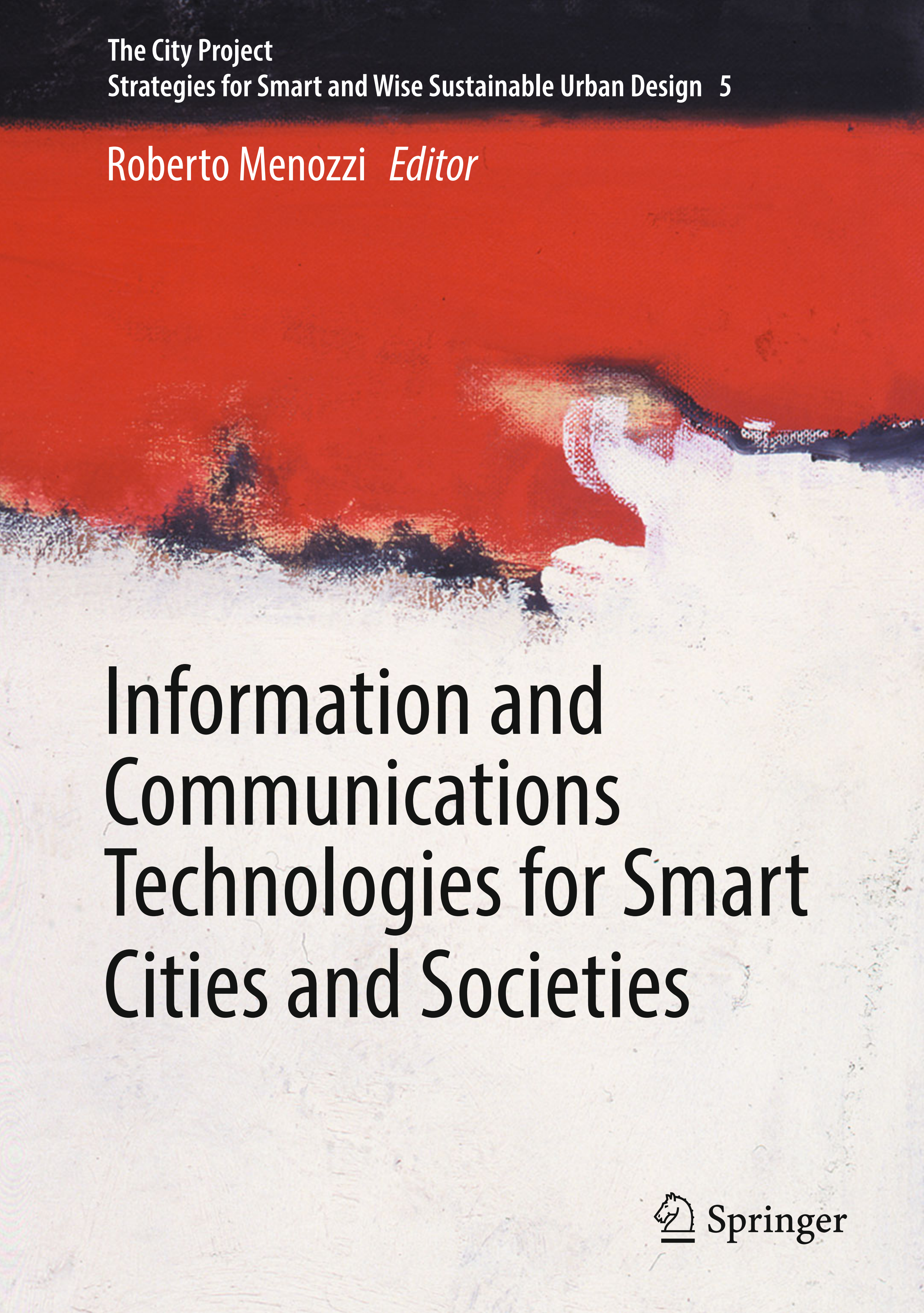

The City Project
Strategies for Smart and Wise Sustainable Urban Design 5

Roberto Menozzi *Editor*

# Information and Communications Technologies for Smart Cities and Societies

Springer

# The City Project

## Strategies for Smart and Wise Sustainable Urban Design

## Volume 5

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The cover of the book series The City Project features a painting by Carlo Mattioli (C. Mattioli, *Estate in Versilia*, 1974, oil on canvas cm. 118 X 70, Catalog n. 1974D0029, Courtesy of Fondazione Carlo Mattioli, thanks to Anna Zaniboni Mattioli)

*The horizon of poppies painted by Carlo Mattioli between the dark background of the forest and the white plane of the wheat, becomes for us, thanks to a transfiguration of meaning that aligns with the attitude towards abstraction rooted in the figure of the painter, a city which is intertwined with its landscape, evoking the idea and the possibility of recomposing a balance and seeking an integration between settlement and environment, between human space and natural element.*

Roberto Menozzi
Editor

# Information and Communications Technologies for Smart Cities and Societies

Springer

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ISSN 2730-6992 ISSN 2730-700X (electronic)
The City Project
ISBN 978-3-031-39445-4 ISBN 978-3-031-39446-1 (eBook)
https://doi.org/10.1007/978-3-031-39446-1

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# Preface

This book collects a series of chapters that originate in papers presented at a workshop entitled: *ICTs for smart cities and societies: what's going on and what's next*. The workshop was hosted by the University of Parma, Italy, in December 2022, with the aim of presenting an overview of current activities in the field of the application of Information and Communication Technologies to the process of city smartification, with particular emphasis on the Italian playing field.

If we see the Smart City as a matrix where application domains and citizens' needs and expectations (the matrix rows) intersect with new and not-so-new technologies (the columns), the chapters of this book belong in both the row and the column categories. For logical reasons, in the book running order the latter precede the former (although a sharp border line between the two categories would be hard to draw).

The eight technical chapters that constitute the core of the book are preceded by a less technical introduction that elaborates on the broad spectrum of opportunities, challenges, and dangers strewn along the road to the Smart City.

Parma, Italy — Roberto Menozzi

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# Sin City to Smart City, or Atonement by Technology: An Introduction

Roberto Menozzi

## Abstract

This chapter aims at proving the reader with an overview of the opportunities, challenges, open questions, and threats, inherent in the broad and somewhat ill-defined phenomenon known as the Smart City. A few key domains are identified and discussed: mobility, health and welfare, security and policing, energy, administration and politics, and education. The core of the chapter is preceded by two sections that propose a historical and cultural angle presenting the Smart City as the technology-redeemed offspring of more troublesome ancestors.

## 1 East of Eden

There is an ambivalence in our view of the city that quite likely dates back from the very earliest times. If from practical, economic, social, and cultural perspectives the city was and still is seen as a uniquely powerful provider of possibilities and opportunities, the artificial, unnatural concentration of people and artifacts, and the progressive separation from the environment—landscapes, colors, smells—that has been the setting of human evolution for millions of years, have been hanging like a dark cloud on the existence of cities and citizens since the earliest experiments.

> And Cain went out from the presence of the LORD, and dwelt in the land of Nod, on the east of Eden. […] and he builded a city, and called the name of the city, after the name of his son, Enoch [1].

In those times few things happened, and never by chance, so we should not overlook or underestimate the fact that the first founder of cities is also the first murderer.[1]

Some ten generations and a deluge after these facts, things were getting out of hand again [2]:

> And they said, Go to, let us build us a city and a tower, whose top [may reach] unto heaven; and let us make us a name, lest we be scattered abroad upon the face of the whole earth. And the LORD came down to see the city and the tower, which the children of men builded. And the LORD said, Behold, the people [is] one, and they have all one language; and this they begin to do: and now nothing will be restrained from them, which they have imagined to do. Go to, let us go down, and

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[1] I hope it is superfluous to state that here and elsewhere I am using biblical quotes not as historical sources but as witnesses of a *weltanschauung*. As Salustius wrote in *On the Gods and the Cosmos*: *"Now, these things never happened, but always are."*.

R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_1

> there confound their language, that they may not understand one another's speech. So the LORD scattered them abroad from thence upon the face of all the earth: and they left off to build the city.

Here we find a few points that appear to be pertinent to our topic. First, the stigma attached to the foundation of cities has not abated: the undercurrent of resentment for the prevalence of settlers over nomads—first symbolized in the killing of the shepherd Abel by the farmer Cain—runs through the whole book, and in a way resonates with our present preoccupation with finding ways of coexisting with nature and our environment rather than recklessly pillaging the former and reshaping the latter. Second, when their impulse to aggregate appears to approach a critical point—a *singularity*, as we might call it today—the God of *Genesis* scatters men abroad as to avert something unwholesome intrinsic to this concentration. More generally, with startling and rather frightening foresight, some twenty-five centuries ago someone realized that "*now nothing will be restrained from them, which they have imagined to do*"; everyone can build his or her own list of what we have imagined to do, and—for good or bad—carried to completion. Finally, it appears that at some point after checking our Babel enterprise, the God of the Old Testament must have given up, leaving us to our own devices.

A hardly more optimistic view on the birth of the city is that offered by the Italian philosopher and philologist Giorgio Colli, who describes how in post-Homeric Greece—in a time frame ranging from the beginning of the VI to the middle of the V century B. C.—the *pólis* was shaped by fierce competition and envy (*phthonos*) as the place where internecine hostility would be free to unravel, a place rapidly turning into a merciless tribunal for the losing; in combination with a disbelief in any kind of finality, this reflected in the practical Greek political mindset, that is, "*in the instability of their political bodies, in the marked prevalence of a destructive impulse, in the frantic renewal of aimless and meaningless hatred*"[2] [3]. The context could not be father from the book of *Genesis*, but the birthmark is no less ominous.

## 2 A City of Red and Black

Fast-forward through two thousand years that witnessed the splendor of Rome, Byzantium, Baghdad, the spring of Gothic architecture, the Florence of the Medici, and the rise of the dazzling capitals of powerful nation-states extending their tentacles to the boundaries of the known world and beyond, two thousand years during which cities were the undisputed focus of human activity, desire, ambition, endeavor, creativity, a whole era in which ostracism and exile were dreaded like death by active citizens, and in a sense *were* death as far as their higher faculties—political, artistic, or professional—were concerned.

This infatuation for the city and its never-ending eruption of life, wealth, ideas, and human intercourse—which for a long time seems to have effectively silenced the ambivalence I mentioned before—comes officially to an end with the spasms of the Industrial Revolution and the rise of Romantic sensibility. The pace of the revolution and of the urban metamorphosis appears all of a sudden to outstrip the human capacity for adaptation,[3] and a flood of social and economic transformation uproots willing and unwilling alike in a collective upheaval displacing men and women culturally no less than physically. At the opposing pole of a newly deified Nature—the more untamed and unaccommodating, the better—the city appears to Romantic eyes as a place of unmitigated suffering and bereavement, a place of exile and painful longing [4]:

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[2] My translation.

[3] Adapting to urban developments was definitely less challenging in previous centuries: as an example, the Gothic cathedral of Reims was completed a little less than ninety years after the first stone was laid. In modern technical terms, we would call it a case of *quasi-static* evolution.

> *Far from the madding crowd's ignoble strife,*
> *Their sober wishes never learn'd to stray;*
> *Along the cool sequester'd vale of Life*
> *They kept the noiseless tenor of their way.*

Let's not miss the Paradise lost keywords scattered in these lines: *sober*, *sequester'd, noiseless,* seem to spring directly from physical sensations of uneasiness if not revulsion for the lurid confusion of promiscuously teeming cities. Again we find the city noise—and loneliness amid crowds—as the distinguishing element of modern alienation in Wordsworth's *Tintern Abbey* [5]:

> *These beauteous forms,*
> *Through a long absence, have not been to me*
> *As is a landscape to a blind man's eye:*
> *But oft, in lonely rooms, and 'mid the din*
> *Of towns and cities, I have owed to them,*
> *In hours of weariness, sensations sweet,*
> *Felt in the blood, and felt along the heart.*

We live in cities as in exile, longing for our lost motherland. And no wonder: when writers less inclined to poetic abstraction enter into details, we find ourselves beholding positively infernal views [6]:

> *It was a town of red brick, or of brick that would have been red if the smoke and ashes had allowed it; but as matters stood, it was a town of unnatural red and black like the painted face of a savage.*
> *It was a town of machinery and tall chimneys, out of which interminable serpents of smoke trailed themselves for ever and ever, and never got uncoiled.*
> *It had a black canal in it, and a river that ran purple with ill-smelling dye, and vast piles of building full of windows where there was a rattling and a trembling all day long, and where the piston of the steam-engine worked monotonously up and down, like the head of an elephant in a state of melancholy madness.*

Red and black: the Devil's palette; and coiled snakes, a dead river, demented movement, and—once more—incessant noise.

The turn of the century does not bring much relief, according to a quintessential twentieth-century poet like T. S. Eliot: with his *Preludes* we are back in Hell, albeit of a subdued variety [7]:

> *With the other masquerades*
> *That time resumes,*
> *One thinks of all the hands*
> *That are raising dingy shades*
> *In a thousand furnished rooms.*

A bit further on, the blackness of *Hard Times,* far from having washed away, appears to aspire to universal coverage [8]:

> *The conscience of a blackened street*
> *Impatient to assume the world.*

Unlike in Dickens, though, the metaphysical nature of whatever went wrong elicits some measure of compassion for the city-hell itself:

> *I am moved by fancies that are curled*
> *Around these images, and cling:*
> *The notion of some infinitely gentle*
> *Infinitely suffering thing.*

A few years later, *The Waste Land* makes the connection explicit again with a direct quote from Dante's *Inferno*[4] [9]:

> *Unreal city,*
> *Under the brown fog of a winter dawn,*
> *A crowd flowed over London Bridge, so many,*
> *I had not thought death had undone so many.*
> *Sighs, short and infrequent, were exhaled,*
> *And each man fixed his eyes before his feet.*

The throng of somnambular City clerks[5] of Eliot's vision harks back to *Hard Times* [6]:

> *It contained several large streets all very like one another, and many small streets still more like one another, inhabited by people equally like one another, who all went in and out at the same hours, with the same sound upon the same pavements, to do the same work, and to whom every day was the same as yesterday and tomorrow, and every year the counterpart of the last and the next.*

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[4] *Inf.*, III, 55–57. Technically, and significantly, we are in Hell's vestibule, where the souls of the pusillanimous are forever bound to aimless wandering.

[5] A processions of brain-dead workers that seems reminiscent of both Dickens's and Eliot's appears in the opening sequences of Fritz Lang's *Metropolis* (1927), the very first image of which is a steam engine piston working "*monotonously up and down, like the head of an elephant in a state of melancholy madness*".

In *The Fire Sermon* section [10], another city takes on the role of signifying perdition when Eliot quotes St. Augustine's *Confessions*[6]:

> *To Carthage then I came*

immediately followed—to avoid misunderstandings—by the flames themselves:

> *Burning burning burning burning.*

What centuries of uneasiness did, what modern technology in its aggressive earliest forms exacerbated, can our gentler, leaner and sleeker technology undo? Can the sins of the City be washed away by digitalization, by ever-faster and capacious communication networks, by artificial intelligence? In a way, this is the challenge known as Smart City.[7]

## 3 The Smart Hereafter

Let us begin this section setting some boundaries to our expectations.

Partly because intellectuals tend to grow tired of keywords as soon as ordinary people start using them, and rapidly turn to busying themselves to invent new ones, and partly because the adjective *smart* ended up smacking of technology a little bit too much, thereby—understandably—becoming suspicious, there has been a tendency among the most enlightened to upgrade the idea of *Smart City* to that of *Wise City*. A noble and perhaps even necessary aspiration, but one that tends to shift the attention from the practical playing field—where engineers and others are willing and able to deploy their newest contraptions—to a higher but somewhat less well-defined level of intervention, if not straight to Utopia [11]:

> *For wisdom is the property of the dead,*
> *A something incompatible with life; and power,*
> *Like everything that has the stain of blood,*
> *A property of the living.*

However, one must not necessarily share Yeats's somber view of human affairs to focus on the more circumscribed arena of *smartness*, where a perfect storm is gathering of powerful new technologies craving for applications, growing user expectations and perceived new needs, aspirations to pressing, if often ill-defined, ideals of sustainability, and—last but certainly not least—colossal material interests that would be harder to channel in the direction of *wisdom*.

Let us then move to outline some considerations about the possible impacts of the Smart Revolution on a few key aspects of cities and society.[8]

*Mobility* is one of the key pillars of the Smart City paradigm.

On one hand—or *internally*, we might say—our inefficient and even irrational, dirty, noisy and often unsafe way of transporting ourselves and our goods is under universal scrutiny in search for more intelligent, environmentally

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[6] Book III, chapter I: "*Veni Karthaginem, et circumstrepebat me undique sartago flagitiosorum amorum*," where once more we find a reference to the unnerving city noise, albeit in a metaphorical context.

[7] I am not unaware of the fact that there is more to smart cities than technology; yet, it is undeniable that the Smart City paradigm was conceived first and foremost in connection with digital technologies, and the EU itself officially adheres to this rather restrictive definition: "*A smart city is a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business*" (https://commission.europa.eu/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en).

[8] I trust that the reader who has patiently borne with me up to this point will not be surprised or disappointed by not finding here the usual literature review or overview of existing projects, initiatives and good practices, but instead a stream of free-form musings and open questions. Anyone looking for a wealth of up-to-date information and resources on Smart Cities can refer to the IEEE Smart City initiative web pages (https://smartcities.ieee.org/), while a good look at the technological and scientific state of the art is offered by the proceedings of the annual *IEEE International Smart City Conference (ISC2)*. In both instances, the perspective is that of engineering and information and communication technologies, but then again, that is also the perspective of this book, and its Introduction.

friendly, safer and ultimately inobtrusive solutions. Inevitable and blissful as these developments sound, self-driving vehicles, automatic routing, structural carpooling, and the programmed phasing-out of traditional combustion engines, all contribute to a tendency to take the management of mobility out of the single citizen's hands, which is likely to encounter significant resistance and to become one of the factors exacerbating the chasm between the Smart City citizen and the dweller of lands less affected by *smartification*, a human type that traditionally does not look upon the beehive mindset with much fondness; for future reference, let us file this as a *chasm factor*.

On the other hand—*externally*—the tendency is one of reducing the need for mobility, through virtual workplaces, e-commerce, distance learning, and virtual reality. Undoubtedly, there is a significant—if difficult to quantify—share of traditional mobility that could be happily dispensed with,[9] but a non-trivial question arises as to where should we draw the line, both in terms of mandates and of personal choices; dismissing the problem is not advisable, lest we encourage a novel, hyper-connected, secular form of monachism, or the escapist extremes of P. K. Dick's *Perky Pat Layouts*[12],[10] either of which defies the very idea of *pólis*. We will brand this potentially dangerous drift as a *dissolution factor*.

On the front of *health and welfare* the progress of technology promises ubiquitous and continuous monitoring of health conditions and lifestyles, aiming at what we could call—with venial impropriety—efficient *preventive maintenance* of body and mind. Alongside with the economic driving force—preventive maintenance appears to be a sound economic choice for humans no less than for machinery—our aspiration to better and longer lives is such a primeval and primary force that we can consider it a fact of nature not unlike the law of gravity.

However, even if we set aside the inconvenient observation that *longer* and *better* are inherently at odds with each other as the final act unravels—we trust that medical as well as pharmaceutical science will make *better* last longer and the bitter end as short and sweetened as possible—the fact is that long lives make economic sense as long as they are productive lives; or, to say it in a more polite and palatable way, longer lives pose an all-around sustainability challenge.[11] Shall we be ready and willing to contribute our labor to society well in our seventies or eighties? And, if so, what contribution could that be in a rapidly evolving techno-centered work market?

At a more philosophical level, it is worth asking ourselves how much of our right to privacy and even to unwholesome and self-harming behaviors and lifestyles we are willing to relinquish in this bargain. Whether we consider a perfect welfare state, or an unfettered capitalistic, free-market healthcare system, or—more realistically—any intermediate solution, the individual right to *wrong* behaviors and lifestyles must inevitably be conceived as hostile, by taxpayers in the former case, by insurance companies in the latter, with the result that in either scenario healthcare coverage may become contingent on the total disclosure of our real-time physiological dashboard. Here is another potential *chasm factor*, isolating those who fall or willingly drop off the grid.

*Security and policing* is another field where opportunities as well as threats are rather obvious. Nearly ubiquitous monitoring and Internet of Things—or Internet of Everything—connectivity, coupled with Artificial Intelligence and Big Data analytics, are potentially disruptive technologies in the field of crime prevention. However, a statistical knowledge-based approach for detecting, forecasting and inhibiting criminal behavior implies some degree of

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[9] An awareness serendipitously fostered by the recent COVID-19 pandemic.

[10] I do not think it unfair to define Virtual Reality as digital (as opposed to chemical) hallucination.

[11] I have argued elsewhere that humans are *unsustainable* animals. Among other proofs that fall well outside the scope of this chapter, see Richard Fleischer's *Soylent Green* (1973) for an example of perfectly sustainable and perfectly inhuman solution to the problem of population aging.

privacy intrusion and even profiling that is at odds with the fundamental rights of individuals in free societies. We will have to be extremely watchful here: politically speaking, security and crime prevention and repression are an easy sell, but while security concerns are clear and immediate, the side effects and the threats to individual freedom and rights are subtler and likely to become apparent in the medium-to-long term, at a point when reversing the trend could prove very difficult.

*Energy* is both a key enabler and a critical piece of the Smart City puzzle. To begin with, clean energy itself, its grid integration and distribution require *smart grids* and energy-hogging computation and data handling, in order to manage and control energy fluxes that—with the increased penetration of renewable energy sources—become more complex, erratic and bidirectional: the shift from the classic paradigm where user-defined *demand* is met practically in real time by the dispatchable *offer* of large conventional power plants, to one in which power generation is largely disconnected from user demand,[12] is a technically daunting revolution in which high-performance computation and big data will likely play a key role. More generally all of the information and communication technology developments and rampant applications point to increasingly intensive computation and extensive data management. While remarkable progress and innovation is underway,[13] flipping the digital coin (a *bit* commutation) comes with an inevitable energy price, and thermodynamic considerations—if nothing else—appear to set an absolute limit to how cheap this price can get [13], indicating that, no matter what brilliant tricks technology will pull, the present and projected exponential increase of computational workload must be mirrored by exponentially increasing energy consumption, sooner or later reaching unsustainable levels.[14] To be sure, before hitting this thermodynamic wall we will have to solve much more pressing technical problems, like for example devising ways to build energy-thrifty data centers, and information and communication technologies will have to prove powerful enablers of clean energy production, energy efficiency and saving just in order to pay their own electricity bill. In this context, *electrification* (e.g., of mobility) is expected to play a major role; however, besides being a last-mile solution that per se does not solve the problem of primary energy production, significant upscaling will require colossal infrastructure investments and pose major technological and supply-chain challenges.

Finally, the economic cost of clean energy, including the need for intensive research funding and government incentives, is liable to be another *chasm factor* dividing affluent countries from developing economies that would in principle be entitled to the cheap-and-dirty approach that made affluent countries affluent in the first place.

*Administration and politics* will not be less affected than the other sectors mentioned so far.

The process of de-localizing and de-materializing administration and bureaucracy is well

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[12] Depending as it does on sunshine and wind speed, for example.

[13] For instance, check https://rebootingcomputing.ieee.org/.

[14] A particularly interesting aspect of this argument [13] is that the ultimate thermodynamic lower bound to the energy cost of a single elementary computational operation stems from the irreversible nature of the operation itself, i.e., from erasing the memory of the state preceding the operation (for example, adding 3 and 5 to get 8 is irreversible in the sense that this 8 might just as well come from 2 plus 6, or 7 plus 1, etc., hence from the sum one cannot infer which were the addends). In other words, some energy must be spent (as dissipated heat) to make output signals independent of their history: the alternative would be admitting the existence of *slightly different* 8's depending on their being the result of 3 plus 5, or 2 plus 6, or 7 plus 1, etc., which in the long run of the computation would clearly become unsustainable. Ultimately, we have to pay a price for the luxury of forgetfulness. Apart from obvious practical considerations, a short story by J. L. Borges, *Funes the memorious* (*Funes el memorioso*, in *Ficciones*, 1944), brilliantly shows the devastating effects of a lossless memory.

under way, with—generally speaking—significant benefits to the comfort and peace of mind of citizens: accessing on-line services with digital identities, for example, saves time, is ubiquitous, and reduces or eliminates the need for synchronization with public servants' (sometimes mind-boggling) office hours. A transparent bureaucracy is likely to rank high in every citizen's Smart City wish list, and the route appears to be clearly set in this respect. Another potential benefit in the interaction between citizens and the administration is the shift from a *radial* model—in which citizens interacts with individual branches of the administration, depending on the problem at hand, as if with separate, independent, and mutually non-communicating entities—to a *cloud* model with a single access point and full information sharing among all branches. However, in a thoroughly virtualized and dehumanized administration glitches may become exasperating if not impossible ordeals for the citizen, unless and until the human ability of coping with the unexpected and the unforeseeable is embedded in the system via advanced Artificial Intelligence or, in the short term, savvy intervention of human intelligence (if not compassion). Even in this reasonably optimistic scenario, however, digitalization is potentially a serious *chasm factor* that threatens to widen age and cultural divides in a realm where no one should be excluded.

At a higher level, as Science and Artificial Intelligence progress to approach a status of unassailable authoritativeness, and the Smart City becomes the living laboratory where their brave new solutions are experimented, what room will be left for *politikà* in the *pólis*? Will Information and Communication Technologies be used to enhance political *participation*, or will the prevailing trend be the fusion of citizens into Big Data, and digital-twinning of our cities, a trend arguably incompatible with the original idea of citizenship itself? As far back as in 1958, Hanna Arendt very clearly pointed out a potential drift toward tyranny that our technocratic future may have a hard time dispelling [14],

> *when everything that is not everyday behavior or automatic trends has been ruled out as immaterial.*

Once more, we find the re-emergence of currents that have been recognized and feared for a long time, and would therefore be extremely unwise to dismiss:

> *[…] although statistics, that is, the mathematical treatment of reality, was unknown prior to the modern age, the social phenomena which make such treatment possible—great numbers, accounting for conformism, behaviorism, and automatism in human affairs—were precisely those traits which, in Greek self-understanding, distinguished the Persian civilization from their own.*

The evolution of the *pólis* into a Smart City, the fusion of what used to be irreducibly individualistic into Big Data, the translation of the "*least conformable body politic known to us*" into a digital twin for the sake of efficiency, convenience, comfort, and in the name of the "*harmony of interests*", may well lead to the end of politics as we know it:

> *Statistical uniformity is by no means a harmless scientific ideal; it is the no longer secret political ideal of a society which, entirely submerged in the routine of everyday living, is at peace with the scientific outlook inherent in its very existence.*

To classify this as a *dissolution factor* may turn out to be an understatement.

Finally, if the Smart City were a room, I believe *education* would be the elephant in it. Can a city be smarter than its citizens? Unfortunately, yes, with dystopic consequences once again pushing toward a *dissolution* of the true idea of citizenship (a happy user or consumer is not per se a citizen). Two aspects in particular are worth pointing out.

First, the educational divide is likely to become the most critical *chasm factor* of all. In spite of the spectacular—and often sinister—feats of genetic engineering, the *Brave New World* [15] description of dystopia—conceived at a time where the Marxian idea of *class* still appeared to make sense, and based on state-controlled reproduction and breeding—is, as of today, neither likely nor necessary to harbor suspicions on our social future: education much more than chromosomes is likely to be the main dividing factor and ranking criterion. The good news is that education is something we can handle—in principle—more easily and better than other social factors, if we just set out to do it. However, such an *education*-driven approach to social mobility and efficient use of human assets requires massive long-term investments that do not pay quick and visible political dividends.

The second aspect has to do with what *kind* of education we will need. Regardless of which cultural field or human activity domain we may consider, as technology progressively displaces the human brain and pushes the meaning of "menial task" to higher and higher levels—to the point where what is today the job of a good integrated circuit designer, or that of a good medical doctor, will be considered menial—education will have to become ever more critical, historical, philosophical, lest it become a mere commodity. Taking one step further, humans will become outdated and ultimately useless in the formation of scientific and technical *consensus*—our ability to memorize, fetch, sort, and process data is far too limited to compete—and the one, last, irreplaceable human asset will be our potential for heresy. If this is the case, we should ask ourselves if our present educational system and our culture at large are a good breeding ground for heretics, or else tend to favor the cultivation of inquisitors: my own answer to this question is not very optimistic.

## 4 Conclusions

I have argued in the previous section that in each one of the several domains examined the Smart City evolution carries, along with unprecedented opportunities for our lives as citizens, potential *chasm factors*—creating or widening divides among city dwellers, or between citizens and non-citizens—and even *dissolution factors* threatening the very fabric of the City as we know it and the idea of citizenship itself. While *chasm factors* can and should be mitigated by enlightened supervision, foresight, and education, *dissolution* may be inherent in the smartification process itself: as the workplace, the marketplace, the *agora*, tend to get blurred in the physical domain and are replaced by their virtual counterparts, as the *social* aspects or labor, of commerce, and of carrying off the business of our lives in general tend to vanish in the process, what will be left of the *distinctive* character of the thing we call a City? Will we end up defining a city on the basis of some arbitrary threshold of population density, with boundaries invisible to the eye and to the perception of inhabitants? In other words, the Greek *pólis* and all the subsequent incarnations of the idea of City were founded on a very clear idea of who and what was excluded as much as of who and what was included. Since powerful economic, social, and environmental drives, no less than an aspiration to equality, advise to steer toward inclusion rather than the other way, we are left with one final question: will the ultimate Smart City be no city at all?

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# Data Integration in a Smart City: A Real Case

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**Abstract**

The introduction and continuous integration of Internet of Things (IoT)-oriented technologies in urban environments leads to enhanced solutions in several domains (such as mobility, health, energy management, environmental monitoring, etc.), thus making a city "smart" and ultimately benefiting the everyday life of its citizens. As IoT systems are widely known to be producers of (often a very large amount of) heterogeneous data, in this chapter we discuss a modular and scalable approach to handle IoT-based data collection and management in a real smart city case, namely, that of the city of Parma, Italy. The proposed IoT infrastructure, the core component of which is a logical processing entity, acting as *middleware* and denoted as "city2i®," in charge of "digesting" the heterogeneous information generated by multiple data sources, allows the municipality to monitor the city status (from multiple perspectives) and to highlight "hidden" correlations among collected data.

## 1 Introduction

In recent years, the concept of *smart city* has been rapidly spreading, in connection with numerous urban contexts and particularly with the application of Information and Communication Technologies (ICTs). This is enabled by the cooperation of academic and industrial worlds, together with governments, institutions and citizens. From a general perspective, a smart city is a city that aims at becoming more livable, sustainable, and attractive for both citizens and potential visitors [1]. This goal requires the municipality to consider the involvement of different entities (such as businesses, multi-utility companies, public transport, and other service-related

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R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_2

stakeholders), which need to cooperate by creating working groups with heterogeneous competences from different city-related areas of intervention. Illustrative activities, which may increase the “smartness” of a municipality, include: efficient energy and resource management, environmental monitoring and protection, optimization of private and public vehicle usage and transport costs (e.g., targeting a shared mobility model, electric mobility, and car pooling), and others [2–5].

Besides, Internet of Things (IoT)-oriented infrastructures and technologies have significantly emerged in the last few years, supporting a large variety of devices, also denoted as *smart objects*, which can be helpful in the city context. For this reason, IoT technologies are considered as key enablers for the actual implementation of the smart city concept [6, 7], allowing the collection of huge amounts of data, which can then be synergistically managed through Artificial Intelligence (AI) algorithms and, in general, (big) data analytics [8]. Therefore, IoT deployment is spreading in different urban areas, with continuous growth of the number of heterogeneous connected devices equipped with different types of sensors and actuators. Considering these scenarios, it is clear that the communication infrastructure is the first key aspect to deal with in future smart cities, since connectivity is generally required *anytime* (during both daytime and night-time urban activities), *anywhere* (namely: in indoor environments, such as buildings; in outdoor environments, such us roads, parking areas, and parks; and also with mobile nodes, such as vehicles or bikes), and *anyhow* (between wireless personal devices —ranging from citizens’ laptops, smartphones, and tablets— to constrained and battery-powered IoT devices).

IoT smart objects deployed in a city are often characterized by different communication technologies and capabilities, and interact with the environment according to different paradigms, e.g., Human-to-Machine (H2M) or Machine-to-Machine (M2M). Taking into account different urban application scenarios, a heterogeneous set of communication technologies and different network architectures may be adopted, aiming at guaranteeing reliability and efficiency depending on the specific features of the services to be provided to citizens. In most cases, connectivity among IoT devices is guaranteed through flexible and low-cost wireless connections, e.g., through wireless mesh networks [9–11]. Generally, wireless short-range communication technologies are preferable when *end-to-end* communications are not possible because of power limitations or physical obstacles. In these cases, *multi-hop* device-to-device communications can be employed to transfer information from IoT nodes (the data sources) to data consumers (e.g., border routers, Cloud servers, users’ applications, etc.). In other deployment conditions, *star* network topologies, based on long-range communication technologies and enabling *one-hop* communications, are preferable. This can be the case of outdoor urban environments where direct and reliable communication links between a central “hub” and several IoT nodes within its coverage are available. Relevant examples of viable solutions are IoT deployments based on Long Range Wide Area Networks (LoRaWAN) [12] and NarrowBand IoT (NB-IoT) [13], currently attracting much interest in smart city scenarios where a large coverage is needed, with minimum infrastructure support and energy consumption.

The complexity of urban scenarios prevents the use of a single connectivity technology for all the possible monitored areas and, consequently, for all the services that can be implemented. Rather, a hybrid and flexible networking infrastructure, combining heterogeneous technologies, is required. The most relevant communication technologies employed in smart city contexts can be summarized as follows, on the basis of the transmission range and communication data rate [14–18], with pros and cons detailed in Table 1.

- Low-Power Wide Area Networks (LPWANs): these networks are designed to interconnect battery-powered devices with very low

**Table 1** Pros and cons of relevant communication technologies employed in smart city contexts

| Technology | Pros | Cons |
|---|---|---|
| LTE-M | Good coverage and roaming, acceptable power consumption, suitable for mobile and static devices | Not adapt for large amounts of data, target low-rate applications, asymmetric data transfer (with limited downlink channels) |
| NB-IoT | Good power consumption in poor coverage conditions | Suitable only for static devices |
| LoRa/LoRaWAN | Low power consumption and cost, secure bidirectional communication | Low data rate and throughput |
| 4G/5G | High data rate, bandwidth, coverage, and flexibility | Additional SIMs required (until eSIMs will not be natively integrated into equipments), M2M traffic to be accommodated |
| IEEE 802.11 | Lack of wires, user can move, no need to be stuck at one place | High signal attenuation, limited service radius, less stable compared to wired connections |
| IEEE 802.15.4 | Power saving, collision avoidance, low cost, open standard | Short range, low data rate and throughput, lack full interoperability |
| BLE | Low cost, easy to install, native support in modern equipments | Short-range communication, secure flaws |

bit rate (on the order of b/s) over very long distances (on the order of km). Due to their low cost, wide coverage, and straightforward setup, LPWANs are being deployed in scenarios where small amounts of data have to be transmitted by a large number of devices [19]. LPWANs typically operate in both unlicensed and licensed frequency bands, and are based on different (open or proprietary) standards, such as LTE-M [20] and the above-mentioned NB-IoT[1] and LoRaWAN.

- Cellular (e.g., 4G/5G): thanks to its improved features, such as very low latency (below 1 ms) and very high bandwidth (over 10 Gb/s), 5G is emerging as one of the primary enablers for IoT. Hence, 5G can be considered as an enabling communication technology for smart cities, allowing thousands of IoT devices to be connected, regardless of their location, and supporting applications such as smart traffic systems, public safety, enhanced tourism [21], security and surveillance [22].
- Wireless Local Area Networks (WLANs) and short-range networks: many use cases in smart cities require the deployment of "regional" (namely, covering a limited spatial area) and, in some cases, "individual" networks (such as Personal Area Networks, PANs). In this context, available communication technologies span from IEEE 802.11 to IEEE 802.15.4 and Bluetooth Low Energy (BLE) [23].

A heterogeneous communication architecture allows continuous and ubiquitous sensing in urban contexts, leading to large volume of produced data, which can be represented according to multiple formats. These data potentially represent a valuable asset for cities since, if properly processed, they can help to significantly

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[1] LTE-M and NB-IoT are formally a cellular technology. However, the use of the available resources is typical of an LPWAN and, therefore, we consider these technologies in this category.

improve the efficiency and effectiveness of several operations related to city management and administration. However, because of the absence of common platforms and clearly-defined (and open) standards, the majority of data produced and collected in a city are generally stored and secured in proprietary data centers, only accessible with dedicated software solutions that act as isolated "verticals" developed by the vendors.

Recently, the development and deployment of frameworks or middlewares targeting smart cities has been addressed in the academic literature. As a reference, [24] presents an overview of the wide landscape of IoT-enabled smart cities, considering a selection of relevant municipal initiatives around the world having IoT as the key enabler for realising the smart city paradigm. More in detail, the objective in [24] is to identify the key IoT technologies concurring in the smart city realization and the key challenges that are currently being addressed for the success of smart cities. Among other aspects, the following problems are highlighted: (i) solutions based on the use of proprietary IoT platforms cannot be replicated across cities that often suffer from vendor lock-in (i.e., they cannot easily buy and integrate components or applications from different vendors); and (ii) public administrations cannot, on their own, fully take advantage of the smart city paradigm since they are consumers of services, but they are not actively engaged in the smart city as producers of valuable information that would bring forward new services, and contribute to a virtuous cycle with many benefits.

The problem of interoperability between different smart city systems has been addressed also in [25], where a set of requirements is defined for interoperability (in accordance to five different aspects for the smart city concept, namely, syntactic, semantic, network, middleware, and security) after collecting and analyzing studies on heterogeneous IoT systems.

Moreover, additional surveys have been presented in the literature in the last few years [3, 26–28], all intended to clarify and highlight possible ways in which IoT technologies can be employed in infrastructure projects to enhance both productivity and responsiveness. In [26, 28], projects or frameworks are presented focusing on the following specific topics or services: transportation, energy, parking, waste management, general monitoring, and healthcare. Other works do not focus on a single specific application or topic, but provide a more general approach [29, 30]. [27] presents IoT frameworks for smart city applications, in turn comparing technologies and architectures, and finding that they share, in general, an architecture with the following four layers: (i) a sensing layer, (ii) a network layer, (iii) a middleware layer, and (iv) an application layer.

Based on these survey results, an abstract five-layered IoT framework concept for smart city applications is proposed to address the needs of smart city applications as a reference for successful IoT framework implementations. To this regard, the main aspects addressed by the proposed framework concept are sustainability, decentralization, autonomy, security, and modularity.

With respect to the aforementioned state of the art, the main novelty of the middleware-oriented architecture proposed in this chapter is related to the actual implementation of a framework targeting the municipality of a smart city (since citizens are often targeted by applications provided by vendor's commercial platforms); the goal is to integrate data collected by different systems, thus building a new tool for accurate understanding of city processes.

It is also important to remind that independent and isolated "verticals" developed by vendors: (i) are not natively designed to interoperate and communicate with each other, and (ii) do not aim at contributing to a common urban data management infrastructure. This motivates an always-increasing need for novel, open, and scalable platforms and frameworks that can help in the collection, integration and analysis of complex smart city data. This is fundamental to extend the services that a "smart" city can provide to its administration, citizens and visitors, thus building a new data management and utilization paradigm.

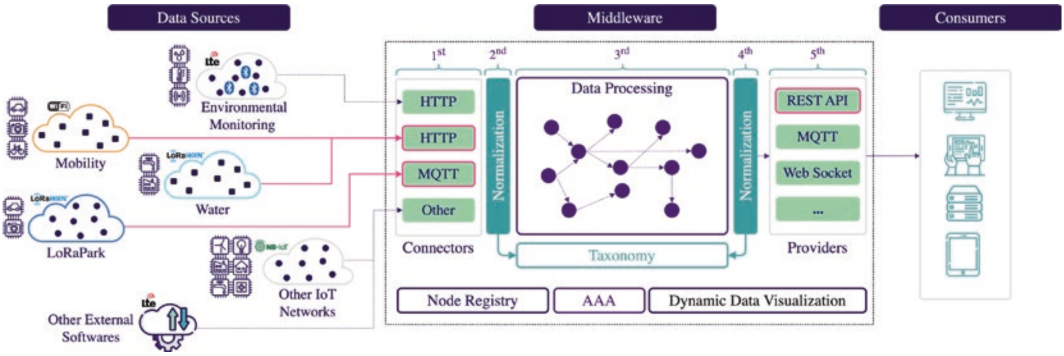

**Fig. 1** Overall representation of the proposed IoT-oriented infrastructure working on top of its core component, denoted as middleware. The components and modules currently defined and deployed in a Proof of Concept (PoC) in the city of Parma, Italy, are highlighted with pink solid lines and colored clouds.

Motivated by the previous observations, in this chapter we present and discuss a novel, modular and scalable approach to handle IoT-based data collection and integration in a real smart city case, given by the city of Parma, Italy. The proposed IoT infrastructure, the core component of which is a logical processing entity acting as middleware and denoted as "city2i®," is designed to extract shareable knowledge from heterogeneous smart city data. The middleware, on top of a heterogeneous data collection infrastructure, allows to transfer streams of data from IoT devices (Far Edge) to the Edge and, eventually, to the Cloud. This, in turn, provides the municipality and the citizens with a tool that, by integrating different systems, allows to monitor the entire city status (from multiple perspectives), and also to highlight "hidden" correlations among (IoT) data potentially collected by different (IoT) "verticals."

