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This book is dedicated to the ioCity project team

Preface

Nowadays, societies and cities are constantly evolving to be more innovative and intelligent. The local agents are concerned with pollution and the environmental impacts on the towns. They want more sustainable cities, moving towards mobility alternatives capable of reducing congestion, time, accidents and pollution. The agents create attractive and engaging experiences for the citizens privileging "green" actions. The biggest challenge comes from industries that need to be able to respond to societal changes and people's demands. The industry is the key to achieve healthy and sustainable society. The citizens are also concerned with cities and want a more inclusive and connected community. Overcoming these problems is a significant challenge for European cities. However, to solve them, the involvement of all the stakeholders is crucial.

In this sense, it becomes essential to understand what is being done in cities, how industries can contribute to creating a sustainable society and what types of innovation are performed.

The book *Sustainable, Innovative and Intelligent Societies and Cities* covers several transversal topics applied to Smart Cities and Society like Gamification, Security, Data Science, Industry 4.0 and Tourism.

This book shows some trends and applied solutions, and it is organized into four parts to show that cities and societies are:

1. Analytical, Descriptive and Predictive
2. Attractive, Engaging and Fun
3. Healthy, Secure and Sustainable
4. Innovative, Connected and Monitored

To better understand the book's content, the section "About This Book" briefly presents each part and chapter.

Guimarães, Portugal — Carlos Filipe da Silva Portela

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The editor thanks Rita Miranda for their valuable work assisting him with this Special Issue. The editor also appreciates Springer's help in developing, validating and publishing the book. This book was developed under the scope of the project NORTE-01-0247-FEDER-045397, supported by the Northern Portugal Regional Operational Programme (NORTE 2020), under the Portugal 2020 Partnership Agreement, through the European Regional Development Fund (FEDER).

About This Book

This book is divided into four parts:

1. Analytical, Descriptive and Predictive
2. Attractive, Engaging and Fun
3. Healthy, Secure and Sustainable
4. Innovative, Connected and Monitored

The **first part** presents some studies and explore a set of data science approach which can help to get insights and best practices from the cities:

The chapter "Towards Data Lake Technologies for Intelligent Societies and Cities" presents a practical approach and, consequently, a technological solution to enforce the importance of using Data Lakes to turn cities more sustainable.

The second chapter shows "An Analysis of Smart Cities Initiatives in Portugal". This work analysed 68 initiatives, compared them and identified best practices and strategies of Portuguese cities.

The chapter "Intelligent Dashboards for Car Parking Flow Monitoring" presents an online analytical processing system capable of real-time tracking cities' parking flow.

The next chapter "Tourist as a Smart Tourist: A Review" did a depth study about projects where the tourist can be more intelligent by promoting the concept of tourist-as-a-sensor.

The **second part** of the book is composed by four chapters and highlights a more participative and collaborative aspect of societies.

Chapter entitled "Smart Tourism Design: Take Experience and Resource Integration as the Core" purposes to promote the sustainable development of smart tourism from the design perspective. The authors designed a conceptual framework for developing intelligent tourism destinations and providing insights for stakeholders of smart tourism destinations.

The following chapter "Sustainable Mobility: How to Gamify and Factors to Better Success" explores gamification in the context of mobility and analyses the success of game elements and mechanics in supporting behaviour change towards sustainable urban mobility. Based on such analysis, the authors provide some recommendations on using gamification, which works and is great for the citizens.

Chapter "How Do Citizens Want to Participate in Smart City Programs? Some Answers from Greece" tries to answer the question: How do citizens want to participate in smart city programs? The chapter presents the results of the public survey sent to Greece citizens. As a result, the study underscores the fact that researchers must study societal issues, while public administrators must organize intelligent, transparent and efficient dialogue with both experts and citizens.

Chapter "Sociable Smart City" presents the concept of the Sociable Smart City and analyses the impact of smart cities in society and how a sociable, smart city may empower and engage people, enhance citizens' activities in social interactions, and improve quality of life and culture. The authors developed an approach to show that a smart city should not only focus on technology but also on social and cultural aspects.

The **third part** shows some approaches to turn a city more healthy and sustainable.

Chapter "Fostering Healthy Food Habits Through Video Games" presents the results of an experience that used video games to promote healthy food habits in society. The authors developed a prototype and evaluated it with two questionnaires. Achieved results showed the importance of developing incentives and mechanisms to encourage the use of the proposed action to improve learning and nutritional education.

The next chapter is "Smart Solutions for Sustainability: RDI for Urban and Societal Transitions Requires Cross-Sectoral Experimentation Platforms". This chapter presents a practice-borne knowledge-action model and discusses two key criteria for success in generation options for sustainable cities and societies.

The next chapter "Protecting Organizations from Cyber Attacks: An Implemented Solution Based on CyberArk" details the impact of cyber security on an organization, alongside the consequences of a malicious actor gaining access to privileged accounts, and presents a solution to show how organizations can protect from cyber attack using CyberArk.

The chapter "A Sustainable Framework to Manage Plastic Waste in Urban Environments Using Open Data" addresses one of society's most significant problems: plastic production. The authors presented a framework to help manage plastic waste in urban environments to turn communities more sustainable.

The next chapter "Mapping Industry 4.0 onto Eco-city Transitions: A Knowledge-Action Matrix" shows an action-matrix based on the literature review that can be used to promote eco-transitions in cities. The authors discussed a selection of examples illustrating smart city technologies, urban renewal, energy transitions and climate changes, with emphasis on efficiency-resilience tradeoffs.

The **last part** presents a more innovative and connected part of cities with a particular focus on industry.

Chapter "Smart Roofs System: Moisture and Temperature Monitoring on Smart Roofs" addresses the urban heat island effect and presents a solution using a water-based polymeric membrane with infrared reflective additives. This approach helps to promote buildings' sustainability and energetic efficiency by ensuring high thermal reflectance, preventing overheating and cracking, reinforced with a smart textile substrate that includes coupled moisture-and-temperature sensors for monitoring water infiltrations.

The next chapter entitled "Next-Generation Fashion Ecosystem: A STVgoDigital Approach" analyses one of the biggest industries that move society: the textile. They designed an approach to create a digital ecosystem that brings together the main stakeholders of the textile and clothing industries to promote an environment that offers more significant interaction and customization, fostering new business and production models to fulfil current market demands in terms of customization and sustainability.

The next chapter presents a new solution to monitor "Public Transportation Occupancy Rates" using ubiquitous passive technologies. The chapter presents the first approach to implementing a low-cost system that tracks the occupation rate on a bus.

The last chapter "Remote TrafficLight System to Support TrafficLight Maintenance" addresses problems that weaken road traffic in urban areas. The authors developed an improved light scatterer and a traffic light controller composed of a sensor/actuation system for detection/prevention/correction of malfunctions and generation of data and alerts through an online platform, respecting all the standards applied to road safety.

This book is helpful to decision-makers, managers, students or professors that act in the area of Industry 4.0 and Smart Cities. The book addresses a lot of emerging concepts. It is useful to those who want to understand better the working environment, the society and what is researched and innovated in these areas.

Contents

Part III Healthy, Secure and Sustainable

Part I
Analytical, Descriptive and Predictive

Toward Data Lake Technologies for Intelligent Societies and Cities

Geymerson S. Ramos, Danilo Fernandes, Jorge Artur P. de M. Coelho, and Andre L. L. Aquino

1 Introduction

Data lakes are appropriate solutions to scalable systems, enabling storage and analysis of heterogeneous data in its raw state for knowledge extraction [1]. This approach requires metadata generation and management to provide a high-quality data catalog through well-defined policies and tools. In addition, users have access to integration features, logical and physical organization, and scalable storage and processing power [1]. These features make data lake an effective solution for data management and value generation for smart cities.

The International Data Corporation forecasts that, by 2025, the global amount of data will reach 175 Zettabytes, which is ten times the volume of data generated by 2016 [2]. According to this report, IoT (Internet of Things) [3] devices, the base of smart city applications, will produce most of these data. The problem is not that we have too much information. It is just that we do not know what to do with it [4]. In smart cities, big data are collected from several heterogeneous devices and systems, stored, integrated, and analyzed holistically [5]. For example, the data can refer to the geospatial indication of autonomous cars and drones' location over time; text and images from social media; video from surveillance systems; temperature, humidity, and pollution measurements collected by sensors distributed over the environment; and conventional structured data from multiple information systems [6].

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Smart cities emphasize the interconnection between systems to produce data about themselves, allowing information sharing between different platforms. We can achieve the sharing with ubiquitous monitoring, data analysis, and homogeneous representation of all information in a unified framework [7]. For example, Healthcare can improve with preventive care services, diagnosis and treatment tools, healthcare records management, and patient care [8]. Likewise, big data can benefit transportation systems to optimize routes and schedules, accommodate varying demands, and increase environmental friendliness [9]. Governments are also benefiting from the "smartification" revolution. Smart governments are improving the electronic government (e-gov) concept based on the orchestration of smart city services by implementing open data policies and deploying IoT-based public services [10, 11]. Applications in the public sector provide more effective and efficient administration due to improved performance and government transparency [12]. The new approaches for creating value from data transform how governments across the globe interact with citizens, make policies, and deliver services [10].

The proper design of a data-driven smart city's service is vital as it can integrate analytical systems that would pave the way to identify related ideas and knowledge [13]. The possibilities are endless, but they are bounded by the availability of advanced technologies and tools [14]. Moreover, the design, improvement, and operation of big data offer significant challenges due to the highly dynamic and evolving environment of smart cities [15]. The comprehension of data usage is also a constraining factor [16]. Some works have addressed using big data in a smart city to identify challenges in specific applications, including transportation, public safety, and sustainability [16]. Nonetheless, a limited number of investigations have focused on general knowledge, regardless of its application area [13]. New systems for known and integrated big data analysis are urgently needed, as well as for specific data types [14]. Data lakes have been receiving attention due to its capacity to handle general and specific applications independently of big data variety. Traditional time-tested solutions used data warehousing for management and processing. A data warehouse is a classic integrated storage system designed to perform massive analysis [17]. However, while still relevant and robust for structured known sources, these solutions are not suited for semi-structured and unstructured data [18].

This work aims to provide an overview of data lake technologies and recent literature contributions while also discussing its relevance in the context of sustainable smart cities. We present general concepts, the most common data lakes architectures, technologies, and applications in the mentioned context. We also discuss cognitive bias and how decision-makers can mitigate it or use it in their favor. Finally, we propose a data lake architecture suitable for smart cities and improved with a robust metadata management system composed of the most promising techniques in the literature. We hope that the contents of this work can provide insights for data engineers, scientists, analysts, and decision-makers in the various stages of developing a data-driven application.

We organize the remaining sections as follows: Sect. 2 contains the work's methodology. Section 3 presents data lake architectures and technologies. Section 4 provides an overview of the use of data lakes for smart city applications. Section 5 summarizes issues on cognitive bias in data-driven decision-making. Section 6 discusses a data lake architecture for smart societies. Section 7 shows the study case of the proposed architecture. Section 8 presents the conclusion and final considerations.

2 Methodology

We provide a general view regarding data lakes and their applications in a smart city context. We discuss crucial data lake architectures such as the zone architecture [1], the pond architecture [19], and the lambda architecture [20]. We also discuss the most recent relevant tools for data storage and processing [21, 22]. Furthermore, we discuss smart city applications and their heterogeneous data context, used to improve life quality through health, mobility, environment, and economy.

It seems logical to use and evaluate data lakes on smart city applications. Data lakes can handle multiple heterogeneous data sources while obeying data governance and providing analysis resources for fast and systematic decision-making processes. The topics of cognitive bias discuss how we can unconsciously be affected by misinterpretation tendencies and how decision-makers can mitigate it or use it in their favor. By considering the relevant technologies and aspects of data lake applications in a smart city context, we propose a zone-based architecture and a study case as an initial data lake application for analyzing the geographic distribution of users benefited by three local Brazilian governmental systems, specifically of Alagoas state.

