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Smart cities and enabling technologies: influences on urban Facility Management services

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Abstract. The application of innovative Information and Communication Technologies (ICTs) to the field of Urban Facility Management (UFM) outlines new possibilities for optimizing existing services and for developing new services based on the key concepts of: Internet of Things (IoT), Big Data, information sharing and smart applications. Such ICT-based services could potentially be able to: transform the demand for infrastructures and physical assets; participate to requalification processes; influence the sustainability of the built environment as well as the economic value of urban areas. Starting from this premise, the paper deals with the contents and the current results of an ongoing research whose aim is to propose sets of classification and coding rules and a framework for identifying, analysing and linking Smart Cities (SC) domains and sub-domains, related UFM services and the various levels of enabling ICT technologies. The application of the proposed framework to a selected representative sample made up by both European Initiatives (e.g. H2020 projects) involved with SC solutions at the urban scale and virtuous cases of cities that have implemented smart solutions, allows to collect, allocate and process information, in a unified way, in order to:

- identify and describe the current main trends within each of the SC domains (e.g. mobility, energy, waste, building, governance) and sub-domains;
- implement a taxonomy of UFM services, including related characterising parameters and stakeholders;
- identify and analyse, according to reading keys, smart UFM services that may have meaningful impacts (accessibility, transport, land-use, etc.) on urban areas;
- draw the current innovative scenarios of smart UFM services enabled by ICTs, characterized by information sharing (Big Data flows) and by the integration of physical and digital infrastructures and assets;
- highlight the emerging and widespread enabling technologies for smart UFM services, related to each of the layers of the technological infrastructure (e.g. sensing, network, platform, analytics, applications);
- investigate the possibility of the creation of context-aware communities through the inclusion of multiple social components.

The research, which is part of the PRIN research “Metropolitan cities: economic-territorial strategies, financial constraints and circular regeneration”, aims at providing interpretive keys and structured information, useful to study, evaluate and compare possible influences and impacts of the smart UFM services on the sustainability of the urban environment and on the dynamics of property values. The scenario that emerges from the analysis is inscribed in the broader framework of the circular economy where, with the support of ICTs -based services, cities can put in place virtuous processes to reduce, recycle and reuse waste.



1. Introduction. Exploring the Concept of Smart City

The latest years of the 20th century have been characterized by the rising of two major phenomena, the increasing urbanization and the spread of Information and Communication Technologies (ICTs) [1]. The growth of urbanization has been dramatic over the past two decades [2], we have witnessed the progressive abandonment of rural areas towards cities which can offer many opportunities in terms of education, work opportunities, social life and quality of life in general. Oracle (2011) in its White Paper of June 2011 states that urbanization is nowadays a continuously growing phenomenon that it is expected to further intensify [3]. Moreover, according to Lierow (2014), by 2050 it is expected that the 70% of the population will live in cities [4]. This phenomenon has two main implications, on one hand it causes an increase of the cultural level and a growth of the economic conditions of the city, on the other hand the concentration of people within the city causes a variety of technical, social, economic and organizational problems that undermine the economic and environmental sustainability of the city [5]. The increase of urbanization implies increased levels of traffic, pollution, gases emission and waste and social inequality which generate negative implications both for people and environment. Consequently, the impacts of the concentration of people within cities are reflected in a higher energy consumptions and pollution levels, increased volume of urban waste, fewer adequate infrastructure, decrease of social cohesion and so on [6]. More in general, the urbanization process has impact of different nature and intensity on the main issues related to the economic development, the social development and the environmental protection [7]. As a consequence, cities at the global scale started to seek for optimal solutions in order to efficiently handle and face new challenges. In the nineties, the urgency to successfully face these challenges and these impacts began to animate the debate of policy makers and urban planners and managers around the world, triggering them to find smarter way to manage cities. In parallel, the exponential development of the Information and Communication Technology (ICT) sector in those years led policy makers, urban planners and urban managers to pay a great attention to technological solutions, investigate their potential contribution in facing these issues. In this context the term Smart City started to be introduced and used by the stakeholders of the sector, recognizing the support of the new ICTs in enhancing the planning and management of cities contributing to the reduction of the aforementioned urbanization impacts by offering:

- advanced capability of monitoring, analyzing and interpreting city and citizens' behaviours [8] [9];
- innovative solutions for integrating physical and digital infrastructures for improving services [10] [8] [11];
- advanced techniques and procedures to exploit information both to optimize the decision-making processes and to improve the operational coordination of activities;
- ICT-based solutions to enhance the responsiveness of the city to changes in context conditions;
- supporting collaboration between municipalities, business community and citizens [12] [7] [10] [9].

Thus, the concept of Smart City as testing ground to investigate ways to exploit and take advantage of new ICT-based solutions, as well as new approaches to urban planning and living [13] [5] became to spread globally. In the late nineties, the Smart Growth Movement, which promote new policies for urban planning [14] [15], introduces and formalizes the paradigm of a smart development of urban areas, understood as conscious development careful to the issues of environmental, economic and social sustainability, and moreover it initiates the gradual diffusion of Smart City projects around the world. In particular, the concept of Smart City begins to spread by finding its foundations in the creation and management of intelligent infrastructures, advanced digital services and in the creation and support of human connection. The concept of smart city growth, understood as above, includes three main axes [16]: sustainability understood in its three meanings (social, environmental and economic); governance and intelligent control of the territory, its infrastructures and physical assets and the services offered by and for them; social inclusiveness and territorial cohesion. Therefore, a Smart City has the objective of achieving these objectives using ICTs, thus digital technological infrastructures and solutions based on technological solutions declined and applied in the various areas of interest in urban planning and management. Despite a great spreading of ICT experimentations for an advanced urban planning and

management, over the years, this diffusion was not followed by a common practice in the design and implementation methods. Therefore, the different approaches to the paradigm of Smart City concretized by the various countries have led to dissimilar initiatives and policies according to the different features, properties and needs of the different countries. Thus, these different ways of understanding the city makes it difficult to identify nowadays a common and unambiguous definition of Smart City that is consolidated and shared at a global scale. Over the years, only a limited number of studies have systematically investigated, analyzed and described the nodal points, issues and key impacts related to this new urban phenomenon of Smart Cities. To date, there are many definitions of Smart City, evidence that currently there is not a clearly and unanimously established Smart City vision [5] and probably the achievement of a comprehensive definition of Smart City is still far [1]. Obviously, this is also due to the fact that the concept of Smart City itself is still emerging and therefore the work of definition and conceptualization is still on-going. Indeed, nowadays the notion of Smart City is expressed through different definitions, shades of meaning, nomenclatures and contexts all over the world and, moreover, there is also a wide range of adjectives largely used - properly and improperly - as variants of the term "smart" as, for instance, intelligent, advanced, sustainable, digital, livable, etc. which increases the lack of clarity around the definition of this concept. Within the professional and academic fields, a multiplicity of Smart City definitions have been proposed till now, as showed in Table 1.