## 2 A New Data Integration Environment

### 2.1 The Middleware Architecture

The middleware is a modular software platform representing the core of the proposed smart city-oriented infrastructure. Its main goal is to integrate the data generated by all the possible data sources that are available in the city context, such as heterogeneous IoT networks, external software services used by the municipality administrators, public open datasets available in the Cloud, and so on. The high-level architectural representation of the middleware, together with its connections to external entities (data sources and consumers at the input and at the output, respectively), is shown in Fig. 1.

The data sources may be highly heterogeneous and correspond to IoT deployments and software services (with different purposes) active in the urban context. IoT data sources rely on specific technologies (e.g., sensing resources), communication protocols (e.g., LoRaWAN, WiFi, BLE, TCP or UDP, MQTT, CoAP [31], etc.) and data formats, depending on the tasks to be performed and the required performance. As an example, Fig. 1 includes a LoRaWAN-based IoT network deployed for the city environmental monitoring, including temperature, humidity, and pollution sensors. Another scenario may involve a WiFi-based IoT deployment to monitor mobility flows in specific areas of the city (e.g., pedestrian, bike or vehicle counters on the roads). Other possible data sources may involve external software acquired by the municipality (e.g., administrative software), as well as *open data* and services deployed in the Cloud: in this case as well, data sources may rely on a specific approach to transfer information (e.g., REST APIs, WebSocket, MQTT, etc.) and data formats (e.g., JSON).

The main components of the proposed middleware-oriented platform can be summarized considering the following five layers highlighted in Fig. 1:

1. *Connectors*, needed to integrate data sources;
2. *Normalization module*, responsible for knowledge extraction;
3. *Taxonomy module*, required to represent smart city information;
4. *Data Processing module*, in charge of custom processing on the data;
5. *Normalization module*, responsible for representing new data.

In the following, all these components will be further described, together with other additional modules required for the proposed architecture's life cycle.

Each data source is integrated in the middleware through specific software components, denoted as *Connectors*, which are implemented to integrate data streams from a specific (and, from a top-down perspective, *atomic*) data source. The set of connectors can thus be considered as the *first layer* of the middleware. This layer has to be extended, with the implementation of a new connector, to support the integration of any new data source (e.g., if the municipality decides to deploy a new IoT system in the city). In fact, connectors depend on the specific technology and paradigm implemented by the manufacturer/vendor of the newly deployed system.

The *second layer* of the middleware corresponds to a component, denoted as *Normalization module* (which is also present in the output layer), responsible for knowledge extraction. This module, in accordance with the platform's *Taxonomy module* governing the information representation rules and policies valid inside the middleware itself, translates *raw* data acquired by connectors into one or more integrated information streams, with a common data structure that can thus be managed by subsequent middleware modules. More in detail, the goal of the Normalization module is to create high-level, geo-localized, and integrated *data overlays* identifying and semantically labeling input data streams (e.g., temperature values, parking information, air pollution indicators, etc.) that may be obtained by completely different data sources, but that are logically coherent. In practice, the Normalization module maps each *raw* piece of information generated by data sources to one or more taxonomy's entries (on the basis of its ontological meaning) and associates each value with an absolute timestamp and geographic coordinates. The result of this preliminary operation is a set of basic data overlays, composed by similar data, obtained through the integration of different data sources by the middleware. As an example, a "city temperature overlay" may derive from the integration of geo-localized heterogeneous temperature sensors (developed by different manufacturers and vendors) deployed in the city with open data publicly available in the Cloud. This kind of data integration is instrumental to subsequently manage information in a more contextualized way, regardless of the specific technology used by sensors to collect data, and by data sources to transmit them.

The *third layer*, corresponding to the *Data Processing module*, has been designed to perform processing tasks on basic "normalized" data overlays generated by the previous layer. The structure of this module is intended to be highly modular and configurable, following a Big Stream-oriented approach [32, 33] able to cope with very large amounts of information to be managed. The Data Processing module is composed by a set of modular processing units that: (i) take one or more data streams as input; (ii) perform custom operations defining the *behavior* of each "atomic" processing node; and (iii) generate one or more information streams, related to one or more taxonomy's entries, as output. The operations performed on the data can span from simple statistical tasks (e.g., mean, standard deviation, etc.) to complex data fusion tasks, as well as AI-based processing. To this regard, pictorial examples of how the AI can intervene in the data processing may include: (i) air quality prediction based on pollutant levels sensed by IoT devices spread across the city; (ii) traffic and mobility flow management based on cellular signals' strength obtained from *third-party* data sources; and (iii) water consumption forecasting in public buildings based on data collected through smart metering solutions. There is no actual limit to the specific operations that can be implemented in single processing units, as the set may be freely extended depending on the final data overlays of interest for smart city administrators, as well as for citizens and visitors. The aforementioned processing units can be defined and included in the *Data Processing module* as needed by the smart city municipality, building a sort of graph where data streams connect different processing steps. We remark that this highly-modular infrastructure introduces latency at each processing unit "crossed" by multiple data streams. These latency components are, in general, unpredictable, depend on the specific algorithm or computational complexity needed for the implementation of the desired behavior, and are independent of the architecture itself. Nevertheless, the middleware has been designed to minimize the latency needed to forward data between two consecutive processing units [32, 33].

The *fourth layer* is associated with a *Normalization module* similar to that of the *second layer* and dedicated to data provisioning. Hence, the information output by this module is normalized cooperating with the internal cross-layer Taxonomy module, in order to provide data with a format coherent with the taxonomy used in the overall system and with the reference domain of the smart city.

Finally, the generated high-level information should be output by the middleware to interested external entities: this can be performed through different sets of data access mechanisms, which are denoted as *providers* and constitute the *fifth layer* of the middleware. In detail, each provider may act in a *passive way*, waiting for requests from external entities, as well as in a *proactive way*, publishing data as soon as these are available. Relevant examples of data provisioning are HTTPS REST APIs, subscriptions to MQTT topics, and WSs. Different providers' modules can be implemented to extend the platform and to satisfy the requirements given by external applications or developers, interested in creating innovative services using the information overlays generated by the proposed middleware.

The following additional modules, with respect to those of the five operational layers, are relevant in the life cycle of the proposed IoT-oriented architecture.

- *Node Registry module*: in charge of maintaining the list of IoT nodes acting as data sources for the IoT infrastructure, with information related to the nodes attached to data streams. This information may be useful for data consumers.
- *Authentication, Authorization, and Accounting (AAA) module*: responsible for controlling the access to the resources by both connectors and providers.
- *Dynamic Data Visualization module*: in charge of visually representing, upon request, the information handled by the IoT middleware. Being part of a modular solution and aiming to adhere to the middleware's taxonomy, the design of the Graphical User Interface (GUI) should reflect the heterogeneity of the IoT data flows, too [34]. In particular, it should allow to dynamically build customized User Interfaces (UIs) on the basis of data and information descriptors (e.g., XML- or JSON-based).

The aforementioned modules allow the proposed IoT architecture to provide smart cities' administrators with a unified tool, that can be seen as a sort of city's control panel. This allows to extract knowledge in a "simple" way from heterogeneous urban data sources, hiding technical aspects to the municipality, citizens and visitors, since they lack the cecessary technical skills. As an example, heterogeneous data streams can be integrated and classified through the taxonomy module as "similar," even if the physical data sources are completely different (e.g., manufactured by different vendors). This allows to have a comprehensive overview on the available data from the entire city perspective, which on the other hand is generally prevented by limited vertical applications provided by the single systems' vendors.

As detailed before, the cross-layer Taxonomy module is crucial in the proposed middleware architecture. In fact, it provides a unified ontology to label the information overlays inside the proposed infrastructure. This module allows to classify and normalize data provided by both external data sources (after the acquisition step through the connectors) and the middleware itself (in the Data Processing module), providing a coherent information flow to external customers. The resulting classification is then shared to interested entities through providers. To this end, the entries composing the taxonomy should be selected in order to be assigned to possible data generated by IoT objects deployed in the smart city, such as, for example: environmental monitoring data (e.g., indoor and outdoor temperatures, pressure, humidity, air- and weather-related parameters, etc.), energy and resources utilization data, mobility- and traffic flow-related data, and others. As mentioned before, besides IoT systems, data sources can also be external and of a different nature (e.g., Cloud data): the taxonomy has to take this into account.

## 3 A Real Use Case: The City of Parma

In order to validate the proposed IoT-oriented middleware-based architecture directly *in the field*, inn this section we present an overview of its adoption (currently in progress) in the city of Parma, Italy. The city of Parma has implemented relevant Proofs of Concept (PoCs) to investigate how to offer enhanced services to its citizens and visitors, for example through the deployment of various LoRaWAN-based IoT systems, connected to the LoRaWAN city network infrastructure deployed by BT Enìa Telecomunicazioni S.p.A.[2]

One of the PoCs focuses on smart parking and urban mobility solutions.[3] More in detail, monitoring the parking availability is a relevant activity in a smart city context, as it is important both for citizens, who would like to find vacant parking spaces for their vehicles during their working days, and for the municipality, to verify parking sustainability (in terms of available parking spaces) and to detect improper utilization (e.g., missing payments, unlawful utilization of parking lots reserved for disabled people or for loading/unloading goods). Several IoT options are available for parking monitoring, depending on cost, number of lots to be monitored, and environmental conditions. In the city of Parma, the following two types of parking monitoring system have been evaluated in different downtown areas and are integrated as IoT data sources in the middleware.

- *Magnetic* IoT nodes (Parking Spot Sensor provided by Kiunsys[4]). A single IoT node is inserted directly in the asphalt in each single parking lot to be monitored, providing a "free/busy" (binary) status information.
- *Optical* IoT nodes (provided by things2i[5] and denoted as "park2i®") installed on top of the parking area to be monitored. This node provides data in two different modes, depending on the device configuration: (i) a list of "free/busy" (binary) statuses of parking spaces in the area; or (ii) the aggregated occupancy percentage of the entire parking area.

Beside the first PoC focused on parking sensors, the municipality of Parma started to deploy different IoT LoRaWAN devices, to cover different applications. In particular, the municipality identified the following five different "pillars" of interest.

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[2] http://www.btenia.it/.

[3] This topic has been of particular interest for people visiting the city of Parma, Italy, which was the Italian Capital of Culture in the years 2020–2021: https://parma2020.it/en/.

[4] https://municipia.eng.it/prodotti/parking-spot-sensor/.

[5] https://www.things2i.com/.

**Table 2** LoRaWAN-based IoT nodes currently deployed in the city of Parma, Italy, and integrated in the middleware

| Type | Manufacturer | Model | Number of IoT nodes |
|---|---|---|---|
| Water metering | Midomet | Midomet LoRa Pulse/Analog | 4 |
| Parking monitoring | things2i | park2i® | 4 |
| Parking monitoring | Neosystems | Neosystems parking sensor (NPS) | 39 |
| Cars counter | Nablaquadro | LoRa traffic sensor | 13 |
| Bike and people counter | Parametric | Traffic sensor | 3 |

- Large parking area monitoring (e.g., "park-and-ride" areas in the city, as well as supermarket parking lots) through the deployment of park2i® nodes.
- Single parking space monitoring, to monitor the use of specific or particular spaces (e.g., for handicapped people) through magnetic IoT nodes, as mentioned before.
- Mobility data collection through the deployment of bi-directional car, bike, and pedestrian counters along roads and bicycles lanes of particular interest for the municipality (e.g., limited-traffic zones and public bike paths).
- Water resource consumption monitoring in public buildings through the deployment of water metering sensors.
- Additional heterogeneous sensors, not related to a specific application but of future interest for larger deployments (e.g., noise sensors, trash volume and location sensors, etc.).

For the sake of clarity, in Table 2 we give a summary of all the LoRaWAN-based IoT nodes deployed in the city of Parma and integrated in the middleware.[6] The choice of the listed commercial IoT devices has been left to the municipality of Parma, which, together with its collaborators and providers, acquired and deployed the devices depending on the "pillars" of interest and the existing communication infrastructure.

Following the proposed smart city-oriented IoT middleware-based architecture, the *first integration step* required to add the IoT nodes deployed in Parma is the Node Registry module, storing all the details about each specific IoT device—such as manufacturer, model, serial number, transmission technology—and a reference to a specific device descriptor (in JSON format) containing the list of the resources monitored by the specific IoT device (e.g., temperature, humidity, passages, etc.), with a consequent mapping to one or more taxonomy entries known by the middleware itself. Then, the JSON descriptor is shared among all the IoT devices of the same type: as an example, with reference to the aforementioned parking monitoring scenario, two different descriptors should be added to the IoT architecture in order to describe the corresponding data sources. Another relevant piece of information stored in the Node Registry is the geographical location of the nodes (namely, GNSS-based latitude, longitude, and altitude values), required to link the sensed data with their respective location in Parma. Ultimately, this allows to build a "parking city overlay."

The *second integration step* is required to develop the connectors, in order to manage the different transmission modes and data rates. To this end, each connector has to acquire the data stream from its data source, based on the specific communication protocol. Then, exploiting (i) the JSON descriptors of each IoT device mapped in the architecture and (ii) the taxonomy definition, the Normalization module normalizes the data format, making it coherent for subsequent utilization in the middleware's processing units. As an example, with reference to the city of Parma, the data received by parking sensors are mapped using taxonomies such as `parking_status` (with `true` and `false`

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[6] The IoT nodes listed in Table 2 refer to the time of writing, as their relative number and nature will be updated based on upcoming needs and future decisions.

**Fig. 2** Overview of the middleware data sources deployed in city of Parma, Italy

as possible values), whereas data arriving from pedestrian counters can be mapped with `left2right_counter`, `right2left_counter`, and `temperature` values (as these IoT devices have also an *on-board* temperature sensor).

At this moment, since in the city of Parma only LoRaWAN IoT devices (managed by a single LoRaWAN network operator) are considered in the PoCs, the following types of connectors have been developed.[7]

- HTTP Webhook connector, which *passively* receives data streams from the LoRaWAN Application Server (namely, through HTTP POST requests sent to the middleware's connector endpoint each time an IoT device sends a new LoRaWAN uplink message).
- MQTT connector, which *passively* receives data streams through a subscription on MQTT topics of interest, on which data will be published by the LoRaWAN Application Server.

An illustrative representation of the proposed IoT-oriented middleware-based architecture applied to the city of Parma has already been shown in Fig. 1, where the deployed components and systems are depicted as colored clouds, forwarding their data through the pink solid lines.

Once the device integration in the IoT middleware has been completed, a comprehensive and unified view of the city status can be derived. In fact, it is possible to define a custom UI to show live data from a single IoT device or aggregated data from all available data streams with the same label (e.g., `parking_status`). No further considerations related to the specific deployment platform for the UI (e.g., desktop, mobile, Web, etc.) will be discussed here, as the *presentation layer* can be considered as an *add-on* for the consumers, as defined in the Dynamic Data Visualization module of the middleware. To this end, Fig. 2 shows a prototypical middleware Web-based dashboard for the city of Parma, providing an overview on the installed IoT devices and their location in the city, with reference to the "pillars" (or topics) of interest for the municipality.

The *last* step pertaining with the integration involves the Data Processing module, in turn using the integrated normalized data to perform complex operations. As an example, in the case of parking lots monitored with different IoT

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[7] Additional connectors are under development based on the new data sources to be integrated.

Piazza Caduti del Lavoro:
Transit count (last hour):
85

Via Trento:
Transit count (last hour):
47

Limited traffic area: via Osacca
Transit count (last hour):
108

**Fig. 3** Example of UI corresponding to complex overlays aggregated by specific middleware's processing units. In this case, the UI refers to a limited mobility area ("zona 30").

technologies, it is possible to create dynamic UIs based on the nature of the data sources, while developing custom data processing units for data fusion. In general, the middleware allows to activate processing units performing statistical operations on historical data, calculating values such as the average parking duration, the number of status changes and so on, as well as detecting correlations with other data overlays that can be available in the same city area. In the current deployment in the city of Parma the following types of processing units have been developed.[8]

- Counter data management: since the deployed car counter only provides an "absolute" count (starting from the time of installation), a processing unit has been developed to calculate the "relative" increments with respect to the time frame of interest.
- Limited-traffic-area monitoring: as shown in Fig. 3, in order to allow the municipality to benefit of a clear overview on the access to limited-traffic areas in the city, a processing unit (based on the knowledge of the locations of several car and bike counters) is in charge of computing the amount of vehicles currently present in specific areas.
- Data format conversions, or geographical filtering: in these cases, the developed processing units are in charge of uniforming the notation of the information received from data producers, or returning a data subset based on a specific geographical area selection, respectively.

The first implementation of the middleware has been deployed in 2022 and has been collecting data for about 8 months, with increasing number of data sources. Being a modular architecture, its performance is difficult to evaluate, since it depends on several aspects. Despite the complexity, some preliminary considerations can be made. The data acquisition time, defined as the time elapsed from the generation time (declared by external data sources, e.g., the LoRaWAN Application Server) to the time when the information is stored in the middleware and associated with a taxonomy entry, is shorter than 1 s in over 98% of the acquisitions, with an average input data rate of 13 new data entries per minute. This acquisition time, however, can increase

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[8] As for the additional connectors mentioned before, newly specific processing units are under development based on the needs of the municipality, in terms of enhanced services to be provided to the end-users.

in an unpredictable way if data sources require custom processing in the *Data Processing module*.

Moreover, the proposed middleware-oriented architecture is designed to integrate streams of heterogeneous data sources (from both IoT devices and external software tools). In particular, the maximum number of sources that the system can handle depends on several factors, such as:

- the data generation rate (e.g., LoRaWAN devices should abide by duty cycle constraints);
- the payload size;
- the paradigm or custom processing required for data acquisition (e.g., connectors for external software can follow a polling paradigm through REST API, but also a publish/subscribe model).

To this regard, the proposed architecture is highly modular, making it possible to add new components depending on the workload (e.g., add a specific virtual machine to handle the data flows of a specific connector). The cost is directly related to the complexity of the final architecture and can be billed to the municipality as a periodic subscription fee.

Even though the IoT deployment in the city of Parma is still at an early stage, the proposed middleware-oriented architecture represents a useful tool with wide applicability, since it hides all the technical details related with the deployment of heterogeneous devices (each one with its own technology), which may not be of interest for the municipality. Moreover, it allows to build an urban dataset without the need to access vertical applications by different manufacturers. The collected information can then be forwarded to external entities through specific data connectors. For example, this may include historical data in a specific time range, made accessible through HTTPS REST APIs for statistical purposes, as well as *live* data forwarded through a WS-based channel to developers working on mobile Apps for citizens.

## 4 Conclusions and Future Integration

The diffusion of IoT technologies in urban contexts, together with data analysis (also based on AI techniques), plays a key role in the implementation of the concept of smart cities aiming at enhancing the citizen's quality of life and improving the city's administrative processes. IoT often pertains to different domains, such as: environment and pollution monitoring, health care and education, energy and resources management, and mobility. Unfortunately, the lack of shared and common standards and platforms has generated the diffusion of proprietary and disjoint vertical applications. These verticals allow to collect large amounts of data from a city but, at the same time, are not designed to communicate with each other for data fusion. This chapter discussed a smart city IoT-oriented middleware-based architecture, whose aim is integrating heterogeneous data generated from multiple sources, in order to allow a municipality to monitor the city status from multiple perspectives. This allows to highlight (sometimes discover) "hidden" correlations among heterogeneous IoT data by building synergies between isolated systems. The core of the middleware is the utilization of a shared taxonomy and the concept of connectors, which perform the following operations: data collection, data format translation, and data normalization for each class of data sources (IoT systems as well as external software tools). The modularity and scalability of the proposed IoT architecture allows to hide the heterogeneity of possible data sources and technical aspects of the adopted communication protocols, thus providing a city control panel for the municipality to monitor processes and to build new services that can simplify the city management, and optimize the citizens' and visitors' experience. Finally, for the sake of validation of the proposed IoT middleware-oriented platform, its actual experimental deployment in the city of Parma, Italy, has been discussed.

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# Monitoring People's Mobility in the Cities: A Review of Advanced Technologies

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**Abstract**

The knowledge of how people move in urban areas is helpful for the effective deployment of many city services, such as planning and management of transport mobility services, management of security procedures during crowded public events, and design of new public spaces. In the last decade, several technologies have been exploited to collect relevant data to get key insights on the number of people that gather in different points of interest, the amount of time the people spend there, and how frequently people return. This chapter reviews the latest technological solutions that have been developed in this field which exploit the following data sources: radars, lidars, cameras, Wi-Fi sniffers, CDRs, and crowdsourcing applications. It also provides an analysis of the pros and cons of each alternative, the achievable accuracy, and the types of areas that can be monitored.

## 1 Introduction

The term mobility refers to the intentional movement of people from one location to another. This movement can be performed through different modes of transport (e.g., walking, train, bus, private cars) according to the needs of the people and the availability of infrastructures and services along the route between the origin and the destination. Monitoring urban mobility has essential applications related to marketing [1], public administration [2], tourism [3], public security [4], safety [5], and transports [6]. Additionally, statistics about mobility help identify and localize deficiencies or weaknesses of an urban environment that might cause damage to people or property [6].

Systems to monitor urban mobility often aggregate heterogeneous data that comes from various sources and implement data fusion to improve the quality of monitoring and control. Moreover, historical data trends can be used to

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R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_3

create models of transport systems, run simulations, and train Machine Learning algorithms to predict future events [7]. Proper data analysis makes it possible to identify trends and patterns, pinpoint high-traffic areas, and predict future traffic flows. Overall, these technologies are used to improve traffic management, public safety, and urban planning.

Automated systems generally have the convenience of collecting data in real time, yet they provide information on crowding at points of interest defined by the entity collecting the data. This fact might limit the study of flows of people who may move with origins and destinations outside the monitored geographical area. Usually, in order to capture this pool of data that could be missed, it is necessary to seek the cooperation of users (e.g., with periodic surveys) or permission to collect data from their smartphones (e.g., with special apps). However, it is important to consider the privacy and data security implications and ensure they are used ethically and transparently.

The strictest regulation about privacy is the European General Data Protection Regulation (GDPR), which defines personal data as “information relating to an identified or identifiable natural person” [8]. The identification of a person can be direct or indirect. Direct identification derives from the measure or observation of unique physical characteristics (e.g., fingerprints or face recognition) or the use of strings that users employ to identify themselves (e.g., name, email). On the contrary, indirect identification requires access to additional data with respect to that captured with the technologies under analysis (which, alone, cannot identify people). The additional data typically come from external sources. For example, indirect identification can be related to an object the user carries (e.g., a personal ticket, smartphone). In order to protect the privacy of people, data is usually anonymized (or pseudonymized). In other words, personal data can be processed to separate the identity of people from the technical measurement (e.g., flow monitoring).

Monitoring crowds in a smart city is an area of research that can exploit various technologies to collect, analyze, and process real-time data related to mobility activities. This chapter presents some of the main modern technologies used for this purpose that have been developed during the last decade. The order of presentation starts from the ones that only count the number of people to move to the ones that contextualize data with information about gender, age, and fine geographical tracking. The technologies presented in this chapter are:

- Radar and Lidar Technologies: ranging technologies allow the detection of objects and people and measuring their distance from the sensor. They are mainly used indoors because of their limited measurement range. This technology is used to count people in an area or a vehicle. However, it usually does not allow tracking. It is still widely used because of its low price and simplicity. More details are given in Sect. 2.
- Processing of Video Streams with Deep Learning: cameras are the most common method for collecting data about crowds in a smart city. These systems can be installed in public areas such as streets, parks, subway stations, and shopping centers. The data collected include information about the movement of people, the number of people in a specific area, and the duration of their permanence. Video analysis based on computer vision hugely improved the detection of people and their activities with Machine Learning algorithms. A deeper analysis of these technologies can be found in Sect. 3.
- Analysis of Wireless-Network Traffic: another technique to gather data on crowds is to collect and analyze data originating from personal smartphones. Assuming that every person has at least one device, specific sensors capture and analyze anonymously the messages transmitted by smartphones to count and track people in outdoor and indoor scenarios. Methods of Wi-Fi and

Radio-Frequency (RF) traffic analysis are described in Sect. 4

- Analysis of Call Data Records (CDR): CDRs are data structures collected by phone-service providers to track telephone calls and other telecommunications transactions. Their main aim was the management of customers' billing, but nowadays, new applications have been explored. CDRs also provide comprehensive information on gender, age, and geographic tracking constrained to the cell to which the phone is connected. An overview of the analysis of CDR Data for monitoring people's mobility in cities is offered in Sect. 5.
- Collection of Data from Personal-Device Apps: Crowdsensing techniques often involve personal smartphones in collecting users' data. This data usually has high geographical resolution and profile users by asking for their collaboration to compile forms or collect personal information. Moreover, these data can be cross-referenced with Floating Car Data (FCD), data collected by in-vehicle devices measuring their positions, route, and speed. Even though FCD provide accurate and secure vehicle information, the origin and destination of users do not always correspond to public transport service stops. These methods are illustrated in Sect. 6.

The next sections review the solutions for people mobility monitoring following the above order. The chapter ends with a review of performance and a comparison between the presented technologies.

## 2 Radar and Lidar Technologies

Radars (Radio Detection And Ranging) and Lidars (Light Detection And Ranging) are sensors to detect the presence of objects (including people) and measure their distance (ranging). These sensors emit electromagnetic radiations that propagate and are intercepted by the surfaces of objects on their way. The intercepted energy is then absorbed and/or re-irradiated in a direction that depends on the angle between the surface and the wave emitted by the sensor [9], butusually comes back to the sensor generating an echo. The "Time of Flight" (ToF) is the time needed to reach the target object and to get back to the sensor, and is proportional to the object's distance. The distance or range $d$ of the object from the radar is given by the multiplication between the speed of light ($c_0 = 3 * 10^8$ m/s), at which all electromagnetic waves propagate in standard conditions and half the ToF ($t$):

$$d = \frac{c_0 * t}{2}$$

Radars usually have a bidirectional antenna that can be used both for transmission and reception. The antenna produces a narrow directive beam and acts as spatial filter to provide angle resolution and identify the direction of the reflected radiation (azimut) [10]. Lidars are analogous to radars, except they are based on discrete pulses of laser light. They emit intense and focused beams of light to measure the time a light beam travels from a source to a target and back to the light detector, and the direction of the reflected wave [11]. Nowadays, many commercial radars and lidars implement functions for people counting. Some sensors also have options to detect movement direction and speed. For example, it is possible to count pedestrians and cyclists separately.

Moreover, one of the main advantages of sensors is their compliance with the GDPR: even though radars and lidars create a 3D map of their surroundings, they do not collect any personally identifiable information about people [8]. However, the incapability to identify people complicates the tracking. Radars and lidars track people by collecting sequences of positions and the direction where people are moving. These approaches are often aimed at monitoring indoor or delimited areas and placed in entrances and exits, so the number of people is given by subtracting the number of outgoing passages from the number of incoming passages. This approach can also be used to monitor the flow of vehicles on the road. These sensors can be integrated with low-resolution cameras to improve accuracy and allow tracking without endangering the privacy of people [12, 13].

Radar applications for detecting and identifying human targets are currently topics of great interest in the scientific community because of the variety of use cases they embrace (e.g., autonomous driving, search and rescue operations, intelligent environments, etc.) [14]. Considering different types of radars, millimeter-wave radars are preferred because they have high tracking accuracy and can identify and track multiple persons simultaneously, unlike other techniques. The tracking of people is possible through processing the raw data (sparse point clouds with time references) with neural networks. The authors of [15] claim to obtain median position errors of 0.16 m and identification accuracy of 89% for 12 people with deep recurrent networks.

Regarding lidars, similar solutions have been studied. Modern lidar systems have multiple coordinated emitter-detector pairs rotating 360 °C multiple times per second, which collect sufficient samples to reconstruct a precise 3D model of an area. Each sensor rotation gathers a cloud of points that neural networks process with the samples collected in the previous scans to reconstruct dynamic scenes of moving objects and people [16]. The processing of lidar data is similar to the one of camera data: like pixels in camera images, lidar points (or voxels) are grouped to identify and discard irrelevant objects that constitute the background. This procedure is crucial because, differently from cameras, a lidar alone cannot rely on textures or colors to disambiguate objects, leading to classification errors between multiple human targets and objects. Kalman filters are applied to compensate for these kinds of errors.

Generally speaking, aggregating multiple data sources (data fusion) can improve the monitoring and prediction of people mobility. Data fusion can be performed in different ways [17]:

- Sensor fusion: the diversity of sources is used to preprocess the data to obtain more accurate and complete analyses. Redundancy is exploited to clean the outputs of sensors before storage and analysis. In this case, the less reliable output can be discarded (i.e., a sensor returns an error).
- Feature-based data fusion: Statistical and Artificial-Intelligence (AI) methods process features coming from different data sources to mine the information deeply. Examples of this kind of data fusion are systems that combine radar or lidar information with data collected by cameras.
- Decision fusion: automatic systems usually include decisional functions (e.g., thresholds to trigger alerts) that might be influenced by multi-source data features. Thresholds and weights of the features can be dynamically updated in real-time to adapt to new scenario conditions. For example, cameras might be less accurate in scarce light conditions. Table 1 lists the past works that have studied different applications of the Radar and LIDAR technologies.

## 3 Processing of Video Streams with Deep Learning

Cameras are one of the most widely used technologies to monitor people's flows due to their versatility. By appropriately placing cameras, it is possible to monitor very large areas compared to those monitored by other types of sensors. On the other hand, it is necessary to use appropriate shape recognition algorithms to be able to identify people and their activities.

Over the last fifty years, people recognition algorithms have undergone considerable

**Table 1** Relevant papers on the Ranging Technologies for counting people

| Approach | References |
|---|---|
| Radar applications for indoor monitoring | [9, 18] |
| Radar applications supported by low-resolution cameras | [12, 14, 15] |
| Lidar applications for indoor monitoring | [16, 19] |
| Lidar applications supported by low-resolution cameras | [13, 20] |

improvements, becoming faster and more accurate. In particular, the enormous availability of data has enabled the use of Deep Learning (DL), a field of Machine Learning (ML) that is based on artificial neural networks organized in several layers. Thus, DL technologies have overwhelmingly dominated almost all computer vision fields, including crowd monitoring. Indeed, the popularity of Neural Networks rapidly increased their efficiency thanks to their high capacity to understand features useful for identifying shapes with high accuracy.

However, this approach still has many drawbacks, including vulnerability to occlusion, target deformation, and light changes. Due to these issues, image features are often not easy to extract, which can significantly affect people counting and the statistical analysis of pedestrian flows. Originally, crowd monitoring was performed using people detection-based approaches, applying image filters for detecting people through sliding windows that executed operations on pixels.

There is a variety of neural networks that can be used for people counting or tracking, depending on the application context (Table 2). These networks can be used to count the number of people in a given area based on images or videos or to predict the number of people in an area based on historical pedestrian traffic data. Some of the most commonly used neural network architectures for people counting are:

- Convolutional Neural Networks (CNN): CNNs are among the most commonly used neural networks for people counting. This type of network can be trained to recognize people in an image or video and then count the number of people in an area [21–23]. A widely used example of this architecture is the You Only Look Once (YOLO) network, which is a network that is used for real-time object detection, even in very crowded environments [24, 25]. One of the main advantages is that the network has detection and counting in a single model and has very little computational requirements.
- Generative Adversarial Networks (GAN): GANs are a type of neural network that can be used for image synthesis. This type of network can be trained to generate realistic images of a crowd density or augment data in the dataset [26–29]. An implementation of GAN architecture is Conditional GAN (cGAN), which is one type of GANs used for people counting. The basic idea in those networks is to add conditional information to the input of both the generator and discriminator networks. In the context of people counting, this conditional information could be metadata about the scene or environment, such as camera location, time of the day, or weather conditions, that could improve the accuracy of the generated outputs.
- Recurrent Neural Networks (RNN): Although RNNs can potentially be used for a wide range of tasks, they are not typically used for pedestrian recognition and counting, as this is generally considered to be a computer vision problem better addressed by other architectures. However, RNNs can be integrated with other neural network architectures as part of a more complex pedestrian detection and tracking system. For example, RNNs could be used to model the motion of pedestrians over time, while a CNN is used to classify the pedestrian in each video sequence frame. Overall, the choice of the supporting technology depends on the specific details of the problem at hand and the types of data that need to be processed. RNNs learn to model the temporal dependences of pedestrian traffic data and make predictions based on this modeling. The authors of [30] introduced the long short-term memory (LSTM)

**Table 2** Relevant papers on processing of video streams with deep learning

| Approach | References |
|---|---|
| CNN networks trained to recognize people | [21–23] |
| YOLO methods for real-time object detection | [24, 25] |
| GANs to augment datasets with synthetic images | [26–29] |
| RNN to capture long-term dependencies in sequential data | [30] |

architecture, which has become a popular and widely used type of RNN due to its ability to capture long-term dependences in sequential data effectively.

In general, the analysis of video streams is supported by DL techniques that extract features from images to detect the presence of people, and track them. Moreover, the input of neural networks can be enriched with metadata that contextualizes the environment and corrects errors due to its characteristics (e.g., different light conditions during the day). The high accuracy of these methods made them the most popular technologies for monitoring crowd flows. On the other hand, the privacy regulations established by many countries limit their usage if people are recognizable.

## 4 Analysis of Wireless-Network Traffic

The ubiquitous usage of personal mobile devices, such as tablets, smartphones, and smartwatches, led to novel opportunities for collecting comprehensive data on individuals to track their movements within cities, while respecting their privacy anonymously. In recent times, extensive research has focused on transforming smartphones into useful tools for creating indicators to measure human presence.

This approach assumes that each person carries one personal device that emits electromagnetic signals while its wireless interfaces (i.e., Wi-Fi interface and cellular antenna) are active. These electromagnetic signals can be collected and processed to extract features that characterize the single device. Thus, tracking individuals through their mobile devices is becoming one of the most common passive techniques as it does not require any specific action by the users, such as installing a particular application on their device. Of course, the collected data must be anonymous or pseudo-anonymous to protect users' privacy, so it is usually preferred to collect management data.

The main approach of this type is based on the analysis of Probe Requests. Probe Requests are management messages of the Wi-Fi protocol that a mobile device regularly transmits while searching for Access Points (APs) to connect to. Typically, these messages include the Media Access Control (MAC) address, a globally unique identifier of network cards. Not-randomized MAC addresses expose users to the risk of being tracked because they can be easily cross-referenced with other data to associate the MAC address with the owner/user identity.

To safeguard the privacy of smartphone users, Google, Apple, and Microsoft have implemented algorithms that generate random MAC addresses. These algorithms perform the MAC randomization contained in management frames (called Probe Requests) both during the search and after the association with APs. Since the generation is periodic and always random, the impact of MAC address randomization on mobile device tracking has been disruptive and detrimental, making it more challenging. As a result, it is no longer possible to directly reconstruct people movements merely by observing the MAC addresses of smartphones.

Amidst this context, the academic community has been actively exploring new methods to exploit these signals without violating people's privacy. Vanhoef et al. [31] and Matte [32] initiated a series of investigations into the feasibility of device tracking through Probe Requests, where the emphasis is placed more on the metadata embedded within the requests rather than on MAC addresses. Figure 1 shows the structure of an IEEE 802.11 Probe-Request Frame, which is composed of a MAC header, a Network Data part, and a Frame Check Sequence (FCS). The MAC header contains some control fields (Frame Control, Sequence Control, and High Throughput Control or HT Control), the duration of the whole message, and three addresses. These addresses are the Destination, the Source addresses, and the BSSid (Basic Service Set Identifier) that is used to keep the traffic within the same WLAN even though it has multiple APs. The content of the Network Data part

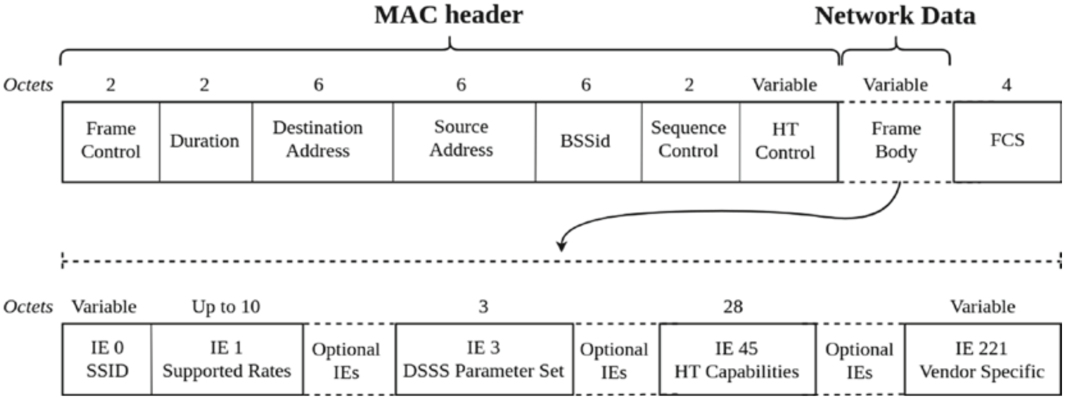

**Fig. 1** Probe-request Frame in the IEEE 802.11 standard

depends on the type of Frame, but it usually contains metadata called Information Elements (IEs) or tagged parameters. The IEs in Fig. 1 are usually in Probe Requests. IE 0 or SSID (Service Set Identifier) is a string that identifies an AP and is used to connect faster with known APs [33]. This field might use a wildcard or a default value. IE 1 or Supported Rates is a list of supported rates that can be extended with the IE 50 or Extended Supported Rates. IE 3 or DSSS (Direct Sequence Spread Spectrum) Parameter Set element contains the identifier of the channel used for the transmission. IE 45 or HT (High Throughput) Capabilities contains several fields that advertise optional capabilities. Finally, IE 221, or Vendor Specific element, is an optional field to carry information defined by the vendor. This field is optional but, if present, it is the last IE of the packet.

For further details, the last revision of IEEE Std 802.11 [34] describes the structure of the Management frames, the list of the IEs contained in Probe-Request frames, and the IE formats.

Moreover, Probe Requests are sent as a group of frames called burst. Bursts are typically separated by a constant time interval called inter-frame time, which could also be used as a feature. Hence, crowd monitoring has re-emerged as a relevant topic in the literature after the randomization of MAC addresses became more common. Several authors are encouraging the scientific community to explore Wi-Fi Probe Requests for crowd monitoring, creating datasets [35–38] while also ensuring the privacy of users, particularly in the context of smart cities [39]. Two main subcategories for Wi-Fi traffic analysis can be identified:

- Metadata fingerprint. There are several IEs in the Wi-Fi standard. Some of the Information Elements are constant for Probe Requests sent by the same device. This principle is exploited to create a signature of IEs that recognizes a single device.
- Sequence number and bursts analysis. Given a Probe Request, it is always paired with an incremental number ranging from 0 to 4096. This number is the sequence number, and it is useful for reconstructing the information separated into different packets. Furthermore, it is easy to identify bursts from a single device by looking at the increment of sequence numbers over time by exploiting the fact that bursts have constant inter-frame times and that the sequence number is incremented each time by one unit.
- Hybrid metadata fingerprints and burst analysis. It is possible to implement both metadata fingerprinting and burst analysis to improve the accuracy of the analysis.

In the current state of the art, a new approach is emerging, Radio Frequency (RF) identification. This approach is based on acquiring the analog radio signal, generally using Software

**Table 3** Relevant papers on the Wi-Fi approach for counting people

| Approach | References |
|---|---|
| Metadata fingerprints: analysis of information elements into the Probe Request | [31, 49, 50] |
| Sequence number and bursts analysis: temporal analysis of Probe Request frames | [51–53] |
| Metadata fingerprints and burst analysis: combining temporal- and content-based fingerprints | [54, 55] |
| Modulation-based RFF: exploiting modulation errors | [44, 56–59] |
| Transient-based RFF: exploiting preamble messages | [60–62] |
| Deep-Learning based RFF: using neural networks combined with transient-base and modulation-based approaches | [43–47, 58, 63] |

Defined Radio. Transmitting devices can be characterized by microscopic anomalies in their antennas that lead to imperfections in the signals they transmit. Hardware anomalies are unique and difficult to reproduce, as well as the imperfections of the transmitted signals, allowing for the extraction of features to identify specific devices, which is called Radio Frequency Fingerprinting (RFF). The are several approaches for RFF [40]. In fact, the hardware defects might produce quantization errors (due to the conversion of the analog signal), carrier frequency offsets (due to up-converter effects), non-linear distortions (due to amplifier imperfections), and/or phase noise and IQ imbalance (due to modulation non-orthogonality) [41]. Therefore, RFF techniques include:

- IQ imbalance. Ideally, modulated signals can be decomposed into two sinusoids that are offset in phase by one-quarter of a cycle (90 °C). These two elements are respectively named the In-phase and Quadrature (IQ) components. IQ imbalance results from the imperfection of the orthogonality of these two axes and the mismatch of their gains [42].
- Transient-based, Spectral Fingerprinting. The transient-based approach entails identifying unique features that are observable in the radio turn-on transients, which manifest at the onset of transmission. This technique involves detecting the specific signal characteristics that occur during the transmitter's turn-on phase, wherein the signal amplitude rises rapidly from the channel noise level to the signal level [43, 44].
- Deep learning. Deep learning-based methods have been gradually penetrating the field of RF fingerprinting research involving both modulation-based and transient-based approaches. This is the reason why deep-learning approaches have become the current state of the art [43, 45–47]. This is mainly due to the recent resurgence of Machine Learning techniques, which have been fueled by the rapid growth of computational capabilities and the availability of digital data. Frequently these methods exploit the high performance of Convolutional Neural Networks (CNNs). Even though CNNs have been designed for image processing, they can extract RF features if the original data is converted into images. Authors of [48] achieved an identification accuracy of 99.1% when classifying 54 target ZigBee devices.

Furthermore, the RFF methods presented in this section are employed to identify known devices securely with supervised algorithms. Thus, the uniqueness of the features calculated for each device should allow the clusterization of signals according to their source, leading to new device-counting and tracking techniques (Table 3).