These systems refer to (i) a platform dedicated to the training of IT professionals and the dissemination of opportunities offered by companies or technology institutions (in Portuguese https://oxetech.al.gov.br/), (ii) a system to help encourage the practice of sports through the intermediation between athletes and sports institutions (in Portuguese https://cae.selaj.al.gov.br), and (iii) a registration system for a government social assistance program to help families in financial poverty and extreme poverty condition (in Portuguese https://cadastro.cria.al.gov.br/). For such analysis, the databases of these systems have been integrated logically with the data lake, and the provided data serve as input for evaluating user distribution. We discuss the performance evaluation of the data lake queries for this particular analysis and its methodological approach in Sect. 7.

3 Data Lake Architectures and Technologies

In recent years, we have seen the surging of many data lake architectures. The concept of zones is the most used in these architectures. Each zone corresponds to a stage of data refinement [23]. In this methodology, data collected from external sources are logically assigned to an ingested data zone [1]. We transform the data improving the quality; thus, the outcome can move into the following zones [1].

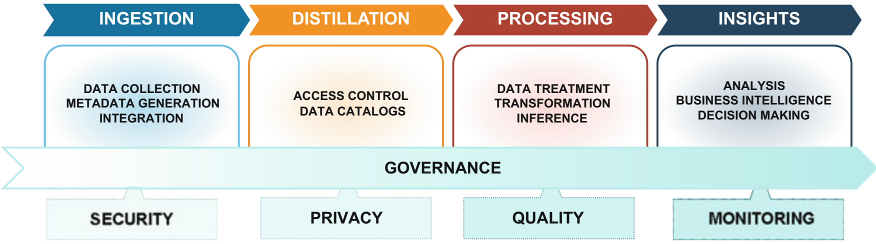

Fig. 1 General data lake zone architecture

Such transformations run until the data reach the maximum level of maturity at which it is ready to be analyzed by decision-makers [24]. Figure 1 presents a general representation of a zone-based architecture composed of four zones to perform data Ingestion, Distillation, Processing, and Insights.

In addition, a data governance layer traverses all the zones to assure data security, privacy, quality, and monitoring [23]. Data governance requirements are different for each zone. At the ingestion zone, data must satisfy conditions for security and consistency. The distillation zone should enforce data privacy by controlling access. The processing zone reinforces data quality, and the monitoring zone provides reports on the health of specific components and the general infrastructure of the data lake. Data governance should increase and stack as the data follow through the ingestion to the insights zone. However, this is only one of several variants of the zone architecture. Such architectures generally differ in the number and characteristics of the zones [23].

3.1 Ingestion

The data are stored in raw format or with minimum processing during the ingestion stage. Integrating different applications creates a voluminous non-structured storage unity, highly connected and augmented with metadata [1]. The aim is to minimize and avoid information loss by not prematurely processing data during the ingestion stage. The main features of data lakes lie on the late binding aspect, and some differences between the mentioned approach and early binding are presented in Table 1, adapted from Fang [25].

Late binding has no predefined schema. The input is unfamiliar and fluid and can be structured or unstructured. The storage's purpose is to ingest and save data, which is eventually processed when needed. Although there is no unique structuring, data must be well documented and associated with its metadata to facilitate discovery through the data lake catalog. Users can serve themselves to process, evaluate, and extract information from diversified and heterogeneous sources [24]. Early binding is well suited to known and predictable sources. Applications have access to treated,

Table 1 Key differences between early and late binding

	Early binding	Late binding
Data storage	Well-defined schema; Ingest data processing; Evaluate data	Ingest data; Data catalog
Users	Consume data; Produce information	Define data schema; Processing consume data; Evaluate data; Produce information
Suited for	Known predictable sources; Reusability; Consistent results	Unfamiliar data; Infrequent usage; Heterogeneous sources

validated, and ready-to-use data consumed consistently to absorb the information provided by analysis, graphs, and results of inference models.

Usually, data lake architectures copy data from the source to a scalable or distributed file system such as HDFS (Hadoop Distributed File System) [21]. There are known sets of technologies to transfer and process data, such as Apache Kafka [22], Sqoop [26], Flink [27], and Samza [28]. We can mention a data table, an XML (Extensible Markup Language) file, or raw text as source examples. In general, data sources are produced and maintained by independent information systems. For an organization that supports them, ingestion by data replication demands additional storage resources [17]. In addition, since such systems continuously generate and update their sources, periodic data updates are also required for the ingestion zone [17]. These concepts are intrinsic to data lake definition.

We can avoid these issues with a federated data lake approach, in which data are accessed directly in its source through distributed query engines (e.g., PrestoDB, Apache Drill, and Hive), which are connected to the databases or file systems [29]. Thus, the data are always up to date, and there is no need for data duplication. The performance loss is one of the problems of this approach. In addition, a search on multiple distinct servers can increase the complexity of queries. There are active research and cache mechanisms to mitigate the problem [17].

Although there is barely any processing in the ingestion zone and data are mainly found in its raw state, many problems and challenges arise from large heterogeneous storage, especially from a data lake perspective. For example, how can a single query hit multiple databases and fetch relevant data from a similar context? For such cases, we can find previous research proposals on the use of semantic integration as a way to match equivalent attributes [30, 31].

This process involves extracting semantics, expressing it as metadata, and matching equivalent data through discovery instead of pre-programming. For example, Facebook's recent efforts use natural databases to query data according to facts presented as short natural language sentences. One of the benefits of neural database systems is that it has no predefined schema. Another convenience is that users can perform updates and queries in natural language forms. For the moment, the success of neural databases depends on overcoming scalability challenges since we cannot scale them to nontrivial databases nor apply them to set-based and aggregation queries [32].

3.2 Distillation

Distillation is the stage in which data is segregated and cataloged according to governance policies and other relevant criteria such as quality and security [1]. Some segregation practices split data between free or restricted access. For example, smart cities allow access to health care, public security, and education applications. The distillation's granularity can be as fragmented as needed to facilitate search and satisfy governance requirements. From a self-service point of view, data lakes should provide a catalog to its users, as presented in Fig. 2. After segregation procedures such as anonymization or access restrictions, we subject each data batch to treatment and validation.

Data scientists, engineers, analysts, and business managers access data at different refinement levels and have different perspectives. As the application's privacy policy demands, we should submit the data to segregation criteria before being available in the data lake catalog. Data quality impacts application and business models [33], and treatment and validation steps aim to produce ready-to-go data to generate fast and accurate results. The lambda architecture [20] proposes a solution to process and serve large amounts of data very similar to the diagram in Fig. 2. If specific data treatment and manipulation are required to boost results, users can access data in its raw state and apply their treatment and analysis.

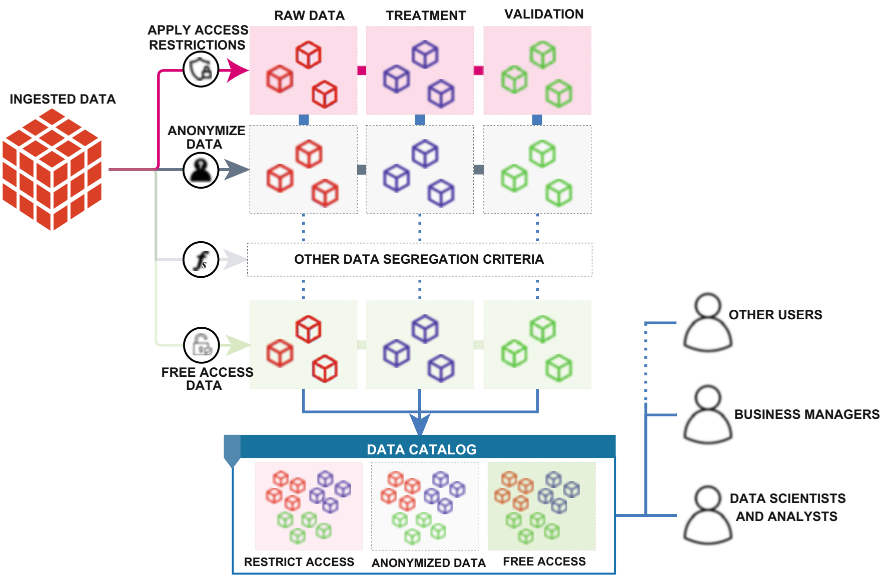

Fig. 2 Data distillation

3.3 Processing

In the processing stage, users should be able to seamlessly manipulate data using automation tools such as Apache NiFi [34]. Big non-processed data give the user more freedom to apply techniques to select features, identifying hidden patterns that otherwise would be erased by premature processing. Future-proofing comes as another advantage since new projects will be able to access the data that at first had no purpose [24], minimizing the impacts of the fast-paced evolution of big data. In Fig. 3, the data can be primarily sourced from the data lake's catalog, processed, and transformed, resulting in better quality data. First, users can store the processing results in the distributed file system. Later, robust large-scale algorithms or machine learning models use the processed and saved data.

With more possibilities to choose from, we can take advantage of feature engineering more broadly to maximize efficiency and information gained from algorithms [35]. Furthermore, since data lakes aggregate multiple data sources, the users can benefit from big-scale analysis in a structured platform that eases

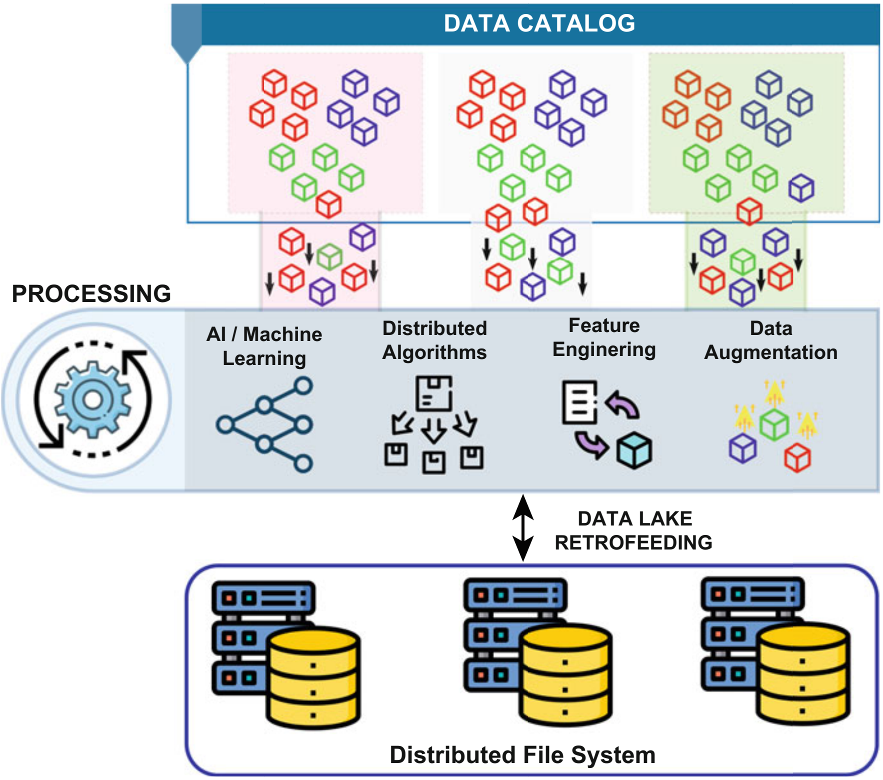

Fig. 3 Data processing

the overhead of experiment replication. We can embed previously recurrent tasks, such as data augmentation performed by data scientists, in the processing zone to speed up the deployment of machine learning and statistical inference models. Data augmentation provides a suite of techniques that enhance the size and quality of datasets [36]. We can store any manipulated and enhanced data in the data lake to future use and information harvesting.

