and (6) they will have at their disposal innovative technologies to interact with urban spaces and assistive technologies that will help them to play their role as a citizen, reporting any problem to the responsible.

Concluding our research, we understand that this proposal is not an all-in-one tool, nor that it is universally applicable to any city that intends to become smarter and more inclusive. Clearly, cities are pluralistic; they have different priorities and, in general, they also have distinct inhabitant's demands. However, the tools we presented in this thesis describe the core subjects that must be considered and detailed in the ISC creation process. These tools can be used as a starting point and reference point to support authorities and professionals in combining users, resources, digital services and urban environments, in order to delineate the boundaries of a particular ISC.

8.1 Limitations

Because we were focused on the objectives defined for this research, some limitations were found in this thesis, and we describe them as follows:

- The application context is the urban environment, even though many of the results found during the development of this research may also be applied to the private environment;

- The particularities of users with mental or cognitive disorders, and the potential benefit that these users could gain from the solutions created in an ISC have not been considered; and,
- Some issues related to the Cloud Infrastructure, such as load balancing in the Cloud due to the processing of requests from a large number of users, security issues, among others, have not been fully explored.

These limitations can be seen as opportunities to continue this work, which can be investigated and developed by other areas of Computer Science and even by other fields of Science.

8.2 Opportunities for Future Work

From this thesis research, we were able to propose and evaluate novel user experience in urban spaces to help improve the urban experience of PwD. While interacting with PwD and domains experts, we not only addressed our research questions, but we also realize that there are open opportunities for future works to improve the way PwD interact with cities and how PwD interact with other citizens in cities, particularly in the following areas:

- Including people with cognitive disabilities as beneficiaries of ISC technologies;
- Exploring new interactive devices and interaction modalities to provide a more natural user experience;
- Automating, when possible, the process of registering information about objects, users, places and other entities on the ISC platform;
- Defining and describing metrics to evaluate how inclusive a city is, according to the ISC vision; and
- Evaluating the performance of the entire system with a large number of connected users.

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APPENDIXES

Appendix A: Delphi method

Inclusive Smart Cities: definition

Inclusive Intelligent City (ISC) is a set of digital technologies used to help people with disabilities in urban spaces, enabling them to move around cities independently and perform their daily activities autonomously.

People with disabilities will be able to use these digital assistive technologies - such as cell phone, smart cane, smart glasses, smart clocks, digital bracelets, among other alternatives - to interact with objects available on streets and avenues such as buildings, bus stops, traffic signs, landmarks.

Task #1

Instructions:

- Read the following statement and answer the subsequent questions

---

Figure 1 shows the political structure of the Inclusive Smart City.