## 5 Analysis of Call Data Records

Call Data Records (CDR) are data structures to store telephonic activities, such as calls or other transactions (e.g., text messages). Even if no standard defines their format, some key fields are always included (see Table 4). Indeed, usually, each record contains a time reference of when the communication was made, the phone numbers of the sender (A-party) and receiver (B-party), the call duration, the size of the

**Table 4** MNOs define the structure of Call Data Records because an International Standard is not defined. CDRs usually contain the information listed in the table

| Information contained in CDRs | Description |
|---|---|
| A-party | Phone number originating the communication |
| B-party | Phone number on the other end of the communication |
| Time and date of call | Reference of when the communication was started |
| Call duration | Duration of the communication |
| Sequence number | Unique identifier of the communication |
| Entering-exchange route | Base Station that connected the A-party to the network |
| Exiting-exchange route | Base Station that connected the B-party to the network |

transmitted data, and the geographic location of the cellular Base Stations (BSs) that routed the communication. Mobile Network Operators (MNOs) collect CDRs to manage their customers' billings, perform diagnostics, and design networks. CDRs provide high-resolution data about individuals and populations, which allows the mapping of interpersonal relationships. Due to the confidentiality of their content, CDRs have been mostly considered for disaster management [5], and investigative purposes [4].

CDRs are valuable data resources that are compliant with the definition of Big Data, which are complex databases characterized by 5Vs (volume, velocity, variety, veracity, and value) [64]. The analysis of CDRs allows for generating graphs of cellular BSs used by subscribers. Cellular networks can be considered dense and large sensor networks that already collect data. The localization of the mobile devices is approximated with the location of the cell to which the device is connected. Moreover, CDRs uniquely identify the devices at both communications ends, allowing for their tracking. Consequently, Origin and Destination matrixes can be calculated. The authors of [7] claim they can calculate the number of trips, the distance, and the travel time between couples of cellular Base Stations through CDR data. This kind of analysis can be correlated to the design of new public transport routes to calibrate them according to the demand [65].

**Table 5** Relevant papers on CDR analysis to monitor people flows

| Approach | References |
|---|---|
| Estimation of urban mobility using CDRs | [7, 66] |
| Optimization of public transport using cellphone data | [65] |

Even though most of the research on cellular data focuses on CDRs, signaling traffic is a more powerful source to calculate mobility patterns [66] because it contemplates a much larger number of devices. All devices that are connected to the cellular network, including smartphones, tablets, navigation devices, and On Board Units (OBUs), produce signaling traffic even when they are not participating in communications. Differently from previous studies, which considered only the CDRs, the novelty of this approach is the observation of idle devices. However, the localization of active devices is more accurate than that of idle ones: in the first case, the localization is at the cell level, whereas in the latter case a group of neighboring cells is considered. Another main disadvantage is the need to buy CDRs from MNOs (Mobile Network Operators), which increases the data price and delays its analysis (which cannot be performed in real-time) (Table 5).

## 6 Collection of Data from Personal-Device Apps

As described in the previous sections, many dedicated sensing technologies could be deployed to collect data about crowd flows. However, the level of spatial coverage of these sensors network in the real world is reduced, and the scalability and mobility of these networks are limited. This problem, together with the advancements reached by personal devices, has brought the development of mobile crowd-sensing solutions, of which [67] examines the maturity and suitability for industrial applications. Smartphone sensors have become a valid data source for analyzing human behavior.

In the past, many collection techniques based on interviews were used. Nowadays, Information Communication Technologies (ICTs) create new opportunities to monitor crowd flows. An example is the analysis of data produced by Automated Vehicle Monitoring (AVM) systems, which is called Floating Car Data (FCD) [68–71]. FCD contains real-time information about the location and speed of Public-Transport (PT) vehicles moving in the traffic. However, in this case, only the source and destination nodes within the network are identified, and the so-called last-mile segments are not considered.

On the other hand, mobile apps for crowdsensing ask permission to collect and process data in real-time to study where people are, what they do, and, in some cases, why people are in a specific place or do something [72, 73]. Generally speaking, mobile crowdsensing can be classified into two main categories: participatory [74] and opportunistic [75] methods. In participatory approaches, users voluntarily join the data collection and actively provide useful information. In opportunistic techniques, instead, data are collected and shared automatically without user intervention and, in some cases, without the user's explicit knowledge.

One of the first attempts of participatory mobile crowdsensing is TRIPZOOM [76], which tracks user mobility patterns using a mobile app; the main goal of the project is to optimize city mobility by supporting users to gain insights into their mobility behavior and to incentive them to save $CO_2$ emissions. The UbiGreen [77] app was designed to encourage greener mobility alternatives. UbiGreen is one of the first participatory crowd monitoring experiments that use sensors to estimate transportation modes and monitor user transportation behaviors semi-automatically. It is important to accurately represent the user behavior to devise possible strategies to orient travelers towards more sustainable alternatives. In this context, modern participatory apps are integrated with other tools to realize surveys to collect information about passengers' behavior. According to European guidelines, this is relevant for a smart city where Information Communication Technologies (ICTs) must be integrated with transport and energy for building Transport System Models (TSM) and supporting the Mobility as a Service (MaaS) design processes [78, 79]. In this respect, Quantified Traveler (QT) [80] introduces a virtual mobility counselor in participatory crowd monitoring. QT is an automated smartphone travel diary system that collects location data from participants and processes them to derive trips to raise awareness and encourage better attitudes regarding sustainable travel behavior. Moreover, the IPET platform [81] combines participatory crowd monitoring with the provision of persuasive information. IPET uses a mobile app to track user activities, detect the trip mode, and infer more sustainable routes. These alternative routes are communicated to users using brief persuasive messages to stimulate them to embrace less polluting mobility choices.

After the first phase, during which the participatory paradigm was prominent, the technological advancements that increased the computational capabilities of personal smartphones and the advent of important third-party services have prompted the experimentation of opportunistic solutions. SenseMyFeup [82] is a significant experience in the field of opportunistic mobile app crowds monitoring. The project comprises a mobile application and a scalable back office developed to study human activities in a large urban area. It uses an algorithm that can detect mobility patterns without any intervention from the user. The mobile app captures data from sensors and performs a classification to detect the user's status: "moving", "stopped", or "undefined". A decision algorithm analyzes this data set and classifies whether the user moves effectively. To sense the type of activity (e.g., pedestrian, bike, etc.), SenseMyFeup uses the Google Activity Recognition Application Programming Interfaces (APIs).

Furthermore, SWIPE [83] is an open-source platform for sensing, recording, and processing human dynamics using a mobile app deployed on smartwatches and smartphones, with a platform based on an Android application that collects data simultaneously on both devices. The system produces a large amount of data. It also offers the opportunity to measure crowd density which can be a promising way to identify the regions with worse traffic congestion in the analyzed area. The CitySensing Framework [84] is another interesting experience in the field of opportunistic crowd monitoring. It comprises mobile application components and analytic tools orchestrated in a distributed architecture. It represents one of the first approaches using data extracted from social networks, so it introduces the concept of social sensors data. The mobile app exploits many physical and virtual sensor data such as Global Positioning System (GPS), microphone, camera, ambient light sensor, accelerometer, gyroscope, compass, proximity sensor, temperature, and humidity. Then, it also adds social data detected by the user's interactions in a social network: tags, likes, publications, tweets, and photo posts. Social network APIs are used to extract this kind of data. On the back-end side, various algorithms combine different data types collected.

Once the potential of crowd monitoring systems using mobile apps was clear, the main issue for the researchers became developing a platform for deploying and managing data collection sessions. In this regard, the Itinerum [85] project has tried to face the challenge. The main goal of the Itinerum platform is to enable administration of customized smartphone surveys that can automatically collect location data inspired primarily by travel behavior surveys. The platform is designed to allow survey administrators to customize (with their own questionnaire and prompt questions) and prepare their study very easily. As it arises from this analysis, there are effective solutions to collect key data concerning people mobility. Still, some key issues need to be addressed, one of which is related to end-user device energy consumption. Several researchers investigated how to manage energy consumption, data transfer, computing, and sensing optimally by mobile phones [86–89]. Data trustworthiness and quality are other sensible fields, as a loss of reliability on the captured data can compromise the users' trust. The accuracy and coverage of sensor readings impact the reliability and availability of data. If the data have high reliability and availability, they will have high trustworthiness and quality when used to analyze and solve a real problem. This issue is tackled by researcher in many studies [90–93].

**Table 6** Relevant papers on processing of data from personal-device apps

| Approach | References |
|---|---|
| Participatory crowdsensing | [74, 76, 77] |
| Participatory crowdsensing with custom advices | [80, 81, 85] |
| Opportunistic crowdsensing | [75, 82–84] |

Incentives to stimulate the participation of the users are another critical issue, especially in participatory approaches. The project owners need to motivate individuals to participate in the sensing process to complete a task and to reach the objective. A good incentive mechanism is very important to implement these initiatives efficiently [94–96]. Especially in the GDPR era, security and privacy aspects cannot be neglected. How to protect sensitive personal and location information? This question animates all the scientific community, and various points of view have examined this topic in the last few years [97–101] (Table 6).

## 7 Qualitative Comparative Analysis

This section provides a qualitative comparative analysis of the technologies presented in the previous sections regarding their accuracy, the characteristics of the areas to be monitored, advantages and disadvantages. A summary of this analysis is provided in Tables 7, 8, 9 and 10.

The area that radars and lidars can monitor is small compared to that of the other solutions,

**Table 7** Accuracy of the sensing technologies

| Technology | Accuracy |
|---|---|
| Radar | Over 89% passages correctly detected |
| Lidar | Over 90% passages correctly detected |
| CDRs | The location of the device is approximated with the cellular cell (1–30 km) of the Base Station to whom it is connected |
| Cameras | Over 95% people correctly detected |
| Wi-Fi | Over 90% people correctly detected and over 70% correctly tracked |
| Personal-device apps | Data accuracy depends on the accuracy of the sensors of the personal device |

**Table 8** Area monitored by the sensing technologies

| Technology | Monitored area |
|---|---|
| Radars or lidars | Indoors or delimited area: sensors must be placed in all the passages; indoors or outdoors: the monitored area has a radius of up to 15 m |
| CDRs | The monitored area has the same size and coverage as the cellular network |
| Cameras | Indoors or outdoors: the area can vary between 10 and 20 m of visual cone depending on the height of the installation |
| Wi-Fi | Indoors or outdoors: the area can vary between 10 and 100 m of radius in a circle area depending on the sensing antenna |
| Personal-Device Apps | Outdoor: the area has no geographical limits if users always keep their mobile phones switched on |

**Table 9** Main advantages of the sensing technologies

| Technology | Main advantages |
|---|---|
| Radars or lidars | – Tracking is possible with the support of neural networks<br>– Subjects are not identifiable (privacy compliant)<br>– Ranging technologies are robust to light changes<br>– Components have low-selling costs |
| CDRs | – The covered area is vast and dense<br>– Records are geolocated and allow for the tracking<br>– MNOs already collect CDRs for management purposes (customers' approval is given during the registration to the service) |
| Cameras | – Infrastructures already installed could also be used<br>– They are a widely used and validated technology over the years |
| Wi-Fi | – No actions are needed by the user<br>– Completely privacy compliant<br>– High geographical resolution |
| Personal-device apps | – The covered area is vast and dense<br>– Additional information can be asked the user for profiling<br>– Data is geolocated and allows for the tracking<br>– They exploit the Internet or Satellite network to send data |

so they have to be placed in the passage to indoor or delimited areas to perform the monitoring accurately. Most of the solutions based on radars and lidars are complemented with low-resolution cameras and Neural Network algorithms that improve the overall accuracy without threatening people's privacy. Enriching the output of lidars and sensors is also required in some contexts because the more people are in the monitored area, the more difficult it is to distinguish the individuals. Due to the physical principle behind the operation of these devices, if other objects (or bodies) obstruct the direct path between the sensor and the target, the sensor cannot detect the target. On the other hand, the main advantages of ranging technologies are their low costs and the fact that they count or track people instead of their personal devices. Among the other technologies presented in this chapter, radars and lidars are the best for monitoring people flow in passages with strict privacy constraints and for localizing people accurately in a small area that cannot be equipped with cameras.

Like lidars and radars, cameras cover limited areas. The analysis of camera data makes it possible to distinguish between different demographic groups and can provide detailed information on the location of people. However, camera coverage is limited by the visual cone of the device. Cameras also have the disadvantage that privacy constraints can limit their usage, and their performance might decrease in scarce light conditions. However, they can achieve high performance levels and exploit the infrastructures already installed for other purposes (e.g., surveillance) for counting people. Additionally, they are a technology widely used and validated over the years.

Wi-Fi sniffing has the advantage that it can be used even though the people to be monitored are not visible. Additionally, this approach does not require the active participation of the device owner in the monitoring activity, and thanks to the MAC randomization procedures, user privacy is preserved. However, methods based on the analysis of Wi-Fi traffic have the disadvantage that an intrinsic error is introduced because not everybody carries a device with a Wi-Fi interface switched on. Methods based on Wi-Fi traffic analysis and ranging technologies (lidar and radar) do not cover a very wide area nor provide detailed information on the type of user in the monitored area. However, they can correctly detect a high percentage of people in the monitored area.

CDRs and data collected from mobile apps are generated through the usage of personal devices. MNOs collect CDRs when the phone starts or receives a communication (i.e., a call or a text message). In contrast, after the user's previous authorization, apps collect data from the sensors of smartphones or tablets and convey it to data centers. The device is localized and identified through a unique identifier (e.g., phone number or account identifier) that must be anonymized to allow the sale and/or analysis of the data. The main advantage of these technologies is the size and coverage of the monitored area, which is usually as big as the cellular network. Thus, tracking relies on the user carrying a device connected to the cellular or Internet network [102]. CDR approaches cover more people with respect to the usage of probes because they record data from legacy phones and smartphones even if location functions are turned off, but data ownership limits their real-time usage. The analysis of traffic data from mobile phone communications provides detailed information on the location and movements of people, even distinguishing between different demographic groups, such as gender and age Groups. Yet, the geographic resolution is limited in areas with few mobile phone towers.

Finally, mobile applications using GPS tracks can provide very precise information on people location and movements, but the coverage is limited to people who have installed the application. This method provides detailed information on mobile user demographics and location, but the population sample is even smaller than the one of other technologies. Smartphone-based methods are a better alternative for tracking population groups with common characteristics

**Table 10** Main disadvantages of the sensing technologies

| Technology | Main disadvantages |
|---|---|
| Radars or lidars | – A small number of people is identified<br>– Accuracy decreases as the number of people increases<br>– Sensors must be placed in all the passages<br>– They are reliable only in indoor or delimited areas |
| CDRs | – They contain personal data<br>– MNOs own this data<br>– Real-time analysis is not possible without direct access to the data<br>– The location is approximated with the area of a cellular cell<br>– The tracking of people is indirect (device tracking) |
| Cameras | – Their usage is not always allowed because people are identifiable<br>– Their performance might decrease in scarce light conditions |
| Wi-Fi | – The tracking of people is indirect (device tracking)<br>– No information about the user profile |
| Personal-device apps | – Customers must have a personal device and install the app<br>– Data collection requires the approval of smartphone users<br>– The software architecture needs to be customized depending on the purpose of the monitoring<br>– The tracking of people is indirect (device tracking) |

(e.g., shopping-center customers, members of an organization, etc.) to monitor targeted interventions.

In summary, each technology has its merits and drawbacks. The choice of the most appropriate technology depends on the monitoring objective and the user's specific needs. Remembering that these technologies must always be transparent and in line with applicable privacy laws is important. It is also important

**Table 11** Costs of implementations

| Technology | Cost range |
|---|---|
| Radars or lidars | Low: starting from a few tens of euros per device |
| CDRs | High: 1– 3k€ per month of data for one monitored area |
| Cameras | Medium: usually over 1 k€ for the installation and cabling of a camera |
| Wi-Fi | Low: approximately 0.5–1 k€ for a station to monitor an area of 200 $m^2$ |
| Personal-device apps | Medium: it depends on the level of detail of user characteristics and the extent of the geographical area of the sample. For example, it can be 2 k€ for 5 k unique users in an 85 $km^2$ area. |

to consider the costs for the use of these technologies, which go from a few tens of euros for the installation of a simple radar to thousands of euros per area per month to get the data from CDR analysis (see Table 11).

## 8 Conclusions

This chapter reviewed the advanced technologies for crowd monitoring in urban areas. It has also provided a comparative analysis of these technologies regarding characteristics of the areas to be monitored, advantages, disadvantages, and achievable accuracy. Combining all these technologies to achieve a uniform merged information set is one of the key challenges for managing city services.

**Acknowledgements** This work has been partially supported by the European Union under the Italian National Recovery and Resilience Plan (NRRP) of NextGenerationEU, "Sustainable Mobility Center" (Centro Nazionale per la Mobilitá Sostenibile), CNMS, CN 00000023.

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# Paving the Way to Society/Industry 5.0: The SmartMe.IO Experience

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## Abstract

The social and economic cost of COVID-19 has revealed that prevention strategies are potentially very cost effective by comparison to coping with a pandemic. The actions by Public Administrations and businesses need new approaches in order to benefit in health and quality of life. As a consequence, the concept of Future Cities and Industries as human-centered realities that balance economic and technological advancement to solve society's problems is urgent. It represents a new vision for a resilient society where humans, nature and technology create a resilient and sustainable balance enhanced by data. This new digital transformation results in new resilient and sustainable environments permeated by a sustainable economy and the creation of products and services with low environmental impact and high social impact.

## Keywords

Arancino · Artificial intelligence · Future cities · Industry 5.0 · Resilience · Neurobiologic · Smart cities · Society 5.0 · Sustainability

## 1 Introduction

COVID-19 was not just a rare event, but a symptom of ecological disruption and danger to human survival. COVID-19 has captured the attention of the planet towards the need to adopt new and more urgent measures to counter the pandemic. It almost seemed that the problems related to overheating, lack of food and water and other diseases already known and widely spread expired in the background. Most of these emerging diseases and practically all pandemics, including COVID-19, are caused by microbes in animals which spread rapidly after repeated contact between wildlife, livestock, and people. Combined with the technological reality of highly interconnected and globalized economies, rapid transport and increase in world population, this makes pandemics a rapidly growing risk.

For the next several millennia, cities and respective populations continued to grow in number. Towards the end of the century, the UN

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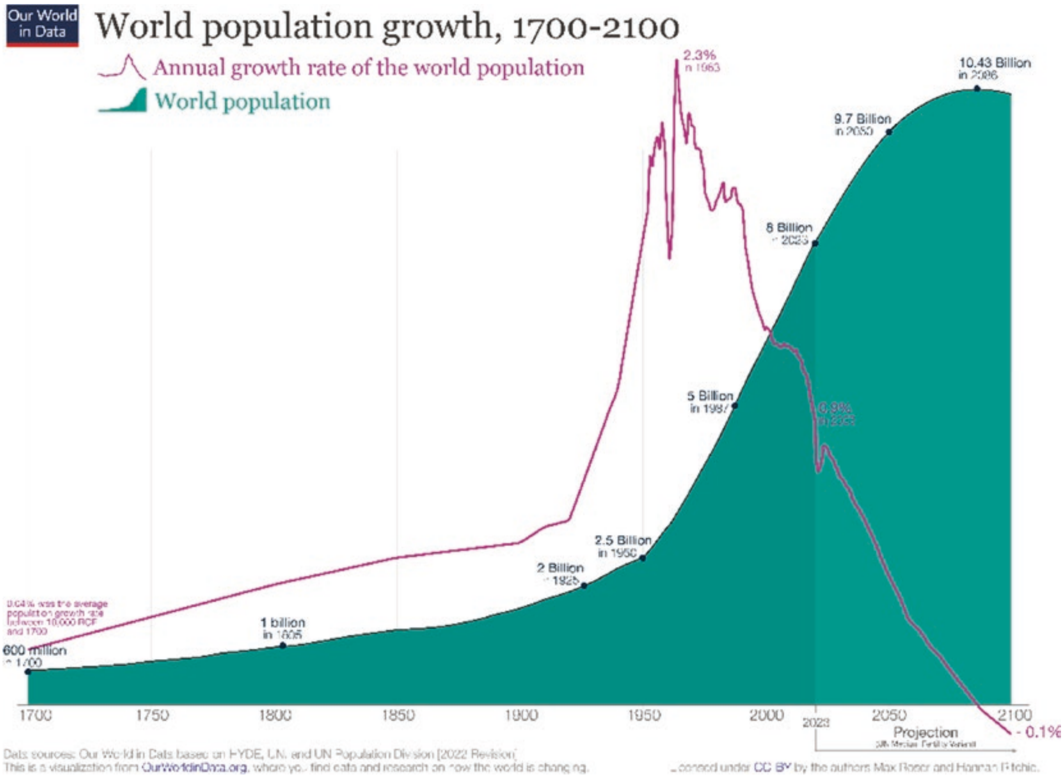
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_4



Data sources: Our World in Data based on HYDE, UN, and UN Population Division (2022 Revision)
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing.
Licensed under CC BY by the authors Max Roser and Hannah Ritchie.

**Fig. 1** World population growth, 1700–2100

expects the global population to reach its peak at around 10.4 billion[1] (Fig. 1).

Figure 1 highlights a comparison between the annual growth rate of the world population (i.e., the percentage change in population per year) and the world population. Since the peak in 1963 the increase of the world population has slowed and today grows by 0.9% per year. However, the growth of worldwide populations means the growth in the access to data and therefore to public and private services based on the use of information technologies.

Rapidly advancing innovation in digital technologies such as Artificial Intelligence (AI), Internet of Things (IoT), robotics, and blockchains, as well as biotechnologies provide augmented abilities to people enabling them to pursue their dreams. Figure 2 shows the growth of Big Data and Hadoop market size in the 2017–2022 time period. As a consequence, the concept of Future Cities as a human-centered reality that balances economic and technological advancement to solve society's problems is urgent.

SmartMe.IO is a company specialized in engineering and implementation of hardware and software systems based on Open Source IoT technologies for management and care of complex environments related to Industry and Smart Cities. The vision of SmartMe.IO focuses on collaborative industries, bioeconomic and creative products and services.

In this paper we present our neuro-biologic approach followed in designing the Arancino hardware stack, i.e., a family of Open Source IoT technologies designed for the production of modular and high customizable electronic

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[1] Source World Population Growth - Our World in Data, https://ourworldindata.org/world-population-growth last visited May 2023.

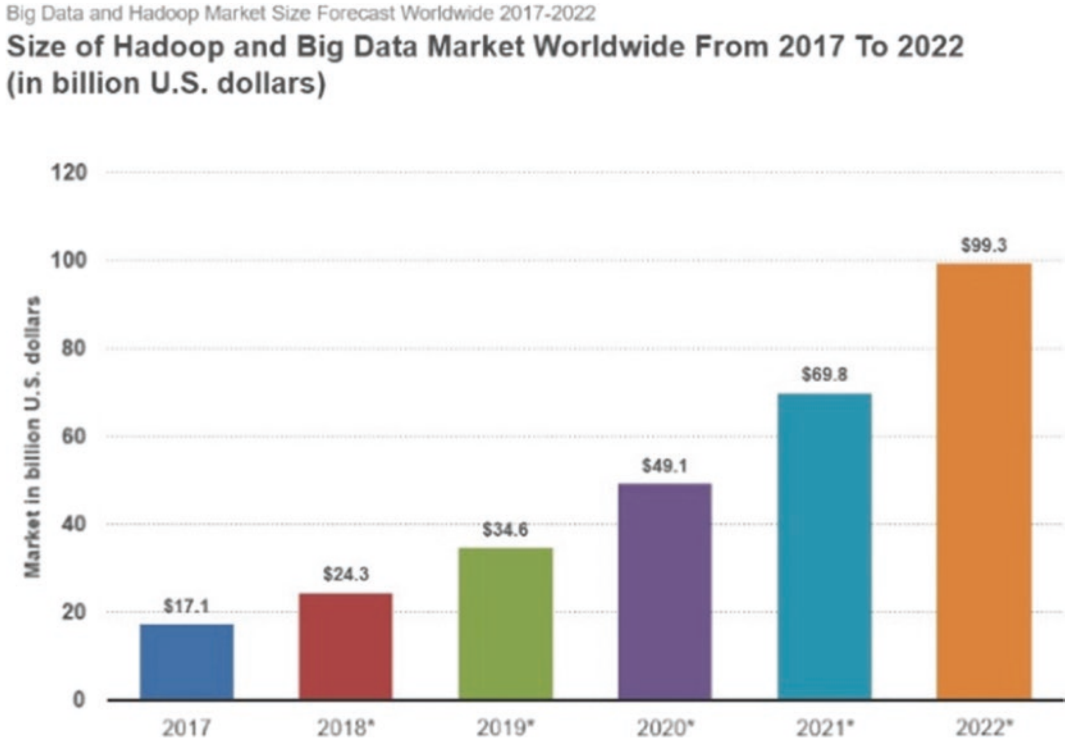


**Fig. 2** The growth of big data and Hadoop market size in the 2017–2022 time period (*Source* statista.com)

devices with processing and communication capabilities at the edge of the IoT network.

We also present the Stack4Things® software framework, an evolution of OpenStack, to manage IoT devices (sensors and actuators) and collect and process data, both at the edge and the cloud. We will describe how a monitoring infrastructure based on Stack4Things® can be setup in a short time and with limited costs.

More specifically, Sect. 2 introduces the reader to the transition from Industry 4.0 to the concept of Society and Industry 5.0. In Sect. 3 we explain how the neuro-biologic approach has been implemented in analogy to the human brain in order to simplify cloud-IoT interaction. Section 4 reports related works concerning the state of the art near our vision in IoT-Cloud applications for Smart Cities and Industries, gaps in the existing approaches and complex challenges. Sections 5 and 6 detail the proposed Arancino – Stack4Things® ecosystem for Cloud-IoT integration in a continuum. In Sect. 7 we show the main steps for a fast deployment of monitoring infrastructures. Finally, use cases are presented and discussed in Sect. 8 and conclusions in Sect. 9.

## 2 From Industry 4.0 to Society/Industry 5.0

After the global financial crisis (2008), i.e., the most serious financial crisis since the Great Depression (1929), the most industrialized countries have oriented their policies towards a political-technological turning point named Industry 4.0. Businesses have focused their strategies on Industry 4.0 issues, with the aim of providing customers with Industry 4.0 compliant tools in order to improve both the safety of operators and the monitoring and control of machines and equipment. Worldwide use of sensors and actuators, both with the expansion of the 5th Generation technologies and the deployment of increasingly intelligent robots and machines, promised to transform Industries in a new advanced reality, as part of the smart city ecosystem. These types of scenarios have generally been identified as smart factories, the Industrial Internet of Things (IIoT), smart industries, or advanced manufacturing. Moreover, the term Industry 4.0 has been applied to a group of rapid transformations in the design, manufacture, operation and service of manufacturing systems and products.

Unfortunately, this historical passage coincided with the Great Lockdown [1]. As a consequence, the application of advanced technologies such as Artificial Intelligence, Machine Learning, Big Data, Cloud Computing, Internet of Things, Digital Twin, Augmented Reality has marked an acceleration, influencing not only the industrial world but also society and human relations. This new digital transformation results in new resilient and sustainable environments permeated by a sustainable economy and the creation of products and services with low environmental impact and high social impact.

Keidanren (Japan Business Federation), the most important Japanese business federation, presented the concept of Society 5.0: an emerging form of society characterized as “Creative Society” enabled by the digital transformation. Society 5.0 follows the societies in which humankind lived in the past: Hunting Society (Society 1.0), Agrarian Society (Society 2.0), Industrial Society (Society 3.0) and Information Society (Society 4.0). This evolution affects not only Future Cities but also Industries. Public Administrations and businesses need new approaches in order to create a resilient a sustainable balance of society for benefit in health and quality of life. Data can drive this process of “society evolution” because data are integral part of our reality and it is not possible to think of a society devoid of data and technology. We are therefore talking about a real new evolutionary phase of society characterized by a return to the centrality of the environment and people in the industrial processes. The vision of Society 5.0 seeks to balance economic development with the solution of socio-environmental problems, in which technologies are used not only for profit but in order to improve the quality of life of citizens.

Society 5.0 is a reality increasingly aware of the environment and the damage that human activities have caused or can cause. This awareness is slowly driving the world's population in correcting our mistakes and addressing environmental issues. We can use AI and IoT applications to help us achieve this.

Industry 5.0 is the title of the report that the European Commission published in January 2021. Subtitle: “Towards a sustainable, human-centric and resilient European industry”. For the European Commission, “Industry 5.0 recognizes the power of industry to achieve social goals beyond jobs and growth to become a provider of resilient prosperity, making production respect the limits of our planet and putting the well-being of workers at the center of the production process”. Two important qualities that must characterize the “daughter” applications of Industry 5.0 are thus highlighted: resilience and sustainability. Although the Industry 5.0 paradigm is new, the European Union defined the term resilience already in 2012 as the “ability of an individual, a household, a community, a country or a region to withstand, adapt and quickly recover from shocks and pressures in a manner that reduces vulnerabilities and risks”.

In the broadest sense, sustainability refers to the “ability to maintain or support a process continuously over time” and it is mainly based on three pillars: economic, environmental, and social. Sustainability is a priority objective for the European Union’s internal and external policies [2, 3]. The United Nations 2030 Agenda includes 17 Sustainable Development Goals (SDGs) intended to apply universally to all countries. The EU is committed to gradually decreasing its greenhouse gas emissions by setting a goal of zero net emissions by 2050. To achieve the goal, the EU must invest in new technologies. As a consequence, the European Commission estimates that Europe needs about €260 billion in extra investment every year over the next decade. On 11 March 2020, the Commission adopted a new circular economy action plan as part of the new industrial strategy. On the basis of the above considerations, it is not enough for Industry 5.0 to use the enabling technologies already present in Industry 4.0.

## 3 Neuro-Biologic Approach

Nowadays both industrial and ready-to-use systems [4] are increasingly made up of numerous subsystems, each with a specific task [5]. IoT devices may be equipped with a microcontroller unit (MCU) and/or a microprocessor unit (MPU). Sensors and actuators interact with each other and with the surrounding environment to achieve multiple purposes through the monitoring and control of natural, civil and industrial environments. The resulting complexity is therefore remarkable both for the monitoring and management procedures, and for the considerable amount of data to be managed. The aggregation of subsystems takes place at different levels, typically proceeding from the simplest ones (edge devices able to perform simple functions using local data), towards the more complex ones (complete subsystems with well-defined operating logics). The management of the single component, however well-structured and complete, is not sufficient to ensure the optimal functioning of the entire system, which instead requires interaction and coordination between its components.

SmartMe.IO has evolved its Arancino technology in a full-stack platform meeting several requirements and in particular resilience and sustainability [6]. This platform is based on the so-called transition technologies, i.e., machine learning, software engineering and partly based on the convergence of interdisciplinary subjects (energetics, problem solving, game theory, learning strategies).

The Arancino architecture, already in the course of its development oriented to the objectives of Industry 4.0, has been implemented in analogy to the human brain (Fig. 3) to simplify cloud-IoT interaction, thus facilitating the implementation of Cyber Physical Systems, exploiting edge and fog computing and adapting seamlessly to artificial intelligence and machine learning solutions.

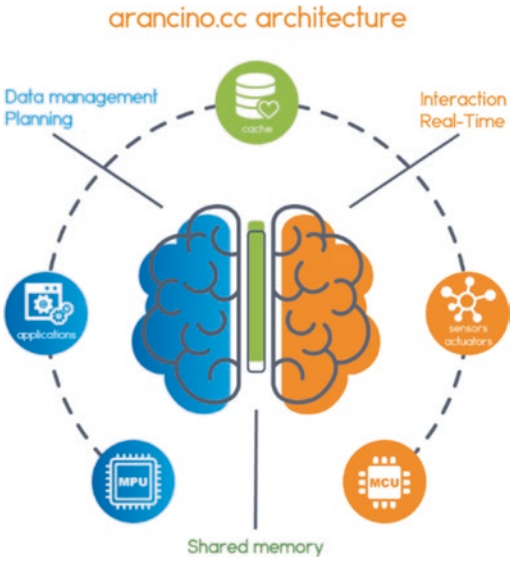
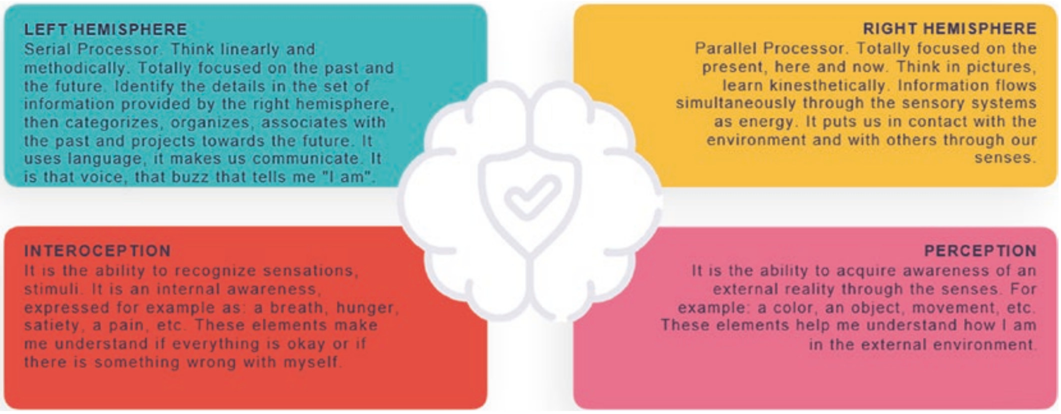


**Fig. 3** Analogy between the Arancino architecture and the human brain

The human brain consists of two hemispheres (right and left) that communicate via the corpus callosum. The right hemisphere is specifically focused on the management of the present, collects the stimuli sent by the different subsystems (internal organs, the five senses etc.) and reacts promptly to the occurrence of events. The right hemisphere is dominant in its ability to recognize faces, spatial abilities, and images (Interaction, Real-time). The left hemisphere, on the other hand, maintains the memory of past experience, identifies and catalogs decision-making paths, constitutes the experience on the basis of which to evaluate optimal strategies, helps to create self-awareness, is aware of the state of well-being of the individual parts and plans how to achieve the objectives while minimizing the use of resources. The left hemisphere is therefore dominant for the functions of calculation and logical and mathematical ability (Data Management, Planning). The activity of the two hemispheres is coordinated thanks to the continuous exchange of information that takes place through the corpus callosum, the element that connects them (Shared Memory). The different



**LEFT HEMISPHERE**
Serial Processor. Think linearly and methodically. Totally focused on the past and the future. Identify the details in the set of information provided by the right hemisphere, then categorizes, organizes, associates with the past and projects towards the future. It uses language, it makes us communicate. It is that voice, that buzz that tells me "I am".

**RIGHT HEMISPHERE**
Parallel Processor. Totally focused on the present, here and now. Think in pictures, learn kinesthetically. Information flows simultaneously through the sensory systems as energy. It puts us in contact with the environment and with others through our senses.

**INTEROCEPTION**
It is the ability to recognize sensations, stimuli. It is an internal awareness, expressed for example as: a breath, hunger, satiety, a pain, etc. These elements make me understand if everything is okay or if there is something wrong with myself.

**PERCEPTION**
It is the ability to acquire awareness of an external reality through the senses. For example: a color, an object, movement, etc. These elements help me understand how I am in the external environment.

**Fig. 4** Schema inspired by neuro-biologic systems between the Arancino architecture and the human brain

specializations of the two hemispheres allow them to work together more effectively.

The reference metaphor is that of a living organism, in which sufficiently autonomous functional organs collaborate with each other by exchanging signals through the nervous system, carrying out specific tasks, while being aware of being part of a single system in which collective well-being depends on the correct functioning of the individual components.

Arancino meets (i) resilience because it makes a system able to anticipate, react and learn timely and systematically from any crisis and thereby ensure stable and sustainable performance; (ii) sustainability because it makes a system able to maintain or support a process continuously over time. Moreover, Arancino implements the neuro-biologic approach as the process of self-control motivated and directed by the system itself, inspired by biological mechanisms.

The schema in Fig. 4 connects interoception and perception abilities respectively to the left and to the right hemisphere.

**Left hemisphere**: Serial Processor. Think linearly and methodically. Totally focused on the past and the future. Identify the details in the set of information provided by the right hemisphere, then categorizes, organizes, associates with the past and projects towards the future. It uses language, it makes us communicate. It is that voice, that buzz that tells me “I am”.

**Interoception**: It is the ability to recognize sensations, stimuli. It is an internal awareness, expressed for example as: a breath, hunger, satiety, a pain, etc. These elements make me understand if everything is okay or if there is something wrong with myself.

**Right hemisphere**: Parallel Processor. Totally focused on the present, here and now. Think in pictures, learn kinesthetically. Information flows simultaneously through the sensory systems as energy. It puts us in contact with the environment and with others through our senses.

**Perception**: It is the ability to acquire awareness of an external reality through the senses. For example: a color, an object, movement, etc. These elements help me understand how I am in the external environment.

The concepts expressed so far can be extended to systems (sensors and actuators) deployed in the environment in order to protect it. This essentially means:

- Integrating Cloud and IoT in a continuum
- Fast deployment of monitoring infrastructures
- Specific applications related to new services deployment in peace operations.

According to the previous definition, this smart ecosystem must therefore be able to respond promptly (in some cases in real time) to both external and internal stimuli in order to adapt its functioning to achieve the sustainability and environmental protection goals. Such decisions may be taken, if necessary, by the subsystems independently. At the same time, systems applying the neuro-biologic approach will need to be able to learn from experience (i.e., through machine learning mechanisms). These mechanisms allow them to carry out planned actions and forecasting strategies at the general system level. The ultimate goal is to optimize resources, maximize efficiency, reduce costs considering both internal and external factors (such as environmental impact).

## 4 Related Work

Johnsen et al. [7] address a scenario where a medium sized smart city in an Alliance nation is struck by disaster. A small multi-national force is deployed to the city to provide relief. The work aims to demonstrate how the challenges could be addressed in IoT applications for a smart city defense operation.

Østergaard et al. [8] highlight the risk that Industry 4.0 would waste the creativity, problem solving and critical capacity of the human being. The consequence would be the failure of mass customization enabled by Industry 4.0 itself. Most importantly, for Østergaard Industry 5.0 represents the return of the human touch in production: the mass customization enabled by Industry 4.0 is not enough because consumers want mass personalization, which can only be had when the human touch returns to manufacturing.

Khare et al. [9] show how the Open Data platform of the #SmartME project has been revised and extended by including a trustless system engaging each stakeholder (the University of Messina, the Messina Municipality, etc.) in the data storage and protection duties. This has been obtained by introducing security features at different levels, and enabling multiple entities and groups to participate at all levels of the data processing and consumption pipeline.

Benomar et al. [10] introduce network virtualization as a fundamental enabler of infrastructure-oriented IoT deployments. The authors present a Cloud-based approach for network virtualization in an IoT context using OpenStack, the de-facto standard IaaS middleware, and Neutron, i.e., its networking subsystem. The authors demonstrate that an IoT deployment without networking resilience and adaptability makes it unsuitable to meet user-level demands and service requirements.

Tricomi et al. [11] focus on how to deal with the case of catastrophic (e.g., potentially disruptive) events. Specifically, they propose a novel software-defined approach for the adaptive management of a Smart Factory infrastructure, centered around business logic rewiring and reconfiguration at run-time across different factory domains.

Pereira Da Silva et al. [12] present a comprehensive understanding of the use of the Fog Computing paradigm in Smart Cities platforms. They provide an overview of the state of the art on this topic also identifying gaps in the existing approaches. Stringent requirements on latency and data processing are challenges in such a context and Fog Computing can support new applications thus increasing volume of IoT data and devices.

Along with its rapid adoption, IoT also creates complex challenges regarding the management of IoT networks due its resource limitations (e.g., computational power, energy, security, etc.). Siddiqui et al. [13] focus on SDN-based IoT management frameworks and provide a taxonomy based on specific categories (i.e., network function virtualization, middleware, OpenFlow adaption, blockchain-based management).

Task scheduling is a critical issue in distributed computing environments like Cloud and Fog in order to provide an optimal distribution of tasks among the resources. Singh et al. [14] presents a comprehensive taxonomic review and analysis of recent metaheuristic scheduling techniques using exhaustive evaluation criteria in the Cloud and Fog environment.

Puliafito et al. [15] discuss the challenges, the state-of-the-art, and the solutions to a set of currently unresolved key questions related to Cyber-Physical Systems and smart cities. The authors identify five main challenges and for each of them the relevant sub challenges and enabling technologies. In particular, the main challenge “human-centric solutions”, that is really important for a Society 5.0 scenario, has the sub challenge “involving human-in-the-loop”. This in turn requires, among others, the Internet of Skills (IoS) enabling technology.

IoS is introduced in [16] as the next-generation Internet: it combines advanced 5G networking, soft/hard robotics, and artificial intelligence technologies. In particular, artificial intelligence can introduce automation in the orchestration operations, especially at the edge of the network, by injecting intelligence even in the form of plugins or functions as described and supporting time-sensitive distributed decision making [17, 18].

In such a Society 5.0 scenario Cyber-Physical Systems promise to be human-centric, serve human needs, and lead to applications that increase social well-being [19].

## 5 Integrating Cloud and IoT in a Continuum

The traditional approach to the design and implementation of a system, whatever it is, focuses on the strictly functional aspects. The issues relating to what is “external” to the system or relating to “how” the system is created or its state during operation, are relegated to the application of shared standards or procedures such as general legislation, environmental impact, rules relating to the impact on health, quality assurance, product certification, sizing standards, etc.

An application area of the IoT paradigm is the preservation of environment and living organisms (e.g., bees). By implanting IoT devices, for example for the monitoring of the pollution level, decision makers can take better charge of preserving nature. IoT can be also used in waste management by preventing the abandonment and permanent accumulation of waste (for example bulky waste), as well as the spillage of industrial sewage thus helping us take better care of our environment. Neurobiologic approach activates a series of actions, specifically:

- Considering all the implications
- Comparing risks and opportunities
- Imaging alternative strategies
- Reacting to critical situations
- Introducing proactivity
- Continuous interaction with the environment.