We can use parallel data processing tools such as Apache Hadoop, which contains MapReduce [1] operations for large datasets. However, since MapReduce saves processing results in the computer's hard disk, it has performance limitations, making it not efficient for fast data [37]. To overcome such limitations, alternative frameworks such as Apache Spark, Apache Flink, and Apache Storm propose an in-memory approach rather than the file system to save intermediate results [1]. We can implement Flink and Storm simultaneously as stream processing engines to real-time data [37].

3.4 Insights

Most business ideas, problem identification, and solution emerge from analysis and reflection of situations and results. So the whole point of a data lake is to provide the feedstock data to fuel information gain. Therefore, users should have access to a framework to highlight the events of a specific business or application. This action occurs through an insight zone available to managers or stakeholders.

We use some available analysis tools, such as Tableau, Microsoft Power BI, and Apache Zeppelin [1, 37], to understand and expose events to managers and stakeholders. Such evaluations enable meaningful analysis and data-driven decision-making for continuous improvement of the success of a specific business or application [38].

Usually, we classify the most important types of decisions in two categories: (i) Decisions for which "discoveries" need to be made in the data (ii) Repeatable decisions, especially on a large scale Thus, decision-making can benefit even under small increases in the accuracy of this process based on data analysis. Data-driven decision-making enables decisions based on data analysis rather than intuition. The more data-driven it is, the more productive a company or government entity becomes [38]. But it is worth mentioning that decision-makers need to be very cautious against decision bias [39].

3.5 Governance

Several factors ensure good governance for every zone, preventing the emergence of vulnerabilities or turning the data lake into a data swamp [40]. Data swamps are unusable or hard to harvest datasets that only generate expenses to their

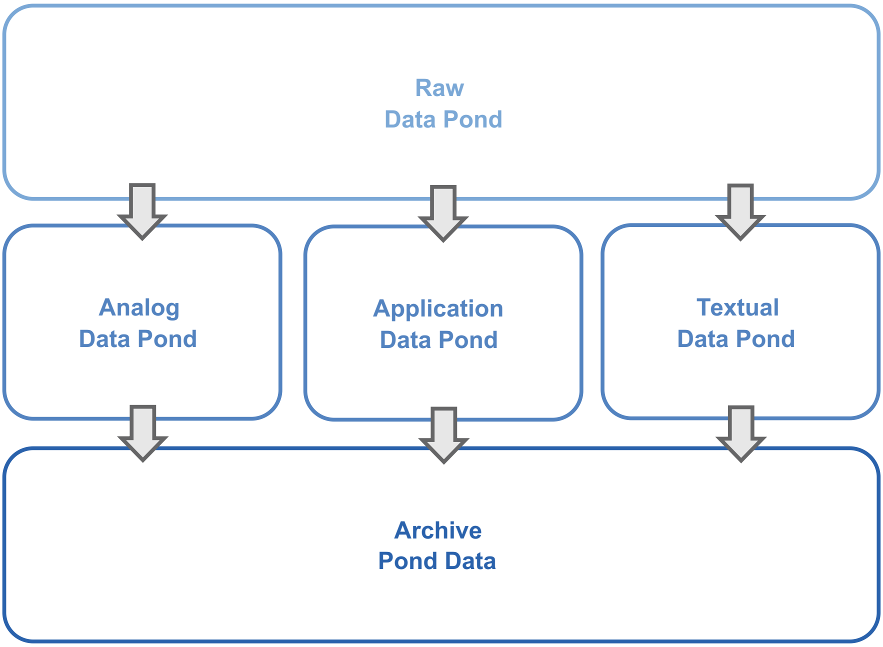

Fig. 4 Data lake pond architecture

maintainers, either by poor metadata management or by inaccessibility to users [1]. Data lake requires meticulous care and monitoring, as they are complex storage solutions with advantages and disadvantages.

Data governance builds the foundation for data management and enforcement of the rules abided by stakeholders and decision-making processes. It covers the planning, monitoring, and execution of data lifecycle management and policies [41]. Lifecycle management refers to processes related to the design, creation, collection, storage, usage, maintenance, enhancement, archiving, and disposal of data [41]. The policies cover all stages of the data lifecycle and involve security, privacy, compliance, and data quality management [41].

All of which involve generating or using stored information or, in this case, metadata [41]. Considering a complex and heterogeneous system like a data lake, a robust metadata management system is imperative for optimized extraction of value and insights [40].

Besides the Zone architectures, there is the pond architecture proposed by Inmon [19]. It is also a way to divide the data management and analysis system into ponds, specific for different data types associated with specialized storage, processing, and analysis systems [19]. Figure 4 shows the mentioned architecture with five data ponds.

The raw data pond handles newly ingested data, redirecting the input to a suitable pond (analog, application, or textual). The analog pond stores and processes high-

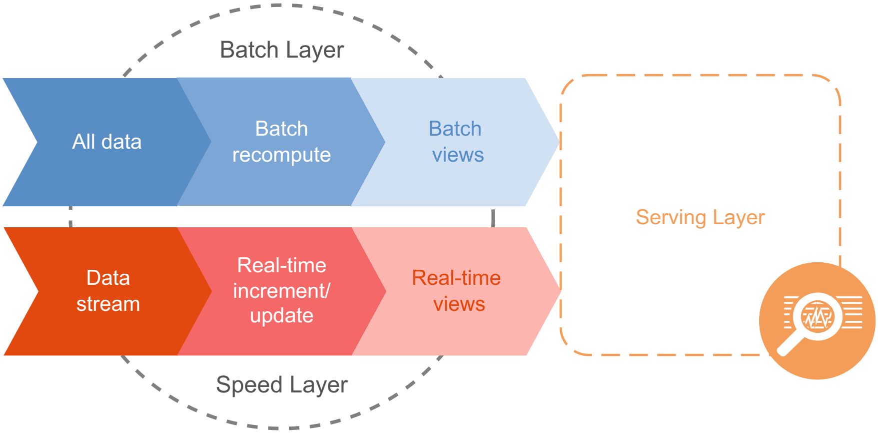

Fig. 5 Lambda architecture

frequency data (semi-structured and generated by IoT sensors). The application pond handles structured inputs from software applications and relational database management systems (DBMS). The textual ponds manage unstructured text and depend on indexing and natural language processing capabilities. Finally, the archival pond stores unused data that will potentially be necessary for the future, including any of the last three ponds.

The Lambda architecture, presented in Fig. 5, can handle large amounts of data and leverages both batch and real-time processing methods [20]. The core aspect of this architecture lies in computing parallel/real-time functions over distributed data. It comprises three layers: the batch layer, the speed layer, and the serving layer [42].

The batch layer is mainly responsible for storage and precomputing batch views for the distributed data [43]. The batch views can provide answers to incoming queries with low latency [20], and as a complement, the speed layer uses an incremental approach to store and update real-time views for recent data [43]. Older data are absorbed by the batch layer [20]. The serving layer is a specialized distributed database that indexes batch views queried in a *ad hoc* and low-latency way [43]. It is also responsible for merging the batch and speed layer, providing real-time results [44].

4 Data Lakes for Smart City Applications

Smart cities have been a hot discussion topic for a while. Global population growth puts pressure on the sustainable use of natural resources while keeping people's life quality. As discussed in Lai et al. [45], some studies and organizations have published standards and key aspects for smart cities, and common features defined by organizations such as the Institute of Electrical and Electronics Engineers Smart

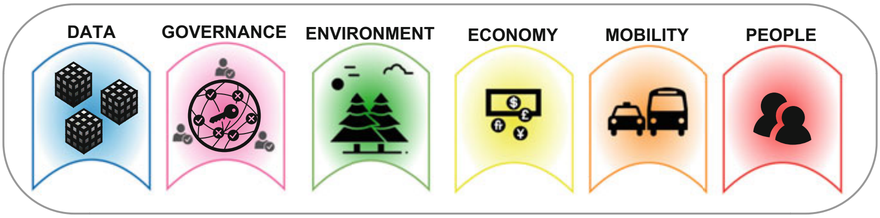

Fig. 6 Smart city domains

Cities Community [46], the Japan Smart Community Alliance [47], and the European Commission [48] include the following similarities: (i) Better living standards through informed decisions with technology to collect, process, and evaluate data (ii) Information exchange through the integration of systems (iii) Improvement of citizens surrounding awareness (iv) Enhancement of sustainability and environmental conservation Each of these features is spread among specific domains [49] (Fig. 6):

– `Data`: Smart cities must harvest heterogeneous and fast-growing data through state-of-the-art technologies to ingest, integrate, process, and produce information that will benefit their citizens. Almost everything can be monitored, stored, and processed, so it is essential to push the boundaries of cloud services and solutions to leverage data [50]. This cornerstone allows us to build better and more sustainable processes by measuring what needs improvement: traffic, urban waste, government services, air quality, health care, etc.
– `Governance`: As discussed by De-Guimarães et al. [51], governance in a smart city depends on the way government works with the participation of various stakeholders and the use of technology, bringing better citizen participation, public and private partnerships to deliver higher quality public service, and quality of life. However, managing expectations while avoiding the conflict of interest of so many parties is difficult. Therefore, data governance must guide the decision-making process with clear transparency and collaboration. Hammad et al. [52] study the potential of successful applications of smart learning environments for emerging technologies with further focus on smart city governance. Some challenges include problems and rules for different domains such as environment, mobility, and economy.
– `Environment`: With climate change and population growth concerns, smart cities started to absorb environmental policies from sustainable cities concepts. According to Hiremath et al. [53], sustainable urban development demands a balance between the development of the urban areas and the protection of the environment. The development must generate positive outcomes such as employment, social infrastructure, and transportation in the urban areas. Examples of applications on smart sustainable cities include waste management [54], reduction of greenhouse gas emissions and energy consumption optimization [55], and agriculture [56].

– `Mobility`: Cities that emanate prosperity certainly attract more people, creating overcrowding and high vehicular traffic problems [57]. Urban mobility issues affect people's everyday life. Work and study routines require individuals to dislocate, a process that often implies a waste of time and emotional stress. To improve the life quality of citizens, smart mobility is advancing with electric and autonomous vehicles, intelligent traffic light control, route planning, and smart parking. We can observe the quality of life improvements with the reduction of air pollution with electric vehicles [58] and a decrease in traffic jams, which in some cases expose drivers to criminal activities at stop points such as traffic signals in metropolitan cities [59].
– `Economy`: The sustainable and optimized use of resources in smart cities impacts the green growth of the overall economy [60]. Still, the challenges of a highly connected and information-rich environment are worth mentioning. Commerce and businesses have to deal with broader competition nationally and globally. There is constant pressure on the government to regulate informal jobs and business models from digital platforms like Uber and Airbnb. These platforms are a "sharing economy" business model where participants borrow or rent assets owned by someone else [61].
– `People`: Initially, the view about smart cities was from a technology-centered perspective, but soon the importance of people appeared as impacting factor that can influence services and applications [62]. The vast adoption of mobile computing and smartphones has created virtual sensors, in which social media feed data to mobile social networks [63]. Consequently, people-centric computing and applications improve smart policies for efficient energy consumption, mobility, and environmental monitoring [64]. In addition, some works show how to use social sensing to manage risks and mitigate the impact of natural disasters [65]. These types of efforts can improve society's overall well-being and security. Still, it is worth mentioning that social media has negative impacts and requires solutions to control problems such as misinformation and hate speech [66], which can rapidly spread in digital environments and create real-world consequences.

We can see that smart cities have many possibilities for applications. However, there are various essential aspects regarding data, governance, and value generation to improve the quality of life, environment, and economy. Since data lakes also deal with multiple heterogeneous data sources, with architecture proposals considering data governance and analysis for fast and systematic decision-making processes, it seems logical to use and evaluate data lakes on smart city applications.