Table 1. Definitions of Smart City.

Author, year	Smart city definition	Keywords
Hall, 2000 [17]	<i>"A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens".</i>	Resources optimization; preventive maintenance; monitor security aspects.
Batty, 2007 [12]	<i>"...a virtual city is a city where bricks and mortar, buildings and their materials are represented as polygons and textures, is digital data. Data is key to our knowledge and understanding of the form of the city but its geometry must be distinguished from its other more substantive attributes which might be both physical and social".</i>	Digital data; virtual space.
Giffinger et al., 2007 [18]	<i>"A Smart City is a city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens".</i>	Forward-looking way in economy, people, governance, mobility, environment, and living; Self-decisive activities.
Caragliu et al., 2009 [19]	<i>"A city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance".</i>	Communication infrastructure; economic growth; quality of life; resources management; participatory governance.
Harrison et al., 2010 [20]	<i>"A city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city".</i>	Physical, IT, social and business infrastructure.
Toppeta, 2010 [21]	<i>A city "combining ICT and Web 2.0 technology with other organizational, design and planning efforts to dematerialize and speed up bureaucratic processes and help to identify new, innovative solutions to city management complexity, in order to improve sustainability and livability".</i>	Organizational, design and planning efforts; Sustainability and livability.
Washburn and Sindhu, 2010 [22]	<i>"[...] the use of smart computing technologies to make the critical infrastructure components and services of a city - which include city administration, education, healthcare, public safety, real-estate, transportation, and utilities - more intelligent, interconnected, and efficient"</i>	Computing technologies.
Gartner, 2011 [23]	<i>"A smart city is based on intelligent exchanges of information that flow between its many different subsystems. This flow of information is analyzed and translated into citizen and commercial services. The city will act on this information flow to make its wider ecosystem more resource efficient and sustainable. The information exchange is based on a smart governance operating framework designed to make cities sustainable".</i>	Intelligent information flow; information exchange.
Shaffers et al., 2011 [24]	<i>"Smart Cities are integrated social, physical, institutional, and digital spaces, in which digital components improve the functioning of socio-economic activities, and the management of physical infrastructures of cities, while also enhancing the problem solving capacities of urban communities".</i>	Management of physical urban infrastructure; problem solving capacities.
Dameri, 2013 [25]	<i>"A smart city is a well-defined geographical area, in which high technologies such as ICT, logistic, energy production, and so on, cooperate to create benefits for citizens in terms of well-being, inclusion and participation, environmental quality, intelligent development; it is governed by a well-defined pool of subjects, able to state the rules and policy for the city government and development".</i>	Well-being; inclusion and participation; environmental quality.
European Innovation Partnership on Smart Cities and Communities. European Commission, 2013 [26]	<i>"Smart cities should be regarded as systems of people interacting with and using flows of energy, materials, services and financing to catalyze sustainable economic development, resilience, and high quality of life; these flows and interactions become smart through making strategic use of information and communication infrastructure and services in a process of transparent urban planning and management that is responsive to the social and economic needs of society".</i>	Sustainable economic development; resilience; high quality of life. ICTs; urban planning and management.

BSI PAS 180:2014. Smart Cities. Vocabulary, BSI. 2014 [27] ITU-T Focus Group on Smart Sustainable Cities, 2014 [28]	<p><i>"Smart Cities is a term denoting the effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens".</i></p> <p><i>"A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects".</i></p>	Integration of physical, digital and human systems. Quality of life; urban operation and services; competitiveness.
Manville et al., 2014 [29]	<p><i>"...a city seeking to address public issues via ICTs-based solutions on the basis of a multi-stakeholder, municipally-based partnership"</i></p>	ICTs-based solutions; a multi-stakeholder, municipally-based partnership.
Ratti et al., 2014 [30]	<p><i>"The idea of a senseable city is to engage in a real-time and ongoing loop of information, between the city and its citizens, towards enabling a more sustainable future".</i></p>	Sensing; Real-time information; loop of information.
Sagl et al.,2015 [31]	<p><i>"Smart cities are complex and dynamic systems that include a wide range of physical and environmental features, as well as social and human-related components and that require smart technological infrastructures with advanced sensing capabilities. Thus, we can say that the major smart city domains are humans, environment and technology".</i></p>	Technological infrastructures; sensing capabilities.
Anthopoulos, 2017 [32]	<p><i>"The utilization of ICT and innovation by cities (new, existing or districts), as a means to sustain in economic, social and environmental terms and to address several challenges dealing with six dimensions: people, economy, governance, mobility, environment and living".</i></p>	ICT; SC dimensions: people, economy, governance, mobility, environment and living

The analysis of Smart City definitions allows to outline some recurrent characteristics that are able to describe the added value offered by the smartness of a city. In particular, despite the multiplicity of definitions, it is possible to observe that the analyzed definition share a vision of the Smart City (Figure 1) which involves three *Pillars* (citizen engagement, ICT infrastructure and urban services) and six broadly recognized *Dimensions* (people, economy, governance, mobility, environment and living). On the basis of this six Smart City Dimensions, it is possible to identify the *Domains* of a Smart City, taking into account the point of view of urban managers who has to manage urban facility management services that cross several domains of interest of a city. In particular, in the context of this article, the Smart City domains have been proposed starting from the analysis of the traditionally conceived Urban Facility Management (UFM) services [33] [34] [35] and thinking of such services as areas of interest to be investigated to define innovative smart UFM services, based on the application of the recent ICT tools and solutions.

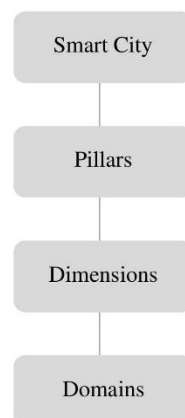


Figure 1. Articulation of the Smart City concept.