Figure 5 shows the Arancino - Stack4Things® ecosystem integrating IoT and Cloud computing in a continuum. Physical or virtual sensors and actuators work at-the-edge of the entire network. End-nodes are connected by using one or more communication protocols or standards. Among these, MQTT is an OASIS standard messaging protocol for the Internet of Things (IoT). It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. Cloud computing, i.e., hosting and provision of computational and / or storage services offered on request through the internet, is designed as a full-stack solution based on Stack4Things® technology. At the highest level of the architecture, Machine Learning algorithms and Telemetry are designed and provided as hyper-customized services (i.e., ad-hoc designed).

## 6 Stack4Things® Services

Stack4Things® is an OpenStack[2] based platform [20–22] that aims at extending OpenStack’s capabilities to deal with IoT deployments. It is a cloud-oriented horizontal solution that provides virtualization, personalization and orchestration of IoT objects, offering an immediate experience on some of the most popular embedded and

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[2] OpenStack: https://www.openstack.org/.

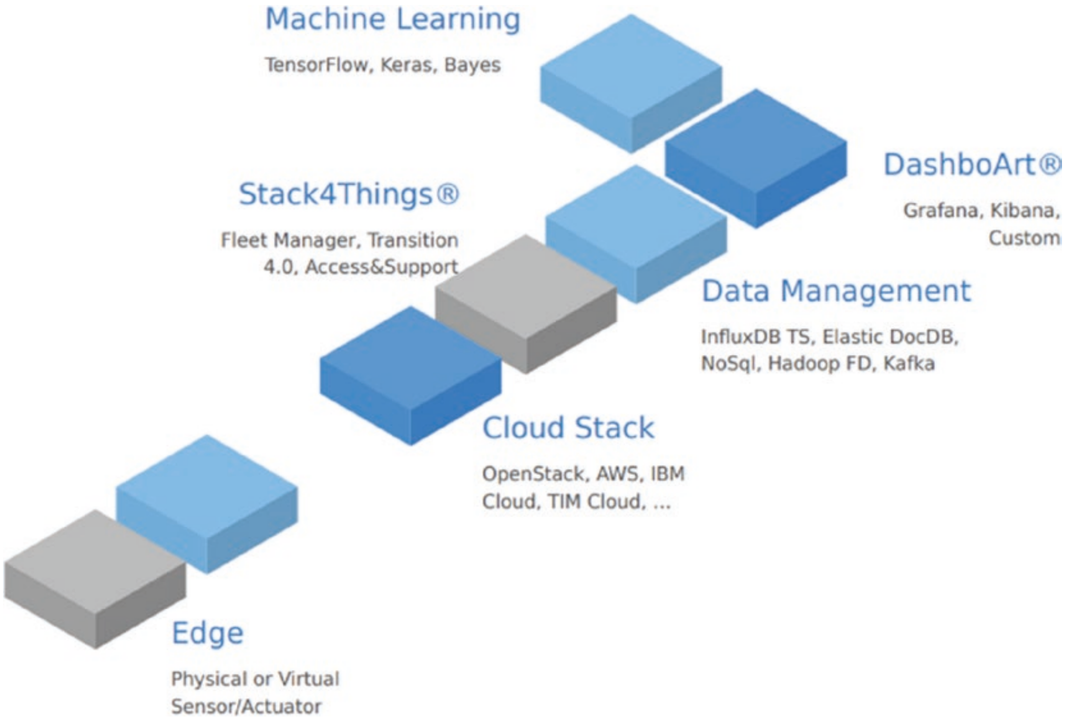

**Fig. 5** Arancino - Stack4Things® Ecosystem integrating IoT and Cloud computing in a continuum

mobile systems. The platform allows to design cloud environments providing extreme versatility in cross-platform use, flexibility in data access (time-series and NoSql databases) and control of individual system nodes.

Stack4Things® allows the exchange of information with IoT devices regardless of their location, hardware, software and network configuration. The platform works only on Linux operating systems and has been released under the Apache license.

Figure 6 shows a block diagram in order to help the reader to understand its architecture. The design of Stack4Things® is split into two subsystems: the first is hosted in the Cloud, where a subsystem called **IoTronic** is deployed; the second subsystem is represented by a number of geo-distributed IoT devices that host the Stack4Things® device-side agents, named **Lightning-Rod (LR)**.

The communications between the Cloud-side, IoTronic, and its device-side counterpart, LR, are built exploiting a mechanism based on WebSockets with a reverse tunneling approach that is able to bypass firewall and NAT systems.

The compatibility of Stack4Things® with OpenStack makes the system able to interact with other (OpenStack) services to provide advanced user facing features such as virtual networking and containerized applications at the network Edge. In a nutshell, Stack4Things® provides the support of (among others):

1. **Authentication/authorization**: using the OpenStack identity service (i.e., Keystone), Stack4Things® can manage users' authentication. Besides, the middleware deals with authorizations to access/manage the (remote) IoT devices.
2. **Remote access and management**: using service forwarding through the Cloud, a user can access (e.g., using ssh or vnc) his/her IoT devices regardless of their localization or networking configurations using a (reverse) WebSocket tunneling mechanism.

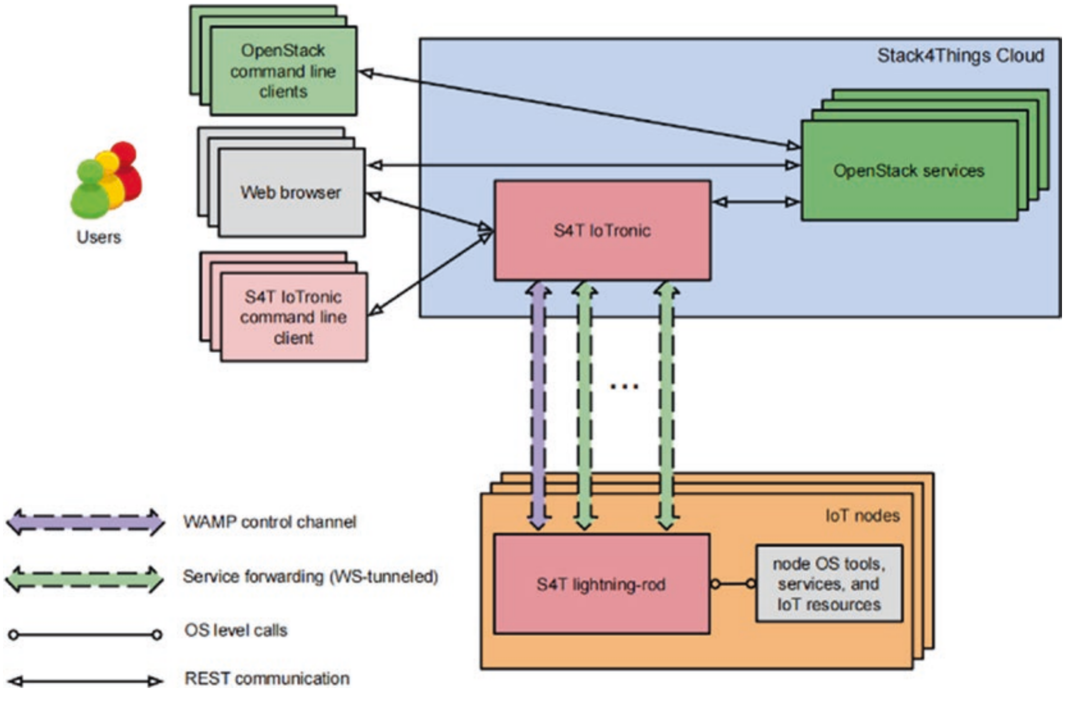

**Fig. 6** Stack4Things® (S4T) IoTronic and Lightning-Rod (LR) agents

3. **Remote customization/contextualization**: through Stack4Things®, a user can define, on the Cloud, the application logic in form of functions and deploy them, still according to authorization and privacy policies, even at runtime, on the (remote) IoT devices. As runtime environments, the platform offers the choice between Python and Node.js.
4. **Networking as a service**: using the Neutron OpenStack project it is possible to provide networking as a service between interface devices managed by other OpenStack services. Innovative plug-ins are included in the main distribution and supported by the Neutron community.

## 6.1 Stack4Things® Virtual Networking

Stack4Things® is used to create virtual networks (i.e., overlays) between distributed IoT devices. Therefore, they can reach each other as if they were on the same physical network (i.e., LAN). To enable this capability, we integrated Neutron, the networking subsystem in OpenStack, with IoTronic. The Stack4Things® Cloud side networking system is illustrated in Fig. 7, which shows a block diagram with two main blocks: the Neutron server and the IoTronic APIs block. We extended the Neutron capabilities to provide networking services for instances (i.e., IoT devices) deployed outside the Cloud (the standard Neutron enables networking services for Cloud-based instances only).

In our approach, we are considering as binding-hosts, where the Neutron L2 agents are running beside software switches, nodes hosting the Stack4Things® WS tunnel agents while the instances are the remote IoT nodes. Consequently, Neutron ports are created and managed on these nodes (i.e., Stack4Things® WS tunnel agents hosts) along with their networking facilities (i.e., software switches).

In our design, the ports are created on the Cloud-side (i.e., WS tunnel agent hosts) yet, they will be attached to our approach instances, which are the remote IoT nodes located at the

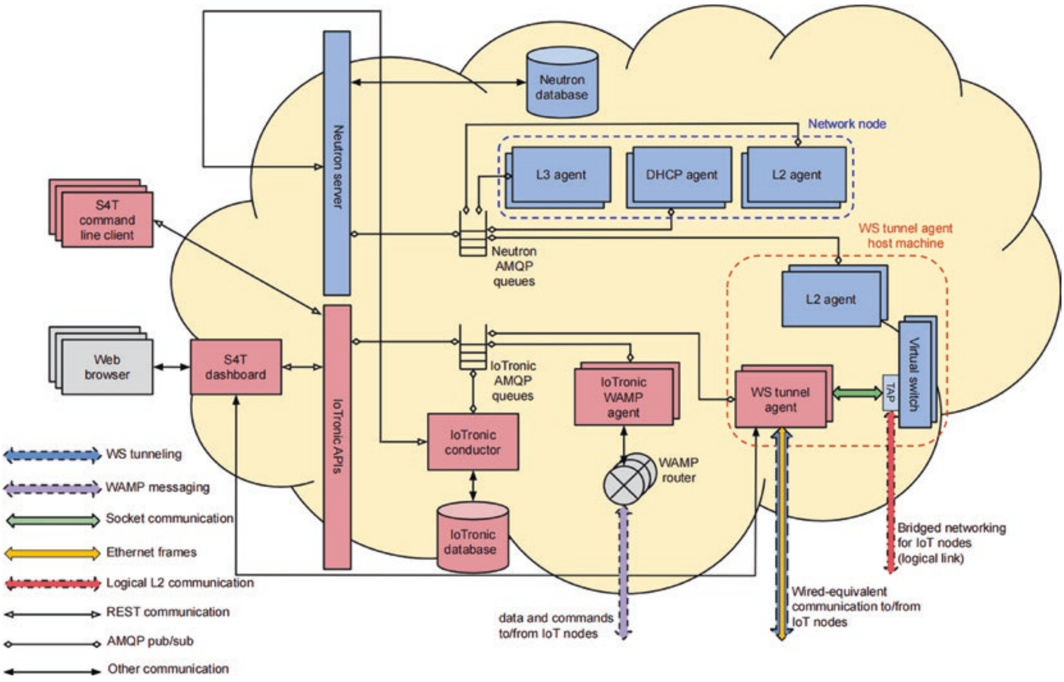

**Fig. 7** The Stack4Things® Cloud-side networking system

edge of the network, where Virtual InterFaces (VIFs) get instantiated.

Stack4Things® design has been thought out considering the typical constraints of IoT environments, thereby making the approach versatile and scalable. On the one hand, the edge nodes are not involved at all in most of the network virtualization duties since they are totally unaware about Neutron involvement, thus making the overall footprint of the solution inherently lightweight for them. On the other hand, since L2 agents and switching platforms are running on the Cloud, the approach provides availability for mission-critical Neutron services and scalability for particular hefty configuration requirements.

The device-side architecture is highlighted in Fig. 8. Data and commands to/from the Cloud are exchanged (WAMP messaging) with the Lightning-Rod Engine by using the Stack4Things® WAMP library. The wstunnel plugin allows the wired-equivalent communication to/from the Cloud. Bridged networking for IoT nodes is implemented via Logical L2 communication and via socket communication with the wstunnel plugin. Data are collected from sensors or transmitted to actuators via General Purpose Input/Output (GPIO) hardware interface by OS level calls.

## 6.2 Stack4Things® Edge FaaS System

Serverless techniques, in particular FaaS (i.e., Function-as-a-Service: FaaS) approaches, can be easily exploited to create IoT slices. Stack4Things® extends the serverless paradigm to the network Edge using the OpenStack FaaS subsystem Qinling. In particular, in order to deploy functions at the Edge on top of IoT devices, Qinling uses IoTronic as the networking driver for the containers (created by Zun [23]). The architecture of the system is highlighted in Figs. 9 and 10.

Zun (ex. Higgins) is the OpenStack Containers service. It aims to provide an API service for running application containers without the need to manage servers or clusters.

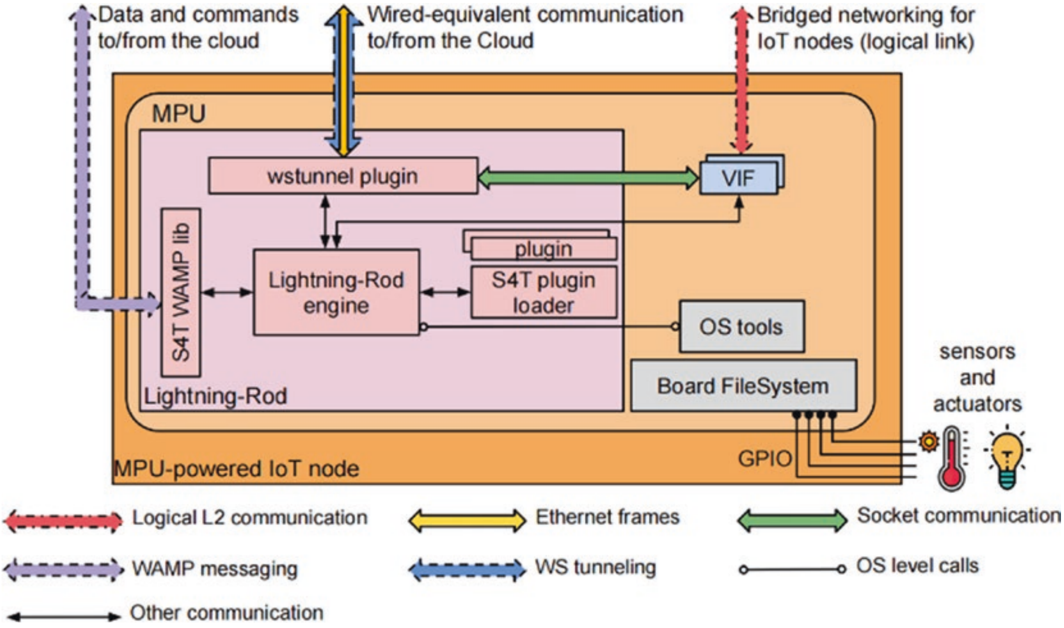

**Fig. 8** The Stack4Things® device-side networking system

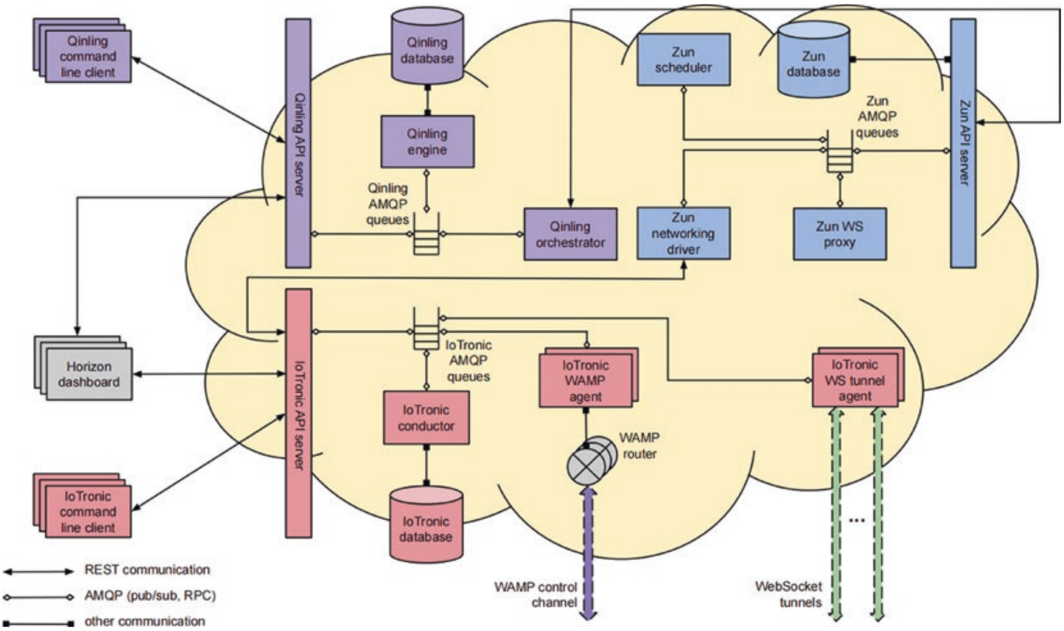

**Fig. 9** The Stack4Things® Cloud-side FaaS system

A user, in order to deploy a runtime/function on a particular IoT device, interacts, through the dashboard or CLI, with the Qinling-API server that forwards the request to the Qinling orchestrator. This latter component cooperates with the Zun-scheduler to identify the IoT device where the runtime/function should be deployed; then, the Zun-API server sends a

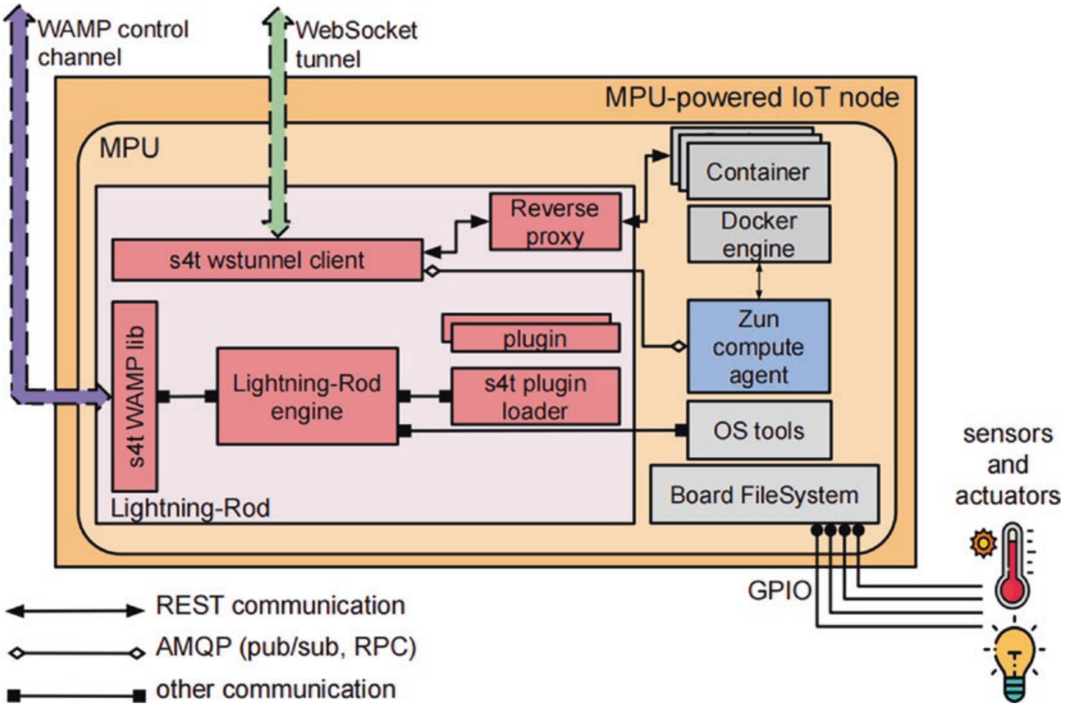

**Fig. 10** The Stack4Things® device-side FaaS system

request to create, on this device, the containers needed (i.e., the capsule). To make users able to reach the capsule and in particular, the runtime container, IoTronic exposes it, on the Cloud side, using a public IP address and a port, then a WS tunnel is created between the Cloud and the IoT device. Hence, a request that reaches the Cloud on that IP address/port will be forwarded to the WS tunnel and reaches the device. On the device-side, the request is received through the Stack4Things® wstunnel plugin and forwarded to the reverse proxy that routes it to the correct runtime.

## 6.3 Stack4Things® Secure Web Services

To merge the cyber-world with the physical one and make IoT an integral part of the Internet, reusing existing Web technologies and standards is a suitable choice. In this case, IoT objects will not be only IP-based devices connected to the Internet, but they become able to communicate/cooperate using the same language. Therefore, they can interact among each other and with other components from the existing Web world. In such a homogeneous environment, smart objects will be able to offer their functionalities (e.g., sensed data) via RESTful Web services (also called Web Application Programming Interfaces (APIs)).

Figures 11 and 12 respectively show the Cloud-side and the device-side web services systems. For example, an embedded system with a temperature sensor that collects measurements from the physical world can provide its real-time sensed data as a smart object service (i.e., a Web service). Therefore, we can build an ecosystem where the smart objects can offer their functionalities as Web services that other entities (e.g., other devices, Web services, applications) can make use of to provide appealing services/applications.

At the MPU-powered IoT node (Fig. 12), data collected from sensors or commands sent

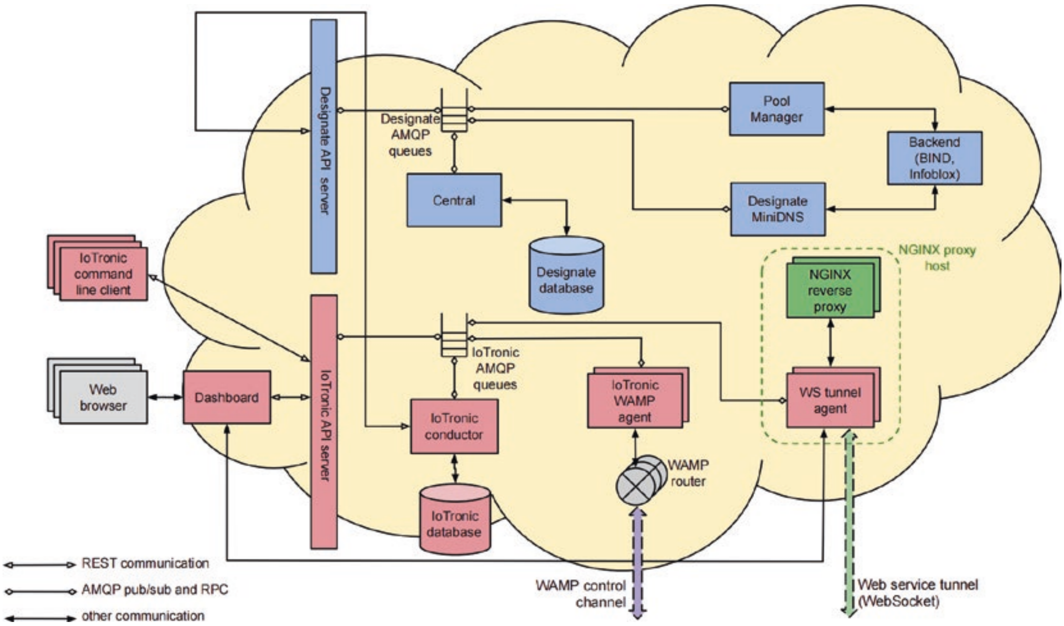

**Fig. 11** The Stack4Things® Cloud-side web services

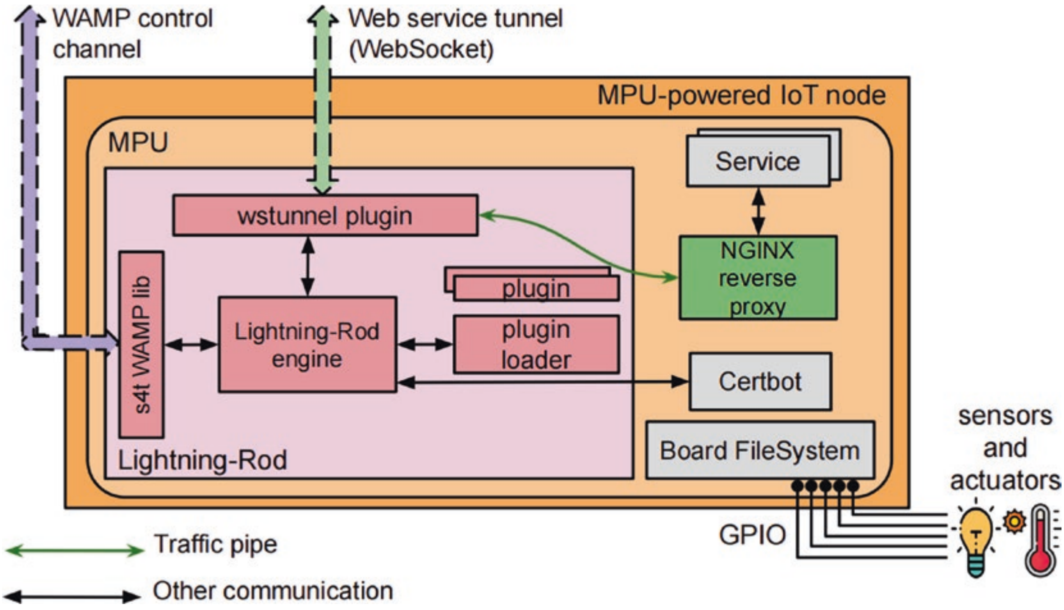

**Fig. 12** The Stack4Things® device-side web services

to actuators are managed by the Lightning-Rod engine in form of automated tasks (Certbot). In order to enable secure communication (using HTTPS) between the services and clients, Stack4Things® integrates within the system an automated approach (i.e., without any human interaction) based on the ACME protocol for X.509 certificates issuance and validation. This approach used the Certbot agent with Let's encrypt Certification Authority (CA).

Stack4Things® through the S4T WAMP libraries provides users with the ability to expose services running on the IoT devices to the Web. This is achieved by integrating IoTronic (Fig. 11) with the DNS-as-a-Service system of OpenStack. This latter subsystem manages the records about the URLs associated with the services running on the IoT devices while IoTronic deals with their reachability (i.e., requests routing) by creating Websockets tunnels and configuring NGINX reverse proxies for traffic redirection/forwarding (traffic pipe).

## 7 Fast Deployment of Monitoring Infrastructures

Starting from the neuro-biological approach introduced in the previous Sections, we can resume the fast deployment of monitoring infrastructures in three main steps (Fig. 13):

- Deployment
- Collection
- Services.

The deployment step mainly consists in the technical setup of sensors and actuators physically placed in the monitored environment. Sensors and actuators are connected by i2c or serial interfaces (e.g., via usb) to the end-nodes at-the-edge of the IoT-Cloud network. End-node devices (e.g., the Arancino boards) are controlled by the on-board microcontroller unit (MCU) and are usually battery powered through low-energy applications (e.g., Bluetooth Low Energy) and low-consumption electronic circuits.

The collection step mainly identifies the communication of the IoT devices with the Cloud. Data collected in real-time from the end-nodes are transmitted through a multitude of wireless technologies (e.g., LoRaWAN™) or by a cabled infrastructure. At the highest level, services that need more computational resources than end-nodes capability are implemented.

Finally, advanced services are deployed on the Cloud so as to automatically provide a feedback to the system. Sensors can be virtualized and services orchestrated in order to optimize management of the computational resources

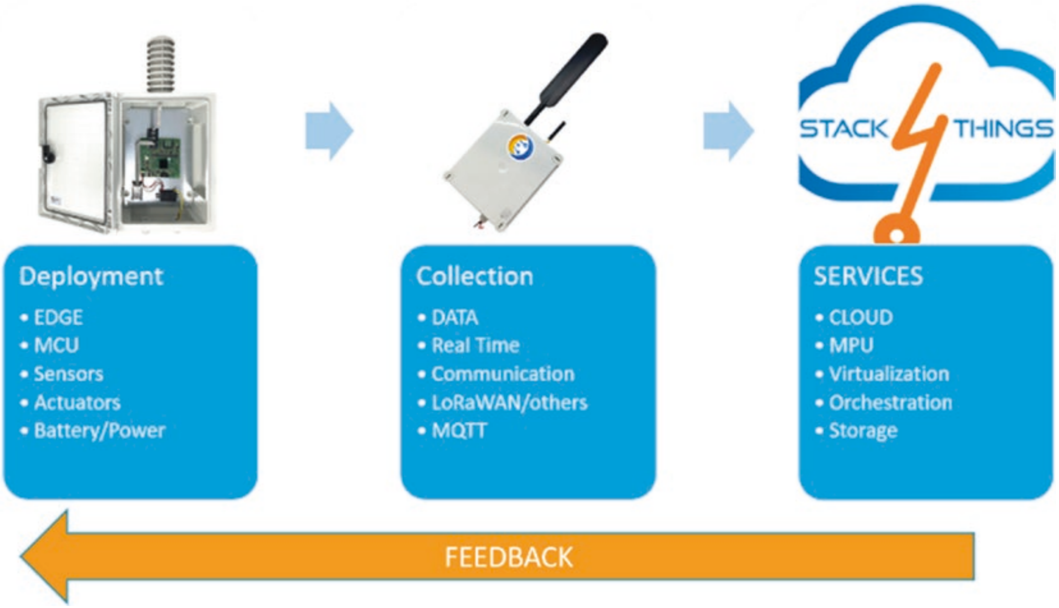

**Fig. 13** Fast deployment and operational flow by using the neuro-biological approach

**Fig. 14** AIR Environmental Station (SME-ES-02)

(e.g., in terms of efficiency, sustainability and resilience to critical events).

Among the main devices used for the aforementioned purposes we mention the following, equipped with the open source operating system Arancino OS:

1. The AIR Environmental Station (SME-ES-02 in Fig. 14) allows the outdoor measurement of environmental, air quality and meteorological parameters. The relative data, i.e. temperature, humidity, pressure, UV power index and density, brightness, PM1 / PM2.5 / PM10, rain, wind speed and direction, are then transmitted for their visualization and analysis via WiFi mobile connectivity. and (on request) 3G /4G/LTE and/or LoRa® (LoRaWAN™ Class A). Moreover, it can be equipped with Smart Camera for Object counting applications.
2. The Environmental Station SME-ES-03 (Fig. 15) is a mobile monitoring station that allows the indoor measurement of environmental parameters such as Temperature and Humidity, Particulate (PM2.5 and PM10), NO2, O3 and SO2. LTE communication (10uA)+GPS, Expansion cards for sensor stacking. It is powered with a 5 V dc voltage with a customizable plastic encapsulation.
3. The picoGW device (SME-PGW-01) in Fig. 16 is a gateway that operates both on the cellular network (LTE / 4G via SIM and special communication module also equipped with a GNSS geolocation system) and on the LoRaWAN™ network. Its operation is based on the Arancino architecture that offers high availability and scalability at low prices.
4. The AI Smart Camera (SME-AI-01) is a device equipped by the Arancino.AI technology for artificial intelligence applications, including indoor minibox or housing with

**Fig. 15** Mobile Environmental Station (SME-ES-03)

**Fig. 16** PicoGW device (SME-PGW-01)

IP protection rating for outdoor applications. It works “On the Edge”: all processing takes place on the smart device and no images are recorded or transferred. It has a vision system for the recognition of classes of objects (see Figs. 17 and 18 as an example of monitored pedestrian and vehicular flows). Each class of objects is recognized by its software package. Main characteristics are: Arancino.AI technology, Crowd detecting, Object Virtualization, Overlay networks of things, Remote control and customization, Device Fleet management and delegation, Fog orchestration, Software-defined, Customizable case.

## 8 Use Cases

In this Section we introduce relevant use cases, the implementation of which is characterized by the use of Arancino and Stack4Things® technologies. Each Use Case represents an experience from which we built the presented

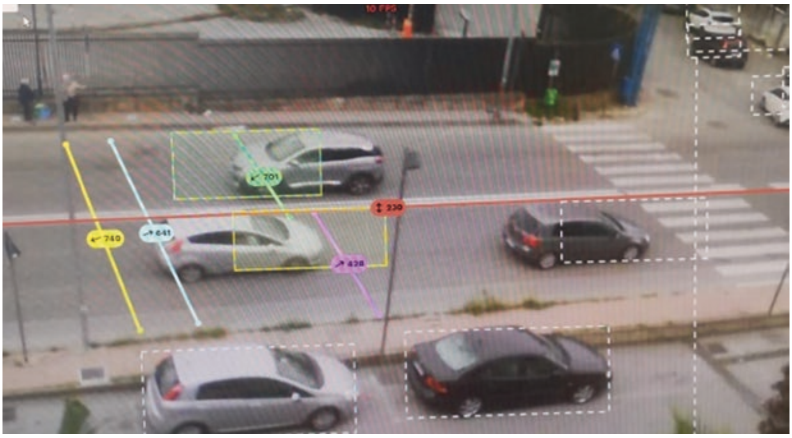

**Fig. 17** Monitoring of pedestrian and vehicular flows

**Fig. 18** Traffic counter dashboard reporting both numerical and graphical representation of four different typologies of vehicles

neuro-biologic approach. Specifically, we have overcome some limitations that we detected with a traditional approach to data collection and processing. Among these, the most important limit was recognized to be the focus on objectives concerning only the functionalities of the controlled system, with no consideration of its health and its interaction with the environment where it is located or where it operates.

## 8.1 USE CASE A: Monitoring of Electromagnetic Field Levels at Radio Base Stations

An interesting application case concerns the Monitoring of Electromagnetic Field Levels at Radio Base stations, in continuous mode and through systems of analysis and correlation of the measured data. The system allows to measure the values of the strength of the electric field E (V/m), in the range of frequencies used for mobile telephony. Low-cost probes are used positioned on the base station (SRB) system. Through correlation algorithms, the system allows to obtain an estimate of the strength of the electric field in sensitive points chosen far from the SRB. From a few measurements recorded at different moments of time, the field radiated in the time domain by the sensors near the base station is reconstructed at many sensitive points in the SRB coverage region. In addition to the recorded measurements, other ''a priori'' information on the plant is also used, such as the patterns of the transmitting antennas, orography of the terrain, urbanization around the SRB as well as the characteristics of the signal transmitted in the sub-band to be monitored.

The solution adopted for monitoring electromagnetic pollution is based on Arancino and Stack4Things® technologies. As shown in Fig. 19 the system involves a star architecture in which a collector (Arancino Gateway) node forms the center to which several end-nodes (Arancino RF Meters) are connected.

Each end-node is equipped with an RF Meter (Fig. 20) for electromagnetic monitoring, with a specific antenna for the frequency range of interest, then it is connected to the star center via a dedicated USB hub. Data acquisition takes place in a synchronized manner at regular intervals. The collector node can perform pre-processing directly on board, then transfer data and results to the Cloud for subsequent analysis.

The RF Meter sensor is a radio frequency power meter capable of covering a frequency range from 1 MHz up to 8 GHz over a range of about 60 dB. Through a suitable external antenna connected to the sensor, the radio signal is acquired and processed. On the collector node (i.e., the gateway) it is possible to read the data of the individual sensors that, with a software-configurable rate (> 0.1 s) perform the radio frequency measurement, apply the tag related to the timestamp, and make the data available to be processed locally to the gateway or send it to the cloud.

## 8.2 Lesson Learned

In this use case we have experienced the implementation of the above-mentioned neuro-biologic approach in which the microprocessor part was used in order to optimize the arrangement of the sensor nodes (microcontroller part) and a series of metrics such as:

- Number of sensors N or their optimal spacing
- Optimal dimensions in the case of sensors placed at different heights
- Optimal radius
- The number of polarizations to be acquired at each of the measuring points (replicating the sensor: RF meter + Arancino Mignon)
- The sampling time intervals between successive measurements
- The reception bands (filters on the antennas used by the sensor)
- Optimal antenna to use.

The above optimizations are an example of functionality closely linked to the interaction of the system with the environment in which it operates.

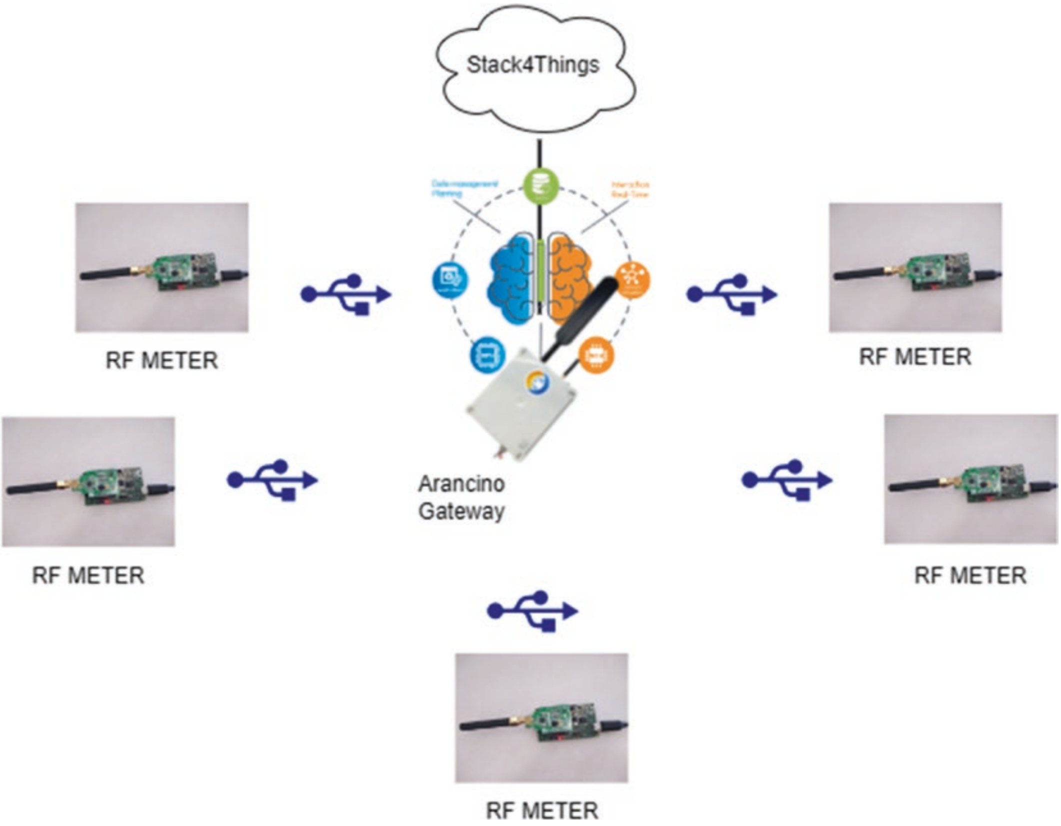

**Fig. 19** Star architecture implemented for the EMF Monitoring

**Fig. 20** Arancino Mignon end-node equipped with RF Meter sensor

### 8.3 USE CASE B: Realization of a Landslide and Rock Wall Monitoring System

An important application case is represented by the work carried out for the realization of a landslide and rock wall monitoring system. The system has been designed to identify in real time movements in progress and their space–time variation, as well as the dependence of the movements on the changing weather and hydraulic conditions of the area. The system allows the decision maker to evaluate the influence of external factors not directly attributable to landslide movement, for example microearthquakes. Data collected from sensors are transmitted via LoRaWAN Low Power, Wide Area (LPWA) networking protocol. The LoRaWAN protocol-based data collection device consists of a Transceiver module and a series of inclinometers and crack gauge sensors connected to it by RS485. The RS485 bus requires the sensors to be connected in a chain. Each crack meter is assigned a unique ID used during the data collection phase to send and receive commands. Each LoRa end-node periodically sends the request to each sensor and collects the received data.

**Fig. 21** Lorenteggio area in Milan

## 8.4 Lesson Learned

The importance of this experience is mainly related to the use of LoRaWAN communication with our Arancino-Stack4Things® system. In particular, it was very useful to better understand the impact of the implementation choices in terms of energy consumption. The logic used is:

- To avoid statically associating sensors to nodes
- To reduce acquisition time, limiting it only to connected sensors

## 8.5 USE CASE C: Implementation of an Interoperability Platform for Future Cities

We present the design and implementation of an interoperability platform based on Arancino and Elastic Stack4Things® technologies.

Specifically, this use case is the application of the Ecosystem for the energy requalification of public lighting systems and related smart services in the Lorenteggio area in Milan (Fig. 21), with the aim of reducing the energy consumption of public lighting networks and installing different types of sensors and technologies typical of an intelligent district (Fig. 22).

Stack4Things® enabled remote device management via the cloud, maintenance, secure end-to-end communication and access to edge systems. The architecture is based on virtualizing the unused desktop resources also organizing them in order to serve the needs of big data processing. More specifically, the Elasticsearch-Hadoop (ES-Hadoop) connector has been implemented in order to get quick insight from big data and makes working in the ecosystem even better.

In particular, the platform implements:

- Intelligent lighting system that allows the adjustment of the intensity of public lighting. This is possible thanks to the combination of several parameters, monitored by the system itself, including traffic intensity, the presence of pedestrians and weather conditions. The adjustment of the light intensity can also take place remotely by the operators, through a dedicated dashboard that shows a summary view on the status of the equipment.