Mehmood et al. [67] present a big data lake for heterogeneous data sources. They discussed data source management from heterogeneous data stakeholders and real-world implementation of data acquisition and storage for heterogeneous data sources. Although the authors implemented the main components for ingesting data, they did not address data quality and security issues, crucial factors for any smart city application. This implementation option is understandable since it is hard to cover all the requirements of a data lake without a reasonable-sized team. Like a smart city application, data lakes require people with different technical knowledge from other domains.

To process big data in smart cities, He et al. [68] store a massive volume of raw data in a data lake. Then, they filter the data later to extract valuable real-time and offline data stored in different databases and used as input to a Hadoop framework for further processing. The data lake is part of a three-plane architecture, namely the data storage plane, the data processing plane, and the data application plane. The storage plane contains data from different sources, which creates an "ocean of data" later subjected to the processing plane and its filters, analyzers, and processing techniques. Finally, the results are used for autonomous decision-making to extract high-quality information.

It is interesting to see the term "ocean of data" in a smart city context. According to Gorelik et al. [24], "a data ocean expands self-service data and data-driven decision making to all enterprise data, wherever it may be, regardless of whether it was loaded into the data lake or not." If we consider a smart city a massive enterprise, would it be a good idea to have a single data lake to handle the whole city's data? Probably not. Is there any entity that requires and uses data integration from a city? Probably yes, most likely government entities.

Smart cities evolve organically, with applications so diverse data that they would demand dedicated data lakes. For example, we can mention the data lake architecture for power grid monitoring and diagnostic systems presented by Li et al. [69]. Likewise, Yu et al. [70] present an integrated framework that merges IoT (Internet of Things), a data lake, data analysis, and cloud computing for manufacturing equipment health-state monitoring and diagnostics. It is reasonable to think that a smart city's data ocean is the integration of many data lakes. Ideally, the modular division of each data lake with its well-established governance rules would contribute to the good functioning of the data ocean as a whole. But it is hard to achieve such a level of integration, especially considering the relation between the many governance layers and how it would affect the decision-making process of the highest stakeholders.

5 Cognitive Bias in the Decision-Making Process

When designing a data-driven decision support system, a critical issue is minimizing human error in decision-making. For example, there is no point in a system storing, governing, processing, and analyzing big data if data analysts and decision-makers repeatedly misinterpret its results and miss the opportunity to mine relevant insights.

Bias and noise (systematic deviation and random dispersion) are different components of error. Some judgments are biased (systematically miss the target). "Others are noisy when people who should agree end up at very different points around the center. Unfortunately, many organizations are plagued by bias and noise" [39]. In real-world decisions, the amount of noise is often outrageously high. For example, doctors offer different judgments about skin cancer or breast cancer for the same patient. In addition, there is considerable noise in unexpected areas, such as in the evaluation of X-rays [39].

In this way, there is a high probability of noise whenever there is a human judgment. To increase the quality of decisions, we need to overcome both noise and bias [39]. The computational intelligence system not only allows dealing with a greater volume of data and processes, speed, and accuracy of calculations but also deals with the mitigation of bias and noise.

Therefore, it is essential to consider the user's cognitive biases and possible applicable choice architecture solutions based on nudges. It is a stimulus, a gentle push, a poke; "it is any aspect of the architecture of choices that is capable of changing people's behavior predictably without vetoing any options and without any significant change in their economic incentives" [71]. Hence, the main option is a nudge when the intervention is cheap and easy to avoid.

To illustrate this, insert a warning already at the beginning of the presentation of a statistical report, namely: a random event, by definition, does not lend itself to explanation, but groups of unexpected events do behave in a highly traditional way. Large samples are more accurate than small samples—these, in turn, provide extreme results more often than large samples do [71]. What is the justification for assuming that biases exist and that there is a demand for embedded intervention?

Logicians and statisticians have well-developed concepts of probability that rival each other very precisely. But for people in general, probability is a vague notion related to uncertainty, propensity, plausibility, and surprise [72]. Not coincidentally, Amos Tversky commented that when dealing with probabilities, most people have only three settings: "it will happen," "it won't happen," and "maybe." Philip Tetlock [73] agrees with Amos' argument and claims to be 99% confident that it captures an essential truth of human judgment.

Kahneman [72] documented various systematic errors in people's opinions about events involving probability. These are known as biases. We explain these errors through two cognitive systems which require choice and concentration: (i) "operates automatically and rapidly, with little or no effort and no perception of voluntary control" and (ii) "allocates attention to the laborious mental activities that require it, including complex calculations."

Most of what we think and do originate in System 1, while System 2 takes over when things get complex. The division of labor between the systems is efficient (minimizes effort and optimizes performance). But System 1 has biases (systematic errors) that it tends to make in specific circumstances and exhibits little understanding of logic and statistics. Also, it cannot be switched off, and it relies on System 2 to control the impulses of System 1 [72]. In practice, we use many shortcuts (heuristics) to evaluate data patterns and make judgments when faced with uncertainty. This strategy is convenient economically but can lead to systematic errors (biases). Heuristics and their biases impact data visualization interpretation and decision making [74, 75].

Hastily drawing conclusions based on limited evidence is so crucial to understanding intuitive thinking that Kahneman [72] named it WYSIATI (What You See Is All There Is). He argues that System 1 "is radically insensitive to both the quality

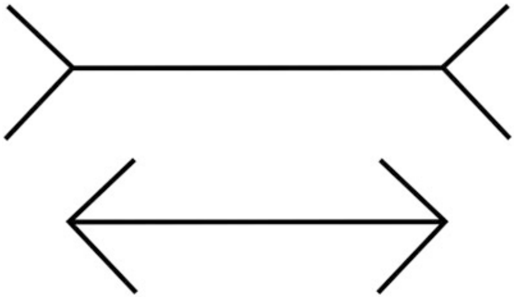

Fig. 7 Müller–Lyer illusion

and quantity of the information that gives rise to impressions and intuitions." Philip Tetlock and Dan Gardener [73] report that Kahneman's WYSIATI is the greatest of all cognitive illusions.

The fact is that even the most privileged brains make obvious mistakes and that is precisely what makes systematic errors visible. "And there is no way we can make ourselves bulletproof, as the famous M'uller-Lyer optical illusion illustrates" [73] (Fig. 7). You are wrong if you think the top line is longer than the bottom one. You can verify it by measuring with a ruler. The lines are the same length, and if you have measured the lines, your System 2 has a new belief: the lines are equally long. If asked about the size of the lines, you will say what you know. But you continue to see the top line as longer.

According to Kahneman [72], "you have decided to believe in measurement, but you can't stop System 1 from performing its trick; you can't decide to see the lines as equal, even though you know they are." To resist the illusion, one must learn to distrust the length of lines when there are arrows attached to their ends [72]. Therefore, be wary of extending lines with arrows at the ends.

Kahneman [72] argues that not all illusions are visual. There are the illusions of thought (cognitive illusions). Consider the tendency when forming perceptions or making quantitative judgments about some entity under conditions of uncertainty. Give excessive weight to the initial value (the first information received or the initial judgment) and not modify that anchor in light of later information. For example, product estimates of $9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1$ tend to be higher than product estimates of $1 \times 2 \times 3 \times 4 \times 5 \times 6 \times 7 \times 8 \times 9$. This is called the anchoring bias effect [76].

Cognitive biases result from heuristics (the subconscious decision-making processes in the brain). The challenge lies in shaping an individual's cognitive behavior. Therefore, many efforts exist to modify and improve the decision environment (e.g., Business Intelligence). Unfortunately, this is still more a matter of academic than practical interest. On the other hand, there is a growing interest in cognitive science, visual analytics, and decision-making tools. For example, Ellis [74] reports two central questions related to visualization: (i) is the interpretation of visualizations subject to cognitive biases? and (ii) can we adapt visualization tools to reduce the impact of cognitive biases? You may be wondering if the questions are still relevant in the present.

We have the challenge of staying curious to produce creative insights to mitigate the negative impact of cognitive biases when using data visualization for decision-making. But unfortunately, there is no off-the-shelf solution to systems whose ultimate purpose is to lead a person to make a data-driven decision.

6 Data Lake Architecture for Smart Societies

This section presents a zone-based data lake architecture for Smart Cities and Governments for Smart Societies. Our approach enables ingestion and integration of heterogeneous data sources from IoT systems, social media, data streams, information systems databases, and Data Warehouses. In addition, there is support for virtually ingesting structured data from databases, i.e., the proposed architecture incorporates the concept of federated data lakes. We integrate all data via a HANDLE-based metadata management system [41], which enables manual insertion and automatic metadata extraction and querying of the data through the metadata.

Our architecture (Fig. 8) has the following modules: Data Ingestion, External Databases, Data Warehouses, Distributed File Systems, Storage Systems Monitor, Distributed Query Engines, Distributed Processing Engine, Metadata Management, and User Interface. The white and gray arrows between the modules indicate requests and data flow.

6.1 Data Ingestion

The data ingestion module handles data transfer from its sources into the data lake. Ingestion can occur by transferring bulk data to the distributed file system or streaming data to the distributed processing engine. The former approach is offline, which loads the entire volume of data into the data lake, allowing late analysis. This scenario includes collecting historical data from IoT sensors via Apache Sqoop or social media data from the Twitter API via Apache NiFi.

The other method is an online approach to data analysis, in which it is possible to visualize and process real-time data. Example scenarios transfer to processing instantaneous measurements from IoT sensors via Apache Kafka or tweets via Apache Flume. The data ingestion module is a set of distributed systems for collecting big data from databases or APIs.

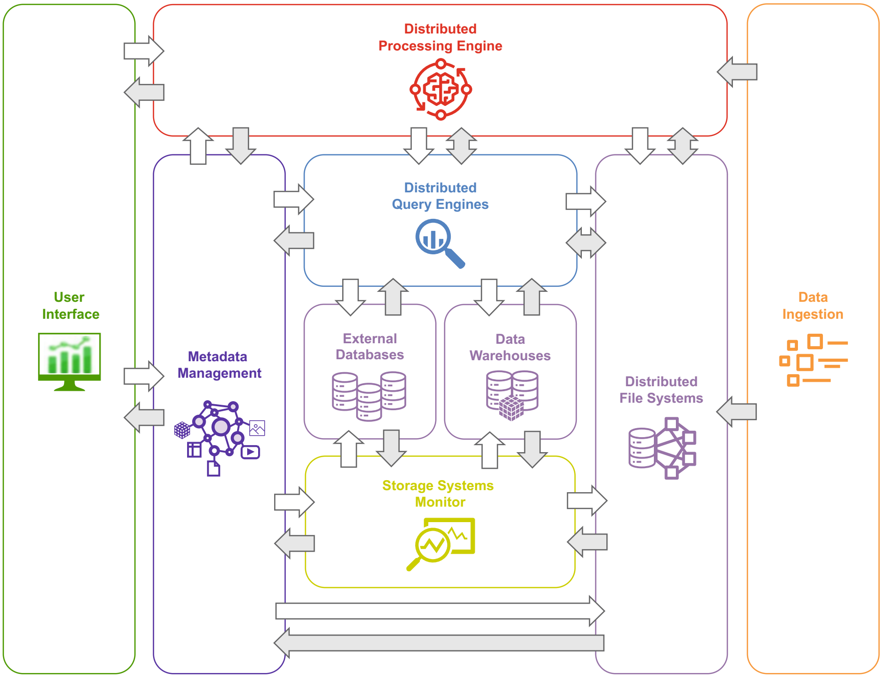

Fig. 8 Proposed data lake architecture

6.2 External Databases and Data Warehouses

Since the proposed architecture considers a federated approach, the data lake continuously connects to the virtual databases and performs different queries when necessary. This strategy allows constant access to up-to-date data. The External Databases module represents databases that fit this case. In addition, we integrate data warehouses into the data lake to cover scenarios where there are data warehouses deployed, and we need to connect them to the overall ecosystem.

6.3 Distributed File Systems and Storage Systems Monitor

The Distributed File Systems Module contains repositories that will store, in a distributed way, all data transferred to the data lake and all data resulting from the processing. Unlike the previously described repositories, the stored data can be structured, semi-structured, and unstructured. We can use Apache HDFS in this module.