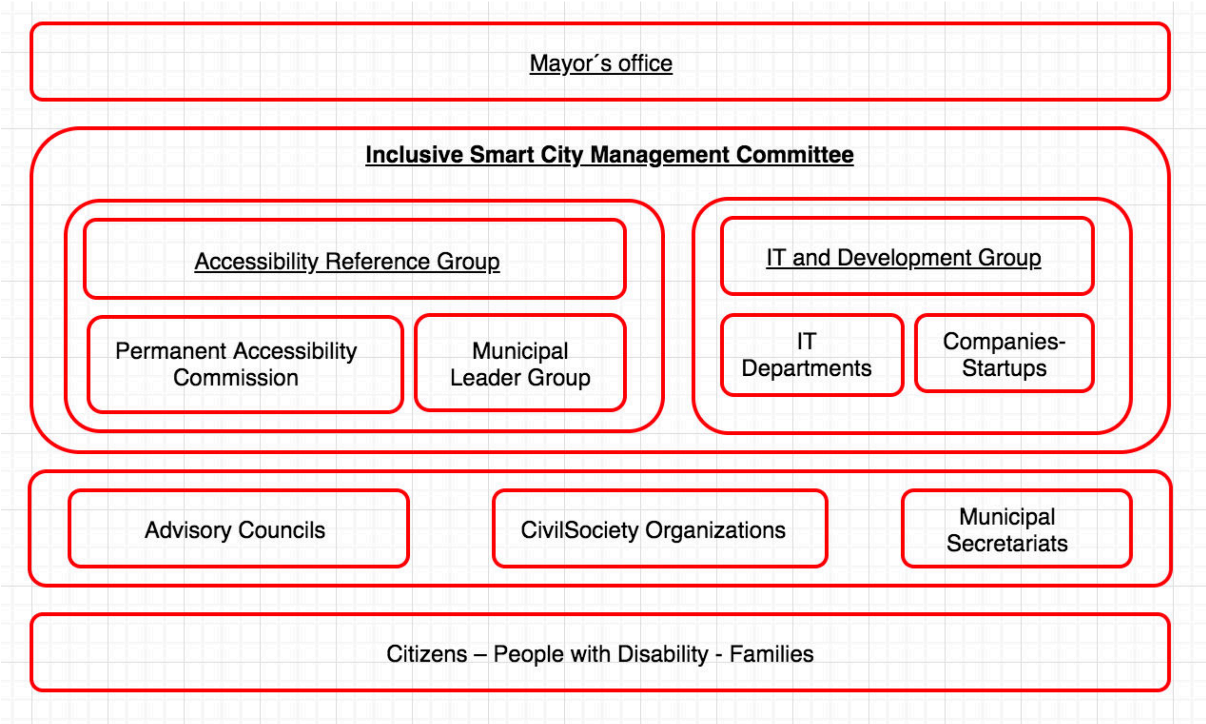

Figure 1 – Local political structure of the Inclusive Smart City.

According to our vision, cities should include in their political structure a new ISC Management Committee:

- ISC Management Committee: institution attached to the Mayor's office responsible to elaborate, execute and follow up projects of digital urban assistive technologies. The Management Committee is formed by two groups:
  - Accessibility Reference Group: support the Management Committee concerning accessibility issues. It is formed by:
    - Permanent Accessibility Commission: elaborates accessibility policies;
    - Municipal Leader Group: supervises the accessibility policy implementation.
  - IT and Development Group: responsible for elaborating technical definitions, defining technological solutions and development processes, user tests, among other technological aspects. The activities of this team can be conducted in a isolated or collaborative way by:
    - IT Departments: IT departments of the municipal official institutions, such as local agencies and secretariats;
    - IT companies and Start-ups:

PwD's demands, as well as the request of ordinary citizens and PwD relatives, are collected by Municipal Advisory Councils, Civil Society Organizations, and Municipal Secretariats and then forwarded to the ISC Management Committee

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Task #1

Questions:

- Do you agree with the components of the ISC and their goals? Do you recommend any modifications (inclusion and exclusion)?
- Do you agree with the proposed hierarchy for the ISC? Do you recommend any modifications in the hierarchy of the ISC?

Task #2

<u>Instructions:</u>

- Read the following statement and answer the subsequent questions

Figure 2 depicts the ISC implementation and operation methodology

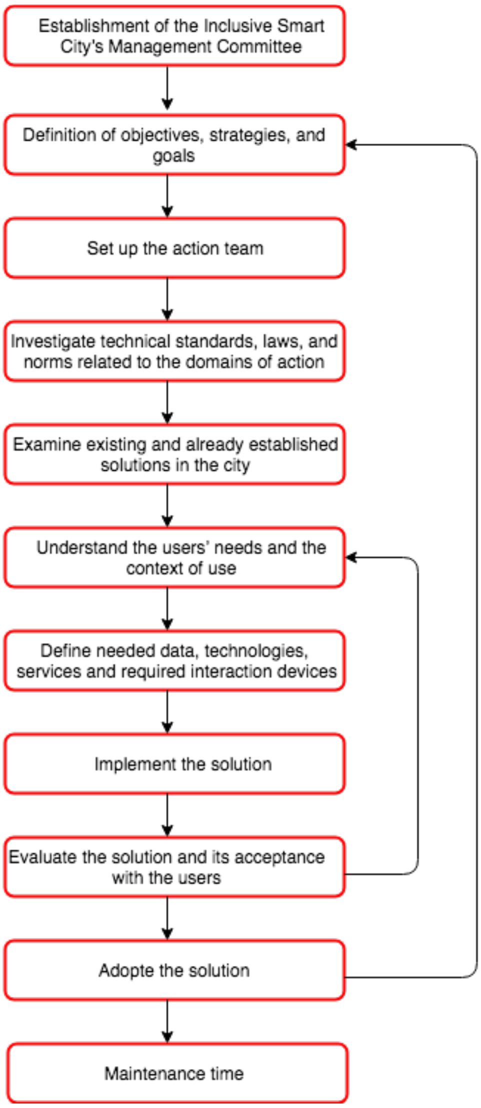

Figure 2 – ISC policymaking process.