2. Methodology

2.1. Conceptualizing smart city pillars, dimensions and domains

The Pillars of a Smart City are represented by Citizen engagement, ICT infrastructure and Urban services (Figure 2). In particular:

2.1.1. Citizen Engagement. An informed and active social fabric represents the core of Smart Cities. In fact, the development of Smart Cities must be guided by the community, even before giving space to

investments in technological solutions. Citizens are an invaluable source of information for the understanding of issues and needs in terms of quality and appropriateness of the provided urban services. Therefore, urban planning and management should be based on the outcomes of a preliminary phase aimed at identifying and analyzing the root causes of the problems - capitalizing on all that informal informative base represented by the experiences and opinions of the inhabitants - to design better urban services able to produce tangible and appropriate results to intercept the real needs of citizens. Technology alone is not the agent of change. Citizens have the role of the main catalyst that accelerates smart city initiatives. In fact, the success of a Smart City is determined primarily by the degree of citizen involvement in the creation of the Smart City itself. Therefore, the dialogues among citizens and policy makers, urban planners and managers are fundamental for the planning and action strategies and in particular for the collection feedbacks aimed at adjusting and improving the current and future policies. Moreover, with respect to technology, the level of engagement of citizens plays a fundamental role to reach a satisfactory level of acceptance of technological tools and solutions, thus citizens should be supported in the development of their digital mentality and competence, for example through information campaigns delivered through open portals of sharing and exchange of information about the concept of Smart City and its different peculiar aspects of interest.

2.1.2. ICT infrastructure. The ICT infrastructure and the connectivity represent a key element for Smart Cities and their advanced planning and management. Converging physical and virtual worlds, by means of a robust network of applications and devices connected through an object-enabled infrastructure capable of collecting and transmitting data flows (Big Data) in real time, local authorities can improve their capability of detecting, monitoring, understanding and interpreting urban phenomena. They can now monitor in real-time key city functions, from traffic control, to public transport, to surveillance cameras, to sensor systems, to air quality monitoring, and so on, in order to mitigate or prevent urban issues and undesired events. Indeed, the numerous developments in the field of information management, Internet of Things technologies, the capabilities of Big Data Management & Analytics, as well as the wide and widespread development and diffusion of technologies for the detection of different aspects of the urban environment (infrastructures, buildings, green spaces, pollution levels, etc.), are opening innovative monitoring and control scenarios useful for the optimization of decision-making processes. In light of this, it is possible to conceive the Smart City as an urban network, whose nodes are represented by physical assets (buildings, physical infrastructures, etc.) that act as information terminals interested by a flow of bi-directional information (in- out) with the city [8]. In fact, physical assets, thanks to IoT and connectivity, are able to be linked within the urban complex system, becoming units for collecting inputs and exchanging outputs, contributing to increase the levels of knowledge of the city and its on-going and future phenomena and the levels of control of city management processes [8].

2.1.3. Urban services. Services here means both services to/on the territory and governance services. As regards the services on/to the territory, therefore the urban facility management services, it is possible to integrate the ICTs to optimize the traditional services and propose new end-to-end services able to increase the level of citizen satisfaction, implementing at the same time solutions able to reduce operating costs as well as the impact of the city - and its services - on the environment. In particular, nowadays the attention of local authorities is focusing on the design, implementation and management of solutions for cities - based on the application of new technologies and innovative business models - characterized by shared information and network approach. As regards governance services, the key innovation lies in the development of new possible models and processes for managing knowledge and flows of people, materials and energy, passing from vertical management models (linear processes and single decision-making centers where departments dedicated to different city domains do not communicate with each other and do not exchange data) to integrated and collaborative management models, based on the integration and the sharing of information, favoring horizontal collaboration among departments - capitalizing in a centralized way the available information useful to all departments - concretizing the advantages deriving from the network approach.

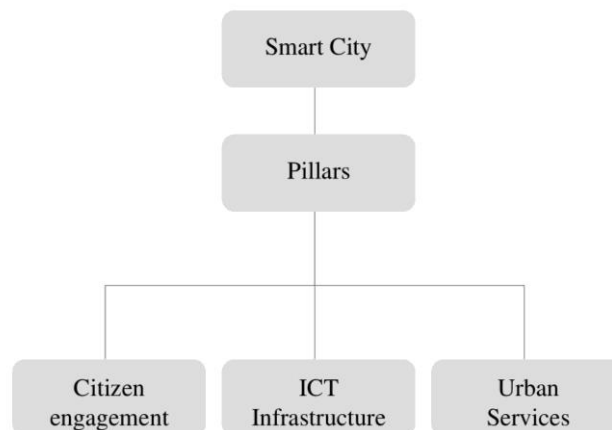


Figure 2. Smart City Pillars.

The six dimensions of the Smart City are nowadays commonly recognized and accepted worldwide by practitioners and academics. In particular (Figure 3):

2.1.4. Economy. A high degree of economic competitiveness is considered one of the key drivers for an intelligent city. In particular, the term Smart Economy identifies a holistic concept that includes: ICT-based innovation, thus the activation of ICTs and the production and delivery of advanced services (e.g. e-business and e-commerce); new products, services and business models which have the potential to enable an increase in productivity; the establishment of virtuous interconnection and integration - at local, national, international and global scales - of physical and virtual flows of goods, of services, and also of skills, knowledge and best practices. In fact, the foundations of a Smart Economy are represented by innovation, entrepreneurship, labor market flexibility, integration with international markets and transformation ability [36] [37] [29] [38] [39] [40] [41].

2.1.5. Governance. Smart Governance is a cross-cutting matter with respect to the various areas of the Smart City. It includes: (i) connection and integration between public, private, civil organizations - at the national, international and global scales - so that these actors can work together to achieve common goals, acting as a single body with a critical mass capable of enabling innovation; (ii) the promotion of innovation in the provision (interface and delivery) of public services to the citizen, exploiting technology to create advanced means and tools to inform, communicate and create dialogue between the subjects mentioned in point (i). The main enabling tool to achieve this goal is presented by ICTs that are able to activate inclusive processes, to share knowledge among stakeholders, to ensure interoperability between systems and to create and feed databases over time. It is possible to state that the foundations of a Smart governance are: participatory decision-making processes, transparency and open data. These represent the key requirements for the establishment of an e-government, thus for the provision electronic (public and social) services provided for example through desktop or mobile apps [39] [42].

2.1.6. Mobility. The term Smart Mobility refers to the level of local and supra-local accessibility, to the availability of ICTs to prepare sustainable, available and safe transport systems. The focus is therefore on the infrastructures and on the transport and logistics systems and on how they can be integrated, supported, improved and innovated by ICTs. The applications of ICTs aim, therefore, to achieve sustainable, secure and interconnected transport systems and they involve, for example, trams, buses, trains, subways, cars, bicycles and pedestrians in situations that use one or more modes of transport. Relevant real-time information - appropriately accessible to operators and / or to the public - is exploited in order to improve the efficiency of transport networks and services and their management in the short,

medium and long term, to reduce costs and CO₂ emissions, provide feedback to citizens and improve their level of satisfaction.