The purpose of the Storage Systems Monitor Module is to provide reports, when requested, about the health of the nodes that compose the distributed file systems. It is worth noting that this is also valid for the Data Warehouses Module since its data resides in a similar system. Apache Ambari can perform the monitoring task. Additionally, we can track the activities of the distributed systems and external databases through their logs.

6.4 Distributed Query Engines

This module is responsible for conducting queries to all the structured data in the data lake. It makes it possible to wrap different data sources into a single complex query performed in a distributed environment. It is possible to use more than one distributed query engine in this module for performance gains. An example would be to have one engine to query HDFS (like Apache Hive) and another to query the external databases and data warehouses (like PrestoDB and Apache Spark).

6.5 Distributed Processing Engine

This module processes the data accessible in the data lake. This data can come from data streams for real-time analysis or previously ingested data bulks (either locally stored or logically integrated). The processing requests can come from: (i) User interface, in which the data refinement, analysis, and results are stored in the distributed file system regardless of its structure (ii) Metadata management, which executes distributed algorithms on the data to generate the information needed to create the metadata model

The distributed processing engine can access the structured data through the main engine of the Distributed Query Engine Module and the other data through the distributed file system API. Examples of systems that can ideally occupy the processing module are Apache Spark, Apache Flink, and Apache Storm.

6.6 Metadata Management

The Metadata Management Module is responsible for logically integrating all data and making it accessible to the user through homogeneous modeling. It also stores and manages meta-information about the use and performance of the data lake. As shown in Fig. 9, this module presents four components: Metadata Extractor, Graph Database, Query Translator, and API.

The metadata extractor is the system responsible for building and periodically updating the data lake's metadata model. It accesses the available data through the

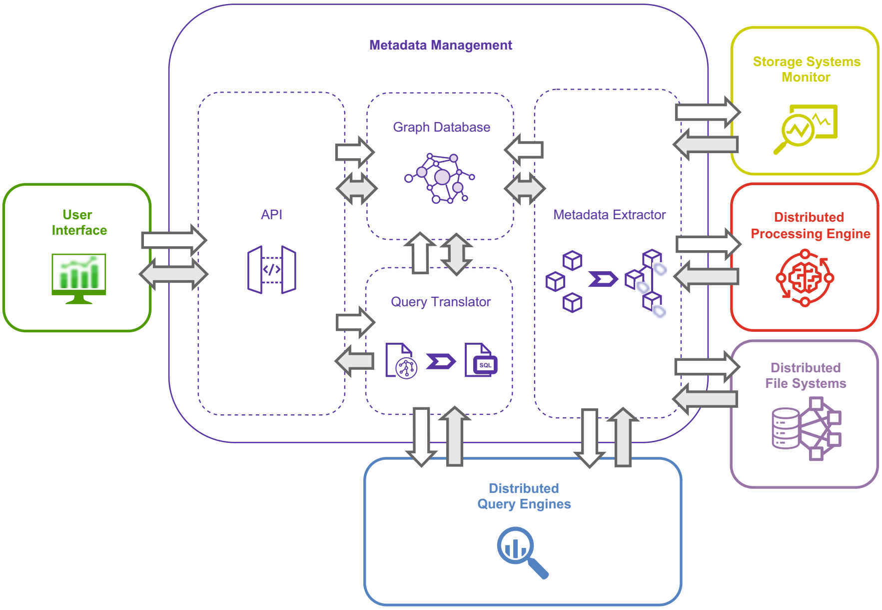

Fig. 9 Metadata management sub-modules

Distributed Query Engines (structured data) and the Distributed File System API (unstructured data). In addition, it is possible to check the data lake's health, which is under the supervision of the Storage Systems Monitor. Nevertheless, since there is a large volume of data under the data lake management, it is inevitable to delegate almost all the computation required to provide the metadata model to the Distributed Processing Engine.

This system employs different methods for extracting various metadata, all of which are integrated into a single model following the HANDLE framework [41]. We are using one of the methods proposed by Yu et al. [77] to extract descriptors and perform automatic semantic labeling of data sources. This approach produces a semantic graph, which is fully compatible with HANDLE.

The organization proposed by Nargesian et al. [78] for navigating data lakes is also an important method. However, it undergoes some adaptations to turn its resulting DAG into a semantic graph compatible with the proposal of Yu et al. This study is enough to map each non-terminal node (which does not represent a column) in the DAG into a semantic node of the type Concept.

This strategy allows integration of the two approaches since the former generates a hierarchy of concepts where edges can define a generalization/specialization relationship. Moreover, these approaches complement each other since one is for numeric values and the other for texts. Merging these strategies will provide greater integration of different data sources while preserving the navigability of the data lake through better organization.

The strategies generate the metadata model and store a graph database through extraction systems, such as Neo4j and GraphDB. The User Interface Module can access this stored model through the API of the Metadata Management Module. This strategy allows the data lake user to browse the semantic graph/organization. It integrates the various stored data and views information about that data such as descriptions, physical location, structure, zone, who used it and when they used it, and information about the data lake infrastructure.

Furthermore, the user interface can use the physical location of the data to build complex queries and data analysis procedures to be performed in the processing module. However, it is also possible to uniformly query the data using the metadata model and ignoring its structure and physical location. The query translation system executes this strategy by receiving queries in a format compatible with semantic graphs (such as SPARQL). This query identifies the data sources by querying the metadata model, performs the necessary queries to the data access mechanisms, and returns the results.

Squerall [29] implements this strategy. However, this only allows queries to structured data sources and only uses semantic labeling, not exploiting the wealth of available metadata such as granularity, zone, and data accesses. Additionally, the Metadata Management Module API provides features for the user to insert data descriptions, load ontologies, and manually perform labeling on the metadata model.

6.7 User Interface

This module provides the user interface, creating the bridge for data or metadata requests, insertion, processing, and analysis. If the systems generate or store new data, the User Interface forwards such information to the Metadata Management Module. This way, the latest data is integrated logically into the metadata model, inserting information such as its storage location, zone, and the reference of the processed data and its origin.

7 Case Study

We analyze the geographic distribution of users benefited by three local Brazilian governmental systems, specifically of Alagoas state. These consist of: (i) A platform dedicated to the training of IT professionals and the dissemination of opportunities offered by companies or technology institutions (in Portuguese https://oxetech.al.gov.br/) (ii) A system to help encourage the practice of sports through the intermediation between athletes and sports institutions (in Portuguese https://cae.selaj.al.gov.br) (iii) A registration system for a government social assistance program for poverty and extreme poverty families (in Portuguese https://cadastro.cria.al.gov.br/)

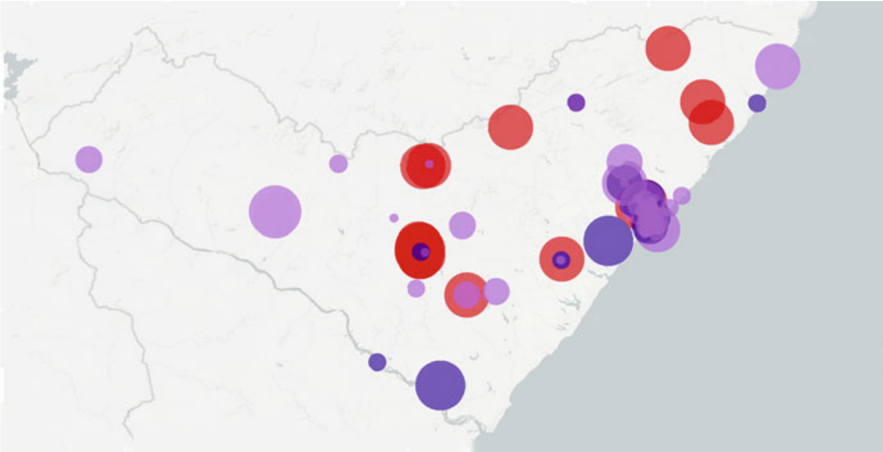

Fig. 10 Geographic position and the proportion of users of each system

We choose this application because of its potential to identify the regions most benefited by these programs and their capillarity and reach. In addition, it allows managers to locate the regions with the most significant lack of government incentives to plan complementary initiatives. For this analysis, the databases of these systems have been integrated logically with the data lake, i.e., they are included in the External Databases Module.

We used a sample of unique ZIP code values to perform the above analysis, and their respective absolute frequencies were requested. Next, we delegate these queries to the distributed query engine according to the execution flow in Fig. 11. Finally, through an application in the User Interface Module, the user requested the desired data in their respective databases with PrestoDB, which returns the results shown in Fig. 10 to the application.

After querying the ZIP code values and their counts, the application obtains latitude and longitude coordinates to draw the circles on a map (Fig. 11). They have a diameter proportional to their respective frequencies. The colors red, blue, and purple indicate data from the social assistance program, the system for promoting sports, and the platform dedicated to the training of IT professionals. The web application for data visualization uses the Streamlit framework. For privacy reasons, we modified the ZIP code data and its frequencies to generate Fig. 10, not reflecting the actual state of the distribution of users and systems that integrate the data lake.

Due to the volume of data, queries in data lakes are a big challenge, especially if the data is in different systems. Through search, data must be found, joined, and returned. Without mechanisms for generalizing search terms, users must inconveniently perform the same query multiple times for different databases. Therefore, efficiency and performance are important factors. This generalization mechanism resides in the distributed query engine in the proposed architecture. It includes a set of one or more connected computers, each acting as a coordinator or worker node.

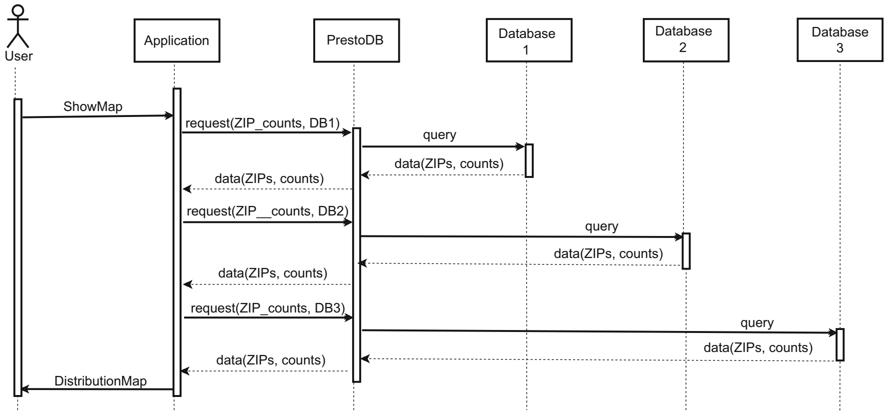

Fig. 11 Data Lake execution flow for generating the user map

The former is responsible for receiving query requests, distributing them among the worker nodes, and combining their results. The latter performs queries on the connected databases and returns the result to the coordinator node. This approach makes it possible to establish multiple configurations from the number of nodes involved, which impacts the performance of the system and the data lake.

To evaluate the performance of this database access tool, we performed repeated queries with the following settings: (i) **Single node**: PrestoDB is installed on a single computer, acting as both the coordinator and worker node of the search system. The experiment's computer has 32 processing cores and 64GB of memory. (ii) **One coordinator and one worker**: We install PrestoDB on two computers, where one acts as the coordinator node and the other as the worker node. The machines are on the same network, and both have 32 processing cores and 64GB of memory. (iii) **One coordinator and two workers**: To the previous configuration, we add one more worker node to the local network. The third machine has 8 processing cores and 20GB of memory.

The performed queries produce the graph in Fig. 10. For each setup, the queries were executed 30 times, and we computed the elapsed time to run them and get their results. Figure 12 presents the box plots of the elapsed time values for each PrestoDB configuration. It is important to note that the queries were performed through the Web application, which is connected to a network external to the PrestoDB network, implying that the results are subject to Internet connection delays.