According to Figure 3, the projects related to ISC initiatives follow the steps:

1. Setting up of the ISC Management Committee;
2. The Management Committee define the goals and priorities of the ISC;
3. The Accessibility Reference Group supports the Management Committee to define the problems to tackle and define a set of actions to solve these problems;

4. The Management Committee define the multi-experts teams to work in each action;
5. The experts teams seek for existing standards, norms, and regulation on the same domain of the action they are responsible for;
6. Experts investigate similar solutions already available in the city;
7. Each experts' team try to understand the users' need and the problem context;
8. The team should investigate the functionalities of interactive devices and other technologies to solve the problem;
9. Develop of the digital urban assistive technological solution;
10. Evaluate the solution created until the users approve it. While users do not aprove, the experts' team must go back to Step 7;
11. When the solution is approved, it can be adopted and be used in urban spaces of the ISC. The team should go back to Step 2 and revise the strategies and goals of the ISC taking into account the new adopted technological solution.

Task #2

Questions:

- Do you agree with the steps proposed to the ISC implementation and operation methodology? Do you recommend the inclusion or exclusion of any steps?
- Do you agree with de description of each step?

Appendix B: Survey – The human experience in public spaces

This survey has been developed to evaluate the experience of people with disabilities when they have to leave their house/office to perform activities in public areas.

The survey seeks to identify problems and barriers that people with disabilities face when they are in public spaces.

We respect participants' privacy. Any provided information will be treated confidentially and used for academic matters. No identifying information will be collected, published or transferred to any other person.

You may stop answering the questions whenever you want. Please complete as many questions as you can, or choose to answer.

Consider public space as the sharable social space outside of your home, office, classroom etc. Generally, public spaces are open and accessible to people. Examples of public spaces: streets, avenues, subway stations, building entrance halls etc.

1. Are you a person with a disability?
* Mark only one oval.
a. Yes
b. No

2. If you answered YES to Question 1, which disability?

3. Age?
* Mark only one oval.
a. Under 18 years old
b. Between 18 and 29 years old
c. Between 30 and 44 years old
d. Between 45 and 64 years old e. 65 years or older

4. Gender?
* Mark only one oval.
a. Male
b. Female
c. Other

If you answered "Other", please, name it.

5. City? *

6. Country? *

7. For which of the following activities you do connect to the Internet using a smartphone or other equipment? (Check all answers that apply)
a. I don't use the Internet

b. Play music, videos or games
c. Make or receive phone calls
d. Read daily news
e. Send and/or receive mails, SMS messages, Whatsapp messages
f. Use social networks (such as Facebook, Twitter, LinkedIn etc.)
g. Pay bills
h. Other activities

If you answered "Other activities", please, describe them

8. How often do you use your mobile device (mobile phone, tablet …) to access apps or to connect the Internet? Mark only one oval.
a. 1 to 5 times a day
b. More than 5 times a day
c. I don't have any mobile device but I connect to the Internet using other equipment(s)
d. I don't have any mobile device and I don't connect to the Internet

9. Do you connect to the Internet when you are outside or in public areas?
Mark only one oval.
a. Yes
b. No

10. If you answered YES to Question 9, what for?

11. Which of the following activities do you perform outside of your home/office and where your mobile device would help you taking into account your current position? (check all answers that apply) Check all that apply.
a. Find people that are near to you
b. Check the weather forecast
c. Find local events
d. Finding information about public transportation (for example: location of a bus stop, subwa y station, bus timetable …)
e. Access information about commercial products/services around where you are
f. Find a home/apartment to buy/rent around where you are
g. Access online maps/ Get directions to go from where you are to another point in the city
h. Contact a cab or any other transportation network business to take you from one place to another
i. Play location-based games (such as PokémonGo Game)
j. Other activities

If you answered "Other activities", please, describe them

For questions 12,13, 14 and 15, imagine the following situation:

You have an extremely important appointment in a neighborhood where you have never been before and you aren't familiar with the area.

12. How would you get information about the neighborhood and how to arrive at the meeting on time?

13. What kind of information about the neighborhood do you think is useful to have before leaving your home to go to the meeting?