2.1.7. Environment. The term Smart Environment includes several issues related to the following general topics: sustainable management of resources; management of energy, water, physical assets, waste, etc.; enhancement and control of the attractiveness of natural conditions; management, control and reduction of pollution. The activities of monitoring and control of relevant parameters - concerning the above mentioned areas of interest - are improved by the integration of ICTs, which open up new opportunities such as widespread monitoring thanks to sensor networks, a detection of real-time values and the possibility of analyzing the data collected in order to optimize decision-making processes and management strategies in the short, medium and long term [8]. ICT can also support the creation of national and international networks of stakeholders in sharing experiences and knowledge in order to support the definition of environmental objectives and appropriate policies.

2.1.8. Living. The term Smart Living, meant as a unique and integrated concept and approach, includes factors such as cultural and educational facilities, personal health conditions, individual safety conditions, housing and accommodation quality, tourism facilities, tourist attraction and social cohesion [37]. The main goal of Smart Living, which is also realized through the integration and application of ICTs, is therefore the increase in the quality of life of citizens that can be evaluated through the measurement of the levels of endowment, availability and quality of physical and digital assets and infrastructures related to the above mentioned factors included in the concept of Living. ICTs can improve the capability of analysis and interpretation of the social behavior in order to monitor and prepare strategies, instruments and tools able to promote social cohesion and the creation of social capital.

2.1.9. People. The term Smart People involves several aspects (e.g. skills, attitudes, functions, utilities, etc.) related to citizens, or better to "Smart Citizens", which can be read according to the following keys: (i) IT skills, i.e.: ownership of adequate know-how, skills and competences for using ICTs; access to education and training on ICTs; etc.; (ii) characterizing personal factors, such as participation in public life, flexibility, creativity, tolerance, level of education and qualification, openness, etc.; (iii) factors relating to citizenship. For example, human and social capital, social and ethnic plurality, cosmopolitanism, participation in public life, the level of inclusiveness, etc.

Therefore, Smart Cities include, among their basic requirements, the "Smart Citizens" as an enabler of advanced, inclusive, sustainable and innovation-promoting cities.

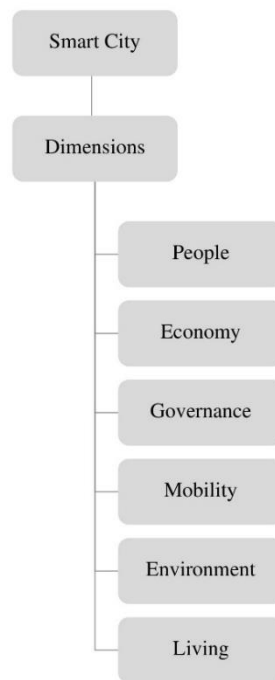


Figure 3. Smart City Dimensions.

Furthermore, it is possible to further classify the aspect of a city proposing some *domains* of the Smart City as areas of interest related to the urban Facility Management (UFM) services [33] [34] [35]. In particular, the proposed domains (Figure 4) represent domains of investigation of possible application of IoT and Big Data Management paradigms to optimize and innovate the current management models both at the strategic and at the operative levels. Specifically, the proposed domains of a Smart City are:

- *Building*. This domain involves the management of buildings (including both technical elements and technological systems) and of the hard and soft services offered by/to them.

- *Energy*. This domain involves the urban energy management, thus the management and maintenance of urban plant systems including - among others - electricity, street lighting, renewable energy production and management, etc. In other words, energy management includes planning and operation of energy production and energy consumption units on the urban territory.

- *Environment*. This domain involves the planning, management and control of environmental aspects of urban territories (e.g. air quality, pollution, noise, natural resources, biodiversity, land use, green areas, etc.).

- *Governance*. This domain refers to urban governance meant here as the range of urban public soft services to citizens, thus those services that implies a direct or indirect interface between citizens and government institutions at different levels. Moreover, this domain also include the allocation and management of social and material resources by government institutions (at all levels) to efficiently handle urban transformations.

- *Mobility*. This domain refers to all the possible private and public systems, means and infrastructures of transport of people and goods within the city - including cars, trains, trams, buses, metros, cycles and pedestrians - as well as their management, operation and maintenance.

- *Safety & Security*. This domain refers to the facilities and services aiming at defending the safety and the security of people. In particular, it involves for instance the management of private or public security systems of surveillance both of buildings, roads and other urban assets which contribute to monitor and control the safety and security of people.

- *Waste*. This domain involves the urban waste management, including the management of the solution for the storage, collection and treatment of waste of various nature (e.g. organic, plastic, etc.) and various sources (e.g. citizens, industry, etc.) within the city.

- *Water*. This domain refers to the urban water control and management (including ground water, drinking water, sea and ocean waters) focusing on the monitoring, modeling and control of the water conditions characteristics, water levels, and quality levels.

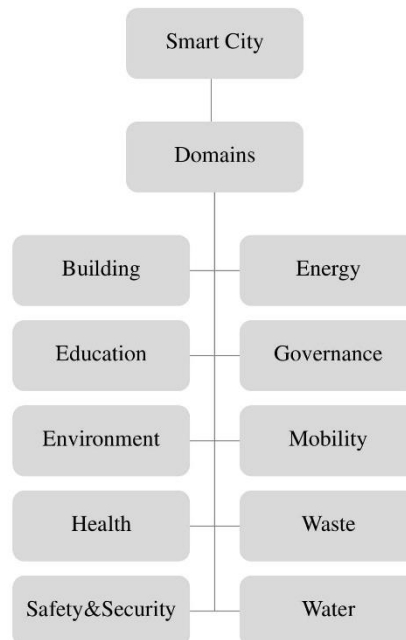


Figure 4. Smart City Domains.

2.2. Case studies review and analysis: service management trends within Smart Cities

If on the one hand the dimensions (Fig. 3) of a Smart City have already been defined, classified and described in both the academic and professional fields, on the other the UFM smart services that can be identified according to the Smart City domains (Fig. 4), as well as the technologies that enable the smartness, remain difficult to define and they have not yet seen an harmonization and a shared standardization. Therefore, an in-depth analysis of case studies on the European scale was necessary in order to be able to identify the services of UFM implemented by the different cities and the related enabling ICTs. The sample has been defined selecting cities that: (i) are/were involved in projects dealing with ICTs applications in urban management and service management founded by EU under the FP7 and/or H2020; (ii) are developing/ have developed initiatives, policies, proposals of guidelines and/or strategies concerning ICTs integration in urban FM service management. The sample (Table 2) involves cities that cover the majority of countries within the European areas.