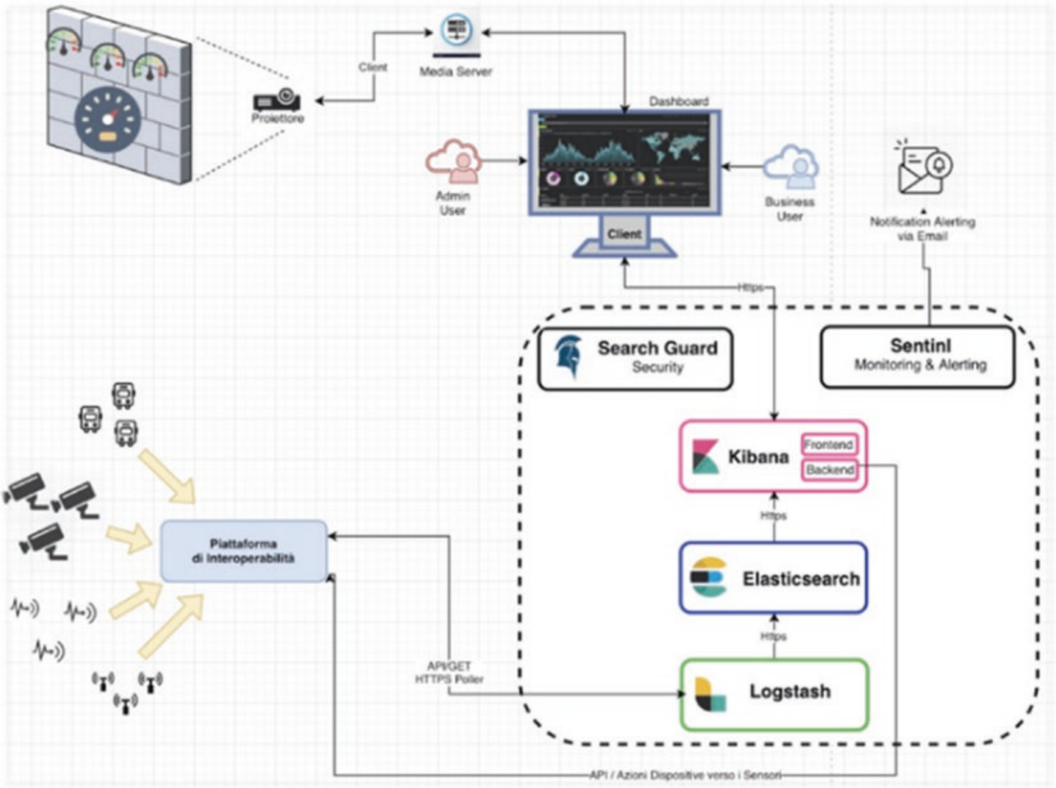

**Fig. 22** Elastic Stack4Things® interoperability platform

- A system integrated in Open WiFi Milano for the public and free dissemination of the Internet signal.
- Cameras integrated with the city's video surveillance system, whose images are transmitted to the operations center of the Local Police.
- Smart cameras for video analysis.
- Environmental sensors for monitoring the level of electromagnetic emissions.
- Sensors for monitoring the status of parking spaces.
- Sensors for controlling the filling level of waste bins.
- Smart microphones for recognizing loud noises.

The information listed above is displayed on a single dashboard for use by operators and with specific views based on the profile. Figure 23 shows the dashboard for the monitoring of the level of electromagnetic emissions.

### 8.5.1 Lesson Learned

The above-mentioned use case is the first integration of Elastic and Stack4Things® technologies. With the final goal of further interconnecting People, Government, Businesses and Industry, the project introduces the role of interoperability to shape the Society 5.0 paradigm by enabling a human-centric and resilient society.

## 8.6 USE CASE D: Infrastructure Monitoring

A leading company in the field of technological innovation has developed an innovative system of diagnostics of stability and/or compliance with the architectural model of buildings, such

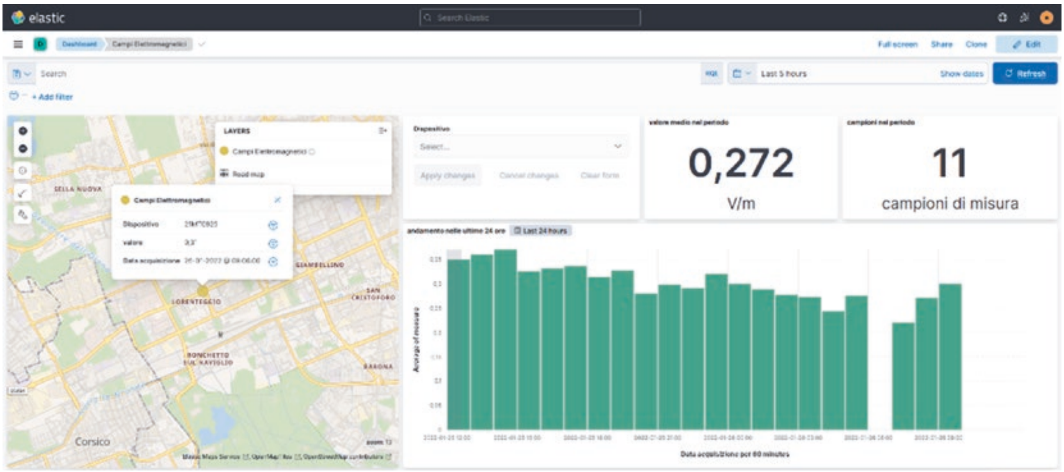

**Fig. 23** Elastic Stack4Things® Interoperability Platform

as roads, tunnels, bridges, pylons, antennas and other structures. As well as public and private buildings, rocks, soils and natural sites can be considered in order to identify any critical issues, in place or over time, about endurance and stability. SmartMe.IO has designed, developed and created the Gateway level of the system and the related interfacing modules for data processing and the Cloud.

### 8.6.1 Lesson Learned

The experience of SmartMe.IO in this field is very important: the development of new functionalities of the Iotronic platform, lightning-rod (LR), and the integrations to the Iotronic-dashboard (i.e., the main software components of Stack4Things®) are a clear example of software customization finalized to measure resilience in infrastructure in terms of both direct and indirect impacts. These include resilience to sudden shocks (e.g., disaster resilience) and to slow-onset impacts (e.g., climate change) and indirect impacts (e.g., pollution).

## 9 Conclusions

SmartMe.IO has focused its strategy on Future Cities and Communities issues, specifically in order to satisfy several objectives in terms of resilience, sustainability and creativity requirements. Prevention strategies are mandatory for Public Administrations and businesses in order to protect the health of citizens and to improve the quality of life. In such a context a fast deployment of monitoring infrastructures is mandatory and a human-centered approach is important to achieve a resilient society where humans, nature and technology create a resilient and sustainable balance enhanced by data. In this Paper, we introduced the SmartMe.IO vision. Specifically, we presented how SmartMe.IO has evolved the Arancino and Stack4Things® technologies by implementing the neuro-biologic approach. Specifically, we highlighted how IoT and Cloud can be integrated in a continuum to quickly deploy a monitoring infrastructure. Moreover, we presented the use cases that we consider the most important experience that drove us to adopt a new neuro-biologic approach to develop new proactive IT systems. Future works regards the research and development of new intelligent software agents to deploy customized solutions for both industries and smart cities contexts. The goal is to evolve the actual Arancino-Stack4Things® ecosystem as a common platform extended to new smart applications based on Artificial Intelligence and Blockchain technologies for predictive maintenance, traceability of products (especially in the agrifood chain), quality of production cycles and citizens' quality of life.

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# Ubiquitous Technology for Health

Paolo Ciampolini, Guido Matrella, Niccoló Mora
and Federico Cocconcelli

**Abstract**

The Smart City concept relies on the use of Internet of Things (IoT) technologies to allow for intelligent services to be integrated throughout metropolitan areas, providing innovative services and improving the quality of life. As technology advances, such services become increasingly accessible to a larger population share, and to elderly and frail users in particular.This paper provides an overview of research carried out at Department of Engineering and Architecture, University of Parma, geared towards improving the lives of elderly people by leveraging IoT technologies, also in the framework of recent collaborative-research projects.

## 1 Introduction

According to the European Union (EU) definition [1], a smart city is "a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business."

The term "smart" is increasingly being used to describe the use of innovative digital technologies to reduce complexity, maximize efficiency, and increase functionality in sectors such as urban transportation, water distribution, waste management, energy consumption, public security, as well as services aimed towards senior citizens. This last point is linked to the well-known demographic issues that foresee for many European countries (including Italy) the inversion of the demographic pyramid, with the most populous age group becoming that of the elderly [2].

The recent pandemic crisis, due to Covid-19, revealed the potential impact (and, to some extent, the need) of new digital technologies in the field of assistance, health, rehabilitation, and remote monitoring services. This holds true in the case of care activities, where technologies may support and optimize the work of operators, and allows for personalized, safer, and better-quality treatments, deliverable at the user's home. But it also holds true in the much wider scenario of prevention, where technologies may be exploited to incentivize healthier lifestyles, to motivate people in complying with medical advice and to check for symptoms of diseases as early as possible. Prevention practices, however, need to be framed in usual daily life activities and places, not necessarily limited to a clinic

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R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_5

environment, but encompassing the whole living space, including homes, offices, leisure places.

The effectiveness of deployment of such technologies, however, relies on the user's perception of their accessibility, usefulness, ease of use, and invasiveness. From this point of view, Internet of Things (IoT) technologies may play a strategic role: IoT devices, indeed, inherently lend themselves to non-conventional human interaction schemes, requiring to the end-user little technological skill, or no skill at all.

IoT technologies have thus found many different applications in the assistive field [3].

In this paper, we briefly elaborate on the deployment of services based on IoT technologies in the real-life context. Some perspectives of IoT-enabled service are illustrated in Sect. 2 below. Use cases are then discussed in Sections 3 and 4, with reference to recent projects. Conclusions are finally drawn in Sect. 5.

## 2 The Role of IoT Technologies

From a technical point of view, smart services come from the capability of inferring, measuring and evaluating human actions: to this purpose, sensors of many kinds can be connected through internet communication, resulting in a heterogeneous perception layer feeding a wide knowledge base. Sensor technology improvement makes inexpensive and accurate sensors increasingly available, this resulting in rich, multi-dimensional data pictures. Once gathered at the cloud level, such data, however, need to be converted into relevant information, suitable for powering useful services. Sensible data processing is needed to convert raw data into sound information: depending on the specific aim, much personalization could be needed.

*Telemedicine*

Conventional IT-based health services may include, for instance, well-known telemedicine services, in which specific medical conditions can be monitored from remote, by relying on the acquisition of given physiological information through patient (or caregiver) self-management. For example, simple devices can be used to measure parameters such as heartbeat frequency, blood pressure, blood oxygen concentration, etc. and to transmit them over the network to the general practitioner or to the healthcare system specialist. Data trends are monitored, looking for anomalies or disease symptoms: this avoids the need of having the patient meet the doctor for measurements and allows for much more continuous monitoring, thus resulting in prompter and more perceptive evaluation. Physiological data most often are given specific reference ranges. Although possibly adapted to the patient age and health conditions, the availability of such ranges may allow for straightforward assessment. Telemedicine is supported by mature technologies, and has been proved to be quite effective in many different fields. Nevertheless, it is not diffused yet as its great potentials may imply: the most relevant obstacles, apart from cultural issues, come from a couple of main factors: first, equipment needs to be simple enough to be operated by the patient himself (or by his informal caregivers), who possibly lack specific technology skills. This actually narrows significantly the range of parameters suitable for self-management and thus limits the dimensionality of the remote picture. Second, the effectiveness of such remote monitoring inherently also relies on the diligent compliancy with the prescribed schedules and modes. This compliance can often be overlooked, due to boredom, inattention or even to cognitive impairment (relatively more frequent at older ages). In short, telemedicine performance may greatly depend on user's awareness and skill, which, in some cases, may pose a limit to its full exploitability.

*Behavioral monitoring*

IoT technology may help in overcoming these limits, both by allowing for simpler management techniques by introducing less-intrusive, complementary monitoring techniques, based on behavioral analysis. Many medical conditions, in fact, may manifest themselves with changes in some behavioral features: e.g., reduced physical activity, wake/

sleep cycle disturbances, changes of daily life habits. Relevant examples include congestive heart failure (CHF), chronic obstructive pulmonary disease (COPD), cognitive decline, just to name a few chronic conditions that feature relatively high prevalence in elderly population. Behavioral tracking may rely on simple information, such as presence sensors, bed/chair occupancy sensors, door opening, etc. Such kind of sensors, indeed, lend themselves to continuous monitoring, at the same time requiring virtually no skill from the end-user. Behavioral monitoring can effectively complement the remote management of physiologic parameters indeed, increasing time-continuity and dimensionality of the monitoring. Extracting reliable information from behavioral patterns, however, is a delicate process, inherently depending on very individual features. Apart from gross anomalies, in fact, a "reference" behavior is hard to be assumed, the "normal" conditions largely varying based on personal habits and needs. This implies "smarter" data processing, capable of assessing meaningful changes and trends based on the knowledge of personalized behaviors, thus calling explicitly for machine-learning and artificial-intelligence techniques.

A simple example of the relevance of behavioral analysis is given in Fig. 1a, which represents the density plot of activation pattern of a passive-infrared (PIR) presence sensor, located close to the bathroom in a sheltered house flat, where a then 85-years-old lady was living. Color maps the activity intensity, with warmer colors indicating more activity. The plot spans over a three-year period (horizontal axis) and describes daily activity (vertical axis), showing a quite regular daily habits pattern, with activity in the dressing room mostly occurring at wake-up time and at bedtime, represented by the two lighter bands. But, by checking along subsequent days, a relative decrease of activity is made evident by the color fading. In Fig. 1b, a cross-sectional density plot is shown, highlighting the decline in physical activity, which eventually resulted in a fall. Although consisting of a merely retrospective analysis (i.e., no prediction process was in place at that time), this example makes it evident how even inexpensive and non-intrusive techniques such as a PIR sensor (which was originally installed for automatic lighting, and then given IoT communication capabilities) can provide relevant information, if data are suitably processed.

So simple a concept can be extended to include many different IoT sensors, providing a more articulated picture, capable of deeper insights (at the expense of smarter processing), to account for effective fusion of heterogeneous data. An example of this approach is given in Sect. 3 below.

IoT technology spans over a much wider application range: although a comprehensive review of such applications goes far beyond the

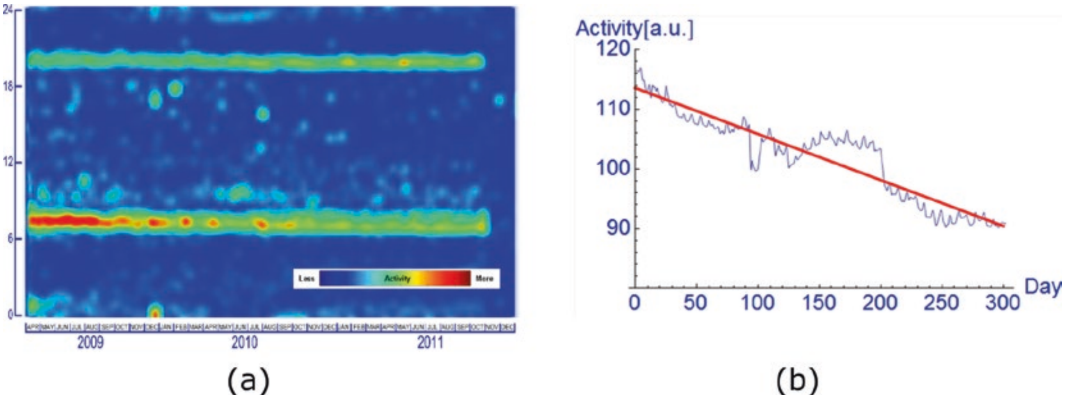

**Fig. 1** Activation density plot, referring to a presence sensor (PIR) deployed for automatic lighting (**a**). Sensor activation detail, referring to a cross-section of density plot above, at a given (8 a.m.) time of the day (**b**)

scope of this paper, we shall pick a few examples here which best fit the Active and Healthy Aging paradigm, potentially impacting on the quality of life, well-being and health of elderly people.

Many simple health practices may indeed take advantage of the distributed intelligence made available by IoT technology.

Conventional devices exploited in telemedicine frameworks, to measure physiological parameters such as temperature, body weight, blood pressure, blood oxygen and glucose concentration, etc. can be connected to the cloud, allowing for data storage in a coherent and safe space, to provide the user with reminders, and to alert the healthcare service in case of anomalies. Also, delivery of medicines can be controlled by smart, cloud-connected pill dispensers, also enabling remote checks from caregivers.

*Assisted living and active aging*

Thanks to the integration of different kinds of devices in the same cloud ecosystem, further channels can be shared for the interaction with end-users, possibly more suitable for their specific skill and needs. Most notably, the development and diffusion of Voice Assistants (VA) enables, also thanks to embedded Artificial Intelligence features, much more natural and personalized interaction with technology, almost completely overcoming the need of training for specific skill. Reminding of health-related tasks, such as taking medications or measuring parameters, comes in a fairly natural and intuitive fashion. At the same time, VA enables further functions supporting safe and independent life, such as automation of home controls including lighting, motorized rolling shutters, HVAC systems, as well enabling much easier communication with relatives and caregivers, thus contributing to safety.

The combination of smart devices, TV, and voice assistants can also be exploited to implement memory and cognitive training through games and pastimes, also providing healthcare specialists and caregivers with a continuous assessment procedure [4–6]. Besides mental health, physical activity plays a key role in slowing down ageing decline: in this case, too, support from (video) communication and VA may provide support and guidance in pursuing physical activity goals. Besides that, IoT technology may introduce feedback paths, by exploiting suitable sensors, which provide the system with information about the activity actually carried out and its compliancy with prescriptions. Physical activity may be assessed by wearable sensors [7], as well as by sensors suitably deployed in the living environment [8]. Environmental sensors have the advantage of being much less intrusive, yet allowing for quite expressive insights.

Figure 2 shows the schematic setup of a non-intrusive approach to heart activity continuous monitoring. It consists of a smart bed sensor, featuring a highly-sensitive 3D accelerometer and a microcontroller board, suitable for the acquisition of sensor data, their local processing, and the transmission of synthesized data over the internet. The device is fixed to the bed frame, requiring no contact with the patient body, and, by analyzing the acceleration

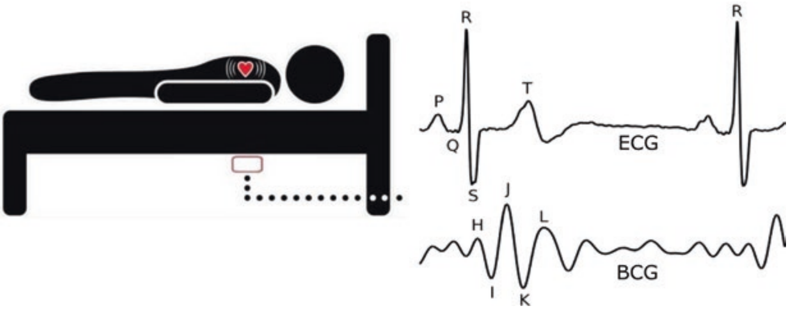

**Fig. 2** Sketch of a non-intrusive balistocardiographic heartbeat sensor, suitable for continuous monitoring during sleep. Obtained BalistoCardioGram (BCG) is compared with reference ElectroCardioGram (ECG).

patterns, can recognize the user presence in bed (which is relevant for assessing wake/sleep cycles and for preventing night falls) and to evaluate the heartbeat frequency and variability. By means of balistocardiographic techniques, managed by the onboard processor, it provides a continuous monitoring of heartbeat and can detect some kind of arrhythmia. The accuracy of this device compares well with simultaneous ECG-based assessment, featuring average sensitivity and precision across subjects and positions of 98.2% and 98.0%, respectively; similarly, a correlation $R^2$ of 98.2% was achieved between BCG and reference ECG measurements, while Mean Absolute Error and Root Mean Squared Error are as low as 3.9 and 5.6 ms [9]. The system can thus be profitably used for continuous, low-intensity monitoring of heart function, causing virtually no bother to the user, effectively complementing Holter techniques, which provide much more detailed information, but are unsuitable for prolonged periods of usage.

The IoT paradigm opens up to a number of similar applications, in which simple sensors are empowered by processing power coming from distributed, ubiquitous intelligence. In the following sections, a couple of experiences are described.

## 3 The ACTIVAGE Project

The first example refers to the ACTIVAGE project [10], funded by the EU under the Horizon2020/IoT-LSP call. ACTIVAGE was a large-scale, multi-centre European pilot project, aimed at building the first European IoT ecosystem with specific aim to the support of active and healthy ageing policies. Different IoT technologies were integrated withing the project, and deployed at nine Deployment Sites (DS), distributed over seven European countries and dedicated to the building of intelligent and assistive environments. Particular emphasis was placed on interoperability, by means of the AIOTES framework [11]. Within the ACTIVAGE framework, one among the DS pilot trials was implemented in Parma, including behavioral monitoring into the follow-up strategy for patients who returned home after having suffered a cerebral stroke event. The project was carried out in cooperation with the regional health service, by involving neurologists, general practitioners and formal, as well as informal, caregivers. The overall system architecture is shown in Fig. 3: a layer of sensors was deployed at each user's home, straightforwardly connected, through Wi-Fi networking, to the system cloud. Here, data processing was carried out, by using several AI-based strategies, to infer relevant information and detect anomalies. Information was fed back to users and stakeholders, by exploiting the electronic health record platform. Different interfaces were used: end-users were enabled to access information through the "Fascicolo Sanitario Elettronico" (FSE, which is the patient-oriented access to health data), whereas doctors and caregivers exploited the SOLE network (the professional-oriented interface).

The sensor kit was designed and developed on purpose, and included:

- Presence sensors, based on passive infrared technology;
- Door/window sensors, based on magnetic switches;
- Bed/chair occupancy sensors, exploiting sensitive mats of different sizes;
- Toilet sensor, based on proximity sensor;
- Smart-pill dispenser (based on commercially available hardware) capable of reminding the need of taking a medication and checking if the medication was actually taken from the pill box.

A common hardware platform [12] was designed for most sensors, based on TI- CC3220 SoC and capable of managing both the local data processing and the cloud communication, based on the MQTT (Message Queue Telemetry Transport) communication protocol. At the cloud level, data are stored and processed: data privacy and transmission safety are duly accounted for by encryption and anonymization strategies.

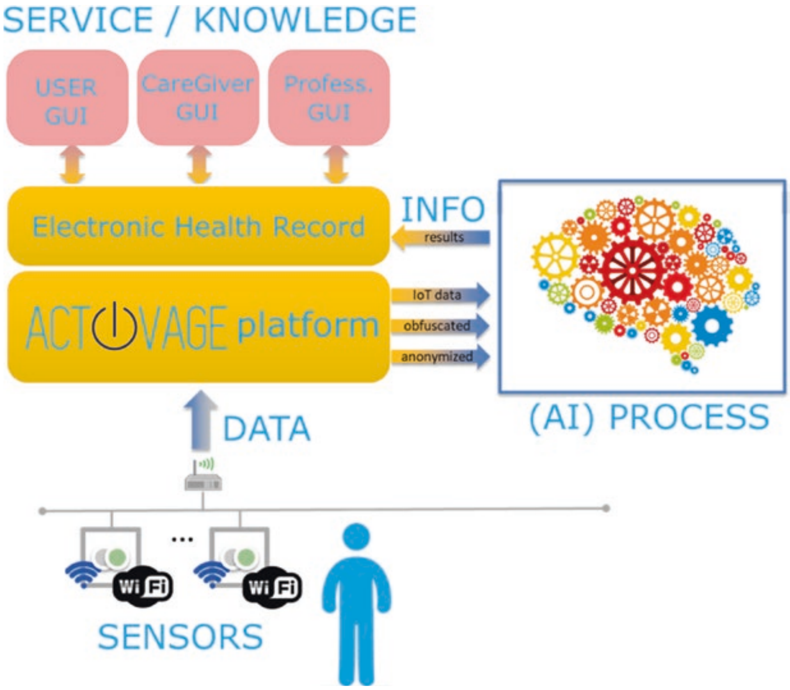

**Fig. 3** ACTIVAGE system architecture and information flow

Information was sought for, related to the specific use-case: stroke recovery is actually quite an articulated process, the assessment of which can be effectively supported by behavioral monitoring. IoT sensors were thus exploited to monitor common user patterns, including bed/rest routines, toilet usage, prescription compliance, kitchen activity, etc. A suite of analytics tools was implemented, to check for behavioral changes (either slow or abrupt) and for meaningful trends: besides real-time processing, aimed at providing alarms on immediate anomalies, statistics- and AI-based algorithms were exploited for off-line data analysis to provide more accurate insights. A complete description of the analysis strategy goes beyond the scope of this paper, and can be found elsewhere [13]. Here, we shall content ourselves with a couple of suggestive examples. First, we might consider the sleep pattern, which is strongly connected to health conditions: however, sleep habits may differ a lot among different persons, and even individually change over time: so, defining a reference pattern as a benchmark in order to assess anomalies in not practical and personalized solutions should come into play. User-specific activity profiles can be assessed by means of a training period, thus working out a typical behavior, which can be assumed as a personal reference: then, current activity can be matched against the reference profile, assuming statistically meaningful confidence intervals, to assess relevant changes. In Fig. 4a, activity profiles of the bed sensor and of the living-room chair sensor are shown, expressing the time-dependent activation probability. Based on the distribution of activation profiles, a customary behavioral profile can be extracted and associated to statistic confidence interval: data (repeatedly) falling off this region may indicate a behavioral change. This is not interpreted in a diagnostic way, but just highlighted and reported to care professionals for assessment of its clinical relevance: nevertheless, such flagging procedure may allow to discover meaningful changes well before they become evident to the caregivers. From Fig. 4a, it is also evident that habits may not be univocal: in the simple example at hand, it is clearly

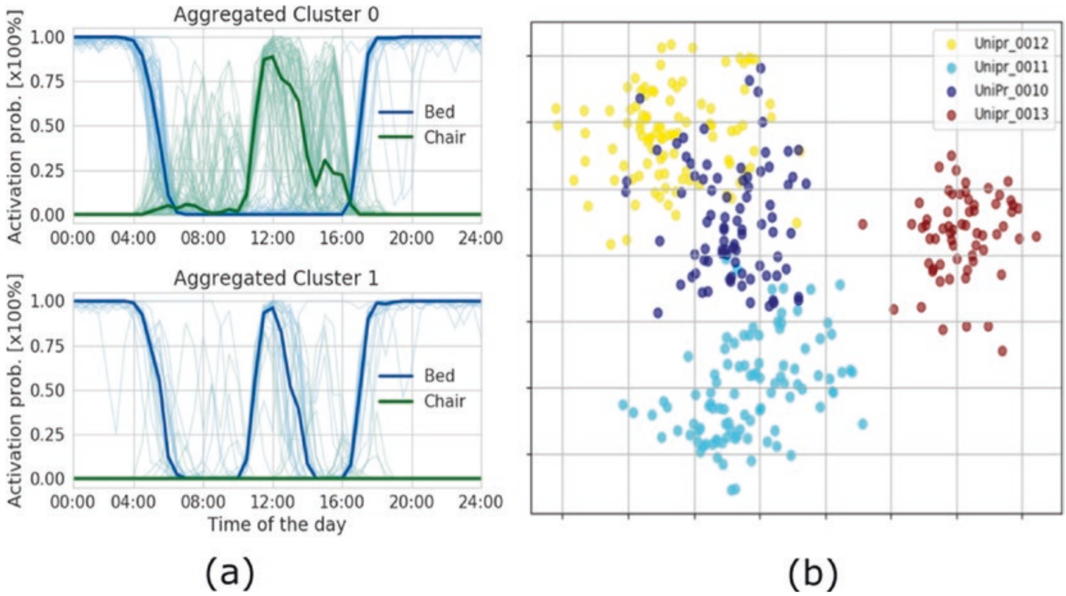

**Fig. 4** Behavioral sensor profiles (**a**) and Multivariate Habits Clustering (MHC, **b**)

visible that in the early afternoon, the user may decide to have an after-lunch nap in bed, or to have some rest in the armchair. Both behaviors are statistically relevant, and neither can be considered "abnormal". Thus, multi-modal analysis is carried out, extracting from initial training and subsequent observation more than one reference profile: all of them are considered customary, and anomalies are tracked when not matching any of them. Similar processing can be carried out for each sensor in the home kit. However, further information can be obtained by fusing data coming from different sensors and looking for combined profiles: a Multivariate Habit Clustering (MHC) has been implemented, by exploiting different neural networks and deep learning approaches. From such processing, data coming from a manifold of sensors can be combined into a lower-dimensionality, abstract representation of daily behavior, suitable for recognizing overall deviations.

In Fig. 4b a representation of this compact representation is given: in particular, six sensor-derived quantities were compressed in the 2D representation shown in the figure. Each marker position refers to the abstract combination of behavioral features on a given day. Different markers refer to different users participating in the trial. Markers actually quite nicely cluster into homogeneous groups, indicating effective representativity of individual habits. By implementing a backward classification scheme (just to check for data meaningfulness) we found 97% accuracy in recognizing the correct individual based on the compressed habit representation, showing how this representation effectively describes individual behaviors. By analyzing single-individual time series of such data, thus, overall deviations from customary behavior can be effectively identified, calling for the attention of health professionals. It is worth underlining how this approach requires from the end-user neither any awareness, nor proactive action, nor to wear intrusive devices: it is therefore a meaningful example of the opportunities provided by ubiquitous IoT sensing.

## 4 The PLEINAIR Project

A second example refers to prevention activities, and more specifically to technologies aimed at incentivizing physical activity, as a component of a healthier lifestyle. The PLEINAIR project was co-funded in the framework of the regional framework POR-FESR2014-2021, and focused on implementing IoT-enabled exercise equipment suitable for outdoor contexts, using devices called OSO (Outdoor Smart Objects) that serve the purpose of introducing gaming and remote monitoring components into conventional physical activity tools. IoT gear allows for user identification, thus enabling personalization of the user experience. The user may indeed receive guidance and feedback calibrated on his specific age, health and personal performance track; this fosters his motivation and engagement, at the same time allowing for continuous monitoring and assessment, linked to his personal health record and to medical and physiotherapist prescriptions. A prominent example of the OSO concept is given by the smart flooring [10] developed in the PLEINAIR framework: to this purpose, standard anti-trauma rubber tiles, usually found in outdoor parks and children playgrounds, were equipped with weight sensors and LED actuators, enabling bi-directional communication with the cloud-based system. The flooring itself is thus both an input device, providing information about presence and location of the user, and as an output interface, displaying color light patterns guiding the exercise game. A modular, scalable architecture was devised, shown in Fig. 5. Each tile (0.5×0.5 $m^2$) embeds 4 piezoresistive sensors (Tekscan Flexiforce A201) and a chain of 40 individually addressable WS2812B LEDS. Distributed control is implemented by local I/O controllers called RIO (Remote Input Output board). Each RIO board communicates with the main flooring controller by means of an I2C bus. The control board, based on a B-L475E-IOT01A Discovery kit from STMicroelectronics, mounts and Arm®Cortex®M4 processor (STM32L4) and an Inventek Systems ISM43362-M3G-L44 module providing Wi-Fi connectivity. Thus, the whole flooring, regardless of its actual size and geometry, is regarded as a unique IoT device: the system is capable of self-configuration, discovering the actual set of modules connected to the bus, and managing the game strategy and execution accordingly. Internet connection is exploited for tracking and recording user performance, to provide feedbacks on user's personal devices (through smartphone/tablet apps) and to check compliance with medical prescriptions (if any). For instance, the classical hopscotch game can be implemented in a digital version, or the user may be prompted to walk along a random path on the flooring by following the light sequence. Errors can be detected, and a score can be given based on accuracy and timing. Challenges are calibrated on the user's age and skill, so that the experience may fit needs of users of different

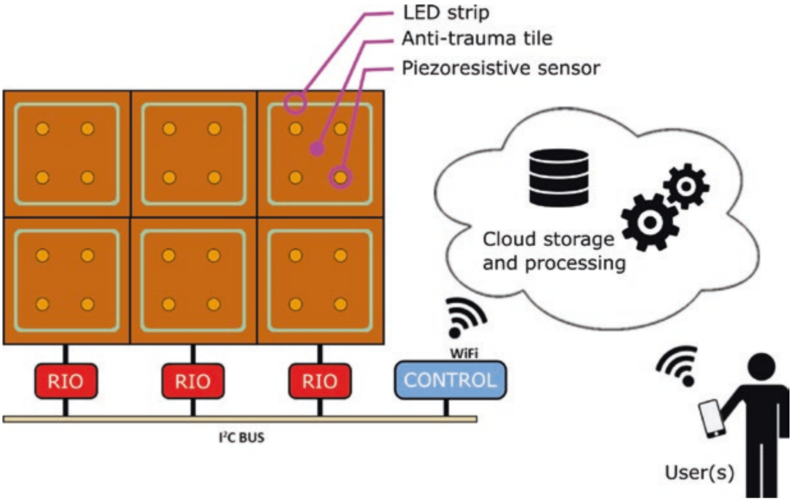

**Fig. 5** PLEINAIR Smart flooring system architecture.

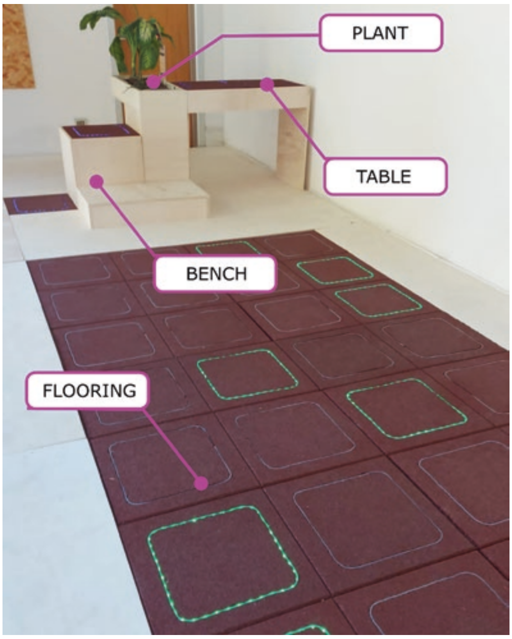

**Fig. 6** PLEINAIR demo site setup

ages and physical fitness. Different games can be managed, by downloading new games from the cloud server, adapting to specific needs and allowing for dynamically changing user experience. In spite of the inherent simplicity of the basic concept, several challenges had to be faced: high performance of the sensorized tiles was obtained, both in term of spatial resolution and in terms of weight sensitivity: loads as light as 300 g can be actually detected, thus making the tile suitable for different purposes. For instance, a test game was implemented, training coordination of people with motion impairments by challenging them to touch with their hands different parts of a single tile, following color pattern indications. The PLEINAR system was demonstrated and tested in a public environment (Museo dell Civiltá Contadina, Bentivoglio, BO, Italy) where it was open to public access for a few months, to provide technical validation and for assessing user satisfaction and acceptance. As shown in Fig. 6, four OSOs were available there: apart from the smart flooring, the sensitive table introduced above and a sensorized squat bench were implemented, together with an additional device, based on the same IoT control architecture, dealing with remote management of a plant cultivation (lighting and possibly irrigation). User from different age classes and physical ability were involved, and interviewed about their experience. The overall reaction was quite positive, with users mostly liking the smart floor experience and appreciating its motivational impact.

## 5 Conclusions

In this paper, some thoughts about the impact of IoT technology on the implementation of smart environments were discussed. IoT availability may result in ubiquitous distribution of intelligence, as well as innovative formats of human-machine interaction, possibly suitable for overcoming access barriers related to specific digital skills.

A couple of examples were discussed, coming from recent projects carried out at both European and regional levels. These projects dealt with both care and prevention strategies: long-term monitoring of stroke patients follow-up was managed by introducing behavioral monitoring techniques, effectively complementing current care practices with no additional burden on the patient. Incentivization of physical activity was instead pursued by implementing smart park equipment, suitable for enriching the user experience, fostering better motivation. At the same time, smart components of these tools enabled adaption and health-oriented monitoring of physical activity, effectively achieving personalization of care and prevention strategies.

Although still needing more extensive trials and engineering efforts, both examples proved relevant concepts, highlighting potential benefits of IoT deployment in the living environment with respect to health and wellbeing management. The rapid development of IoT technology will, in the near future, open up to many further opportunities.

**Acknowledgements** ACTIVAGE project was funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 732679. Authors wish to thank the partners of the Emilia-Romagna Deployment Site: Lepida-Cup2000 (coordinator), ASL of Parma, IBM Reserch GMBH, CNR-ISTI, WIND-TRE Telecomunicazioni SPA, Aurora Domus Cooperativa Sociale Onlus.PLEINAIR project was funded by POR FESR Regione Emilia-Romagna 2014/2020 program under grant agreement No PG/2018/632098. Authors wish to thank other project partners for their contribution: DataRiver S.r.l. (leader), University of Bologna (CIRI) and University of Ferrara (TekneHub), AIAS Bologna Onlus, Ergotek Srl, Sarba Spa and mHT Srl.

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# On Engaging Communities in Smart Societies: Crowdsourcing, Gamification, and Participatory Design for Accessible, Sustainable, and Safer Urban Mobility

Catia Prandi

## Abstract

Smart Cities aim to improve urban life by making cities more accessible, sustainable, and safer. From this concept emerged the idea of smart society. In smart societies, pervasive and innovative technologies and data are exploited to enhance society's overall functioning and well-being. In this context, smart mobility plays a relevant role. This chapter aims to present three case studies, developed as a proof-of-concept (PoC), in the context of sustainable and accessible urban mobility. In comparing them, different dimensions of interest will be considered, such as (i) the community of interest, (ii) the design process, (iii) the exploited technologies, and (iv) the engagement strategies. Ultimately, some final remarks are presented, discussing the relevance of actively engaging communities in creating smart services for our cities and society.

## 1 Background

A smart city can be defined as an urban area that exploits pervasive technology to enhance the productivity, livability, and sustainability of the city for its citizens [1]. This scenario can include deploying sensors, Internet of Things (IoT) devices, and intelligent infrastructure to improve transportation, energy usage, public services, and public safety, to name a few. The overall aim is to create a more connected, accessible, and sustainable city that better serves the needs of its citizens [2].

In this light, the concept of smart societies emerged [3]. Smart societies refer to integrating technology and data to improve the quality of life of their inhabitants. Ideally, smart societies aim to enhance society's efficiency, sustainability, and inclusivity through the intelligent use of Information and Communication Technologies (ICT). To this aim, smart societies use a combination of smart city and smart government concepts to enhance the overall functioning and well-being of society as a whole [3]. A smart society should address several challenges like urbanization, sustainability, resources, transportation/mobility, and health. In the following, we will focus our discussion on the mobility concept as a person's ability to move or be moved (capable of movement).

Smart mobility refers to using pervasive technology and data to improve mobility within a city [4]. It usually involves integrating different technologies like real-time traffic data, GPS, and mobile apps to make mobility more efficient, accessible, and sustainable [5]. In the end, smart mobility aims to make people move

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R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_6

easily within the urban environment and eventually improve a city's overall livability and sustainability, creating a more pleasant and healthy environment for residents and visitors.

When designing new smart mobility services, it is crucial to consider people's needs [6]. There are two main motivations behind this assertion. First, people are the ultimate beneficiaries of smart mobility solutions. Second, people often have an active role in the smart mobility process by using, for example, mobile apps to access data and plan their trips. This means that people need to be involved in the design process, ensuring the creation of smart mobility services tailored to the community's needs and preferences.

Within the Human-Computer Interaction (HCI) field, several approaches have been studied to consider users' needs in the design of services and products. These strategies range from User-Centred Design (UCD) [7], where users are not directly involved in the design process, yet designers create the system considering their needs, to co-design [8] and participatory design (PD) [9], where people have an active role in the design of the system, side by side with designers.

In this Chapter, we will focus on the discussion of some of the main objectives of creating smart mobility services: having more accessible, sustainable, and safer urban mobility. In doing that, we will present three case studies, developed as a Proof-of-Concept(PoC), focusing on different community needs. In particular, three are the communities of interest: (i) people with disabilities and special needs, including mobility and visually impaired people; (ii) citizens and visitors living in a well-known tourist destination, where tourism represents the main income source but it also represents a concern in terms of sustainability; (iii) children who would like to develop their independent mobility. For the three case studies, some dimensions of interest are analyzed, such as (i) the peculiarity of the community of interest, (ii) the design process, (iii) the exploited technologies, and (iv) the engagement strategies. Finally, the paper concludes with some final remarks and general recommendations.

## 2 Related Work

The related work section focuses on three smart mobility macro areas, accordingly with three case studies. In fact, despite being indisputable that urban areas and the people living in them are dealing with daily issues related to mobility, such as traffic congestion, air and noise pollution, and the effectiveness of public transportation, the concerns depend on the specific communities' needs.

### 2.1 Urban Accessibility

Urban mobility is the ability of people to move around the city, living and interacting with the space. Individuals with limited mobility, such as those with disabilities or the elderly, often face accessibility challenges while moving in an urban environment, including obstacles in the urban landscape and public transportation [10]. The absence of information about the accessibility of transportation and the surrounding environment further hinders their ability to move around the city independently [11]. Over the years, several solutions have been developed to provide people with wayfinding and navigation technologies [12]. Wayfinding systems are used to guide people through a physical environment, enhancing the individual understanding and experience of a space. In simple words, the main objective of a wayfinding system should be to aid the users in orienting themselves in a space and then navigating to a specific destination. However, these same devices and software applications can also act as a barrier if their user interface is not accessible or not compatible with assistive technologies. This can prevent individuals with disabilities from fully utilizing these tools to enhance their independent living.