14. What kind of problems would you face on your way to appointment's place?

15. What do you think would help you to solve your problems?

16. How do you usually solve unexpected problems that happen in public spaces?

17. When you arrive in a place where you have never been before how do you discover if the place provides assistive technology for people with disabilities (such as Braille signs, accessibility ramps, elevator etc.) and, if they are provided, how do you find them?

18. Mark the following alphabetically ordered words that describe your feelings when you are outside (check all answers that apply): Check all that apply.
a. Annoyed
b. Bored
c. Confident
d. Confused
e. Disappointed
f. Frustrated
g. Happy
h. Interested
i. Hopeful
j. Pleased
k. Unsure
l. Other

If you answered "Other", please, describe them.

19. How would you describe your overall evaluation of the assistive technology provided in public areas by your city? Mark only one oval.
a. Strongly satisfied
b. Satisfied
c. Neutral
d. Dissatisfied
e. Strongly Dissatisfied

20. Describe the reasons of your overall evaluation of the assistive technology provided in public areas by your city:

21. Have you ever experienced any emergency or embarrassing situation in a public space (such as getting lost or needing to go to the restroom)? If yes, describe some of these situations and how you dealt with it?

22. Could you describe some situations in the city that are impossible to do by yourself a nd in which you need someone's assistance?

23. What does mean the expression "quality of life" concerning living in a city mean for you?

24. Have you heard about progress or innovations for people with disabilities that are provided in other cities that you would like to have in your city as well?

25. How do you think your city could be more efficient helping you and other PwD to perform your daily activities in urban areas?

26. Mark the following goals that you think should be priorities for local government (check all answers that apply).
a. Safe and security
b. Environment
c. Transportation
d. Home energy management
e. Educational facilities
f. Tourism
g. Citizens' health
h. Other

27. Concerning the previous questions (Question 26), would you add other goals?

28. Please add any other comments you may have related to your experiences in urban spaces here:

Appendix C: Detailed information on demographics variables

Disability	Frequency (N=71)	Demographic variables		Frequency (N=71)
Auditory	4	Gender	Male	1
			Female	3
		Age	18-29	2
			30-44	2
		Country	Brazil	3
			United States	1
Mobility	30	Gender	Male	17
			Female	11
			Other	2
		Age	18-29	5
			30-44	15
			45-64	8
			>64	2
		Country	Brazil	21
			Canada	1
			France	5
			Switzerland	1
			United States	2
Multiple disabilities	5	Gender	Male	1
			Female	2
			Other	2
		Age	18-29	2
			30-44	2
			45-64	1
		Country	Brazil	1
			France	1
			United States	3
Visual	32	Gender	Male	21
			Female	11
		Age	18-29	15
			30-44	5
			45-64	9
			>64	3
		Country	Brazil	29
			France	1
			Germany	1
			United States	1

Appendix D: UrbanAssist application – test protocol

Part 1 – Ethics statements

- *Informs participant about privacy and confidentiality issues.*

Part 2 – Pre-test questionnaire

- Age:
- Gender:
- Disability:
- Familiarity with technology:
    - Do you use mobile devices?
    - Do you use Internet on your mobile device?
    - Have you already tagged QR Codes or any other bar code using a mobile device?

Part 3 – Training session

Part 4 - Tasks
Using the mobile application...

1. In front of which building are you right now?
2. Find a bathroom near where you are.
3. Go to Venice Shopping building.
4. You need to discover which store sells headphones for your cell phone. Ask someone for help.

<u>Part 4 – Post-test questionnaire</u>

1. Interacting with objects and buildings that are on the streets seems interesting to you? How can this kind of interaction help you?
2. Is it important to you to know about services and resources that are not available or are in maintenance? In what kind of situations this prior information is important?
3. Having the ability to use a mobile phone to locate an assistant or other person close to where you are and help you is important to you? Can you imagine a situation where this feature would be useful?
4. Considering that in the future you would be able to interact with objects and things in the city, do you feel:
    - a. Annoyed;
    - b. Bored;
    - c. Confident;
    - d. Confused;
    - e. Disappointed;
    - f. Frustrated;
    - g. Happy;
    - h. Interested;
    - i. Hopeful;
    - j. Pleased;
    - k. Unsure; or
    - l. Other?

        If you answered "Other", please, describe it.