Table 2. Sample of cities.

	City	Country
1	Antwerp	Belgium
2	Barcelona	Spain
3	Berlin	Germany
4	Bristol	UK
5	Copenhagen	Denmark
6	Eindhoven	The Netherlands
7	Espoo	Finland
8	Geneva	Switzerland
9	Genova	Italy
10	Lisbon	Portugal
11	London	UK
12	Lyon	France
13	Milan	Italy
14	Munich	Germany
15	Nice	France
16	Padova	Italy
17	Santander	Spain
18	Stavanger	Norway
19	Stockholm	Sweden
20	Vienna	Austria
21	Warsaw	Poland

To analyze all the cities, the same survey template was used (Table 3) which highlights the UFM services offered in relation to the different smart city domains, the implemented ICT solutions, the initiatives and services find the context, the implementation period and the contribution innovation of each service. Data and information to perform the analysis was gathered from the following sources: municipality official documents, websites, communications, etc.; city projects and initiatives websites; EU's Cordis website (FP7 and H2020 projects); academic & research publications. A qualitative comparative analysis was then carried out to identify the main domains of the smart city investigated, to identify the definable smart services of urban FM and to estimate the most recurring smart solutions. The analysis then identified the smart UFM services articulated according to the Smart City Domains. Then, starting from this framework, it was possible to identify recurrences in the nature and in the objectives of innovation (Table 4).

Table 3. Template for city analysis.

City	
Initiative/ Project Sources	
UFM Domain	
UFM Service	
Period (From - to)	
Enabling Technologies	Sensing Level
	Network
	Platform
	Analytics
	Application
Service Innovation strategy	
Improvements and Added Value	
References	

From the results of the case studies analysis, it can be observed how the concept of Smart City, as a strategic vision of effective management of the city, requires a range of elements able to pursue innovation. These elements, recurring in most of the investigated cases, include: (i) technological component; (ii) attention to sustainability issues in its main articulations; (iii) adoption of an integrated

approach to city management. In particular, as regards, the technological component, the case studies analysis has highlighted recurring aspects of interest and trends in the use of ICTs, such as:

- use of digital infrastructures, ICTs and in particular Internet of Things (IoT) for improving the ability of the public administration to collect, manage and analyze data and information;
- activation of virtuous circular and integrated information flows at the urban scale together with standardized communication processes for the exchange of information in real time between the city administration and the citizens;
- overcoming the "physical place" as an unavoidable dimension of the activities, guaranteeing for example multimodal accessibility to useful data and information, as well as to the latest generation of digital services concerning different urban service aspects and thematic areas.

The attention to the issues of sustainability is a recurring aspect within the analyzed Smart Cities, in particular the attention of the municipalities focused on:

- environmental sustainability, in terms of quality of the urban environment, conscious use of available resources, more careful use of energy sources and reduction of environmental impact;
- economic sustainability in terms of proper management of the resources of the cities in order to create value and maintain them over time, enhancing the specific nature of urban and territorial services and the ability of the city to attract human and financial capital;
- social sustainability, in terms of valorization of human capital, inclusion, participation and training of citizens, and improvement of the quality of life.

Another common trait, as mentioned above, regards the adoption of an integrated approach to the management of the city, with a view to the broader participation of all stakeholders in urban governance overcoming siloed approach and preferring a network-based approach among administrative departments of the city administration as well as among citizens and the city administration representatives. In particular, the analysis of the case studies shows the implementation - by municipalities and city managers - of a common and recurrent approach, i.e. the systemic approach. It is an approach that refers to the city as a whole, transversely to its different domains, considering the city itself as a complex and integrated socio-technical system able to support and enable innovation. Within this approach, the governance represents the main dimension and it aims at achieving a participatory and inclusive approach able to increase not only the ability to govern the network, but also the development of active citizenship. At the center of this challenge there is the construction of a new kind of common good, i.e. the large technological and immaterial infrastructure that makes people and objects dialogue, aiming at integrating information, generating intelligence, producing inclusion and improving citizens' everyday life. The analysis of the case studies has highlighted as municipalities are implementing innovative ICT-based solutions aiming at providing optimized and high-quality services to citizens. The applications of these solutions concern the different Smart City Domains, each city focuses more on certain domains according to its vocations, its objectives, the needs of its citizens, etc.. For example, it is possible to notice how the city of Santander has a well-structured technological component (pervasive sensor network, connection with citizens and analysis software) mainly aimed at interaction between administration and citizen and among citizens themselves in favor of active, cohesive and inclusive citizenship. The city of Barcelona, instead, exploits the technological potential mainly to strengthen its industrial / tertiary districts, as well as to create new ones, promoting and facilitating virtuous circular governance models based on shared knowledge and on a three-party collaboration: public sector, academic and research field and private market. In order to achieve this goal, the municipality of Barcelona has created Living Labs, providing shared workspaces, acting as ideas incubators and hub for stakeholders, stimulating and accelerating in this way the industrial and social innovation also through the direct participation of citizens in the development and in the validation of innovations. Moreover, the city of Berlin is implementing an integrated approach to the management of the different domains of the city, implementing several interdisciplinary projects that are able to exploit synergies from the public sphere, research and academic field, as well as businesses fields. The projects, aimed at using ICTs to develop concrete solutions, mainly focus on: energy management, transport, mobility, logistics and healthcare industry. This projects cover production processes, services and technologies as well as infrastructures, which will be integrated, networked, mutually supported and