Over the last decade, a significant amount of research has been carried out to study and develop wayfinding software and devices that aim to improve the quality of life for individuals with disabilities as they move through the urban environment [13, 14]. In 2021, Prandi et al.

presented a systematic mapping survey where they analyzed 111 out of 806 papers published in the period 2009–2020 [15]. The wayfinding systems were analyzed considering six dimensions. First, they exploited the used device, such as smartphones (e.g., [16, 17]), web applications (e.g., [18]), wearable devices (e.g., [14]), and smart devices (e.g., [19]). Then, the context of use, that is, indoor (e.g., [19]), outdoor (e.g., [11]), or both (e.g., [20]). The target user is another analyzed dimension; applications can focus on a single target (i.e., blind users [21]) or a larger community (i.e., people with special needs [22]). The used data source is another dimension of interest; examples are open data and/or official data (e.g., [23]), data provided by users through crowdsourcing and/or crowdsensing mechanisms (e.g., [21]), multi-source data (e.g., [24]).

In this first case study, we exploited a mobile and a web wayfinding system designed to consider the special needs of people with impairments, exploiting multi-source data to provide personalized paths.

## 2.2 Sustainable Mobility and Tourism

Smart cities have arisen as a potential solution to the sustainability issues resulting from the rapid growth of urban areas [25]. Smart mobility plays a vital role in fostering the sustainability of an area. The tourism sector is strongly related to the ability of people to move and travel, and is one of the largest industries globally, rooted in mobility as a form of capital [26]. In destination islands with delicate ecosystems to preserve, this source of revenue can pose sustainability challenges [27].

Due to the widespread use of innovative and interconnected technologies, the world has become highly connected, enabling access to vast amounts of data to gain new understandings and knowledge. These pervasive technologies allow researchers to examine the overall effect of complex human and economic activities, such as tourism (e.g., [28, 29]). To this end, several technologies have been developed. As an example, different strategies can be employed to sense mobility flows. Some projects analyzed mobile phone data (e.g., [30, 31]). Others used GPS traces (e.g., [32]). Interesting is also the possibility of gathering information using Wi-Fi technologies (e.g., [33, 34]). Finally, some studies exploited social network usage (e.g., [35, 36]).

When discussing sustainability and mobility, collecting data on environmental conditions is essential. Over the last few decades, various research initiatives have utilized citizen science contributions and participatory sensing, including crowdsourcing and crowdsensing, to identify and monitor a broad spectrum of environmental characteristics [37]. Such attributes range from physical characteristics (as urban accessibility [11]) to actual measurements (such as noise [38], air quality [39], and so on), including also environmental-related dimensions (such as biodiversity [40]). In some instances, participants provide written reports on specific observations such as weather conditions [41], hydrological monitoring [42], and daily precipitation [43]. Some researchers have also developed specialized hardware to achieve specific objectives (e.g., [44]). Several initiatives have involved citizens using smart devices, exploiting their built-in sensors to create a network of participatory sensing (e.g., [45]).

This second case study presents a platform composed of a low-cost community-based pervasive collaborative infrastructure to sense the presence and movement of people exploiting passive Wi-Fi tracking and a web-based application that combines and visualizes the data collected by the sensing infrastructure and other urban data sets (such as energy consumption, weather information, and $CO_2$ emission).

## 2.3 Children Independent Mobility

Children's independent mobility could be defined as the use of public space by people under 18 years unaccompanied and unsupervised by adults [46]. Independent mobility for children has been shown to significantly impact their well-being, social and cognitive development, and spatial awareness [47]. Despite the growing investment in urban mobility and incentives for sustainable use of public transport and shared mobility, the trend of declining independent mobility for children is evident in several countries [48]. At the same time, the rise in mobile device ownership presents exciting opportunities for location- and map-based applications and services specifically tailored for children.

The focus of several location-based approaches designed for children, including mobile apps and wearable devices, is on tracking the child's movements and whereabouts to increase safety and security and address the concerns of parents [49, 50]. However, many of these studies neglect the needs and desires of children and their caregivers and instead concentrate on ICT issues [51, 52]. A limited number of studies have included children and caregivers in the evaluation process, raising concerns about the impact of new technologies, privacy and ethical issues, security, and the caregivers' false sense of security [53, 54].

This third case study aims to involve children and caregivers in the early stages of designing future location-based technologies to understand the challenges and limitations of these systems.

## 3 The Three Case Studies

In this Section, the three case studies defined in the previous section are detailed, with a particular focus on some dimensions of interest, such as (i) the community of interest, (ii) the design process, (iii) the exploited technologies, and (iv) the engagement strategies.

### 3.1 Urban Accessibility and Personalized Path

With the aim at mitigating the problem of lack of information about urban accessibility, and to facilitate people with special needs to experience the urban environment, we designed and developed a wayfinding system called mPASS (mobile Pervasive Accessibility Social Sensing) [11]. In a few words, mPASS aims to provide people with special needs with personalized geo-referenced information and routing services to provide users with personalized and accessible paths. In the following, the platform will be presented, focusing on the different dimensions of interests.

Community of interest

In designing the system, we focused on the needs of people with special needs. In particular, we considered the needs of people with mobility disabilities (either permanent or temporary) and visual impairment (either partial or complete). Nonetheless, the community of interest can be extended to all the people with particular needs, such as healthy elderly people, people with temporary health conditions, children, pregnant women, or mothers with baby strollers. In fact, based on the person's needs, a personalized path can be accessible, safer, brighter, less crowded, etc.

To consider the needs of such a diversified community, we modeled the user's profile in terms of (i) urban accessibility and (ii) E-accessibility. Through the urban accessibility profile, the user can declare which architectural elements (Accessibility Point of Interest—aPOI) represent barriers (steps, stairs, objects blocking the walking path, etc.) and which represent facilities (audible traffic lights, zebra crossing, wheelchair ramps, etc.), using labels such as "neutral", "like", "dislike" and "avoid". This classification allows us to manage situations where an aPOI can be a barrier for one person and a facility for another. For example, a blind user can set as "like" a stairway because it can represent a reference point for orientation, while clearly it represents a barrier for a wheelchair user. On the basis of these preferences, mPASS computes a route that comes across the liked aPOIs when feasible, gets around the disliked aPOIs if possible, and always rejects the avoided aPOIs.

Through the E-accessibility profile, the user can customize the mPASS interface and interaction in terms of accessibility of information. The main selection is related to textual/graphical representation of the map and the personalized path, where the user can choose specific styles and customize the visualization. Moreover, we exploited cartographic techniques for rendering of the maps, making them accessible. For example, we applied the Map-to-text technique to provide users with visual impairments with a textual description of the personalized paths.

The Design Process

To design the system, we exploited a universal design approach [55]. We first collected users' needs and requirements with a questionnaire. We engaged 60 European users (including blind people and people with impaired vision, wheelchair users and users with physical impairments, deaf and hard of hearing users, and elderly people). The questionnaire reveals some relevant information. To provide some examples here, 63% of the participants usually use GPS navigation systems to get information about urban pedestrian paths, and 70% of the users declare they trust systems that provide geo-referenced information based on crowdsourced data. Moreover, all the users declare their willingness to use a mobile system that provides personalized pedestrian paths on the basis of their specific needs and preferences. 80% of the users claim they could afford a 30% longer path to reach their destination if the path is tailored to their preferences and needs. 73% of the participants would prefer choosing a longer path in order to avoid a detected barrier that is not actually present on the path instead of meeting an undetected barrier in their path. Most of the users (81%) expressed their willingness to share their personal data and information about their preferences, including details about the routes they usually follow in their daily life. We also interviewed 15 participants to collect additional data.

Accordingly, with the questionnaire and interview output, we designed and developed a first prototype. To evaluate it, we involved three blind people, three wheelchair users, and four elderly people, equipped with their mobile devices (mounting different versions of Android and the assistive technologies they usually rely on) and our mPASS prototype. The participants appreciated our system; in fact, all of them declared that the interface and the interaction mechanisms were clear and easy to be used.

The Exploited Technologies

To provide effective routing/mapping services, mPASS needs to reach a critical mass of data (in quantity and quality), which is very difficult to achieve. In fact, data need to be trustworthy enough to avoid errors about a specific barrier or facility and dense enough to decide about a path effectively. To this aim, we designed mPASS to integrate different data sources. (i) Crowdsensing and participatory sensing—data produced by the user's smartphone, exploiting built-in sensors (i.e., gyroscope, accelerator, and GPS). While data sensed by a single user can be considered inaccurate, multiple sensing of the same aPOI makes the data valid. (ii) Crowdsourcing—information produced by users interested in reporting urban accessibility. The report can include textual information and multimedia (pictures, video) data. Even in this case, multiple data support the validity of the gathered information. (iii) Authoritative reviews—many authorities and organizations (e.g., local administrations, disability rights organizations, hotel associations, etc.) do official reviews about indoor and outdoor accessibility. Usually, these evaluations are too few to be significant in computing a route, but they are surely valid. Accordingly, we defined a data model that keeps into consideration the origin of the data and its level of trustworthiness [11, 24]. Then, we implemented it in a client (mobile and web)-server architecture.

The Engagement Strategies

In designing the system, we encountered a relevant challenge. As previously mentioned, an effective crowdsourcing/crowdsensing system needs a dense, trustworthy, and updated dataset of aPOIs. This is especially hard to get in mPASS since the main target population (people with disabilities) represents a small group of citizens compared with other communities. In addition, in order to evaluate data trustworthiness, our system requires multiple mapping of the same urban element. Finally, data should cover all the urban areas (i.e., not only the most frequented areas); this is a problem for people with disabilities who are unlikely to move freely in the environment.

To overcome this problem and enlarge the data contributors community, we investigated gamification strategies in designing mobile applications targeting young adult walkers. In particular, we designed and implemented two mobile apps: (i) a gamified app, called HINT! where the user obtains a piece of a puzzle every time she/he reports an aPOI; the completed puzzle corresponds to a voucher; (ii) a pervasive game, called GeoZombie where the user's goal is to stay alive, avoiding being eaten by zombies. While trying to do that, the user is exploring the surroundings while reporting the location of aPOI for the mPASS application in order to get weapons and ammunition to shoot the zombies [56].

To evaluate our approach, we engaged 50 undergraduate students using the three apps (mPASS, HINT! and GeoZombie) for one week each. Results proved that the game mechanics increased the students' wiliness to contribute to the system [57].

## 3.2 Sustainable Mobility and Tourism

In this case study, we collected data about mobility through the use of cutting-edge technologies and a smart object infrastructure. The main objective was to use the data to provide: (i) citizens and tourists with personalized location-based services to increase the use of public transportation; (ii) locals with interactive data visualization systems to foster sustainability awareness.

The case study was conducted in Madeira, an Atlantic Ocean archipelago, a popular tourist destination. With 270.000 inhabitants, Madeira attracts more than 1.3 million tourists per year, with significant impact on the economy but also on the environment, especially considering that Madeira accounts for 80% of the biodiversity of the European continent. For these reasons, the archipelago represents a unique testbed for investigating sustainable mobility. The following subsections will present the case study, focusing on the defined dimensions of interests.

### Community of Interest

In this case, we focus on two communities that are very distant if we consider the way in which they experience the island, i.e., tourists and residents.

Due to its volcanic origin, the main island is very mountainous, making buses the only feasible public transport system. Despite that, tourists prefer to pay for a private mode of transportation to explore the island freely. This can be motivated by the fact that tourists usually enjoy the island for a relatively short time, and want to get the most out of the island experience. Additionally, several bus companies run on the island, making the public transportation system difficult to navigate for a foreigner, and the language can be a barrier as well.

Considering locals, the private car remains the most frequently used means of transportation. There are different reasons for that; some are grounded in society and culture, others are simply related to the convenience (in terms of ease, comfort, and efficiency) of moving around the island with a private car. Having said that, a change of behavior can be fostered in this community by increasing the awareness about sustainability. To this end, we engaged residents in the deployment of the smart objects infrastructure and also in the evaluation of the final system.

### The Design Process

Considering the overall idea of investigating how pervasive digital technologies can be used to improve the adoption public transport systems, their efficiency and convenience, we launched an interaction design challenge to redesign the local bus stops [58]. A group of international master-level HCI students participated in the challenge. The first phase in the design process involved students researching in the field to understand how users interact with the bus stops and how they use public transportation to find opportunities to improve the system and engage more users. Several problems were discovered, such as accessibility, difficulty in extracting information using the static map and timetable panel, and lack of real-time information. The results from the exercise were the ideation and early-stage prototyping of innovative sustainable mobility solutions for tourists in the city of Funchal [59].

Citizens were also included in the evaluation of a data visualization system (called ViTFlow), designed and developed to increase awareness about sustainability (and the effect of mobility) in the island [34]. We first collected the users' reactions and feedback in a preliminary field study during a local public event, shadowing the users and taking notes of their interactions with the system and comments made aloud. Then, we used an online survey to collect quantitative data about the sessions and interactions, leaving the users free to interact with the system as long as they wanted. The obtained results were very positive. Considering the interaction with the system, most users enjoyed it, found it simple to use, and the information very easy to understand.

The Exploited Technologies

We aimed to gather location-based mobility data by deploying a cost-effective system to offer personalized services and promote sustainable mobility solutions. To achieve this, we deployed a low-cost community-based Wi-Fi passive tracking infrastructure, called Beanstalk [60], which we complemented with environmental condition-detecting sensors. We installed our routers for the Wi-Fi passive tracking in 65 points of interest and 20 buses across the entire Madeira island to ensure widespread coverage. Moreover, we deployed 10 low-cost environmental stations. We collected a vast amount of real-time data about mobility flows through the Wi-Fi passive tracking system. We used such data to implement different interactive systems [59]. For example, we prototyped a mobile app able to provide real-time information about buses (including their level of crowdedness) and weather forecasting at the arrival destination, to inform about air quality and $CO_2$ level, to exploit machine learning to learn about the users' habits and suggest more sustainable behavior.

As anticipated in the previous section, we also designed and developed an interactive web-based data visualization system, presenting different data affecting the island's sustainability, with the final aim of increasing the awareness of locals. In this case, we integrated several sources of information besides the Beanstalk, including: tourism flows, common mobility paths, tourist distribution, energy consumption, and $CO_2$ emission.

The Engagement Strategies

Particularly interesting is the fact that we engaged locals to deploy the routers (needed for the Wi-Fi passive tracking) across the whole island. In fact, Beanstalk is a community-based infrastructure in the sense that we asked citizens to install our routers in their facilities, such as restaurants, bars, and strategic touristic points of interest. To stress the fact that we did not promise them any reward or benefit, but only the possibility to access the collected data.

Considering the community of tourists, we employed gamification to motivate them to use public transportation [61]. Thanks to the developed infrastructure (the Beanstalk infrastructure together with iBeacon sensors), our mobile app could detect the tourist inside the bus and at the tourist destination. To add more details, the iBeacon sensors (Bluetooth low energy proximity sensing) were installed in the tourist points of interest to detect the tourist (i.e., a check-in/out mechanism) and to provide special and authentic touristic content related to the visited location. Additionally, we implemented typical gamification mechanisms, such as points, badges, and achievements, to stimuate the tourists' participation.

## 3.3 Children Independent Mobility

This case study aimed to exploit smart technologies to increase children's independent mobility. In particular, considering the increasing popularity of mobile devices among children worldwide, we saw a compelling research opportunity in the design of a children-targeted location-based application. As for the other two case studies, details about the different dimensions of interest are presented in the following.

#### Community of Interest

We considered children between 9 and 12 years as our main community of interest. The decision was based on two main motivations: (i) at that age, children start craving for more independence; (ii) an analysis of several articles that report on the increasing number of children (9–12) owning a personal mobile device.

Considering the specific target, we also decided to include the children's parents in the picture. Indeed, a location-based app for children of that age needs to be approved by the parents first. Interesting to notice, this community will not be the one using the final technological product, but it is fundamental in designing its characteristics: parents, in fact, need to consider the app safe/secure to use, respectfulof the child's privacy, and not susceptible of becoming a threat.

#### The Design Process

To collect children's needs and requirements, we engaged the community of interest in a participatory design process, following the children as "protagonists" [62]. We performed two activities, exploiting two methods to grasp design implications: (i) cognitive maps as a research method, and (ii) scenario-based design.

In the first activity, we engaged children in drawing the cognitive maps of their journey from home to school. We conducted the study involving 70 fifth-grade students (9–12 years old) at three different public schools in Funchal (Madeira), and 27 sixth-grade students (11–12-year-old) from Lisbon. After the drawing phase, students replied to a brief survey and some of them responded to a face-to-face interview. The analysis of the drawings, survey, and interviews led us to define a set of 10 themes related to landmarks and design ideas for the creation of digital maps for children, to be exploited in the location-based mobile app [63, 64]. Children also directly reported some design suggestions, as presented in [65].

In the second activity, seven families (nine children and seven adults) were engaged exploiting scenario-based design, storyboards, and questionnaires. To begin with, participants were asked to reply individually to a pencil-and-paper questionnaire. Then, we used scenario-based design and storyboards/pencil-and-paper questionnaires to interactively collect qualitative data about how children and their parents/caregivers perceive the future design of a child-targeted locative system. Data were collected, analyzed, and discussed, generating some design implications in terms of children's preferences and parents' concerns [51].

Finally, the developed prototype was tested by engaging four children, using an adapted version of the System Usability Scale (SUS) for user testing with children [66].

#### The Exploited Technologies

Exploiting the output of the design sessions, we prototyped a location-based wayfinding Android application. Through the app, the child can select his/her preferred avatar. The avatar is then used as a marker on the map, oriented based on the child's direction and actual position. Moreover, the child can simply click on the map to add points of interest and landmarks or add friends or family contact. The child can also select an area of interest in the map (drawing it with a finger) and see all the relevant points of interest and landmarks in that area. The system also provides eco-feedback to increase the child's awareness about sustainable mobility.

#### The Engagement Strategies

Some children mentioned the possibility of exploiting gamification in the locative mobile app. One child suggested: "the application could enable the user to have points if s/he catch things like Pokemon type of thing and this way, people could collect those things and learn about the city" [65]. Another one suggested: "[The app] could notify us about monuments as we walk back home. And we could gain medals if we walk a lot. We could also gain coins if we go to certain places. The coins could help us to have an avatar instead of that annoying dot that we have. (...) I do not know, it could even be a way to personalize with our face. An avatar of a person/character, or so" [65].

In particular, children envisioned three ways to exploit gamification: (i) gamification and customization, as, for example, the use of a personalized avatar; (ii) gamification and safety, as, for example, suggesting trust itineraries that can be enjoyed by the child while learning something new related to the city and its culture, having the further benefit of gaining points; (iii) gamification and e-Ticket, as, for example, exploiting the e-Ticket to gain points and receiving badges.

## 4 Final Remarks and Conclusion

This chapter presented three case studies in the context of smart mobility for a smart society. The case studies have been analyzed considering four dimensions of interest, which are: (i) the community of interest, (ii) the design process, (iii) the exploited technologies, and (iv) the engagement strategies. In the following, some final remarks and lessons learnt are reported.

Community of Interest

First of all, when designing smart mobility services, it is fundamental to reflect on the community of interest for which the system is being designed. Each community has characteristics, needs, and requirements that have to be considered to provide the community with an efficient and successful service. The community can be "at large" (i.e., locals) or very specific (i.e., children in the 9–12 age range). Indeed, the more the community is diversified, the more difficult it is to collect all the requirements, needs, and expectations. In such a case, it becomes fundamental to focus on what all members have in common to be part of a specific community so as to extract the core needs. As an example, in the second case study, we considered two large communities, i.e., tourists and locals. In both cases, before starting the design process (see next subsection), we analyzed each community to extract the main interests and needs, at a high level, without entering too much into the details of the diversified members.

That said, in two of the three case studies presented above, we showed how sometimes defining one main community of interest is not enough to ensure the success of the implemented services. In particular, in the case of urban accessibility, the engagement of young adults turned out to be critical to reach the critical mass of data needed to provide accessible and trustworthy paths to people with disabilities (the primary target group). It is crucial to notice that this need was generated by the use of crowdsourcing as the main way to collect data and feed our way-finding algorithm. Crowdsourcing is a call to the public to participate in the data collection. Still, in this specific context, the community of people with disabilities is limited in number and in the freedom to explore the environment, requiring additional communities to come to help. Considering a different context, in the children's independent mobility case study, we resorted to parents to make sure to design a system that they approve and allow children to use. Indeed, parents are not the main target group of our service, but ignoring them can lead to wrong design decisions and, consequently, to an app that children can not install or use.

The Design Process

The target community can be very diversified; hence, a universal design approach should be employed to be inclusive and consider the needs of all people, especially those with special needs and disabilities.

Involving people in the design process is also very important to collect requirements and needs and design the new services based on them. This can be done with different degrees of involvement. Requirements and needs can be collected through field observation (users are not directly involved) or through questionnaires and interviews (users are directly involved in a specific phase of the design process or evaluation). For example, we performed field observation in designing new services for tourists and locals. This method allows designers to passively observe and take notes of people's behavior when interacting with the public transportation system. This method can provide interesting output, particularly when involving people actively is impossible. Then questionnaires are a powerful method to collect information in terms of requirements and needs. Indeed, designing a clear and compelling questionnaire is not always an easy task. Still, once this obstacle has been overcome, it allows the collection of data offline (no need to perform physical sessions with users) and, if widely distributed, can allow managing a relevant number of answers in a limited time. In the urban accessibility case study, the questionnaire data we collected were fundamental in understating the community's interest in using a system like the one we were about to develop, its feasibility, accessibility concerns, etc. Interviews are a more interactive way to collect data, allowing researchers to go deeper into the discussion and collect richer data than questionnaires. The downside is that interviews are time-consuming both for the designers and users, often resulting in a limited number of involved people. Often, questionnaires are used to drive (structured) interviews. In the third case study, where we engaged children, we exploited an alternative type of questionnaires, called "pencil-and-paper questionnaire", together with storyboards. This questionnaire typology requires live interaction between the researcher and the engaged people. Finally, the ultimate degree of user engagement is through co-design and participatory design as methods to directly engage some users representing the community of interest in developing the technology (not only in collecting needs and requirements). These methods allow to design the solution for and with the community, and have to do with the technology itself (functions, user interfaces, tools, etc.), not just requirements.

The methods and solutions to adopt depend on the community, the context, the available time and budget, and the number of participants (to name the main apects).

The Exploited Technologies

Technologies vary based on the provided services. Crowdsourcing and data fusion proved to be effective methods to collect rich data while resorting to people. Crowdsourcing has unique advantages: it allows for collecting up-to-date information, data that can not be collected automatically or using sensors, and data related to a vast territory (users just need to have the app). At the same time, it has limitations. First of all, if the crowd does not participate in the data collection or loses motivation, the system becomes inoperable (no data, no functions). For this reason, motivation strategies are fundamental to avoid this risk. This limitation becomes very clear in case study one (urban accessibility).

An IoT infrastructure can be exploited as an alternative to collect data when data can be collected without the contribution of people. In particular, in the second case study, we employed a low-cost passive Wi-Fi infrastructure to count people in a specific location and collect real-time data about mobility flows. Another technology that can be used to know the user's location is iBeacon. In fact, iBeacon sensors can be used to detect a person's smartphone within a short proximity.

In general, when discussing technologies for providing services, it is crucial to design and develop a mobile app. We can highlight two relevant motivations: (1) the widespread diffusion of smartphones; (2) the possibility of knowing the users' location, a piece of essential information when providing services in the context of smart mobility. In the third case study, we intensely focus on the design of a mobile application for children, but, in general, in all the three cases studies, a mobile application was developed. It is important to notice that the app needs to be customizable by the user. In fact, all the apps were developed considering user preferences and needs, making the system personalized and customizable. For example, in mPASS, the user can configure his/her accessibility requirements but also the needs in terms of aPoIs. In the second case study, the app was able to exploit machine learning to learn about the users' habits and suggest more sustainable behavior. In the children case study, the avatar appearance can be personalized based on the child preferences so as the interface and the information to display in the map.

The Engagement Strategies

Gamification (and, more generally, game thinking) has proved to be an effective way to engage different communities of interest. As such, gamification has been employed in all the case studies as a way to motivate users and make them enjoy the provided services. Nonetheless, it is worth noticing that the adopted strategies changed based on the specific community of interest. In fact, one solution does not fit all; contrariwise, it is crucial to design the correct strategy for the specific community. When engaging young adults in the first case study, we designed two different strategies: a gamified app (HINT!) exploiting external motivations and a pervasive game (GeoZombie) exploiting internal motivations. With the former, HINT!, we collected a high number of aPoI reports, since users wanted to receive the voucher (one voucher every six reports). With the latter, GeoZombie, we obtained fewer reports but more distributed across the environment since the virtual zombies ran toward the users, pushing them into areas where reports were missing and needed. In the second case study, gamification was used to engage tourists in two different ways: providing them with original content and virtual gadgets about the visited area, and with basic game mechanics such as badges, leaderboards, and points. In the third case study, children themselves suggested using gamification in the app to personalize the avatar, or to gain points the more they walk or use sustainable means of transportation.

It is important to highlight that gamification is a well-known strategy to answer the need to engage users, but it is not the only one. Over the years, researchers have proven gamification efficacy in motivating users, although it tends to work well only in short-term campaigns. This is one of the main limitations of the use of gamification.

Limitations

As presented and discussed in the previous subsections, all the employed methods or strategies have advantages but also limitations. In general, we would like to point out the main limitation that is common with the three case studies: we developed them as a proof of concept (PoC) to prove that the suggested solution can work in a real word scenario. This means that we did not run them for an extended, continuous period of time; we merely prototyped the system and tested it with the specific community of interest. Although this can be considered a critical limitation, it is essential to unravel the main motivations behind the creation and deployment of the three systems: designing, implementing, and validating smart mobility services, engaging an inclusive and diversified community, and eventually extracting guidelines and best practices to employ in real work solutions. Focusing on these objectives, the developed PoCs proved the feasibility of the proposed innovative solutions.

**Acknowledgements** Even though this chapter is the result of some personal reasoning, several colleagues helped me in the design and development of the three case studies. In particular, I would like to thank: Prof. Paola Salomoni and Prof. Silvia Mirri for the accessibility case study; Prof. Valentina Nisi and Prof. Nuno Nunes for the tourism case study; Prof. Claudia Silva for the children case study.

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# European Smart City and Urban Transport

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## Abstract

Cities are facing challenges to increase sustainability in the current and future scenarios. Smart city is a possible solution for facing these challenges. This paper has the main objective to investigate the level of advancements of the smart city paradigm at European level. A specific focus is on the Urban Transport, which is one of the three pillars of the European smart city paradigm, with Information and Communication Technologies (ICT) and Energy. Two approaches are followed for the investigation: a top-down approach, from the indications of the European Commission (EC) to the smart city projects implemented by the European cities; a bottom-up approach, from the initiative promoted by European cities about sustainable urban mobility, with a specific attention to the Mobility as a Service (MaaS) paradigm. The obtained results show that EC is spending great efforts for implementing the smart city paradigm to increase sustainable urban mobility. However, the integration among the three pillars is, at today, limited. In the smart mobility sector, this is even more apparent. The great part of the MaaS initiatives pay a specific attention to ICT issues but they require more insights about integration among ICT, Transport System Models (TSM) and Energy productions and consumptions. The final aim is improving transport planning and designing processes aimed at improving urban sustainability.

## Keywords

Smart city · European Union · Sustainable development · Urban planning · Urban mobility · Transport · ICT · MaaS

## 1 Introduction

Cities are facing challenges connected to sustainability that, in an imminent future, will became harder. The United Nations focused on these challenges in the Agenda 2030 that sets out the 17 Sustainable Development Goals (SDG). SDG 11 aims to "Make cities inclusive, safe, resilient and sustainable" (UN 2015). The goals have been specified with specific targets and indicators (UN 2018).

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R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_7

The literature highlights the Smart City paradigm as a possible development urban direction to pursue sustainability (Russo et al. 2014, 2016; Zhao et al. 2021; Correia et al. 2022).

Setting its long-term goals and strategies, the European Commission (EC) posed a specific focus on urban challenges, specifying the smart city paradigm based on three pillars (Fig. 1): urban energy production and consumption (energy); urban transport and mobility (transport); urban Information and Communication Technology (ICT) (EC 2012).

Urban mobility constitutes a critical factor for residents, businesses and visitors. At the same time, it implies relevant effects in terms of traffic congestion, air pollution, and related socio-economic costs, or more in general, economic, environmental and social sustainability (Batty et al. 2015). Sustainable mobility is crucial for reaching different SDGs that directly and indirectly refer to the need of more sustainable, accessible, inclusive and efficient transport and territorial interrelated systems (Akuraju et al. 2020). In this context, public transport and organized city logistics could represent a valid transport alternative because they contribute to increase sustainability in terms of improvements of traffic management performance and reduction of pollution (Campisi et al. 2023; Hickman et al. 2013).

The European Court of Auditors has analyzed the commitment of cities to increase sustainability in the urban mobility sector. The obtained results show that, while many efforts are underway to define plans [e.g. the Sustainable Urban Mobility Plan, SUMP (EC 2019)], the concrete reduction of emissions in the cities is limited (ECA 2020).

The general objective of this paper is to analyze the European process and its related products to implement the Smart City paradigm, with the integration among the three pillars. The specific objective is to verify the progress of the paradigm in the urban mobility sector. To achieve these objectives, two different approaches are used (Fig. 2):

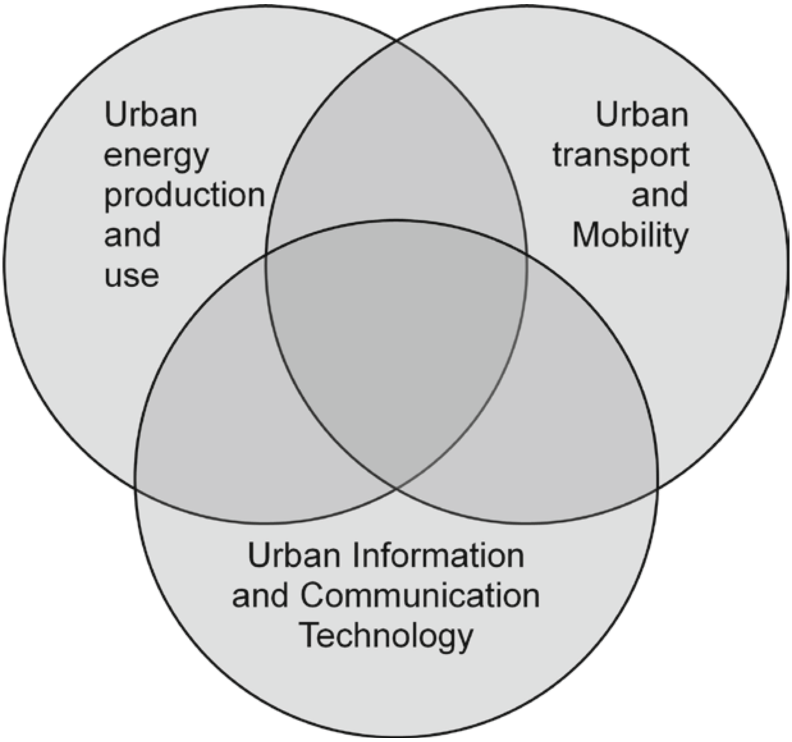


**Fig. 1** European smart city pillars (EC 2012)

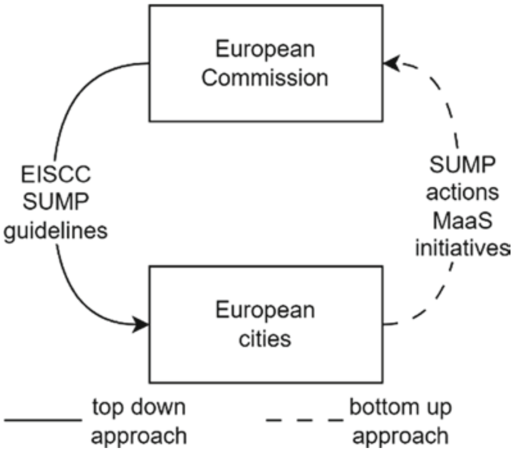


**Fig. 2** Top-down and bottom-up approaches

- top-down approach, which starts from the indications, initiatives and guidelines produced by the European Commission and ends with analysis of smart city projects implemented by the European cities (e.g., SUMP guidelines);
- bottom-up approach, starting from the initiatives implemented by European cities about sustainable urban mobility, with specific attention to the implementation of the Mobility as a Service (MaaS) paradigm, and ending with the verification of integration among the three pillars (e.g., SUMP actions).

After this introduction, the paper is organized in three sections. Sections 2 and 3 are organized according to the paper's objectives: Sect. 2 follows the top-down approach and it presents the results of a survey on the main European smart city initiatives promoted by the European Commission (EC); Sect. 3 follows the bottom-up approach and it reports the results of a survey carried out by the main European cities, by focusing on the implemented MaaS initiatives. Section 4 concludes the paper with a discussion about the obtained results and some conclusive remarks and future developments of the research.

## 2 European Smart City: Top-Down Approach

This section analyzes the European smart city initiatives following a top-down approach: starting from the European Commission indications (Sect. 2.1), the focus is on the transport pillar (Sect. 2.2) analyzing European cities that implemented these indications with specific projects (Sect. 2.3).

### 2.1 The European Commission Indications

The European Commission defined the Smart City paradigm in 2012, with a directive that introduced the three main pillars set out in the introduction (Energy, Transport and ICT) (EC 2012). The connection among the three areas depends on the advancement of meta-path regarding three main nodes (Russo et al. 2016, 2021, 2022; Russo 2021; Russo and Rindone 2023):

- theories, or science that study urban phenomena;
- rules, or laws, guidelines, and plans aimed at the regulation of urban dynamics;
- implementations, or concrete interventions that modify the actual configuration of cities.

These advancements imply the need to use new interdisciplinary approaches to address current and future challenges related to urban sustainability in its three main components: social, economic and environmental (Martin et al. 2018, 2019).

To put these advancements into practice, the European Commission has activated the European Innovation Partnership for Smart Cities and Communities (EIP-SCC), as a derivation of the Smart Growth strategy (Russo et al. 2014). This is a community that includes universities, companies and public administrations that work together to face the city challenges (Macrorie et al. 2022). One of the first documents of the EIP-SCC was the Strategic Implementation Plan (SIP), subsequently specified with the Operational Implementation Plan (OIP) (EC 2013, 2014).

Smart city European plans indicate three priority vertical areas:

- *Sustainable Districts and Urban Environments* (SDEU), connected with energy production, distribution and consumptions problems and solutions;
- *Sustainable Urban Mobility* (SUM), connected with challenges and solution for increasing people and freight sustainable mobility;
- *Integrated Infrastructures and Processes* (IIP), connected with material and immaterial infrastructures, including ICT.

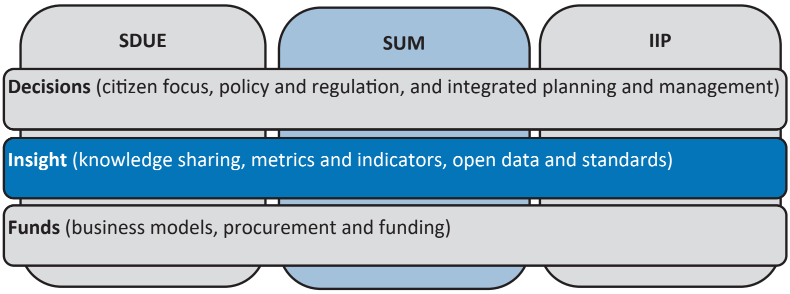
The integrations among the three priority vertical areas is reached by considering different points of view (for instance private and public). The focus is on eight aspects, grouped in three horizontal classes:

- *Decisions* (citizen focus, policy and regulation, and integrated planning and management);
- *Insight* (knowledge sharing, metrics and indicators, open data and standards);
- *Funds* (business models, procurement and funding).

When the vertical areas are developed in an integrated manner, the EIP-SCC approach becomes effective. It means that all the three priority areas are addressed simultaneously by approaches belonging to the horizontal classes. In the following, we focus on the *SUM* vertical priority area and the *Insight* horizontal class.

A schematic representation of the European Smart City framework is shown in Fig. 3, which focuses on the Sustainable Urban Mobility priority area, its action cluster, and initiatives developed by EIP-SCC.

For making operative the EIP-SCC approach operative, the common working tool is the "Marketplace of the European Innovation Partnership on Smart Cities and Communities" (M-EIP-SCC) (EC 2022a, b), a web platform that collects and groups data and information relevant to smart city development, including policies, guidelines, and implementations. The platform is the main tool for engaging, matching, and committing the main stakeholders involved on SUM vertical priority area and related issues that intersect the other two smart city pillars (Energy and ICT).



*SDUE: Sustainable Districts and Urban Environments; SUM: Sustainable Urban Mobility; IIP: Integrated Infrastructures and Processes*

**Fig. 3** European smart city framework (adapted from EC 2013). SDUE: Sustainable Districts and Urban Environments; SUM: Sustainable Urban Mobility; IIP: Integrated Infrastructures and Processes

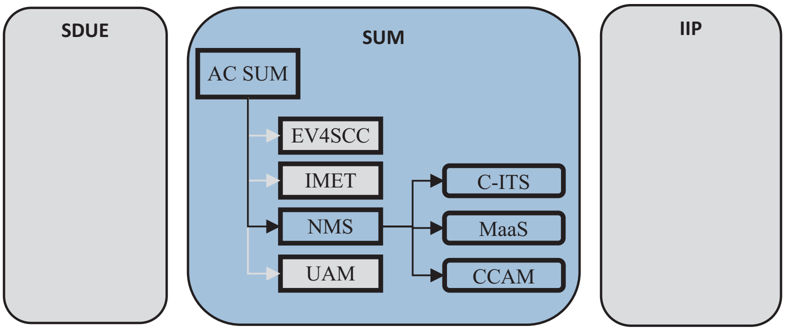
## 2.2 The Sustainable Urban Mobility Area

The SUM area regards problems and solutions for increasing sustainability of urban people and freight mobility. These issues constitute the contents of the *Action Clusters* (AC) named “Sustainable Urban Mobility” (AC SUM). The AC is an operative tool of EIP-SCC that groups different stakeholders deriving from different public and private sectors (for instance, universities, public administrations, private business operators) (EC 2023). Generally, AC members work together on specific issues related to smart cities. They share knowledge and expertise with the aim to identify gaps at national and local level that need to be filled at European level. In the specific case of urban mobility, AC SUM brings together public administrations and transport operators interested in finding mobility solutions and support their implementation in European cities. The final aim is to increase knowledge for understanding city needs and, then, the corresponding tailored solutions. The last version of the AC SUM involves 213 active members that are working on four initiatives:

- Electric Vehicles for Smart Cities and Communities (EV4SCC);
- Intelligent Mobility for Energy Transition (IMET);
- New Mobility Services (NMS);
- Urban Air Mobility (UAM).

All the initiatives developed by AC SUM work on *door-to-door multi-modal real-time urban mobility* for contributing to the increasing of sustainability and, more in general, the quality of life of citizen and competitiveness of business. By focusing on the NMS, in 2014 European Commission embedded the “New Mobility Services partnership” into AC SUM. Since 2021 the partnership involves 174 partners including public authorities, industry, researchers and citizens working for deployment and market NMS in the urban context (Fig. 4).

Cooperative Intelligent Transport Systems (C-ITS), Cooperative, Connected and Automated Mobility (CCAM) and Mobility as a Service (MaaS) are the main goals of the NMS partnership for increasing sustainability in urban mobility (EU CIVITAS 2023). One of the main challenges pertains to the transformation process from theory to European rules and best practices; among these, the recent theoretical concept of seamless mobility translated into Mobility as a Service (MaaS), which is an emerging paradigm enabled by sharing



*SDUE: Sustainable Districts and Urban Environments; SUM: Sustainable Urban Mobility; IIP: Integrated Infrastructures and Processes; AC SUM: Action Cluster Sustainable Urban Mobility; NMS: New Mobility Services; C-ITS: Cooperative Intelligent Transport Systems; CCAM: Cooperative, Connected and Automated Mobility; MaaS: Mobility as a Service*

**Fig. 4** Action cluster Sustainable Urban Mobility (SUM) and initiatives. SDUE: Sustainable Districts and Urban Environments; SUM: Sustainable Urban Mobility; IIP: Integrated Infrastructures and Processes; AC SUM: Action Cluster Sustainable Urban Mobility; NMS: New Mobility Services; C-ITS: Cooperative Intelligent Transport Systems; CCAM: Cooperative, Connected and Automated Mobility; MaaS: Mobility as a Service mobility and developments of emerging ICT (Kamargianni et al. 2016). MaaS is a user-centred form of mobility that combines information and potentialities of ICT tools, Transport System Models (TSM) inside public or private Decision Support System (DSS), with the aim of offering an alternative to unsustainable mobility, often based on the use of private cars (Matyas 2020; Vitetta 2022). MaaS represents an opportunity to promote sustainable urban mobility. Over the last few years, also thanks to the development of technologies and field experiences developed in funded projects in the smart city field, the paradigm does not only address the integration between ICT and transport but also the issue of energy resources and environmental impacts (Russo 2022; Russo and Rindone 2023).

The literature on the scientific advancements regarding the Mobility as a Service (MaaS) paradigm is the subject of Sect. 3.1.

## 2.3 European Smart City Initiatives

The M-EIP-SCC platform collects in a database the information about each EU-funded Smart Cities (EUSC) project in relation with the specific thematic fields, concerning three different territorial scales: urban area portion (energy of an urban area) or a single building (energy of a single building), either existing or new. Table 1 summarizes the smart city thematic fields present in the M-EIP-SCC platform in relation to the territorial extension.

The advancement of the European smart city process are analyzed by performing a desk survey conducted starting from the information offered by the M-EIP-SCC platform. The period considered in the investigation goes from 2012 to 2022. The projects concerning the “Mobility and transport” field were investigated. The cities involved in the projects constitute experimental sites to verify the feasibility of the smart city concept.