5. What limitations or drawbacks do you see in the technology you have just used?

6. Consider the statement: "Assistive technologies that allow you to interact with objects and things in the urban space can increase the independence and autonomy of people with disabilities.". Do you:
    - a. Strongly agree;
    - b. Agree;
    - c. Feel neutral;
    - d. Disagree; or
    - e. Strongly Disagree?

Appendix E: Publications

During the period of preparation of the present thesis the following scientific contributions were presented, reporting the related studies in development by the PhD candidate:

de Oliveira Neto, João Soares, et al. "When Wearable Computing Meets Smart Cities: Assistive Technology Empowering Persons With Disabilities." Examining Developments and Applications of Wearable Devices in Modern Society. IGI Global, 2018. 58-85.

de Oliveira Neto, J. S., & Kofuji, S. T. (2016). Inclusive Smart City: An Exploratory Study. In Universal Access in Human-Computer Interaction. Interaction Techniques and Environments (p. 456–465). Springer, Cham. https://doi.org/10.1007/978-3-319-40244-4_44

de Oliveira Neto, J. S., & Kofuji, S. T. (2016). Inclusive Smart City: Expanding design possibilities for persons with disabilities in the urban space. In 2016 IEEE International Symposium on Consumer Electronics (ISCE) (p. 59–60). https://doi.org/10.1109/ISCE.2016.7797370

Magami, F. M., Pérez-Alcazar, J. J., Nakano, F., Silva, A. L., de Oliveira Neto, J. S., & Kofuji, S. T. Abordagem semântica para o desenvolvimento de sistemas de suporte a ambientes inteligentes inclusivos. CSBC – Congresso da Sociedade Brasileira de Computação, São Paulo, 2017.

ÉCOLE DOCTORALE
Sciences et technologies de l'information et de la communication (STIC)

Titre : Villes Intelligentes Inclusives : théorie et outils pour améliorer l'expérience des personnes en situation d'handicap dans l'espace urbain

Mots clés : Accessibilité, Villes Intelligentes, Personnes en situation de handicap, Technologie d'assistance, Internet des objets.

Résumé : Les villes ont eu recours à des technologies dans plusieurs domaines pour améliorer la prestation de services publics, répondre aux demandes des citoyens et mesurer la consommation de ressources naturelles. Connues sous le nom de Villes Intelligentes, ces initiatives visent à améliorer la qualité de vie des citoyens et ont déjà eu un impact positif sur la manière dont les citoyens interagissent avec les espaces urbains, les services et les uns avec les autres. D'autre part, les espaces urbains peuvent être considérés comme une menace pour l'indépendance et l'autonomie des personnes en situation d'handicap. Nous avons utilisé une approche multi-instruments pour collecter des données auprès de différentes parties prenantes – personnes en situation de handicap, professionnels travaillant avec des personnes en situation de handicap, experts liés à l'accessibilité et décideurs politiques, – afin de comprendre les obstacles rencontrés par les personnes en situation de handicap. Nous avons d'abord élaboré une définition du terme Ville Intelligente Inclusive, ainsi que nous avons proposé des outils pour soutenir les praticiens et chercheurs engagés dans le développement de technologies d'assistance numériques : une méthodologie d'implémentation et fonctionnement, un modèle conceptuel et une architecture de système sont proposés dans cette thèse.

Title: Inclusive Smart Cities: theory and tools to improve the experience of people with disabilities in urban spaces

Keywords: Accessibility, Smart Cities, People with Disabilities, Assistive Technology, Internet of Things

Abstract : Cities have used technologies in a number of areas to improve the delivery of public services, meet the demands of citizens, and measure the consumption of natural resources. Known as Smart Cities, these initiatives aim to improve the quality of life of citizens and have already had a positive impact on how citizens interact with urban spaces, services and with each other. On the other hand, urban spaces can be considered as a threat to the independence and autonomy of people with disabilities. We used a multi-instrument approach to collect data from different stakeholders - people with disabilities, professionals working with people with disabilities, accessibility experts and policy makers - to understand the barriers faced by people with disabilities. We first developed a definition of the Smart Inclusive City, as well as proposed tools to support practitioners and researchers engaged in the development of digital assistive technologies: an implementation and operation methodology, a conceptual model, a business model, and a system architecture are proposed in this thesis.