implemented through ICTs. Moreover, the Smart City Berlin Network, a working group initiated by Berlin Partner for Business and Technology and TSB (Technology Foundation Berlin) - that includes more than 100 companies as well as science and research institutes from Berlin - was instituted with the aim of promoting implemented smart initiatives in order to establish Berlin as one of the leading smart cities in Europe [43]. Another example of a city that has implemented an IoT environment (sensors, digital network infrastructure, software for data management, applications for citizens' interface, etc.) in order to optimize the services offered to the citizen is London. Indeed, the GLA - Greater London Authority has invested its technological capital in the creation of the London Datastore. This huge data archive - made available by the London municipality for free to every citizen and anyone who intends to develop services for citizens, according to an open-government scheme - collects and stores data about different domains and aspects of interest of the London reality such as for example: public transport, traffic trends, economics and medium / long-term economic forecasts, population, accident records, inventory of atmospheric emissions, taxes, private accommodation renting, etc.. Mobility is perhaps London's flagship: plans to optimize and innovate the public transport network, monitoring projects and parking displays, electric bike sharing systems, represent only some of the successful initiatives already implemented. Furthermore, the city of Copenhagen - very active on the theme of Smart Cities - is developing a digital platform with the aim of fostering large-scale co-creation and public-private innovation partnerships for the development, testing and validation of urban IoT applications and services. This platform has been designed to be open, standardized, data-driven, service-oriented and user-centric. The main initiatives proposed through the platform regard, among others: smart mobility and parking, smart waste, air quality, environmental and work sustainability and use of public spaces. All the initiatives use technology and exploit information networking (open database of the platform) to enable the efficient management of the municipality and the easy access to applications and public services from citizens. The smart urban initiatives are promoted by the Copenhagen Solutions Lab, a venture supported by the government established with the aim to coordinate all the smart projects, creating and exploiting possible synergies [44]. One of the main project promoted by the Copenhagen Solutions Lab is "Copenhagen Connecting" which aims at bringing together citizens, government, businesses, and research organizations in building a data-collecting infrastructure able to collect real-time data from devices spread across the city. In particular, smart mobility is the most investigated field. Indeed the data-network infrastructure is able to collect real-time data from Wi-Fi access points installed on streetlights to track the movement of Wi-Fi-using devices in cars, buses, bikes, smart-phones and wearable devices. These anonymized data can then be analyzed to monitor how pedestrians, cars and bikes move through the city. The analysis of this information has allowed researchers to create an intelligent traffic-management system to optimize traffic flow and limit congestion, minimizing the CO₂ emissions caused by traffic congestion. Moreover, by connecting the data-network infrastructure with traffic lights, parking systems and charging stations for electronic vehicles, it is possible to direct the traffic in real time and to help citizens to find parking spaces. Moreover, another investigated domain is smart waste, indeed Copenhagen Connecting also plans to install sensors in garbage cans to optimize the waste collection routes improving the efficiency of the waste management service.

Table 4. Results of the Smart Cities analysis: trends for SC Domain and innovative service strategies.

SC Domanin	Key Innovative Service strategies	where
Energy	<ul style="list-style-type: none"> ▪ Data analytics provide insights into the urban and district scale energy demand for: <ul style="list-style-type: none"> • peak hour identification and localization (GIS); • identification of best-neighboring candidate areas for extra energy supply in case of power failures. ▪ Smart lightning systems for improving the citizens' perception of safety of urban areas. 	<ul style="list-style-type: none"> • Eindhoven, Netherlands • Milan, Italy • Padova, Italy • Stockholm, Sweden • Espoo, Finland • Nice, France
Waste	<ul style="list-style-type: none"> ▪ Ultrasonic Fill-level Sensors for Containers: wireless ultrasonic sensors for efficiently monitoring of waste fill-level of containers. ▪ Smart Waste Planning & Optimization: geo-localization data from wireless bin fill-level sensors to enable the most efficient smart waste collection. ▪ Predictive Waste Management Analytics: data analytics for delivering actionable insights (e.g. optimized collection routes for maximum efficiency) that reduce costs and increase revenues. 	<ul style="list-style-type: none"> • Berlin, Germany • Vienna, Austria • Barcelona, Spain • Lisbon, Portugal • Stockholm, Sweden

Building	<ul style="list-style-type: none"> ▪ City Waste Management Platform: truck drivers can use mobile apps to scan, confirm and report on any event; improved users' interaction and automatic billing for on-demand waste collection. ▪ Real-time monitoring of energy consumptions ▪ Real-time adjustment of energy distribution ▪ Improved O&M and cleaning services: from scheduled to condition-based strategies ▪ Real-time monitoring of users' behaviors to improve space management 	<ul style="list-style-type: none"> • Stavanger, Norway • Warsaw, Poland • Antwerp, Belgium • Lyon, France • Geneva, Switzerland • Lisbon, Portugal • Genova, Italy • Berlin, Germany • Munich, Germany • Genova, Italy • Milan, Italy • Nice, France • Bristol, UK • Stavanger, Norway • Eindhoven, Netherlands • Antwerp, Belgium • Santander, Spain • Berlin, Germany • Munich, Germany • Santander, Spain • Barcelona, Spain • Copenhagen, Denmark • London, UK • Eindhoven, Netherlands • Berlin, Germany • Munich, Germany • Santander, Spain • Barcelona, Spain • Copenhagen, Denmark • Stockholm, Sweden • Eindhoven, Netherlands • Bristol, UK • Lisbon, Portugal
Environment	<ul style="list-style-type: none"> ▪ Wireless sensor network for monitoring a range of environmental parameters (e.g. CO₂, dust, sound, humidity, temperature, etc.) to assess and improve the city experience. ▪ Monitoring of the quality of air through wireless sensor networks and network of smartphone-based air pollution monitors that allow individuals to track pollution levels in real time and feed a central database of air quality trends citywide throughout the day. 	
Mobility	<p>Real-time monitoring and communication for:</p> <ul style="list-style-type: none"> ▪ Public transport (e.g. real-time updates of waiting times, etc.) ▪ Parking management (e.g. real-time updates of available parkings, etc.) ▪ Traffic management (e.g. real-time updates of traffic conditions, notification of best routes, etc.) 	
Governance	<ul style="list-style-type: none"> ▪ Open platforms of municipalities provide digital government services (e-Government) - public services provided by PA institutions are handled electronically, fostering communication with PA and integrating citizens into public affairs. ▪ Collection and use of citizens' online feedbacks to support decision-making and generate smarter policies. 	
Safety & Security	<ul style="list-style-type: none"> ▪ Platforms with capabilities for call handling and dispatching, intelligent mapping, field communications, data reporting, and analysis to achieve a common operating city picture for intelligent response. ▪ Sharing and combination of real-time CCTV video surveillance networks of municipal agencies with other public and private security systems for problem detection and cooperation of agencies and personnel. Involved fields: cyber security, traffic incidents management, traffic safety, street lighting, smart grids security, emergency services coordination, fire services, crime detection, personal safety and tourism safety. 	
Water	<ul style="list-style-type: none"> ▪ Smart water meters (mobile-enabled) together with sensors on electric motors, pumps, valves, etc. and smart waste management software applications enable water conservation benefits as: <ul style="list-style-type: none"> • Improved leak detections, reducing non-revenue water; • Optimized pressure management, reducing energy consumption and leakage; • Improved billing accuracy. ▪ Smart Water Platform for supporting the end-users participation in improving the water distribution systems, and the interactive cooperation between the water suppliers and the final users. 	<ul style="list-style-type: none"> • Santander, Spain • Barcelona, Spain • Bristol, United Kingdom • Lyon, France • Milan, Italy

2.3. ICTs, IoT and Big Data as enablers of Smart Urban Facility Management services

In the context of urban services management, the ICT infrastructure has multiple functions, including [29]:

- sharing of information and knowledge;
- integration; interpolation of data coming from various sources and belonging to different fields can generate different information;
- forecast; ICTs can acquire, process, analyze and manage huge amounts of data (Big Data) in order to forecast future potential scenarios and interpret the behavior of the city, revealing patterns and trends and identifying risk areas to improve its ability to respond.