The total list of EUSC projects amounts to 89, involving 48 lighthouse cities and 72 fellow cities. A great part of total projects (75%) has been completed. Among the total list of projects, 18 are named “lighthouse”. Of these, 12 projects regard the thematic field “Mobility and Transport”. The total number of cities interested in the thematic field “Mobility and Transport” is 34, of which: 23 cities are working on the subthematic field “vehicle and infrastructures”; 8 cities are working on the thematic field “vehicles”; 3 are working on the thematic field “infrastructures” (Figs. 4, 5).

By considering the 48 cities involved in the 18 lighthouse projects, it is possible to identify the group of thematic fields addressed in a project. Note that the majority of cities worked on ICT, Mobility and Transport (UT) and Energy with reference to single buildings. Figure 6 depicts different sets and their intersections relative to the three pillars: Transport, Energy and ICT. The figure reports the number of projects and the corresponding involved lighthouse cities.

**Table 1** **EU-funded smart cities (EUSC) projects: thematic field and territorial extension**

| Thematic field | Territorial extension | | |
|---|---|---|---|
| | Urban area portion | Single building | |
| | | Existing | New |
| “Energy system(s) integration” | X | | |
| “Mobility and transport”—“vehicle” | X | | |
| “Mobility and transport”—“infrastructures” | X | | |
| “Information and communication technologies” | X | X | |
| “Positive energy district (PED)” | X | | |
| “Refurbished building(s)” | X | X | |
| “New building(s)” | X | | X |

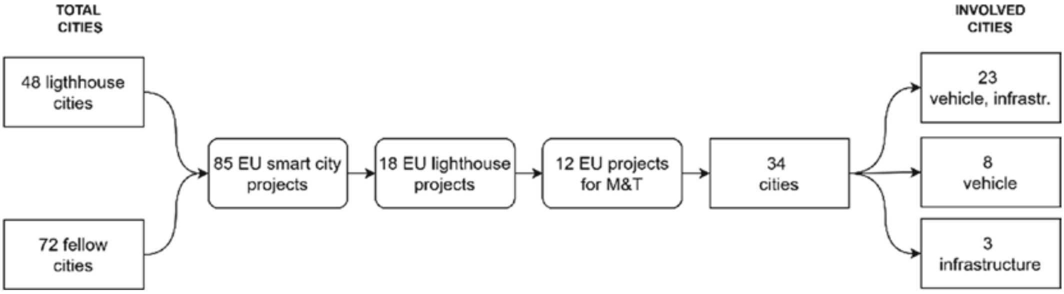


**Fig. 5** Summary of EU smart city projects and cities in mobility and transport (M&T) projects

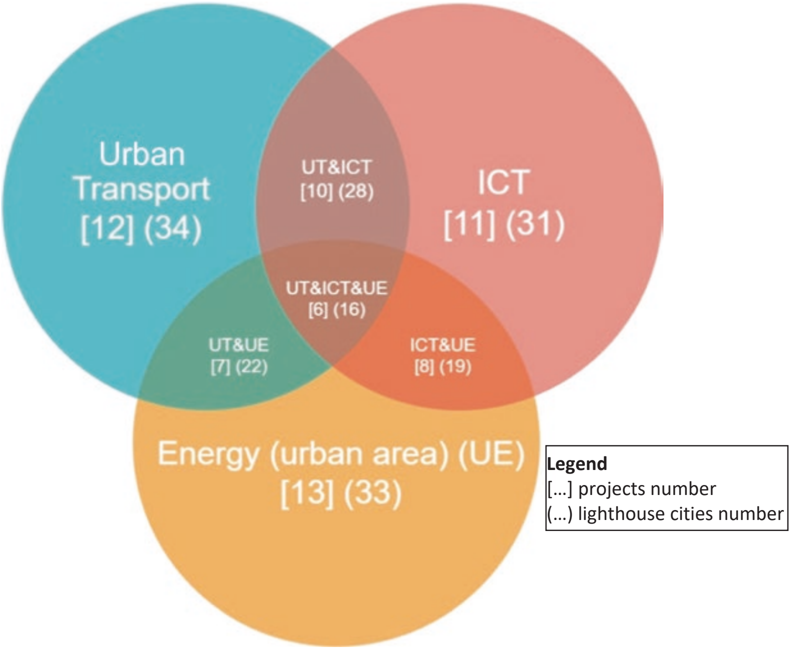


**Fig. 6** Thematic fields of smart city projects and mutual intersections (UT: Urban Transport; UE: Urban Energy)

Figure 6 shows that there is a relevant part of smart city projects that have two common pillars. The greatest overlap is recorded between ICT and transport, with 10 projects involving 28 lighthouse cities. Six smart city projects are fully compliant with the European smart city paradigm, developing all the three pillars.

## 3 European Smart City: Bottom-Up Approach

This section analyzes the European smart city initiatives following a bottom-up approach to investigate if the three pillars are used in an integrated way. The focus is on the Mobility as a Service (MaaS) paradigm (Sect. 3.1); according to the European smart city approach, MaaS interacts with the ICT and energy pillars (Sect. 3.2); some European cities are implementing the paradigm with specific initiatives that consider one or more pillars (Sect. 3.3).

## 3.1 Mobility as a Service (MaaS): Basic Paradigm

The Mobility as a Service paradigm puts into practice a set of consolidated theories about mobility (Banister 2008; Cascetta 2013; Hensher et al. 2020). MaaS moves from the traditional transport approach based on physical infrastructures, isolated operators and limited set of information, to a new concept of smart mobility in which user needs are at the center of a transport system. This is possible through the achievement of interoperability between different actors involved in the urban transport ecosystem (operators of traditional transport services, ICT operators, public administrations). Interoperability is not just about data and immaterial platforms; in order for the MaaS paradigm to become a reality, it is necessary to integrate the material transport infrastructures and services that operate on them, with ICT tools for monitoring, ticketing and payment information systems. New MaaS operators integrate data, information deriving from traditional Transport Service Providers (TSPs) and MaaS Operators (MOs) in order to supply more services as unique travel option. This implies advancements on transport design network methodologies (Musolino et al. 2022) based on user's need (Musolino 2022). The output is a transport system that integrates material and immaterial, governance, institutions and equipment supply components (Rindone 2022).

In the transport sector, the focus shifts from the physical aspects, connected with the infrastructure construction and management processes, to the management and immaterial factors. The final aim is to increase the user's perception that the different transport components (infrastructures and services) are part of an integrated transport system. Using emerging ICT technologies and the provided services (e.g., spatial and temporal, historical and real-time positioning services, mobile hardware and software), it is possible to design and implement an integrated transport system where different travel options are possible deriving from the combination of one or more transport services. The combination among ICT platforms, Internet of Things (IoT), Artificial Intelligence (AI), and blockchain, create travel options tailored on individual mobility needs (Atzori et al. 2010; Russo 2022). MaaS is thus more than a single app or technology. This is a new way of organizing transportation network in terms of infrastructures, services, management and rules for increasing travel users' benefits and social, economic and environmental sustainability or, in a more general way, the goals of Agenda 2030. In this context, the role of public administrators is to facilitate innovation processes of TSPs and MOs.

Smart urban mobility includes the following applied processes regarding the different demand components:

- People mobility and Mobility as a Service (MaaS) concept (Hensher et al. 2020);
- Freight mobility and Logistics as a Service (LaaS) (Klingebiel and Wagenitz 2013), Freight as a Service (FaaS) (Comi and Russo 2022; MIMS, 2022) and Self-Organizing Logistics (SoL) (Schroten et al. 2020; Campisi et al. 2021) concepts.

## 3.2 Mobility as a Service: Advanced Paradigm

The MaaS paradigm is evolving from a configuration, characterized by the use of ICT tools for monitoring mobility, to a more complex ecosystem where the transport system is designed with the support of Transport System Models (TSMs). The final goal is the equilibrium among all sustainability components.

People and freight mobility are observed with ICT tools that collects information about transport supply (Rindone 2022), demand (Senikidou et al. 2022; Musolino 2022) and their interactions (Vitetta 2022). Data and information feed Transport System Models (TSM) that reproduce traveler choices allowing the simulation of transport systems in current and future configurations. The evolving MaaS ecosystem integrates:

- material urban transport infrastructures and services, including 'hard' (e.g., mass urban transit) and 'soft' modes (especially walking and cycling);
- immaterial urban Information and Communication Technologies (ICT) and related services (information, ticketing and payment) for mobility;
- infrastructures for energy production, distribution (e.g., urban grid) and consumption.

The final goal is to achieve an urban sustainable transport system through successive steps of advancement on different MaaS levels (Fig. 7), corresponding to increasing levels of sustainability (Vitetta 2022; Russo 2022):

1. N-MaaS (No MaaS) features no integration because each transport mode operates in a separate way;
2. MaaS 1.0 or I-MaaS only integrates transport system with an ICT platform used by operators and users (ICT MaaS);
3. MaaS 2.0 or T-MaaS enhances MaaS 1.0 with TSM for designing and managing transport system;
4. MaaS 3.0 or S-MaaS (Sustainable, TSM and ICT MaaS) enhances MaaS 2.0 with Environmental Impact Functions (EIFs) for verifying sustainability goals and targets.

## 3.3 MaaS Initiatives in European Cities

Table 2 reports the list of the 12 smart city projects focused on the "Mobility and Transport" thematic field (see Sect. 2.3). These projects are developed by 29 lighthouse cities, out of the total 48.

A web survey has been done by the authors, to check the status of the MaaS paradigm advancements in these lighthouse cities. The survey has two objectives: (1) to verify whether the lighthouse city has launched a MaaS initiative, even at an initial stage (e.g., a pilot); (2) to verify if the initiatives integrate ICT, TSM and Energy issues.

The first objective yielded the results reported in Table 2. 69% of lighthouse cities have started a MaaS initiative.

The second objective is described by the results shown in Fig. 8. Each MaaS initiative has been classified in relation with the three smart city pillars and their mutual interactions. The figure shows the number and the percentage of the 48 lighthouse cities involved in a smart city project (see Sect. 2). The greatest share of initiatives regards only the ICT issue (18 cities, 37.5%). Some of these integrates ICT with TSM (6 cities, 12.5%) and Energy (7 cities, 14.6%)

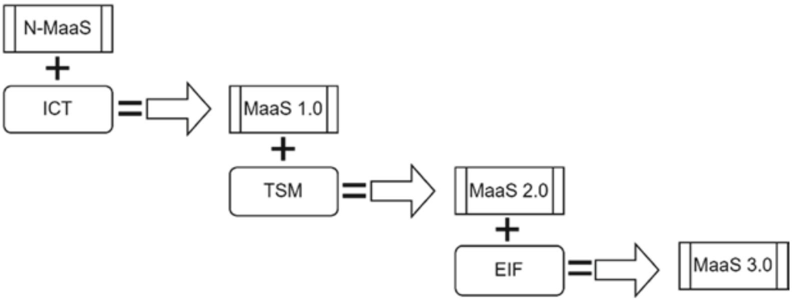


**Fig. 7** MaaS levels (TSM: Transport System Models; EIF: Environmental Impact Function)

**Table 2** MaaS initiatives in lighthouse cities

| City | Population[a] | Smart city project | MaaS initiative |
|---|---|---|---|
| Limerick, Ireland | 94,132 | +CityxChange | NA |
| Trondheim, Norway | 205,332 | +CityxChange | Yes |
| Bilbao, Spain | 1,048,966 | ATELIER | NA |
| Amsterdam, Netherlands | 2,881,048 | CITY-ZEN | Yes |
| Barcelona, Spain | 5,111,749 | GrowSmarter | Yes |
| Hamburg, Germany | 3,341,649 | mySMARTLife | Yes |
| Helsinki, Finland | 1,540,002 | mySMARTLife | Yes |
| Nantes, France | 320,732 | mySMARTLife | NA |
| Tepebasi/Eskisehir, Turkey | 305,632 | REMOURBAN | NA |
| Valladolid, Spain | 425,008 | REMOURBAN | Yes |
| Nottingham, United Kingdom | 337,100 | REMOURBAN | Yes |
| Bristol, United Kingdom | 472,400 | REPLICATE | Yes |
| Florence, Italy | 383,083 | REPLICATE | NA |
| San Sebastián, Spain | 405,089 | REPLICATE | NA |
| Glasgow, United Kingdom | 635,640 | RUGGEDISED | NA |
| Umeå, Sweden | 130,224 | RUGGEDISED | NA |
| Rotterdam, Netherlands | 1,883,116 | RUGGEDISED | Yes |
| London, United Kingdom | 9,002,488 | Sharing Cities | Yes |
| Milan, Italy | 4,985,668 | Sharing Cities | Yes |
| Lisbon, Portugal | 3,008,000 | Sharing Cities | Yes |
| Lyon, France | 2,280,845 | SMARTER TOGETHER | Yes |
| Munich, Germany | 2,927,716 | SMARTER TOGETHER | Yes |
| Vienna, Austria | 1,951,354 | SMARTER TOGETHER | Yes |
| Tampere, Finland | 334,112 | STARDUST | Yes |
| Trento, Italy | 241,386 | STARDUST | Yes |
| Pamplona, Spain | 209,672 | STARDUST | NA |
| Eindhoven, Netherlands | 767,499 | Triangulum | Yes |
| Stavanger, Norway | 237,369 | Triangulum | Yes |
| Manchester, United Kingdom | 556 | Triangulum | Yes |

*NA* information not available
[A]*Source* Eurostat 2023

issues. A limited number of initiatives integrates the three smart city pillars (4 cities, 8.3%).

The case of Helsinki is emblematic. It is the first city in the world that has experimented the MaaS paradigm. In Helsinki, the MaaS implementation produced implications for ICT tools, transport infrastructures and services, as well as for the forms of management and payment of the different transport operators. The role of the rules was decisive because it provided an impulse for all public and private actors involved in the mobility sector so that they could integrate from different points of view, starting from information. Three drivers have been fundamental for the MaaS implementation:

- the public administration commitment, which produced relevant changes in transport regulations, starting from the data and information sharing of different transport operators, and the promotion of public–private partnerships;
- the roles of ICT, essential for integrating and sharing information, TSM implemented on open source or commercial DSS (eg., google API or openstreetmap); an example is the

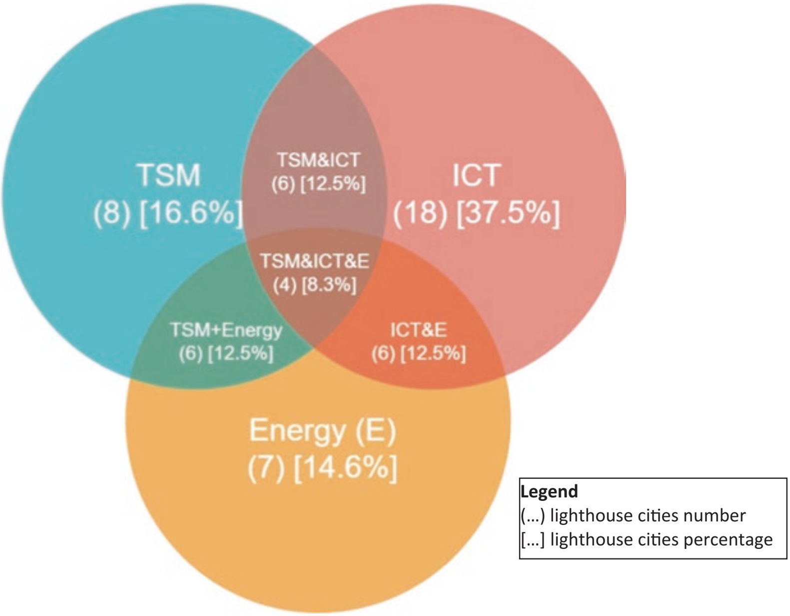


**Fig. 8** Thematic fields of MaaS initiatives and mutual intersections

  Helsinki Region Transport's platform (HSL 2023), which collects data, TSM for supporting TSPs and MOs;
- the role of transport infrastructures and services operators; with the PA commitment, they pursue:
  - physical integration among different infrastructures,
  - modal integration among individual and collective transport,
  - fare integration among financial services of single operators for bundle commerce.

Some European smart city projects are representative of mutual intersections among thematic fields. For instance, the STARDUST project proposes technical solutions implemented in the three lighthouse cities (Pamplona, Spain, Tampere, Finland, and Trento, Italy) regarding the energy, mobility and ICT sectors. A real example is the experimentation of the "e-car sharing" in the Municipality of Trento, consisting in the design and installation of charging stations for electrical vehicles used by private and public operators; among the expected impacts are the reduction of greenhouse gas emissions (about 63% less than in 2021) and energy savings (about 58% less than in 2021). Another example is the "Grow Smarter" project: the city of Barcelona experimented traffic management actions through Macroscopic Fundamental Diagram (MFD); a set of models is built for simulating effects produced by smart traffic light optimization: application of these models is expected to have positive impact in terms of reduction of traffic density and travel time, together with 15–16% reduction in $CO_2$ and $NO_x$ emissions.

# 4 Discussion and Conclusions

## 4.1 Discussion

Smart City is a paradigm for facing current and future urban challenges with the aim of improving sustainability. The European Commission is working to implement the paradigm in European cities, to pursue balanced and integrated development of transport, ICT and energy sectors. This paper investigates the level of advancement of the integration between the three pillars of the city paradigm at the European level.

Specific focus is on the urban transport smart city pillar, which interacts with the other two (ICT and energy). From the results obtained from a survey of funded smart city projects, it emerges that integration among the three smart city pillars is limited. Four European smart city projects are fully compliant with the European paradigm because they addressed all three pillars (ICT, transportation, and energy). In the smart mobility sector, this is even more apparent. The great part of the MaaS initiatives pays attention to ICT issues, but requires more attention to Transport System Models (TSM) and energy production and consumption. There are only four cities implementing the MaaS paradigm including all three European smart city pillars: Espoo, Helsinki, Manchester, Rotterdam. Note that two cities belong to the same country; this confirms the need for commitment at the national level. The final aim is improving the process of planning and designing for improved urban sustainability.

### 4.2 Conclusive Remarks

Most of the analyzed European cities have started smart city and MaaS initiatives. This confirms the attention of cities to the Smart City paradigm and the need to integrate transport with ICT and energy. There is a limited number of real experiences integrating all the sectors related with the three pillars. The main limit of this research is connected with the reliability of the database produced by EIP-SCC.

This research can have further developments following different research directions. It is possible to analyze the impact produced by smart city projects breaking it into sustainability components. Another direction concerns the state of advancement of transportation planning processes. It would be interesting to increase the knowledge about how the three pillars will be implemented in real urban contexts, in this way addressing other lines of research.

**Acknowledgements** This research was partially supported by the Dipartimento di ingegneria dell'Informazione, delle Infrastrutture e dell'Energia Sostenibile, Università Mediterranea di Reggio Calabria and by the project "La Mobilità per i passeggeri come Servizio—MyPasS", Fondi PON R&I 2014–2020 e FSC "Avviso per la presentazione di Progetti di Ricerca Industriale e Sviluppo Sperimentale nelle 12 aree di Specializzazione individuate dal PNR 2015–2020", codice identificativo ARS01_01100.

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# Emerging Information and Communication Technologies: City Logistics as a Pillar of the Smart City

Francesco Russo and Antonio Comi

## Abstract

Recently, the evolution of emerging information and communication technologies (e-ICTs) has been opening the road for developing and implementing new integrated and dynamic city logistics solutions, and subsequently for identifying new frontiers of intelligent transport systems (ITS) supporting the development of smart cities. In this context, the paper reviews the new e-ICTs, pointing out the opportunity that they are offering in implementing actions within the goals identified by the Agenda 2030.

## 1 Introduction

Urban freight flows play a key role in satisfying the users' needs. The freight produced at a given location is transported to other places for consumption, in particular within urban and metropolitan areas, where more than 50% of worldwide population lives (UN 2017). Therefore, it is critical to the life of the city and has been for the last two decades one of the main discussion themes at the international level (Russo and Comi 2004). On the other hand, urban freight transport contributes significantly to unsustainability problems in terms of pollutant emissions, congestion, as well as road accidents (Russo and Comi 2020). For example, in Europe, around 25% of $CO_2$ emissions from the transport sector come from urban transport, and a significant share of road accidents involves freight vehicles (EEA 2022). Furthermore, loading and unloading operations, if not performed properly, can significantly impact urban traffic. In fact, local conditions could push freight vehicles to stop for loading and unloading outside designated spaces, as well as to stop at junctions or along a lane, in both cases causing a road capacity reduction, with subsequent deterioration of network performances, or road accidents (Comi et al. 2022).

In recent years, there has also been growth in urban freight transport due to two reasons. With regard to the supply, the distribution and e-delivery system has become increasingly more complex due to new users' requests and the sprawl of activities to be restocked (including home deliveries). In terms of demand, the e-commerce has been growing considerably, with a large share of user purchases taking place on line (Cagliano et al. 2017; Wang et al. 2021; Castiglione et al. 2022; Meister et al. 2023;

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R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_8

Campisi et al. 2023). The interaction between these two elements led to an ever-increasing number of deliveries and light commercial vehicles in residential areas, generating important impacts on the sustainable development of cities, as well as on the economy. If the arrival of freight is delayed or unreliable, economic losses can occur: lost sales, consumer dissatisfaction, and increase of inventory costs for unsold products. The growth of e-commerce has accentuated these aspects opening new challenges for city planners and operators. In fact, the number of parcels delivered to end consumers is rising, and freight vehicles contribute significantly to congestion especially during peak hours. Couriers have to plan driving and walking routes given that many deliveries destined to end consumers are within limited-traffic areas (Thompson and Zhang 2018). Besides, local conditions could force freight vehicles to stop for loading and unloading outside designated spaces and far from final delivery places. As a result, delivery costs increase causing non-optimised deliveries (both in terms of internal and external costs).

The need therefore emerges to identify measures/actions that allow to pursue the objectives of sustainability ensuring orderly functioning of urban distribution. The objectives to be pursued can be formulated in different ways. The formalization shared internationally is that presented in the Agenda 2030 in terms of Goals (UN 2015) and in terms of targets and indicators (UN 2018). It should be noted that the Sustainable Development Goal (SDG) 11 is of primary interest in relation to city logistics, as it relates to the development of cities. The sustainable organization of the urban distribution of goods has direct impact on other goals and makes city logistics one of the important tools for pursuing sustainable development. However, the city logistics (through their metrics) impacts on three groups of SDG indicators (UN 2018), which can be evaluated by transport system modelling:

- direct impacts, i.e., SDG 3 and 11, defining as direct impacts those that derive from decisions taken only in mobility plans, by the sectors of the public administration that deal with mobility;
- indirect impacts, i.e., SDG 4, 8, 9 10, defining as indirect impacts those deriving from measures decided and implemented also in the development of plans that do not directly involve mobility, by the sectors of the public administration that *do not* deal with mobility;
- conditioned impacts, i.e., SDG 7, 13 and 17, defining as conditioned impacts those deriving from measures decided and implemented in mobility plans or industrial development plans that directly involve mobility, by sectors of the public administration at a different level than the urban one (regional, national, international), or by the private sector.

The evolution of emerging information and communication technologies (e-ICTs) opened the road for developing and implementing new integrated and dynamic city logistics solutions (Comi and Russo 2022; Taniguchi and Thompson 2018) in the context of smart city development, in which transport, and then city logistics, is one of the main pillars (Russo and Comi 2018). These e-ICTs can result in significant advancement for city logistics in all cities within all countries. They give win–win results when the same device systems are used with a cooperative approach among different stakeholders. Key functions include, for example, collecting data, storing data, and analyzing data for improving existing urban freight transport systems. Several projects have been funded within this research addresses (CINEA 2022). Since 2002, the CIVITAS initiative has been working to make sustainable and smart urban mobility a reality for all in Europe and beyond. Projects are being developed to improve many cities. Besides, data related to freight transport (e.g., vehicle tours/trip chains) are obtained analyzing global positioning system (GPS) traces, which are available on a large scale for such uses as fleet management or vehicle insurance. In fact, these GPS data, known also as floating car data (FCD), were largely used for investigating delivery tours as well as for setting up a methodology for demand forecasting (Battaglia et al. 2022; Comi et al. 2021; Romano Alho et al. 2019; Thoen et al. 2020).

The paper is organized as follows. Section 2 summarizes the e-ICTs and discusses how they impact on urban freight transport operations. It also points out the relationships between smart city and city logistics. Section 3 presents the innovations in freight delivery, analyzing pros and cons through the analysis of the results obtained from a real case study. Finally, conclusions are drawn, and the road ahead is discussed in Sect. 4.

## 2 Emerging Technologies and Freight Transport Management Systems

The e-ICTs become every day larger and more popular (Atzori et al. 2010; Knapskog and Browne 2022; Schroten et al. 2020), and focusing on those that are likely to have direct impact on city transport and logistics, we can mention:

- internet of things (IoT), it describes the set of two meta-elements, i.e., physical objects—“things”—that are embedded with sensors, software, and other technologies for the purpose of exchanging data, and a network qualified to link these objects with other devices and systems;
- big data (*BD*), although it is difficult to find a shared and universal definition, it is possible to speak of big data when the data set is so large and complex that it requires the definition of new tools and methodologies to extract, manage and process information in a reasonable time;
- block-chain (*BC*), it is defined as a chain of blocks, in which each block contains value data that are shared and validated;
- artificial intelligence (*AI*), although a large and diversified classification of AI exists, the term synthetically indicates the algorithms that, by analyzing a set of (normal or big) data, allow a decision to be made.

In particular, *IoT* and *BD* are expected to provide significant contribution to the near future of the city logistics in towards *smart* city logistics and, further on, Logistics as a Service (LaaS).

Two definitions are needed here. The first concerns the definition of *emerging technology*, because in this paper a technology is considered “emerging” with respect to the field of applications in transport and logistics. In fact, the four ICTs considered above are already “mature” in their respective fields of the original application (Schroten et al. 2020). The second, that of *advanced ICTs*, considers ICTs that are currently under development, in their respective fields of application, but which, it seems, could soon be internalized in the transport and logistics sectors. An example is the IC technology of the digital twin, which in the case study is the virtual representation of the real system of logistics services.

Supporting the optimization of delivery operations as well as of the vehicle-kms travelled, both internal and external costs can be reduced. Furthermore, referring to the different actors involved in urban freight transport and logistics (for details, see Comi and Russo (2022)), the benefits can be summarized as follows:

- *end consumers* can benefit, on one hand, as citizens, thanks to the reduction of traffic due to city logistics optimization and for the increase of livability due to the improvement of safety and the reduction of polluting emissions; on the other hand, as consumers, with the availability of new delivery services (e.g., instant deliveries, home deliveries, deliveries at pick-up points (Dablanc et al. 2017; van Duin et al. 2020; Galkin et al. 2021; Castiglione et al. 2022; Oliveira et al. 2022);
- *transport enterprises*, among the others, want to optimize the delivery travel time in terms of last-mile operations, i.e., at-customer deliveries, and their part of reverse logistics; *IoT* and *BD* allow them to use actualized and/or real-time information coming from the transport systems;

- *public administrations*, in their different levels and branches, want to improve the sustainability/livability of the city in terms of better use of public urban space (either destined to driving or to parking for loading/unloading operations) with respect to all the different demand components (i.e., passengers and freight), using different mode-services; among other roles, they can supply information on *short-term and long-term parking* and *path in real time*.

Pushed by the ICT innovations, the use of the city is changing, and different fields of knowledge are involved with their own languages (Russo et al. 2014; Russo and Rindone 2023). Referring to the directives issued by the European Union (EC 2010, 2012, 2014), the areas of interest can be defined starting from the smart growth, through innovation, technological platforms and thematic areas: energy, transport and ICTs.

From what has been briefly recalled, it emerges that smart cities are structurally ready to use what is provided by scientific innovations (Russo and Rindone 2023). In fact, this work allows to unify the advances in transport systems and e-ICTs, having the energy problem as a priority goal: both in terms of reduction in generalized cost, and of use, in the last leg of deliveries, of low- or zero-emission systems (*environmental* impact). The current developments and future directions of people-centered solutions applied to transport and logistics operators are explored (EU 2022a). In particular, the analysis evolves in order to incorporate the learning process of travel costs related to the innovations deriving from the use of e-ICTs, and to point out the benefits in terms of internal (operational) and external costs. Therefore, how the internet of things, block chain, big data and artificial intelligence can contribute to innovate freight transport management is investigated. It should be noted that the underlying vehicle-level technologies, such as automation, are out of the scope of this study.

In this context, the first stage is the identification of all components of urban freight transport, seeking to link user needs and features of the tools. The process of updating the knowledge for the user needs to be addressed, analyzing the learning process for the generic user (belonging to the *enterprise*) with the new information that can arrive from his/her experience, or from previous and present information given by the *public administration*.

Transport operators can and should have technological solutions to improve the sustainability and efficiency of their urban freight transport operations as required both by international and local authorities. Solutions based on e-ICTs can reduce the number of kilometers travelled in urban areas, increasing safety, reducing environmental impact, and congestion. Besides, vehicle technological solutions (e.g., airbag systems, or the adaptive braking systems—ABS, traction control System—TCS) do not change the number of truck-kilometers, although they increase safety. On the other hand, automation and, in particular, the connected cooperative automated mobility (CCAM) can open new challenges in city logistics (Schroten et al. 2020), as shown below.

As said above, the main objective of the freight transport management systems is to link user needs and features of the tools. In particular, the problem arises of the modification of knowledge for the user, and it becomes crucial to analyze the learning process for the generic user (belonging to the *enterprise*) with the new information that may arrive from his/her experience, from previous and present information given by the public administration. Then, the focus is on vehicle paths, vehicle routing and scheduling, and on courier routes. Subsequently, the models developed for providing three level of integration are analyzed:

- proactive and tailored-user path advice, i.e., smart routing—*navigation systems*,
- support in defining tour/trip chain for sustainable urban delivery, i.e., *computerized vehicle routing and scheduling*,
- support to couriers in defining routes within inner areas, i.e., *strong access restrictions*.

Among the ICT-based solutions, navigation, computerized vehicle routing and scheduling (CVRS) systems allow couriers to identify optimized routes. Navigation and CVRS systems provide specific route guidance exploiting the information about traffic regulations (e.g., road works, lane directions) as well as distance/time from the final destination. They can determine the best routes among destinations (customers to serve) according to the average configuration of the road network and walking tours. The new generation of navigation and CVRS systems implement the *smart routing* paradigm (proactive and tailored-user advices).

*Proactive* implies that the information is designed in order to preferably anticipate congestion and to address the behavioral choices of road users (de Moraes Ramos et al. 2020; Russo and Comi 2022). Then, to make optimal route choices, information about the traffic situation at the moment of departure is often not helpful. This is because it takes time to drive to the point where a route choice becomes relevant. At that point in time, the traffic situation could be changed. Hence, a prediction of the traffic situation is much smarter. This prediction can even include weather forecasts. Then, smart routing provides individual truck drivers with travel advice that is tailored to their personal preferences and refined based on the previous travel advice.

The CVRSs exploit the potential offered by merging objectives of assigning customers (pick-up and delivery locations) to trucks and determining the visiting order of customers and routes. Vehicle routing and scheduling have attracted considerable attention, but only recently has the research moved forward to include, in the definition of the problem, information on real-time network status, or even a large amount of information on the previous states of all the arcs/links of the network, both used and not used by the driver in his/her past delivery tours (Danchuk et al. 2023; Horn 2006; Musolino et al. 2018; Salehi Sarbijan and Behnamian 2023; Lin and Cai 2008).

In the context of these freight transport management issues, e-ICTs impact both on path choice (Di Gangi and Polimeni 2022) to move among the intermediate customers (e.g., retailers or end consumers), and on delivery-bay choice (short and long time) to serve customers. In particular, *IoT* and *BD* can be considered the main emerging technologies impacting on path choice between two intermediate stops/delivery/customers (updating both of the path utility and of the choice model), even if *AI* could develop advanced algorithms for better use of the opportunity offered by real-time information (e.g., updating the choice of path and suggesting the new one). On the other hand, *BC* allows to manage exchanges of values and protected/reserved data of the delivery (in this way, it is also called internet of values—*IoV*), while *AI* supports the route choice decisions. Few works integrate the learning process of path/travel costs enhanced by e-ICTs, opening the road to future research challenges.

## 3 Merging Past and Real-Time Information

Urban freight distribution concerns the pick-up and delivery of freight using a fleet of trucks. As a rule, vehicles are based in a single depot (warehouse), and the vehicle tours are performed in a single work shift and may include several pick-up and delivery points. The basic information needed is: the location of depots, the location of customers, road network conditions, travel times, traffic regulations, etc. In addition to this basic information, other specific information for each customer, including the daily request for carrying out goods, the designed time windows, designated driver, is given to identify the optimal visiting order and the route for each vehicle. The problem is to find the optimal route (visiting order of customers) that has the minimum total travel cost. Therefore, the delivery problem is formulated as a traveling salesman problem (TSP) and its evolution guided by the e-ICTs is hence formulated as follows:

$$\text{Minimize}Z\left[\tau,\tilde{t}\right] = \sum_{i=1}^{n}\sum_{j=1}^{n} C_{ij}\left[\tau,\tilde{t}\right]\cdot x_{ij} \qquad (1)$$

subjected to some network and service constraints (for details refer to Crainic and Laporte (1997)), and where $C_{ij}$ is the cost of path from customer $i$ to customer $j$ on time $\tau$ of day $\tilde{t}$, $n$ are the customers to serve, $x_{ij}$ is the decision binary variable. For more details refer to (Ghiani et al. 2013; Franceschetti et al. 2017; Comi and Russo 2022).

In brief, the solution of Eq. 1 determines a set of routes that starts and ends at the depot, each one performed by a single vehicle in a way that minimizes the global transportation cost and fulfils the demands of the customers and operational constraints.

In particular, referring to the general problem summarized in Eq. 1, e-ICTs impact on path cost merging the past and current info from the network, which is defined as *learning process of costs*. The complete specification of the costs, by which users consider their choice at time $\tau$ of period/day $t$, requires explicit treatment of the learning mechanism of path cost (*disutility* or utility) attributes ($X$) or, in other words, how experience and information about attributes of path costs on previous days influence the forecast of the current ones. Therefore, the inter-period and the intra-period dynamic processes need to be considered, and subsequently two aspects have to be taken into account:

- the users' *learning* and forecasting mechanism (utility updating model);
- the users' *choice* behavior (choice updating model).

The contributions of *BD* and *IoT* to modify the utility updating model are explained in the next sub-section 3.1, while in the next one 3.2 an example is presented.

## 3.1 The Role of E-ICTs

Let

- $\boldsymbol{C}$ be the vector of path costs for users of Origin–Destination pair *od*, consisting of elements $C_k$, $k \in K_{od}$ (path choice set on O-D pair *od*);
- $\boldsymbol{X}$ be the vector of path attributes for users of O-D pair *od*, consisting of elements $\boldsymbol{X}_k$, $k \in K_{od}$ (path choice set on O-D pair *od*).

The cost of path $k$ can be expressed as the sum of additive ($C_k^{ADD}$) and non-additive ($C_k^{NA}$) components:

$$C_k = C_k^{ADD} + C_k^{NA} \tag{2}$$

Some path costs are likewise *additive*; that is, their path value can be obtained as the sum of link values for all links making up the path. Examples of additive path costs are travel times (the total travel time of a path is the sum of travel times over individual links), or some monetary costs, which can be associated with some or all individual links. Therefore, the additive costs can be expressed as combination of $h$-th attributes of path k ($X_{hk}^{ADD}$, e.g., travel time, monetary cost) through the parameter $\beta_h$:

$$C_k^{ADD} = \sum_b \beta_h \cdot X_{hk}^{ADD} \tag{3}$$

Other path performance variables are non-additive; that is, they cannot be obtained as the sum of link-specific values. Examples of non-additive costs are monetary cost in the case of tolls that are non-linearly proportional to the distance covered or the rest time for long commercial trips (e.g., a 45 min stop after 4 and a half hours of travel, or waiting time at stops for high-frequency transit systems).

Therefore, merging Eqs. 2 and 3, the paths on time $\tau$ of day $t$ can be expressed as a function of path attributes depending on time $\tau$ of day $t$, as follows:

$$\boldsymbol{C}[\tau,t] = \psi(\boldsymbol{X}[\tau,t]) = \psi(\boldsymbol{X}[\tau],\boldsymbol{X}[t-1],\boldsymbol{X}[t-2],\ldots) \tag{4}$$

Path attributes, $\boldsymbol{X}$, can be estimated by users according to a learning process.

Learning occurs both with the evolution of $\tau$ (time of the day) and the evolution of $t$ (generic day):

- for some attributes, the value experienced (tested) in previous periods $\boldsymbol{X}[t\text{-}1]$, $\boldsymbol{X}[t\text{-}2]$, which can be obtained by means of the information stored on *BD*;

- for other attributes, the updating that users perform for each time $\tau$ in day $t$, which represents a real-time network configuration obtained through *IoT* (e.g., real-time vehicle sensors).

Therefore, the contribution of e-ICTs determines the modifications of the generalized travel costs from static to dynamic:

- within-day changes that are achieved with the use of *IoT* (intra-period process);
- day-to-day changes that are obtained with the use of *BD* (inter-period process).

Focusing on the inter-period process, the knowledge coming from *BD* (i.e., data collected in the previous days) can be formulated, using an exponential forecasting filter, as follows:

$$X_{h,ij}^{BD,fo}[t] = \gamma \cdot X_{h,ij}^{BD,\exp}[t-1] + (1-\gamma) \cdot X_{h,ij}^{BD,fo}[t-1] \quad (5)$$

where

- $\gamma$ ($\in ]0, 1]$) is the weight given to the experienced/tested value;
- $X_{h,ij}^{BD,\exp}[t-1]$ is the value of attribute $h$ of path $k$ experienced/tested on day *t-1*;
- $X_{h,ij}^{BD,fo}[t-1]$ is the value of attribute $h$ of path $k$ forecasted/computed on day *t-1*.

The exponential filter of Eq. 5 allows to update the path costs taking into consideration the previous experience of the user and its current forecast. Besides, according to its specification, the past experience weights less as time passes, i.e., the user tends to forget the old experiences.

Finally, the forecast value of $h$-th path attribute at time $\tau$ of day $\bar{t}$, $X_{h,ij}^{fo}\left[\tau, \bar{t}\right]$, can be obtained combining *BD* and *IoT* info as follows:

$$X_{hk}^{fo}\left[\tau,\ \bar{t}\right] = \xi \cdot X_{hk}^{BD,fo}\left[\tau,\ \bar{t}\right] + (1-\xi) \cdot X_{hk}^{IoT}\left[\tau,\ \bar{t}\right] \quad (6)$$

where

- $X_{hk}^{BD,fo}\left[\tau,\ \bar{t}\right]$ is the value of attribute $X_{hk}$ without real-time info, given by *BD* at time $t$ of day $\bar{t}$;
- $X_{hk}^{IoT}\left[\tau,\ \bar{t}\right]$ is the value of attribute $X_{hk}$ realised at $\tau$ of the current day $\bar{t}$;
- $\xi$ ($\in ]0, 1]$) is the weight given to the forecasted value without real-time info given by *IoT* at time $\tau$ of current day $\bar{t}$.

Equation 6 models the user's behavior to combine the past experience represented by the stored information (*BD*) with the current one, coming from *IoT*. This combination considers different user-attributed weights for the two types of information by means of the parameter $\xi$.

## 3.2 Example of Sustainable Urban Delivery

To show the opportunities offered by this approach, a case study is recalled here (Russo and Comi 2021). The proposed planning framework was applied to a case study in Rome. It is assumed that an operator has to serve 10 customers during a working day. For avoiding overlapping, attention is paid to the customer sequence, and only *travel time* is considered as a path attribute ($X$ = path travel time). The results are summarized in Table 1. The first column shows the truck departure time from the depot (*D*), and from each customer (*1*, …*10*). The second column gives the ordered list of customers to be served after the current visit. The third and the fourth columns contain the driving time and the working time (which consists of driving time plus the time spent at customer sites for delivery) of the optimal tour identified in the second column. Finally, the last two columns give the variations of driving and working times offered by the best order list of customers to serve, calculated at the end of the current customer visit

**Table 1** Sequence of customer visits through average and real-time travel time merging ($\xi = 0.70$)

| Departure time | Order of customer visits | | | | | | | | | | | | Driving time (hh:mm:ss) | Working time (hh:mm:ss) | Δ driving time (%) | Δ working time (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Average* | *D* | *4* | *7* | *8* | *10* | *9* | *2* | *1* | *6* | *3* | *5* | *D* | *02:28:45* | *05:08:45* | | |
| 09:30 | D | 2 | 1 | 6 | 3 | 5 | 4 | 7 | 9 | 10 | 8 | D | 02:34:00 | 05:14:00 | 3.53 | 1.70 |
| 10:15 | 2 | 3 | 1 | 7 | 4 | 6 | 5 | 8 | 9 | 10 | D | | 02:04:08 | 04:44:08 | −16.55 | −7.97 |
| 10:53 | 3 | 6 | 1 | 5 | 4 | 7 | 8 | 9 | 10 | D | | | 01:55:01 | 04:35:01 | −22.68 | −10.93 |
| 11:17 | 6 | 1 | 5 | 4 | 7 | 8 | 9 | 10 | D | | | | 02:17:51 | 04:57:51 | −7.33 | −3.53 |
| 11:38 | 1 | 4 | 5 | 7 | 8 | 9 | 10 | D | | | | | 02:01:17 | 04:41:17 | −18.47 | −8.90 |
| 12:03 | 4 | 5 | 7 | 8 | 9 | 10 | D | | | | | | 02:04:53 | 04:44:53 | −16.05 | −7.73 |
| … | | | | | | | | | | | | | | | | |

*Source* Russo and Comi (2021)

with respect to the average one (i.e., that calculated using the average configuration of the network).