Analyzing the graph in Fig. 12, we identify significant improvement in adding a worker node to the single node configuration, which allowed the central node to act exclusively as a coordinator. However, we see no significant improvement in adding a second worker node. Possible causes for this could be the low complexity of the executed queries, the small number of connected databases or the inferior computer specs of the third machine compared to the others.

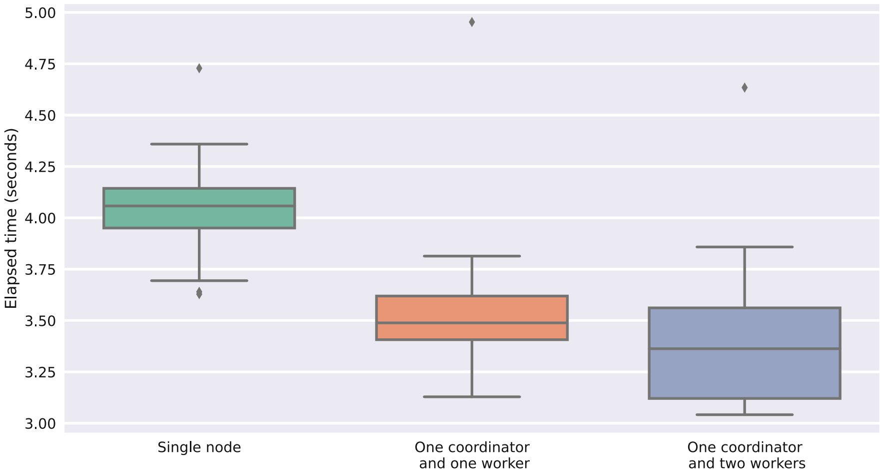

Fig. 12 PrestoDB query times with different configurations

Table 2 Statistics about PrestoDB query time

	In seconds				
Configuration	$\hat{\mu_t}$	$\hat{\sigma_t}$	min	$median$	max
Single node	4.048	0.215	3.628	4.058	4.728
One coordinator and one worker	3.544	0.305	3.129	3.489	4.953
One coordinator and two workers	3.388	0.330	3.041	3.363	4.634

We can see in Table 2 the decrease in the values of average execution time ($\hat{\mu_t}$), median, minimum, and maximum after adding nodes to the system. The improvement is less relevant between the last two configurations since $\hat{\mu_t}$ reduces by 12.45% and 4.4% with the insertion of the second and third node, respectively. Additionally, there is an apparent increase in the sample standard deviation ($\hat{\sigma_t}$) as the number of nodes increases. These last two observations corroborate the graphical analysis with evidence that the third node did not provide significant performance gain.

8 Conclusion

In this work, we discussed data lake architectures and data processing and analysis technologies in the mentioned context. In addition, the topics of cognitive bias discuss how we can unconsciously be affected by misinterpretation tendencies and how decision-makers can mitigate it or use it in their favor. Along with the discussion on data lakes for smart city applications, we also demonstrate initial results and a data lake architecture application designed to integrate government systems and data from Alagoas state, Brazil. The goal is to improve different systems' data integration, search, and analysis while improving governmental actions on behalf of the state's citizens. Nevertheless, one of the limitations of our case study is that our application does not implement the entire proposed architecture. We are currently in its early stage, and it also does not include the metadata management module. We intend to develop these features in future work, altogether with built-in frameworks to enhance data analysis, processing, and organization.

Many data lake challenges and research opportunities come from big data. For example, we can find problems regarding data governance, heterogeneous integration, discovery through catalogs, and automatic metadata generation and management. Another crucial aspect is: how can we extract and connect knowledge from different data lakes, boosting the value generation for smart cities?

Data generation growth will continue pressuring data storage, processing, and analysis technologies. We have seen improvement in information and communication technologies due to solution proposals for big data problems. Data lakes play a crucial role since they consider data in its raw state to provide high-quality data catalogs generated from integrated heterogeneous sources. These efforts help data engineers, scientists, analysts, and stakeholders to improve data-driven decision-making, performed with minimal decision bias. Considering data lakes' broad storage and processing capabilities on heterogeneous data, they are a good fit for smart city applications, especially considering the ubiquity of connected devices and the Internet of Things. Smart cities have many domains, such as data use and governance, mobility, economy, environment, and people's well-being. With data lakes, we can explore possibilities to innovate and maximize benefits for each domain, supporting the growth of sustainable smart cities.

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An Analysis of Smart Cities' Initiatives in Portugal

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1 Introduction

In the twenty-first century, humanity faces the great challenge of the exponential growth of the world's population. In the current year (2021), the world's population consists of roughly 7.8 billion people. It is estimated that more than 55% of the population lives in cities, and according to the United Nations [1], this percentage is expected to reach 68% by the year 2050. Then axes of "smart cities" are smart economy, smart people, smart governance, smart mobility, smart environment, and smart living.

Smart cities emerge as the result of many smart solutions across all sectors of society fueled by a combination of disruptive technologies and social innovations and combining changing human behavior with data and innovative technology [2]. Even though cities constitute only 2% of the Earth's landmass, they are responsible for the consumption of 80% of the planet's resources [3]. Cities leave a tremendous footprint, consuming two-thirds of the world's energy and being accountable for more than 70% of global CO_2 emissions. According to Major, "urbanization requires new and innovative ways to manage the complexity of urban living;

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it demands new ways to target problems of overcrowding, energy consumption, resource management and environmental protection” [4].

One of the solutions to these problems involves the digital transformation of cities. The city’s paradigm, as it is known today, will face several changes – which are fundamental to adapt and keep pace with the exponential growth of the world’s population while keeping attention to the Earth’s finite resources. Moreover, in this sphere, technology emerges as a critical and indispensable tool to enable this “smart” transition.

The complete merger between cities and technology results in the concept under study in this paper: smart cities. Even though there is still no clear and consistent definition of the concept, a “smart city” can be defined as “a framework, composed of Information and Communication Technologies (ICT) to develop, deploy, and promote sustainable development practices to address growing urbanization challenges.” Resourcing to cloud-based IoT (Internet of Things) applications, cities can be interconnected, sharing crucial information about connected objects and machines that transmit data using wireless technology and the cloud. These applications can “receive, analyze, and manage data in real-time to help municipalities, enterprises, and citizens make better decisions that improve quality of life” [5].

These objects and machines can be, for example, as little as a smartphone and connected to cars and buildings. In this way, citizens and communities actively participate and contribute to the city’s “smart” technologies. Investing in this connectivity between devices and data can improve sustainability (resorting to an efficient distribution of resources) and reduce the city’s costs.

Furthermore, facing the current reality of the COVID-19 pandemic, the digitization of processes in cities and, in general, in each country has become even more critical and urgent. It is essential to maintain proximity while keeping distance. It can only be achieved through online stores, services, digital fairs, and other innovative ideas. It is even more essential to strengthen health systems with digital methods that streamline processes that are usually time-consuming and bureaucratic – it is urgent to digitize services and ensure robust networks that allow fast data sharing to combat COVID-19.

The main goal of this study is to present a case study about most “smart” projects and initiatives among Portuguese cities, analyzing the current state of “smart cities” in Portugal. The study was focused on searching for real projects previously implemented and currently in execution and public events related to the topic. This study analyzes 68 initiatives (62 at the city level and 6 at the national level) of Portuguese innovation, despite a lack of information regarding some of the projects. Demonstrating the impact technology has on cities and understanding how it is possible to evolve as a smart city is a step toward the exponential growth of a town and the quality of life of all citizens.

This article is part of the ioCity project and is developed by IOTECH (a startup that aims to solve social problems by developing intelligent and innovative solutions). This research project is supported by public funds and aims to help solve city’s challenges such as mobility. In this way, ioCity proposes, through the analysis of a set of data (sensors, occupancy rate, traffic, and parking, among others), to help the customer make a more informed and real-time decision about car parks and public transport. After analyzing various data, it is expected that a prototype will be modeled and developed that demonstrates a decision-making support system that can be useful to the customer. This article also aims to identify practical solutions for existing smart city projects in Portugal that can be integrated into ioCity [6].

This chapter is organized as follows: the introduction presents the basis for this work. The second one talks about the background of the article and provides crucial information to understand the background of the demographic and technological context in Portugal. The third chapter describes the material and methods used. The next one is about a developed study. In the five chapters, the analysis results are presented and then the discussion of these outcomes. The last chapter is a conclusion and launches the basis for further work.

2 Background

Analyzing the current state of smart cities in Portugal is necessary to acquire solid knowledge and understanding of Portuguese society and demography, as well as the state and evolution of technology in Portugal. To introduce the relevant context of the study, it is first presented the overall Portuguese demography where themes like the state of digitization and the government approach to encourage this transaction were explored. And lastly, an overview of "smart cities" in Portugal is also presented.

According to the study presented in Fig. 1, a developed country in 2050 is expected to have 88% of its population living in cities, more than 8% of the forecast for 2020. For a developing country, a larger and more significant percentage is predicted. From 2020 to 2050, a 16% increase in the population is expected to live in cities. This figure demonstrates that since 1990 the population increase is expected until 2050 for people living in cities [1].

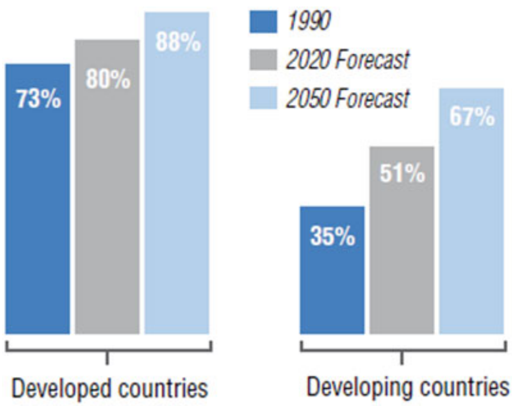

Fig. 1 Percentage of the total population living in cities, 1990–2050 (forecast). (Source: IBM Institute for Business Value analysis of United Nations data [1])

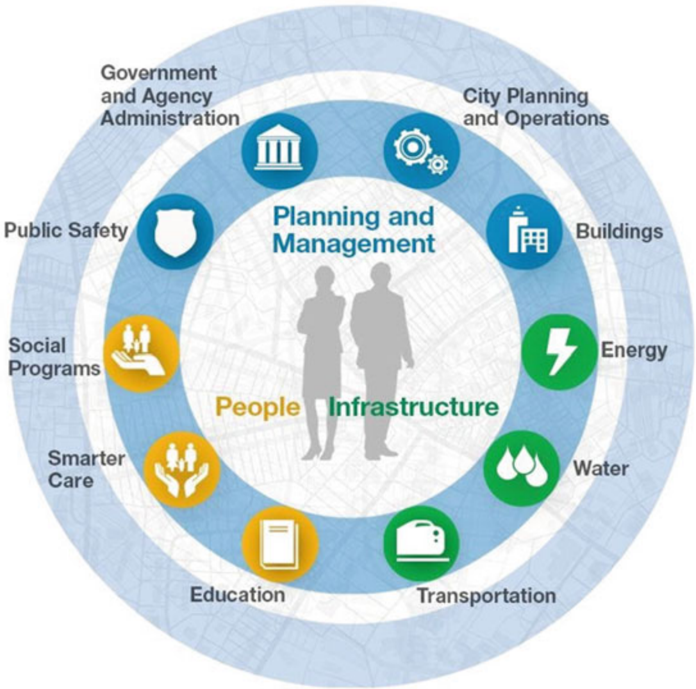

Fig. 2 IBM smart city model. (Source: [7])

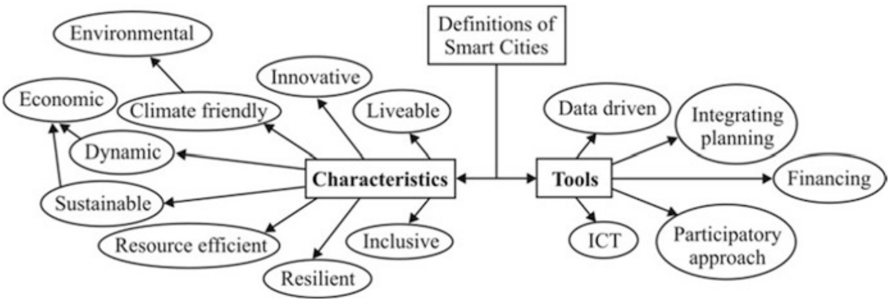

Fig. 3 Characteristics and tools of "smart" cities. (Source: [8])

As already mentioned, an increase in population can bring several problems in terms of mobility, economics, and politics. Smart cities show the impact that technology can have in solving these problems.