With respect to these functions, according to the results of the SC analysis, the main investigated information and communication technologies for urban services management are IoT technologies together with Big Data management. In particular, the main trends in the use of IoT Technology are represented by Sensing Technologies, Open Platform and Real-time Dashboard, Cloud-based IT Services. In particular:

2.3.1. Sensing Technologies. IoT mainly refers to the use of devices and sensors and a wireless communication network capable of relating different large-scale physical "objects" (even without human interaction). The connection of such objects generates large data flows, allowing the physical world to be analyzed in detail and, in many cases, in real time. The information can be used for multiple purposes including, for example, the efficiency in the use of urban resources, the optimization of the urban physical infrastructure, etc. These sensors and IoT devices generate and collect high amounts of large data flows (Big Data) which are characterized by high volume, variety, velocity and variability. The introduction of Big Data management within FM practices may give rise to possibilities for innovation of urban services management, according to two main reading keys. The first reading key concerns the temporal dimension of Big Data and, in particular, the aspect of data availability and accessibility in real time. Indeed, the real-time observation of key parameters allows to read on-going phenomena and to provide the useful information in a timely manner to decision-makers in order to consequently define the most appropriate actions and strategies to implement. The second reading key concerns the Data Analysis, indeed new techniques of analysis of dynamic datasets (e.g. what if analyses, correlations and regressions, descriptive and predictive analyses, etc.) nowadays provide insights and accurate forecasts about future events and phenomena, supporting decision-making.

2.3.2. Open Platform and Real-time Dashboard. The objective of the Open Platform is to promote dialogue between citizens and providers of urban services and to offer citizens a global vision of the state of the city. Platform functions include monitoring and processing large amounts of heterogeneous data: real-time data (such as sensor data), static data and GIS (Geographical Information System) data as well as the storage of such data in a dynamic database. The web interface with users is a real-time dashboard that provides a summary of the current state of the city, allowing users to view the updated real-time information contained in the dynamic database in a user-friendly form (Figure 5). Examples of geo-localized information can be: average road speed, traffic situation, temperature, atmospheric pollution, water pollution, energy supply and consumption, etc. The goal of the dashboard is to provide citizens with an easy-to-understand overview of the city in order to improve their decision-making processes. Platform and dashboards are accessible to citizens (some platforms may require authentication through registration / log in), which thanks to appropriate API - Application Programming Interface can interact (for example: reporting incidents, roadblocks and routes alternatives, etc.) thus enriching the data sets (Figure 6).

2.3.3. Cloud-based IT services. One of the latest technological trends is undoubtedly Cloud-based services or Cloud Computing, i.e. information technology offered as a service. Cloud-based solutions offer IT services, mainly computing services (such as servers, storage resources, databases, networks, software, data analytics, etc.) via the Internet (the "Cloud"). Cloud service providers offer IT functions as services by typically charging the user based on the actual use of offered services. Therefore, these services (compared to In-house option where users have to buy and manage both hard and soft infrastructure), make advanced IT solutions to be accessible by a wider audience of users, overcoming - at least in part - budget limits.

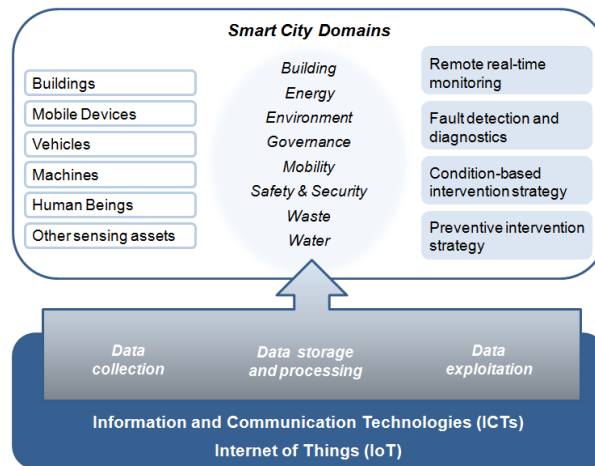


Figure 5. ICTs and IoT for improving urban FM services.

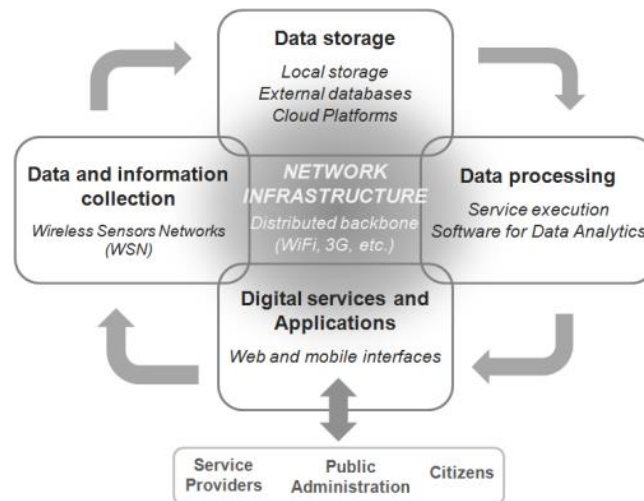


Figure 6. Capabilities of IoT Platforms with respect to FM information management.

3. Results. ICT-based approach for advanced management of urban infrastructures and services: towards a Smart Urban Facility Management

The use of IoT within the urban territory involves a communication infrastructure that allows access - through simple, unified and economic procedures - to a wide range of public services, revealing and exploiting potential synergies and economies of scale that allow:

- the optimization of traditional urban FM services including transports, maintenance, waste, etc. (Table 5);
- the creation of new public services offered via digital networks - Smart Urban Facility Management (UFM) services (Table 5);
- a better management of UFM services, thanks to the availability and accessibility of information in real time.