Focusing on the point of view of transport and logistics operators, the proposed approach allows significant reduction of operational time (*economic* sustainability; about 20%). Besides, shorter paths for serving the same set of customers allows significant reduction of the impact on other network performance indicators (e.g., congestion, pollutant emission and interference with other road users) with significant benefit in terms of environmental and social sustainability.

## 4 Conclusions and the Road Ahead

The work carried out allowed to reach some conclusions, starting from the consideration that the areas of further development interest the following three thematic areas in the smart city field: energy, transport and ICTs.

Considering urban *transport* and mobility, it should be noted that the common tools were designed to solve the single-source shortest path problem for a static network, then guided by the needs to find the shortest path in stochastic and congested networks, considering dynamic situations, several advancements can be identified:

- smart advisors (navigation), i.e.,
  - stochastic network, i.e., the actual link travel times may differ from historical or forecasted one, and the outcome of any decision depends partly on the user's decisions and partly on randomness; the future research challenge is to move from applications using historical data for characterizing the road performances towards those developed for providing dynamic time-dependent advice, and towards those that take into consideration drivers' attitudes and updated choices;
  - optimal travel strategy-based advices; the newest tool should introduce uncertainty into minimum path/tour/route searching and new ways to suggest advice (e.g., travel strategy);
  - list of minimum paths, i.e., the new challenge is the generation of a set of paths not limited to the shortest one, i.e., not only the first best, but also the second best, etc., up to the *g-th* best, until obtaining a set of specific paths;
- from CVRSs to courier delivery problem: couriers, when planning deliveries to citizens as well as to business users (including retailers), need to consider both driving and walking routes (i.e., from delivery bay to customers) to optimize their activities; therefore, there is the need to determine the best delivery bay which allow to minimize the delivery route (*times*) considering dynamic slot openings and taking into consideration that couriers often serve multiple customers from the same delivery bays; the evolution should cover the following challenges, i.e.,
  - to identify the set of preferred delivery zones (*IoT* provides info on their availability);
  - to estimate route costs (disutility/utility; *BD*);
  - to identify the optimal driving and walking route to the customers merging real-time and past costs to forecast the route costs (*AI*);

Besides, the value exchanges can be managed as well as more comprehensive track-and-trace capabilities can be provided (*BC*).

The evolution of what was proposed pushes towards a further advanced level providing, i.e.,

- the formal unitary treatment of the inclusion of e-ICT in the traveling salesman problem (TSP; i.e., routing);
- the opportunity to design a multilevel delivery path (tour) with nodes (points) where walking for reaching the final customers (e.g., retailers or end consumers' homes) is introduced (i.e., courier problem);
- the choice behavior of users (i.e., choice updating model);

- the conditions relating to the search for the solution when different dynamic filters other than the exponential are present;
- double dynamic assignment process.

More generally, it is worth noting that, if the formalization proposed with Eq. (1) is valid in the study of systems from the point of view of the courier/carrier, it is necessary to develop dynamic models that instead consider the point of view of the planner—public administration—(Nuzzolo and Comi 2014), which must know the set of decisions taken by all the courier/carriers, and therefore necessarily introduces additional probability conditions with respect to those previously presented, and here due only to carrier's (courier) uncertainties. In addition, the introduced learning process of path costs can be extended including a further advanced level, providing the opportunity to design a multilevel delivery path (tour) with nodes (points) where walking for reaching the final customers (e.g., retailers or end consumers' homes) is introduced.

Focusing on the opportunity offered by *ICTs*, it emerges that the future developments should exploit collaboration among freight operators and public administration to improve the information available on specific attributes (e.g., the public administration can offer information services on the travel time on the road network that can be used by operators for optimizing their operations). It is the public administration (PA), owner of the intelligent objects, that can organize an $IoT^{PA}$ with other operators for collecting the data, and handle them with a big data ($BD^{PA}$) approach. Besides, city logistics services should be included into the NASs (national access points) (EU 2022b).

Companies can offer new services to customers thanks to the *BC*. For example, they can use information to provide proof of legitimacy or authenticity, and consumers can benefit knowing whether a product has been ethically sourced, is an original item, and was preserved under the right conditions. Besides, very relevant is the contribution on contracts as well as the sharing of data among stakeholders (transport and logistics operators, and retailers) for optimizing deliveries. Smart contracts in *BC* are an important function that is designed to automatically facilitate, verify and enforce the negotiation. This allows the implementation of digital contracts without any central authority.

ICTs can address the development of support systems for making decisions in delivering (*AI*). For example, further challenges refer to the modelling of the choice mechanism and to the use of the sequential choice approach, given that users can update their utility to modify the path costs. For example, when a path $k$ is chosen, and during the travel the user is informed that another path has become attractive (e.g., along the path $k$ there is a road accident or a specific event and the traffic is delayed), the user can update his/her utility in an intelligent *en-route* way.

Furthermore, a unified platform is needed to share technologies with the aim at building the logistics community system—LCS, evolving from Port Community System. A further advancement regards the possibility to organize an integrated software-hardware system, a *digital twin*, where the methods for planning and those for assessing the general Product as a Service business models will be tested for city logistics. The digital twin will be the virtual twin of the real LCS.

Currently used in the city, the optimization approach is devoted to consider each "final" impact and then to introduce measures to limit the impact. A new approach should be developed, which considers the overall urban system with a unified view. Production cycles can be revised by improving their environmental impacts through the management of the energy cycles and the management of the transport and logistics cycle. Examples are: self-production in the city village (wind, photoelectric, solar thermal energy), energy efficiency (storage batteries, grid optimization), energy consumption, digitization of processes. Also, in the context of the *energy* challenge, there is the big theme of the efficiency of propulsion and automation.

Finally, the next research frontier is represented by autonomous deliveries, e.g.

autonomous delivery robots (ADR). ADRs are electric-powered motorized vehicles that can deliver items or packages to customers without the intervention of a delivery person. ADRs can be divided into two types (Arntz et al. 2023; Figliozzi and Jennings 2020; Yuen et al. 2022): sidewalk autonomous delivery robots (SADRs), which are pedestrian sized robots that only utilize sidewalks or pedestrian paths; on-road or simply road autonomous delivery robots (RADRs), which are vehicles that travel on roadways shared with conventional motorized vehicles.

Despite the benefits of using ADRs, challenges also impede adoption and acceptance of ADRs:

- end consumers' point of view
  - ADRs may be perceived as less convenient,
  - consumers who are less technologically inclined may experience technical difficulties with ADRs;
- operators' point of view
  - the need for barrier-free infrastructure,
  - the need for proper regulations,
  - theft prevention mechanisms.

The interest in the non-military use of drones has increased dramatically with successful operations in the delivery of medicine, food, and mail orders (Goodchild and Toy 2018). Focus has been heavily placed on the *economic* and *social* impacts:

- companies anticipate a reduction in transportation costs,
- concerns exist regarding individual privacy rights, and airspace congestion.

However, environmental impacts are highly dependent on the energy requirements of the drone, as well as the distance it must travel and the number of recipients it serves. Drones are likely to provide a $CO_2$ benefit when service zones are close to the depot, have small numbers of stops, or both.

To gain insight into the practical opportunities offered by e-ICTs, or advanced ITSs, and its impact on generalized path costs analyzed in the earlier sections, the following analyses can be considered. For example, the route advisors can evolve moving from those that use historical data to characterize the road performance to those developed for providing dynamic time-dependent advice, passing through those that take into consideration drivers' attitudes. Historical data-based methods analyze historical information in order to extract information about the road network and provide more robust route advice. Historical traffic information can be analyzed with the aim at computing traffic-tolerant paths over time-dependent road networks. Other historical data-based methods analyze and mine trajectory data in order to extract popular routes, given that drivers usually choose routes according to their direct experience and/or their knowledge about traffic. By mining such data, more robust route recommendation can be provided. This work is important for the technicians of companies that can combine information coming from different sources, obtaining the best results for freight delivery. The work is useful both for e-ICT researchers, because it allows one to identify how and where e-ICTs are used in the transportation field, and for transport researchers, because it allows them to define the field of the use of the different e-ICTs, and then to proceed in modelling. However, this modelling framework stresses the interoperability among different fields of knowledge and opens new challenges in the direction of multi-disciplinarity.

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# E-grocery and ICT: Connection and Its Influence in Making the Sicilian Cities Smart

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## Abstract

E-commerce is a new digital and business transaction channel that refers to the sale of items, including daily groceries, i.e., food and beverages, through web-based digital shops. Its rapid growth is also strongly facilitating the development of smart cities while taking advantages of ICT infrastructure and evolving transportation. The recent pandemic and related travel-related restrictions have stimulated the spread and vigorous use of online-based channels, influencing behavioral choices and travel frequencies. The increased diffusion of technology and greater exemplification of digital platforms has helped attract more users predisposed to use e-grocery. There is no doubt that passenger and freight mobility is one of the key issues for integrated planning in urban areas. Therefore, the growth of e-commerce and home delivery is likely to affect the structure and performance of the urban supply chain: the development of smart cities will have to consider last-mile distribution issues with those related to food perishability, influencing the success and profitability of e-commerce companies while assessing which parts of the city may be most "attracted" to online shopping by defining factors and relationships among them. This paper focuses on the evaluation of smart city planning and evolution strategies in the context of Sicily, Italy. Particular attention was paid to residents of the Sicilian hinterland area with critical focuses on infrastructure and transportation services. To have a better understanding of the operation of e-grocery in Sicily, a virtual "snowball sampling" survey was conducted considering users who live in different areas of the island and have the experience of using e-commerce for groceries. This study brought out a number of considerations that can improve and make last-mile distribution more sustainable taking into account the location type (i.e., historic centre, expansion areas and suburbs), consumer behavior and preferences. The data were analysed and processed through descriptive statistical analysis. The results not only highlight the important growth of e-commerce for groceries in Sicily with reference to specific categories, but also pave out the foundation for improvement of planning by allowing the implementation of

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R. Menozzi (ed.), *Information and Communications Technologies for Smart Cities and Societies*,
The City Project 5, https://doi.org/10.1007/978-3-031-39446-1_9

strategies that are based on better interactions between urban space, consumption and flow management of goods to help create smarter and more liveable cities.

## 1 Introduction

The recent pandemic has promoted the use of various technological positives to perform a variety of daily activities such as working, taking classes and buying products [1–3]. The spread of such online activities has changed the travel habits of many users in different parts of the world [4]. In agreement with [5], it is possible to state that in the twenty-first century, where everyone is connected through digital technologies, information and communication technologies (ICT) play a key role in improving healthcare for individuals and wider communities. At present, ICTs are applied in a myriad of areas, demonstrating their importance as a major technological breakthrough for their potential in relieving burden on systems, such as healthcare or academia.

The growing fear and anxiety for travelling, together with the exemplification of web pages and purchasing processes as well as the convenience of receiving them at home have ushered the use of e-commerce [6–10]. A study conducted by [11] shows how the different types of online shopping have evolved in the 28 EU countries, also defining the various types of products most frequently purchased.

While on the one hand, the demand for transport has changed, on the other hand, the need for better appraisal of the criticalities of last-mile delivery and make it greener and more efficient is increasingly emerging. During the last 5 years, about 10,000 new e-commerce sites in Italy have been registered by Unioncamere [12], totalling to an amount of 23,386 registrations as of March 2020. The top 5 regions by number of e-commerce sites are, in order:

- Lombardy (4406)
- Campania (3084)
- Lazio (2762)
- Emilia Romagna (1694)
- Veneto (1620).

In the regions of Northern Italy, where almost half of the Italian population resides, there are more than 62% of people looking for online shopping services, and almost 52% of those inclined to food delivery. These regions are now the most urbanized and have the largest spread of large retail chains (large organised distribution) where food delivery platforms are most prevalent. In Central Italy, on the other hand, only 23% of the population shops online, while food delivery registers at 25%. In Southern Italy, by contrast, slower trends are recorded, with Sicily taking the second place after Campania with 3% of online orders and 5.5% of interest in food delivery. In Sardinia and the rest of the South, the figures for online shopping and food delivery are less than 1% as in Sardinia or Basilicata, for example. Figure 1 summarizes the use of e-commerce, shopping online and food delivery in Italy's four geographical areas.

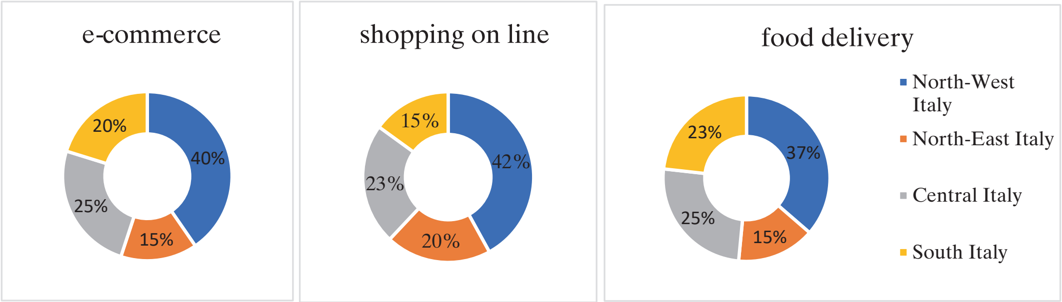

**Fig. 1** E-commerce, shopping online and food delivery distribution in the main geographical areas of Italy

The causes of this quantitative disparity among regions can be found in different commercial structure and the catering industry's preference for delivery modes managed independently by the individual restaurant, but also in a different penetration of the COVID-19 epidemic [13]. It can be assumed that in dramatically affected areas such as Veneto, Lombardy and Emilia-Romagna, consumers were more inclined to avoid leaving home as much as possible, whereas where the lockdown was perceived more as a precautionary measure, the weekly shopping or the pickup of a take-away pizza were considered as activities linked to habitual daily routine. In contrast, the geographical distribution of users interested in e-commerce is broadly similar to that of the population as shown in Fig. 2.

The online Food and Grocery sector can be analysed through a number of parameters such as.

- Penetration rate on total purchases (online and offline): it reached 1.6% in 2020, gaining half a percentage point compared to 2019;
- Value of the average receipt: the value is €64, which was around €50 in 2019;
- Number of orders: over 39 million orders were filled (+21% compared to 2019).

Another element to highlight for the online food market concerns the growth of purchases from smartphones (+68%), which prove to be the main purchasing channel with a share of 59% of the sector and purchases approaching €1.5 billion [14].

As mentioned before, the pandemic had the effect of relaunching and/or creating habits, from Internet shopping to catering, favoring the start-up and strengthening of initiatives that have promoted the consolidation of interesting projects in the food and wine sector, the development of innovative services and the rapid expansion of the ready meals segment. There are three main reasons for the preference of digital over traditional purchasing methods: convenience, price comparability and choice variety [15, 16]. In the grocery sector (which includes food and beverages, personal care and household products), the possibility to have home delivery, to easily compare prices of different brands and stores and to access a wider assortment are the main advantages highlighted by online shoppers.

In choosing the e-commerce site to shop with, elements relating to price competitiveness and service conditions, reliability and browsing experience are particularly important. Product delivery policies also play a significant role. If the convenience of shipping costs is the first factor to consider when choosing an e-commerce site, excessive delivery costs lead to its immediate abandonment. Poor site reliability and prices may also lead to the discontinuation of the purchasing process for one in two buyers [17–19].

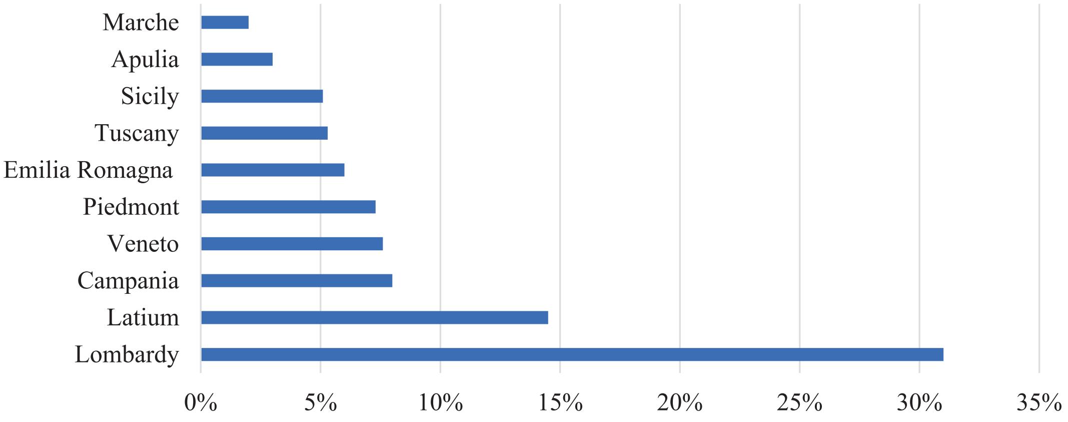

**Fig. 2** 10 Italian regions most affected by e-commerce

The development of e-commerce related to the food sector covers a good percentage of the entire B2C (business to consumer) e-commerce in Italy. This is due to both the direct and indirect effect in the other product sectors, increasing the maturity, trust and awareness of the online buyer [20]. The e-commerce sector is closely linked to the ICT sector. In fact, consider the fact that various e-commerce platforms and services are developed through information technologies that are now widely used in social, commercial and economic contexts all over the world. An improvement of these services requires an upstream evaluation of the study areas by analysing the habits, frequencies, but also the socio-economic details of a reality such as that on a regional scale [21]. A number of studies use customer data to optimize the home delivery of electronic food products with the aim of improving the delivery success rate and optimizing transport [22].

This paper aims to define a first step of a regional scale survey related to the propensity to use e-grocery services in relation to spatial and socio-demographic characteristics of a sample of users analyzed through the chain sampling method. After a brief description of the evolution of the development of e-commerce and e-grocery in Italy, the focus is placed on the regional scale of Sicily by defining a sample of users who were subjected to the administration of a questionnaire that investigated 4 different types of variables. The results provide an initial overview of the aforementioned regional context by providing the basis for the improvement of e-commerce and ICT services and thus, facilitate the definition of strategies for the implementation of smart city models [23–28].

## 1.1 The Spread of Food E-Commerce in Italy

Food and Grocery includes several product types: both food and non-food. The main component of food grocery (about 87%) includes several product categories: fresh, dry, spirits, beverages and frozen. The remaining 13% is associated with personal and household care products (i.e., health and care) sold through online platforms of supermarkets or branded industries. Grocery, in turn, can be divided into three main segments, namely:

- Grocery Food i.e., online supermarket shopping. Among the main factors that have increased this sector is the saving of time and, in many cases, money [29, 30].
- Food and beverage (in Italian called *enogastronomia*) i.e., the purchase of quality wine and typical products. This segment encompasses all online purchases of ‘niche’ food and alcohol products, usually not present in the supermarket offer [31].
- Online catering, i.e., the purchase of ready meals at home. As with shopping from home, home delivery of ready-to-eat food is a sector which is gradually spreading—not only in the most densely populated cities, but also in smaller towns in order to reach an increasing number of potential customers [32].

In terms of geographic coverage, 73% of the Italian population can shop online from a supermarket, although there are some discrepancies between different geographic areas. In fact, while online supermarket shopping services are available in 2020 not only in the regions that are historically covered better (e.g., Lombardy, Lazio, Piedmont), but also in the less served areas, e.g., Abruzzo, Liguria, Sicily, online grocery is clearly less accessible in areas with a lower population density. Moreover, the number of such initiatives decreases drastically as one travels Italy from North to South. On the other hand, before the pandemic, Food and beverage used to be the most mature segment online with an offer capable of reaching a national territorial coverage.

In the case of Grocery Food, there is provincial coverage throughout the territory, although only slightly more than 67% of the inhabitants actually have potential access to these services.

## 1.2 Latest Advancement in the Literature and Takeaways

Starting from the hypothesis that e-grocery is a new emerging commercial channel for the food and beverage market and considering that it combines last-mile distribution issues and those related to perishability of food, it is critical to analyze how this success can be influenced by user demand. It should also be emphasized that the local food supply chain concerns the local production and delivery of food products to consumers in a more economically and environmentally efficient way, but remains a less explored activity. A number of studies have considered this supply chain in conjunction with possible innovative solutions based on ICT and mobile applications [33, 34]. Italy is considered as a reference case, a country among the main world economies with a high level of income and developed industry. However, in Italy there is not much literature about e-grocery. Oncini et al. [35] carried out an experiential classification of food provisioning services and discussed the implications of the growth of the food market. Rontini [36] carried out a national analysis of the changes in the e-grocery induced by new technologies and by COVID-19. Siragusa and Tumino [37] discussed the environmental impact of e-grocery and the traditional food sector looking at the entire supply chain. Aspects regarding purchasing preferences were studied by Maltese et al. [38], who investigated preferences in the e-grocery sector in Rome and Milan through a questionnaire survey. This paper intends to place itself in the same context, the study of purchasing habits on e-groceries, specifying the problem in a different territorial domain. It focuses on the creation and administration of an online questionnaire for the analysis of e-grocery trends in the Sicilian region. We decided to study the Sicilian case due to the specificities of the region. it is among the least developed in Italy, has a context with few large cities, mainly Palermo and Catania, and many small and medium-sized towns. Also, this paper sheds light on the description of the process of statistical evaluation of the data collected in the initial survey and proposes the use of these results as a basis for the formulation and planning of innovative ICT and e-grocery solutions.

## 2 Methodology

Through the administration of a questionnaire survey and the statistical analysis of the collected data, it was possible to define an initial characterization of the users on the Sicilian regional scale, which suggested a number of strategies for improving these services.

The methodological steps of the study are illustrated in Fig. 3.

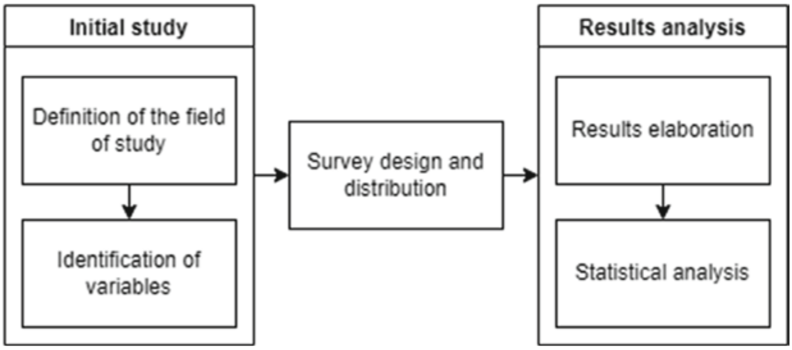

**Fig. 3** Methodological framework

## 2.1 Design and Administration of an Online Questionnaire Using Snowball Sampling Technique

The sample of users analyzed in this research was acquired through the snowball sampling (AKA chain sampling) technique. This is defined as a non-probability sampling technique in which samples have characteristics that are rare to find. In our case study, the rarity consists in investigating subjects that are not usually categorized as e-commerce users, and considering different segments of the population that are often not easily explored (e.g., users who do not use social networks). Therefore, the aforementioned sampling technique was applied, in which existing subjects provide references to recruit the necessary samples for a research study. This sampling method involves a primary data source, nominating other potential data sources to participate in research studies.

The snowball sampling method is based solely on referrals and this is how the researcher is able to generate a sample. In this specific case, a linear type of sampling was used in which the sample group started with a single subject providing information on only one other subject and then the chain continued with only one referral from a subject. This scheme was used by acquiring 260 users in the region of Sicily. Therefore, a survey was administered during July and September 2022. The tool used for the administration was Google Form. With regard to the data, an online questionnaire was designed consisting of four sections:

1. S1: socio-demographic data;
2. S2: residence and possession of means of transport;
3. S3: economic aspects and purchasing habits within the food sector;
4. S4: distances and travel time from different categories of grocery-related activities with respect to residence.

A general overview of the parameters investigated in the different sections is given in Table 1.

All variables had single type responses. Each user took on average less than 10 min to complete this questionnaire. The survey was submitted to users with internet access; since there was also the need to investigate the penetration of e-grocery within the population, no form of selection was made prior to the administration of the questionnaire.

## 3 Results

The variables acquired have made it possible to outline the characterization of users of e-grocery services in Sicily, have described the location of the main central nodes analyzed connected to the sale of food or raw materials, and at the same time have highlighted the potential choices made by users to reach these destinations. The acquired data were processed in a statistical-descriptive way.

Section S1 included closed-form answers. Table 2 shows the main trends for this section.

In particular, the sample analyzed was gender-balanced, and featured a percentage of users predominantly under 35 years of age. The family is mostly composed of 3–4 users.

As far as the spatial distribution of the sample is concerned, it can be seen from Table 3 that there is a slight majority of users living in inland areas and in particular in central-western areas. Almost half of the sample lives in the historical centers while an equal distribution of the remaining part of the sample lives in suburban expansion and rural/village areas.

In addition, the data collected from section S2 and shown in Table 4 indicates that households have typically 1–2 cars, and only 30% have mopeds. As far as sustainable mobility is concerned, more than 45% of the sample do not own bicycles, while less than 10% currently own e-scooters.

Regarding section S3, about half of the investigated users are workers with a salary of less than EUR 30,000 per year, as shown in Table 5.

Table 5 also shows that the main payment method for purchases is credit card, while an almost even distribution of the sample uses debit

**Table 1** Main variables analyzed by the online survey

| | | | | | | |
|---|---|---|---|---|---|---|
| *Section S1* | | | | | | |
| Gender | Age | | Level of Education | | Employment status | Number of household members |
| *Section S2* | | | | | | |
| Province of Residence | Urban area of residence | Car ownership | Motorcycle ownership | Bicycle owner ship | E-scooter ownership | Continued availability of use of a motor vehicle |
| *Section S3* | | | | | | |
| Annual family income bracket | Main payment method used for in-store purchases | Main payment method used for online purchases | | Main payment method used for online purchases | | |
| Average number of weekly food purchases (online) | | Average number of weekly food purchases (grocery store/retail) | Distance from the nearest grocery store | | Distance from the nearest restaurant/fast food | |
| *Section 4* | | | | | | |
| Grocery store distance time (minutes) | | | Restaurant/fast food time (minutes) | | | |

**Table 2** Section 1 variables and sample replies (socio-demographic data)

<table>
<tr><td rowspan="2">Gender</td><td>M</td><td colspan="2">F</td><td rowspan="2">Age</td><td>18–26</td><td colspan="2">27–35</td><td>36–50</td><td colspan="3">50+</td></tr>
<tr><td>108 (45%)</td><td colspan="2">132 (55%)</td><td>94 (39.2%)</td><td colspan="2">68 (28.3%)</td><td>34 (14.2%)</td><td colspan="3">44 (18.3%)</td></tr>
<tr><td rowspan="2">Employment condition</td><td>Worker</td><td>Student</td><td>Other</td><td rowspan="2">Family members</td><td colspan="2">1</td><td colspan="2">2</td><td>3</td><td>4</td><td>>4</td></tr>
<tr><td>120 (50.0%)</td><td>74 (30.8%)</td><td>46 (19.2%)</td><td colspan="2">28 (11.7%)</td><td colspan="2">34 (14.2%)</td><td>66 (27.5%)</td><td>88 (36.7%)</td><td>24 (10%)</td></tr>
</table>

**Table 3** Section 1 variables and sample replies (residence)

<table>
<tr><td>Area of sicily</td><td colspan="2">South and east</td><td colspan="2">Center and west</td></tr>
<tr><td>N</td><td colspan="2">112 (46.7%)</td><td colspan="2">128(53,3%)</td></tr>
<tr><td>Residence area</td><td>City/town center</td><td colspan="2">Urban expansion area</td><td>Scattered houses</td></tr>
<tr><td>N</td><td>118 (49.2%)</td><td colspan="2">62(25.8%)</td><td>60(25.0%)</td></tr>
</table>

cards or cash. On the other hand, for online purchases, only 5.8% of users pay in cash or cash on delivery. About the different types of food purchases, three main methods were compared: online purchases on platforms (i.e., Glovo, Deliveroo, and Just Eat), dinner at a restaurant/fast food and dinner at home with purchased and prepared food. As shown in Table 6, it was found that weekly:

- more than 75% of the sample population do not make any online food purchases;
- on average, only 20.8% make 1 purchase while less than 3% make 2 or 3 purchases;
- the distribution of the sample with regard to the purchase of food in shops is more than 30% i.e., more than 4 times a week;
- almost 40% of the sample make a purchase of food from restaurants or pizzerias while almost 32% do not make take-away food purchases from restaurants or pizzerias.

The offer of small shops and specialized food and wine shops is widespread - thanks to the tradition and many high-quality raw materials that are present in Sicily. The spread of the main supermarket chains is developing in the expanding areas of the city, while the spread of restaurant chains is struggling in several parts of Sicily also because there are numerous *trattorias* and take-away food places in the main metropolitan cities, such as Palermo or Catania. With regard to delivery, services are also taking off in inland cities, such as Enna and Caltanissetta. On the other hand, this service still struggles in small towns.

Observing the data in Table 7, where the distance between origin and destination is examined, it is evident that over 66% of the sample have a grocery store less than 1 km from their home and more than 50% of their homes are very close to a restaurant or *pizzeria*. This highlights a good diffusion of food services in the context examined.

Distance by different modes of transport was investigated to analyze the accessibility to the home-food outlet route.

Table 8 shows that with regard to food shops such as supermarkets, which often sell food and wine, the average walking distance is under 10 min for more than 52% of the sample population. It also shows that almost 70% of users manage to reach a food shop by moped in less than ten minutes.

The data included in Table 8 show how the less homogeneous mode of transport in the context examined is public transport and the related stops: in fact, only almost 37% of the interviewed people manage to use the bus and reach their destination in 10 min (considering waiting and transfer times).

With regard to the restaurant/fast food destination, about 43% of the sample manage to reach their destination in about 10 min while about 36% travel between 10 and 30 min. For example, using a bicycle, 55% of the sample population manage to reach their destination in 10 min.

By motorized transport, on the other hand, more than 60% of the sample can reach their destination by moped in 10 min, while almost

**Table 4** Section 2 variables and sample replies (possession of means of transport)

| Car/motorcycles ever available | Yes | | | | | | | No | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | 200 (83,3%) | | | | | | | 40 (16,7%) | | | | | |
| Number of cars/ family | 0 | 1 | 2 | 3 | 4 | >4 | Number of motorcycles/ family | 0 | 1 | 2 | 3 | 4 | >4 |
| N | 8 (3,3%) | 72 (30.0%) | 98 (40,8%) | 46 (19.2%) | 10 (4.2%) | 4 (1,7%) | N | 148 (61,7%) | 72 (30.0%) | 18 (7,5%) | 0 | 0 | 0 |
| Numbers of bike/family | 0 | 1 | 2 | 3 | 4 | >4 | Number of scooters/family | 0 | 1 | 2 | 3 | 4 | >4 |
| N | 110 (45,8%) | 76 (31,7%) | 30 (12,5%) | 18 (7,5%) | 2 (0,8%) | 0 | N | 222 (92,5%) | 18 (7,5%) | 0 | 0 | 0 | 0 |

**Table 5** Section 3 variables and sample replies (economic aspects)

| Household gross income [€] | <30.000 € | 30.000–50.000 | >50.000 |
|---|---|---|---|
| | 118 (49.2%) | 88 (36,7%) | 34 (14.2%) |
| Payment method (retail) | Credit card | Debit card | Cash |
| N | 132 (55.0%) | 50 (20,8%) | 58 (24.2%) |
| Payment method (online) | Credit card | Debit card | Cash (or cash on delivery) |
| N | 118 (49.2%) | 108 (45.0%) | 14 (5,8%) |

**Table 6** Section 3 variables and sample replies (purchasing habits within the food sector)

| Average number of weekly food purchases (online) | 0 | 1 | 2 | 3 | 4 | >4 |
|---|---|---|---|---|---|---|
| N | 182 (75,8%) | 50 (20,8%) | 6(2,5%) | 2 (0,8%) | 0 | 0 |
| Average number of weekly food purchases (grocery store/retail) | 0 | 1 | 2 | 3 | 4 | >4 |
| N | 36 (15.0%) | 62 (25,8%) | 36 (15.0%) | 20 (8,3%) | 8(3,3%) | 78 (32,5%) |
| Average number of weekly food purchases (restaurant/fast food) | 0 | 1 | 2 | 3 | 4 | >4 |
| N | 76 (31,7%) | 94 (39.2%) | 52 (21,7%) | 10 (4.2%) | 4(1,7%) | 4 (1,7%) |

**Table 7** Section 4 variables and sample replies (distances from different categories of grocery-related activities with respect to residence)

| Distance from the nearest grocery store | <1 km | 1–5 km | >5 km |
|---|---|---|---|
| N | 160 (66,7%) | 76(31,7%) | 4 (1,7%) |
| Distance from the nearest restaurant/fast food | <1 km | 1–5 km | >5 km |
| N | 124 (51,7%) | 102 (42,5%) | 14 (5,8%) |

21% cannot reach it in less than an hour, or at all. By car, 73% of the sample has to travel less than ten minutes. The mode of transport that is shown to be least able to provide connection between origin and destination in a short time (less than 10-15 min) is public transport (Table 9).

The sample analyzed is made of adults under 35 who do not live as singles, but with 3-4 family members (see Table 2). This could be closely related to low wages and the recent crisis that forced many people in Sicily to review their lifestyle habits. Some other features are also critical that are pointed below.

- On a weekly basis, about 23% of the sample make at least one purchase on an online platform.
- With respect to areas of residence, the sample is almost equally divided between city centre and peripheral areas.
- More than half of the respondents are located less than 1 km from the nearest catering business.
- Almost all respondents can easily reach the nearest restaurant by car, while more than half need less than ten minutes on foot.

The characterization of the sample population denotes a few main elements:

1. The average user is an adult under 35 years of age, mostly female.
2. Although the analyzed context is characterized by strong infrastructural problems and difficulties in the connection with the remaining parts of Italy, and in internal

**Table 8** Section 4 variables and sample replies (travel time from different categories of grocery-related activities with respect to residence-first part)

| Grocery store time distance (minutes) | **Walking** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
|---|---|---|---|---|---|
| | N | 126 (52,50%) | 86 (35,80%) | 14 (5,80%) | 14 (5,80%) |
| | **Bike** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
| | N | 144 (60%) | 48 (20%) | 16 (6,7%) | 32 (13,30%) |
| | **Motorcycles** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
| | N | 166 (69,20%) | 28 (11,70%) | 4 (1,70%) | 42 (17,50%) |
| | **Car** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
| | N | 204 (85%) | 24 (10%) | 2 (0,8%) | 10 (4.2%) |
| | **Public transport** | **<10** | **11–30** | **31–60** | **>61 or not available** |
| | N | 88 (36,70%) | 58 (24,20%) | 10 (4,20%) | 84 (35%) |

**Table 9** Section 4 variables and sample replies (travel time from different categories of grocery-related activities with respect to residence-second part)

| Restaurant/fast food time distance (minutes) | **Walking** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
|---|---|---|---|---|---|
| | N | 104 (43,30%) | 86 (35,80%) | 24 (10%) | 26 (10,80%) |
| | **Bike** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
| | N | 132 (55%) | 46 (19,20%) | 12 (5%) | 50 (20,80%) |
| | **Motorcycles** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
| | N | 148 (61,70%) | 34 (14,20%) | 8 (3,3%) | 50 (20,8%) |
| | **Car** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
| | N | 176 (73,30%) | 52 (21,70%) | 4 (1,70%) | 8 (3,3%) |
| | **Public transport** | **<10** | **11–30** | **31–60** | **>1 h or not available** |
| | N | 80 (33,3%) | 54 (22,5%) | 20 (8,3%) | 86 (35,8%) |

connections, too, places to buy food, such as small shops and take-aways are well diffused.

3. On average, such places are easily accessed. This is connected to the wine and food tradition of the region, which in many contexts makes it possible to have small restaurants or shops available.
4. There is a wide availability of individual private transport, while the use of public transport is low. This is confirmed by the studies carried out in the *Integrated Plan for*

*Infrastructures and Mobility* (*Piano Integrato delle Infrastrutture e della mobilità*, PIIM) of the Sicilian Region.

## 4 Discussion and Conclusions

The recent pandemic has stimulated the use of technology and e-commerce, boosting the demand for purchasing goods such as food, and highlighting several critical issues in the last-mile logistics sector. In fact, if convenience in shipping costs is the first factor to consider when choosing an e-commerce site, excessive delivery costs lead to its immediate abandonment. Poor site reliability and unattractive prices can also lead to the interruption of the purchasing process. In the recent years, companies have experienced the limits of their information systems and operations,

A number of research papers shows that the Italian customer prefers click-and-collect, which is offered free of charge, as it provides more time slots for picking up groceries and is faster than home delivery. This is indicative of the fact that, logistics in grocery delivery will have to be improved. Supermarkets will have to work hard, especially in an omnichannel direction, to reach the levels of service of the pure players. Similarly, neighborhood shops are also called upon to reinvent themselves by offering services such as proximity e-commerce.

Therefore, more powerful servers are needed to handle the increase in traffic, i.e., user demand. The study of e-grocery demand makes it possible to define optimal ICT-based solutions that allow the mitigation of certain problems such as inefficient pick-up and delivery operations that often cause most e-grocery pioneers to fail. Particular attention should be paid to the combination of e-grocery/innovative solutions with a focus on fresh food and *zero-km* production (local production).

Among the advantages, online shoppers especially appreciate the convenience of home delivery, the possibility to compare prices and have a wide assortment to choose from, as well as access to exclusive promotions.

The main barriers relate in particular to the impossibility of seeing the products live and choosing them personally. People also continue to use the physical channel to access local and *zero-km* products and to join loyalty programs. The combined use of a decision support system and mobile applications can therefore provide a solution to increase the effectiveness and efficiency of e-grocery operations.

The trend to undertake integrated online and offline purchasing processes, which is present in all product categories with varying degrees of intensity, represents an opportunity to overcome the limitations attributed to the online channel that continue to favor the physical channel.

In the area of food products and home and personal care items, for example, the meeting point between the convenience of home delivery and the impossibility of personally choosing the product to buy can be represented by shopping experiences at the physical shop with the products personally chosen by the buyer, placed in a virtual shopping cart and then shipped directly to the buyer's home, or by a remote shopping experience, with the possibility of viewing real images of the products, so that the buyer can choose them, instead of the salesperson who is in charge of physically composing the shopping cart filled via the web.

In e-commerce, the food component is growing strongly at the expense of the personal care category. Thus, basic ingredients (flour, sugar, yeast, etc.), commodities, ethnic specialties, fresh milk and cream enter the online shopping basket. These purchasing choices also stem from the fact that the Italian population has rediscovered a love for cooking and preparing new dishes, but is also more careful about their monthly spending, due to the recent economic downturn.

At the user experience level, it is also important to develop the e-commerce platform bearing in mind both the aspects that favor the finalization of a purchase and those that may lead to abandoning a site and continuing the customer journey on another channel. In this sense, it is crucial to provide reassurances with respect to the cost-effectiveness of the digital channel compared to the physical one, the advantageousness of shipping costs, the reliability of the brand or retailer, and the security of data processing and payments.

The case study examined outlines an initial layout in a regional context of a somewhat 'confined' island type, characterized by a series of areas where there is currently a reduced possibility of connection (especially for inland areas).

The study defines a first step of investigation through a simple statistical analysis but aims to subsequently analyze the correlation between variables such as the location of residences in urban and non-urban areas with respect to the propensity to buy food online.

An initial survey shows the profile of the e-grocery user, typically female, characterized by an adult age but less than 35 years old, who easily reaches physical places for shopping such as supermarkets or restaurants but who uses online services at least once a week, especially when residing in inner city areas rather than in suburbs.

A number of insights emanate from the results of the questionnaire. The percentage of e-commerce users, still a minority of buyers, makes e-grocery in Sicily a still marginal, albeit expanding reality. The results are coherent with the literature. If cities such as Palermo or Catania already have significant coverage, various small and medium-size towns are often far from e-grocery services; this is also due to the important presence of traditional catering in Sicily that, as emerges from the results of the questionnaire, is present all over the territory. However, the growth of e-grocery in Sicily also requires traditional sectors such as catering to open up to this possibility; this is because the two forms, traditional and e-grocery, are often complementary and not alternative to each other, and are viewed as a way to expand a company's business rather than a way to limit it. This translates into three central elements:

- for managers in the food sector, greater involvement within the e-grocery market, with a greater online presence;
- for public administrations, greater attention to the modification of the vehicular flow induced by the increased presence of delivery vehicles;
- for delivery service managers, fleets of vehicles built in accordance with the decarbonization objectives.

A fundamental element in subsequent developments is the exploitation of this study to determine the correlation between socio-demographic and mobility variables with purchasing habits. Certainly, some characteristics emerge as particularly relevant from the questionnaire, in particular the asymmetry between the choice to purchase and the choice not to purchase e-grocery. Therefore, the calibration of different models that better allow to read these data becomes relevant. In particular, the calibration of a multinomial logit model, under the hypothesis of independence of the e-grocery purchase and non-e-grocery purchase alternatives. For this, it is necessary to increase the size of the survey to provide greater robustness to the data.

The characterization (profiling) of the user is, therefore, fundamental for exemplifying the online purchasing steps and ensuring that devices can represent a tool for integrating physical and online channels, starting with the smartphone, which represents one of the most used tools for making online purchases.

This lays the foundations for the improvement of ICT tools that can facilitate e-commerce, starting with the creation and improvement of web portals that must not only guarantee a shopping experience via smartphone that is comparable to that of a PC or tablet, but can also exploit the characteristics of the device and the user to stimulate buyers to purchase, e.g., by leveraging augmented reality solutions with which they can place a piece of furniture in their home, try on a piece of clothing or accessory through the camera, or use QR codes in-store to gather more information about a product or access online demonstrations of its use and operation.

The evolution of the demand for e-commerce and user profiling, together with the technological spread of WiFi and 5G networks and ICT technologies, will make it possible to improve the development of smart city models by guaranteeing more urban areas in which, thanks to the use of digital technologies and more generally of technological innovation, it will be possible to optimize and improve infrastructures and services for citizens, making them more efficient.

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