Figure 2 illustrates IBM's proposal for a "smart" city which encompasses three main application areas for citizens. Each section entails a range of subareas and projects [7].

A smart city must employ certain features and tools to support the model depicted in Fig. 2. Figure 3 shows a graph with the necessary interconnections between

Table 1 Areas of application of "smart" projects. (Source: [8])

Area of application	Description	Examples
Smart buildings	Smart buildings incorporate the advantages of communication and control systems	Optimizing the hearing systems, ventilation, and air-conditioning
Education and medical and social care	Applications that allow improving the activity in these domains and ensure access to all citizens to high-quality services	Telemedicine for monitoring older people
Smart energy	An intelligent electrical energy system interconnects all utilities and end users via an intelligent infrastructure	Smart grid applications, optimization of network operation, compliance with environmental standards, and smart lighting
Smart grid (smart metering of natural gas, water and electrical energy)	Real-time consumptions metering of energy, water, and natural gas	Consumption information online: wireless intelligent meters
Smart utilities (smart water distribution and smart waste management)	Intelligent management of the water distribution system and wastewater	Intelligent wastewater systems and real-time solid waste monitoring
Smart parking	Managing parking places using sensors and CCTV	Monitoring systems of the vehicles
Integrated supply systems	Synchronizing the supply with the demand and measurement, monitoring, and organization of the transportation around the supply chains of the cities	
Smart and integrated transport	Traffic monitoring and real-time optimization using and combining all transportation means	CCTV for traffic, smart parking networks, and minimizing the environmental impact

the components and tools. Among the characteristics, it is possible to observe, for example, the climate-friendly connection, which is linked to the environment, moreover the link to dynamics and sustainability where both relate to economics. The tools mentioned in the image are data-driven, integrating planning, financing, participatory approach, and ICT (digital infrastructures) [8].

Lastly, Table 1 shows a list of the most common applications, the description, and the examples of the project's purpose. There are several areas where the intelligence concept can be applied, such as smart buildings, education, medicine, social care, and energy. The first example is related to intelligent buildings that can incorporate the advantages of communication and control systems. One of the examples mentioned is the optimization of hearing systems, ventilation, and air-conditioning [8].

2.1 Portuguese Demography

It is necessary first to present statistical data on the country's demographics. According to the Statistics Portugal, the resident population in Portugal consists of 10,295,909 people according to the last information provided (in 2017). One hundred fifty-nine cities distribute this population. The most populated cities in Portugal are located on the country's coast in the following order: Lisbon (the capital), Porto, Braga, and Coimbra. Population density is remarkably higher in the country's coastal zone. Consequently, most services and industries are also located in these areas.

Regarding education and literacy, according to the 2011 census by INE (National Institute of Statistics), the illiteracy rate was 5.2% [9]. Despite being a minimum number, Portugal is still at the bottom of the list compared to the rest of Europe. This indicator may also be one of the causes of the lack of technological and computer knowledge, which presents a barrier to technological innovation.

On another topic, in 2017, according to the Statistics Portugal [10], 71.5% of households have a computer, and 76.9% have an Internet connection. In 2021, 87.3% have Internet connection. To understand the current state of "smart" cities and "smart" projects in Portugal, it is also crucial to present the government incentives for the digital transition and technological innovation.

Since 2016, a strategic plan for digitization has been implemented: INCoDe.2030 [11], "a national initiative to foster digital skills." Promoted through the Coordination Office of INCoDe.2030 Initiative in cooperation with the Portuguese Science and Technology Foundation (FCT), the Portuguese Innovation Agency (ANI), the Ciência Viva, and the Portuguese Agency for Administrative Modernisation (AMA). According to the official papers, this consists of "an innovation and growth strategy to foster Artificial Intelligence in Portugal in the European context."

This plan presents and proposes specific measures and actions for several areas of the country, such as the following:

- Areas of specialization in Portugal with global impact:
  - Natural language processing
  - Real-time decision-making with AI
  - AI for software development
  - AI for edge-computing
- Areas for research and innovation in European and international networks:
  - AI and urban transformation through sustainable cities
  - AI and sustainable energy systems
  - AI, environment, and biodiversity: from forests and green economy to marine species and blue economy
  - AI, mobility, and autonomous driving
  - AI and cybersecurity
  - AI and health

  - AI and industry
  - Fundamental research for the future AI

- Public administration and its modernization:
  - Qualification and specialization

- Inclusion and education: disseminating generalist knowledge on AI:
  - Digital inclusion
  - Education

- New developments and supporting areas in European and international networks:
  - Advanced computing: supercomputing
  - Quantum materials and quantum computing
  - Facing societal challenges brought by AI: ethics and safety

The INCoDe.2030 strategy will be monitored by a committee coordinated by FCT (Foundation for Science and Technology), and its supporting document will be annually reviewed. The program INCoDe.2030 is promoted by the Institute of Support to Small and Medium Enterprises and Innovation – IAPMEI – created in 1975. This institute helps micro to medium enterprises grow through internationalization initiatives and strategies. One of the priority areas is digital transition. In this sense, IAPMEI acts in several plans, participating and promoting a set of programs and initiatives to support companies in this transition. Besides the INCoDe 2030 strategy, this institute also supports the following:

- "Portugal digital" is an action plan designed to be the digital transformation engine of Portugal through the training of people, the digital transformation of companies, and the digitalization of the state [12].
- "Indústria 4.0" (in English, "Industry 4.0") is an initiative integrated into the National Strategy for the Digitalization of the Economy that intends to generate conditions for the development of the industry and national services in the new paradigm of the digital economy [13].
- "Open Days i4.0" – The i4.0 Open Days are also promoted by COTEC Portugal and are part of the "Indústria 4.0" initiative. The objective of these days is to demonstrate how companies can adopt the different concepts of the new paradigm and promote the sharing of experiences [14].
- "Formação da Academia de PME" (in English, "Training of the SME Academy") regularly encourages initiatives on topics related to digital transition. The main goal is to empower the entrepreneurial community with the capacity to answer the challenges posed by the new paradigms brought by this new reality [15].
- "SHIFT2Future" is a program also promoted by CTCV (Technological Center for Ceramics and Glass), TecMinho, University of Aveiro, and ISQ (which coordinates the project) that includes a set of actions to prepare SMEs (small- and medium-sized enterprises) for the digital economy [16].

- "SHIFTo4.0" is a self-diagnostic tool that allows companies to evaluate their state of digital maturity, obtaining, at the end of a survey, a report with guidelines to improve the way forward for Industry 4.0 [17].
- "Enterprise Europe Network" is a support network for SMEs and startups with international ambitions created by the European Commission. In Portugal, this network is formed by a group of public and private entities that are part of a consortium – EEN (Enterprise Europe Network)-Portugal – led by IAPMEI [18].

On another topic, the European Institute of Innovation and Technology (EIT) inaugurated its first facilities in Portugal on June 26, 2019. This installation results from the growing national participation in European programs and will be implemented through the "EIT Digital Braga Satellite" community. It will be the first of these centers in Portugal. It will be based at the "DTx Collaborative Lab – Digital Transformation," with headquarters at the campus of the University of Minho. It is oriented to stimulate innovation and economic development activities through collaboration between higher education institutions and industry in digital cities, digital finance, digital industry, digital technology, and digital welfare [19].

2.2 *Overview of "Smart Cities" in Portugal*

According to the European Investment Bank, Portugal presents one of the highest indexes of digitization among the countries of the European Union: "Portugal is above the average of the EU and the United States (USA) for the "internet of things", in the infrastructure sector, and for platforms, in the services sector" [20].

Considering the "smart" concepts presented in the introduction (Sect. 1) and the data from the European Investment Bank, the main objective of this section is to analyze the current situation in Portugal and simultaneously reflect on what can be done.

Although this data is very encouraging, a recent study showed that only 40% of Portuguese companies had initiated the digital transformation process. Within that percentage, most of them have implemented fundamental processes and strategies, meaning that areas such as accounting, data management, billing, and the legal area are still behind. Therefore, considerable space must still be part of the digital transformation process [21].

In Portugal, the reality of most public processes is old and bureaucratic, and a large part is still done traditionally on paper. Most of the country's management bodies lack modern and functional digital tools – government, finance, justice, hospitals, and education. As previously mentioned, streamlining processes is even more urgent due to the current reality of the COVID-19 pandemic, especially in a country with old and time-consuming management tools.

In this sphere, building intelligent and interconnected cities with innovative and practical tools to manage most processes can be the solution to most of these problems. However, it is essential to mention the importance of informing and educating citizens about digital tools and processes.

A handful of "smart cities" ideas have been tested in several cities, regardless of how much work is still to be done. When investigating this topic, it is possible to observe that the Portuguese media is interested and well-informed, educating the masses on this subject. Several newspapers and magazines have researched smart cities, sharing relevant information on this topic and examples of what is being done in Portugal.

According to the Smart City Index 2021 [22], the city of Lisbon appears in 95th place, yet the previous year scored 75th place. The ranking of the most innovative cities in the world was prepared by the Institute for Management Development (IMD) in collaboration with the University of Technology and Design in Singapore. This index ranks based on economic and technological data and citizens' perceptions of how "smart" they consider their cities to be.

The most relevant entity that should be highlighted is the Portuguese Network of Smart Cities – RENER – also denominated RPCI (Portuguese Network of Smart Cities). RENER (or RPCI) is a living lab created in 2009 and developed by Inteligência em Inovação, Centro de Inovação INTELI (a private nonprofit association) and with partners such as general cash deposits and AICEP (Agency for Investment and Foreign Trade of Portugal).

Initially, the main goal of this project was to analyze 25 municipalities and, later in 2013, analyze another 18 and consider more areas of intervention, these being "energy efficiency, energy sources, water and waste management, governance and citizenship, culture and tourism." In 2012, it developed an "Intelligent Cities Index" to attribute a ranking to Portuguese cities regarding the level of digitalization they present. This index considers a set of indicators integrated into five dimensions, innovation, sustainability, connectivity, governance, and inclusion, each with subdimensions. This index considers the Portuguese of Almada, Aveiro, Cascais, Lisbon, and Vila Nova de Gaia as "smart" [23].

3 Material and Methods

This section describes the material and the methodology used for this paper. Figure 4 presents the workflow of the study. The first step was identifying and finding project documentation considered "smart." The goal was to find as many national and local projects as possible. As such, a general search was carried out based on predefined keywords "smart cities in Portugal," "digital project," and "innovation and process digitization" to identify and select the most important papers to read. Then, the selection was made by name, publication date, and abstract. Data did not add quality, or relevant information was excluded.