Table 5. Classification of Smart UFM services for each Smart City Domain.

SC DOMAIN	UFM FIELD	UFM SERVICE
ENERGY	Street Lighting Management Energy Grid Management	Lighting Monitoring & Control Substation Automation Management Overhead Transmission Line Monitoring Advanced Metering Infrastructure Wide-Area Monitoring and Situational Awareness Demand Response Management Outage Detection, Management and Restoration Intelligent Distribution Management Asset Management Meter Data Management
	Green/ Renewable Energies	Renewable Distributed Energy Resources (DER) And Storage
ENVIRONMENT	Environmental Monitoring	Air Quality Monitoring Air Pollution Monitoring Weather Condition Monitoring Pollen Monitoring Noise Monitoring
	Agriculture	Sensor-Based Field and Resource Mapping Remote Equipment Monitoring Remote Crop Monitoring Livestock Tracking and Geo-fencing Crop Irrigation Management
WASTE	Waste Management	Intelligent Bin Status Monitoring & Dynamic Scheduling Waste Disposal Information Services Asset Management Digital Tracking and Payment for Waste Disposal
WATER	Water Management	Leakage Detection Irrigation Management Pollution Detection Flood Warning Predictive Maintenance of Water Infrastructure Water Consumption Tracking
BUILDING	Building Management	Building Services Building Condition Management Building Energy Management Data-Driven Building Inspections
BUSINESS	Retail	Smart payment services Customer resource management Proximity Marketing
	Logistics	Physical Logistic Services Value-added services Information Integration Services Cash Transactions Services Sales and Marketing Services
EDUCATION	Education	Digitization of Education Lifelong Learning
GOVERNANCE	Citizen Participation Policy Making Online Public Services	Local Civic Engagement Services Urban Data Sharing e-Public Services Proximity Based Information Services
	Patient Centric Supply Personalized Treatment	Telemedicine Online Care Search and Scheduling Online Care Search and Scheduling Integrated Patient Flow Management Assisted Ambient Living Remote Patient Monitoring & Assistance
HEALTH	Public Health Monitoring	Preventable Diseases Surveillance Healthcare Data Management
	Public Safety & Security Management	Real-Time Crime Mapping Emergency services Crowd Management Predictive Policing Intelligent Surveillance
SAFETY & SECURITY	Natural Disaster Monitoring	Structural Health Monitoring Disaster Risk and prevention Emergency Response Disaster Recovery
	Integrated Public Transportation	Predictive Maintenance of Transportation Infrastructure Integrated Multimodal Information Services Digital Public Transit Payment E-Hailing Services Autonomous Transportation Services
MOBILITY		

The services identified and classified in Table 5 are enabled by a concept of "Infrastructure" that embraces the integration of (i) physical infrastructures (e.g. buildings, roads, etc.) and (ii) ICT digital infrastructures and services. In particular, as above mentioned, the ICT infrastructure involves the concept of digital information platform which is able to collect, aggregate and process data in order to support a better understanding of the city behavior and to consequently optimize decision-making processes. These new knowledge bases enable decision-makers to set priorities and to calibrate strategies with the aim of enhancing service quality. Moreover, the application of enabling ICTs to UFM field paves the way to the implementation of the Circular City Model [45]. Many European cities are implementing the transitions towards the circular economy in their agendas, reducing the systemic entropy with the support of cultural projects aimed at empowering the civil society [46]. Closing loops of energy and material flows, Smart UFM can support the processes of:

- resources value maximization, that derives from the recognition of the limited nature of natural resources;
- waste prevention, that derives from the recognition of the limited capacity of Earth to assimilate pollution;
- prioritization of actions in the integrated management of resources and waste.

Furthermore, the innovation trait of the Smart UFM services (Table 5) are represented by:

- Real-time data management. Real-time monitoring through sensors of key parameters and phenomena in order to implement prompt responses to emergencies, corrective and preventive actions to improve the adaptive capacity of urban systems;
- Data Analytics for data driven long-term decision making;
- interaction and communication between citizens and Public Administration for the exploitation of citizens' feedbacks in order to improve service delivery.

Although the concept of open platform implies the connection and integration of information bases and stakeholders into a unique collaborative environment, the current practice of urban management is characterized by a multiplicity of departments - related to the different domains of the city (e.g. Economy, Environment, Mobility, People, etc.) - which are managed independently of each other, in a "silos" approach. This vertical management causes a consequent lack of communication and information sharing between the various actors at the head of the different departments, losing the opportunity to exploit synergies. On the contrary, the concept of Smart City owns a global vision, according to which the smart city is a complex integrated system based on accessibility and information sharing as well as on a participatory and inclusive government, on sharing of resources and on citizen collaboration. According to this holistic vision of Smart City and of the services offered to/by the city itself, the identified smart UFM services should be managed according to a network approach based on horizontal integration among departments and stakeholders.

4. Conclusions

The development of innovative solutions and applications for the management of urban services is constantly growing, driven by technological progress (sectors such as IoT, Big Data, cloud-based services, etc.). The currently most investigated application domains concern mobility management, resource and waste management and energy management. The benefits in terms of optimization of services, efficiency in the use of resources and social inclusion are tangible. However, a problem not to be underestimated concerns the interoperability and horizontal integration of these solutions in order to enable the network approach on which the concept of Smart City is based. This evolutionary scenario: (i) opens up new visions of urban FM as a dynamic and integrated system of heterogeneous services provided with the support of horizontal IT infrastructures that guarantee interoperability and information sharing; (ii) it introduces new categories of services based on real-time monitoring and cloud computing; (iii) it outlines new supply chain models based on the network approach involving, in addition to the

traditional FM stakeholders, new subjects such as telecommunications companies, telephone operators, IT providers, cloud-based service providers, sensor manufacturers, etc. In particular, according to this new vision, the supply chain is no longer configured as a linear sum of suppliers, but as a unitary entity that operates in a coordinated way, sharing knowledge and creating virtuous growth and improvement circles both at the level of the entire chain and at the lower level of the individual suppliers. Overcoming any exclusive focus on ICTs, IoT and Big Data in terms of productivity and efficiency, the outlined perspective emerges as particularly suited for fielding the circular economy paradigm. Through participatory and inclusive processes, Smart UFM services not only strengthen the physical capital performances, making cities more livable, but also offer new economic and employment opportunities. Thus, enabling technologies widen the decision-making arena, promoting virtuous circular dynamics based on stakeholders' engagement, knowledge transfer, strategic decision making and supporting the transition towards a new urban culture of complementarities and synergies.

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