The next step was to nominate each project as an event or application. Step three split the projects into different tables, one with the projects and events applied at a local level (municipalities, cities) and another with projects and events developed at

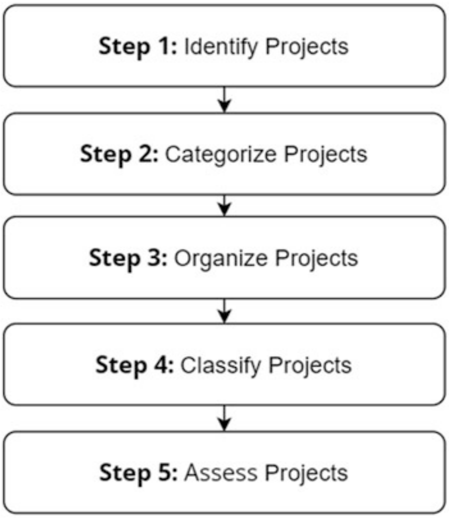

Fig. 4 Case study steps. (Source: Adapted from Refs. [24–26])

a national level. Consequently, it was specified for each project the area in which they should contribute.

The last step, assess projects: assess if each project fits into three subareas – mobile/web app, mobility, and space management.

3.1 Case Study Methodology

When it is difficult to understand a phenomenon studied and its natural context, the case study methodology is used. Some characteristics make this methodology a different research method from the existing ones, namely, elaboration of the research question, procedures, data collection, subsequent analysis, and validation criteria. It should be noted that the research question must answer the "how" and "why" this study is being developed based on a contextual explanation that describes the information system under study, in this case, intelligent cities in Portugal. Table 2 presents research strategies that help develop the methodology [27].

Some of the key features of the case study are enumerated in the following list:

- The study must be developed in a natural environment, based on various sources of evidence and data collected from different media and entities [27].
- To obtain a good result, the researcher must have a positive attitude toward the analyzed data [27].
- Theoretical propositions must be developed, so that data collection and analysis are objective and coherent [27].

Table 2 Case study methodology strategies

Strategy	Question form	Requires control over behavioral events	Focuses on contemporary events
Experiment	How, and why?	Yes	Yes
Survey	Who, what, how many, and how much?	No	Yes
Requirements analysis	Who, what, how many, and how much?	No	Yes
Historical research	How and why?	No	No
Case study	How and why?	No	Yes

One of the processes that complement the case study methodology is benchmarking. In this case, phases 2 (survey), 3 (requirements analysis), and 4 (historical research) of the case study methodology were carried out based on this analytical process.

3.2 Benchmarking

Benchmarking is an analytical process that allows the analysis of other projects/initiatives/companies to identify added value that will make the efficiency and performance of the project under development more complete and adequate [28].

Benchmarking presents five steps that help understand the process necessary for a good change (Table 3). In the table, it is possible to see two columns, one with the name of the step and the other with its description [28].

As described in Sect. 3, a search was carried out on projects, services, or events that included the mentioned keywords. The research strategy was based on manual processes. The relevant information for the topic was found by visiting specific sites and auxiliary platforms such as Google Scholar, Science Direct, Google, Web of Science, Scopus, and the University of Minho repository, where various articles are available. Also, the list of references for a given theme makes it possible to find references to articles relevant to the project's development. Then, the selection was made by name, publication date, and abstract. Considering the background of the report, the data that did not add quality or relevant information was excluded. Only all projects concerning Portugal were filtered.

This survey took place between January 2021 and March 2022. The phases related to benchmarking are described in Sects. 4.2, 4.3, and 4.4.

Table 3 Benchmarking steps

Step	Description
Planning	At this stage, it is essential to understand the objectives and what is necessary to look for to improve the project's performance compared to other existing projects.
Collection of information	After the objectives are well defined, it is necessary to start collecting information about the competing processes.
Analysis of data	With all the information already collected, it is necessary to analyze each process in detail and understand the problems and added value.
Action	It is necessary to understand the changes that will be beneficial and define an implementation plan.
Monitoring	It is necessary to monitor the results to determine success. For this, metrics and objectives must be defined to assess the success of the change.

4 Study

The workflow described in Sect. 3 was followed for the development study, and the methodology is presented in Sect. 3.1.

4.1 Experiment

The first stage involved studying the concept of a "smart city" and all the related terms and projects considered "smart" under that definition. Despite the recent emergence of "smart cities," this study seeks to understand whether such projects are implemented in Portugal. By listing all the projects at each city and national level, it is possible to analyze and conclude the current state of intelligent Portuguese cities (Sect. 2.2).

Before starting any research or analysis on the current state of intelligent Portuguese cities, it is necessary to know the Portuguese demography (Sect. 2.1). This data was researched on INE (Statistics Portugal), the primary source of demographic information.

After considering the reality of Portuguese society and population distribution within the country, it is also necessary to be informed on all the contexts of technology and innovation. In light of this, the statistics and background information on companies, initiatives, and projects related to innovation and technology were researched and presented.

4.2 Survey

After gathering all the statistical information on demographics and the current state of digitization and technological innovation, the primary step of this study was initiated: a survey of all the projects considered "smart," innovative, and technical that would contribute to the construction of intelligent cities. Considering the concepts and the general information researched to define a "smart project" or a "smart city," the survey was developed to find projects and ideas that fit those concepts (described in Sect. 1).

The goal was to find and present a list of all the "smart" projects, initiatives, platforms, and ideas developed in each Portuguese city.

4.3 Requirements Analysis

The collected information projects at the local and national levels could be old and already concluded/finished, current, or futuristic. They could also be of any kind: public or private. The objective is to list all projects as possible to conclude the country's general and current situation.

It is important to recall that this study's stages were initiated, developed, and concluded during the COVID-19 pandemic. Therefore, the research was exclusively conducted using online and digital sources.

Even though there is plenty of information available online, it takes a long time to find updates on the status of each project, specifically if it has already been applied and closed or is still in use in each city or area. Several entities were contacted, and the information is displayed in this study. However, some projects have no contact method, making accessing current and updated information impossible. Furthermore, as mentioned before, due to the present world's pandemic provoked by the virus COVID-19, it is impossible to contact each entity physically.

This study did not consider research projects not applied in a Portuguese Municipality.

4.4 Historical Research

All historical research followed the search strategy mentioned in Sect. 3 to obtain the most relevant articles for the case study. An essential tool to be mentioned is *Smart Cities Magazine*, a quarterly magazine dedicated to sustainable, intelligent cities that covers projects, solutions, and trends in information and communication technology, environment, social innovation, health, education, urbanism, and mobility. This magazine added much content to the survey, allowing to research all projects and ideas nationwide in one place. This way, the most important and relevant information mentioned in this study was filtered and presented.

4.5 Case Study

The case study identified 68 innovative initiatives (62 city and 6 national projects) in Portugal covering several areas, such as mobility, governance, economics, environment, and energy. All these initiatives contribute to the country's evolution and citizens' quality of life. The results of this study are presented in Sect. 5. The workflow of the case study is described in Sect. 3.

After identifying smart city initiatives in Portugal, each was defined as an event or project. Then, two tables were built, one with the initiatives at the local level and another with the initiatives at the national level. For each initiative, the area in which it operates was specified, date of creation, and description, among other relevant characteristics. Finally, assess if each project fits into three subareas – mobile/web app, mobility, and space management.

5 Results

Several projects, digital platforms, and related public events were discovered when researching "smart" projects following the mentioned tools and methods (Sect. 3). Therefore, the case study first presents all the events and the Portuguese "smart" projects.

5.1 Events

Smart cities also assume relevance at the level of the media and the Portuguese social side. A reflection of this is the number of social and cultural events focused on the "smart cities" theme. The first event to be mentioned is the "Portugal Smart Cities Summit," exclusively dedicated to "smart cities," presenting conferences and meetings and providing necessary information regarding this topic. In 2020, due to the world's pandemic, it adopted a digital format.

Another Portuguese event is exclusively related to this concept, named the "Smart Cities Tour." This national initiative consists of thematic workshops carried out in six Portuguese cities. It was developed by the National Association of Municipalities (ANMP) and Nova's Urban Analytics Lab Information Management School in partnership with the Altice Portugal, CTT, EDP Distribution, and Deloitte. The aim is to share knowledge between municipalities, like innovative solutions at the city level, and develop concrete projects event in the "Smart Cities Tour," in which the first edition took place in Valongo in 2020. It was dedicated to the "Challenges and Opportunities for 2030," having "Circular City" as the central theme. The following editions occurred in Évora (theme: Smart Grids and Zero Carbon Energy Communities), Covilhã (theme: Sustainable Mobility), Monchique (theme: Smart Tourism), Oeiras (theme: Intelligent Innovate), and Coimbra (theme: Summit of Mayors) [29].

The last event found was "Smart Travel," dedicated to the thematics of "smart cities" and "smart travel." Since 2014, more than 150 national and international speakers have participated in this event, representing municipalities, institutions, companies, and academia. It focuses on the future of urbanism, tourism, and sustainable ecosystems [30].

Another related topic is the "Annual Conference of the Portuguese Association of Energy Economics" (APEEN). The energy transition and sustainability were the main themes of the 2021 edition, gathering scientists and internationally renowned business innovators.

5.2 Projects

Two types of projects were identified, projects at the local level and projects at the national level. Table 4 presents the list of Portuguese cities implementing intelligent concepts and ideas. These projects may already be finished or still under development. For each identified city, the project's date of creation/implementation is presented and the category (if it is an event or project), the name, and the area in which the project is inserted. Since it is impossible to know whether each project is still operating, a column is provided (info) for the last year in which any news or information about the project was found. Finally, each is evaluated to identify whether it fits into any of the three subareas presented (mobile/web app, mobility (Mob), and space management). These three aspects were analyzed due to the ioCity project, in other words, the importance of having an application with access to all information, promoting and monitoring collective mobility in cities, and having a solution for managing spaces and car parks.

It is important to note that the events mentioned in Sect. 5.1 are presented again in this section. Although the table only shows 10 examples of the most recent projects, 62 projects were identified at the local level. A complete table is provided in the file

Table 4 City-level projects

District	Date	Category	Name	Area(s)	Info	App	Mob	Space
Cascais	2018	Project	C2 – Centro de Controlo de Cascais	Governance	2020	No	No	No
Madeira	2018	Project	Porto Santo sustainable Smart Fossil Free Island	Reducing CO_2 emissions	2020	Yes	Yes	No
Porto	2018	Project	AYR Credit	Environment, economy, and people	2020	Yes	Yes	No
Aveiro	2019	Project	Aveiro Tech City	Infrastructures, 5G, and IoT	2022	Yes	Yes	No
Lisbon	2019	Project	H2O Quality	Environment and living	2022	Yes	No	No
Lisbon	2019	Project	"Intelligent sensors"	Environment and living	2019	Yes	No	No
Porto	2019	Project	URBiNAT	Environment	2022	No	No	No
Porto	2019	Project	SynchroniCity	People	2020	Yes	No	No
Lisbon	2020	Event	UP – Upcoming Energies	Companies and people	2021	No	Yes	No
Braga	2021	Project	B-Smart Famaliacão	People, environment, living, governance, economy, and mobility	2022	Yes	Yes	Yes

attachment.[1] The complementary material presents the description of each referred project.

Table 5 presents the projects that were developed at the national level. Table 5 shows the municipalities, the project's creation date, the category, the name, the area, and the date of the last information found. Access the complete table through the file attachment. The complementary material presents the description of each referred project.

Figure 5 shows the number of local-level initiatives by district. The total number of initiatives created in the country's north, center, and south is counted, as well as projects on Portugal's coast, interior, and islands.

[1] Link with the entire study.

Table 5 National project

Municipalities	Date	Category	Name	Area(s)	Info
Barcelos, Bragança, Viana do Castelo, Porto, Aveiro, Covilhã, Leiria, Lisboa, Évora, and Beja	2016	Project	u-bike	Mobility	2022
National	1991	Project	Via-Verde	Mobility	2022
National	1992	Program	Agenda 21 Local	Environment	2021
Portalegre, Lisboa, and Lagoa (Algarve)	2015	LPWAN	Long Range (LoRa)	Communication	2021
National	2017	Project	Open Days i4.0	People	2020
National	2017	Project/program	C-ROADS PORTUGAL	Communication	2021

Figure 6 shows 68 projects found in Portugal (62 city-level projects and 6 national projects).

The pie chart (Fig. 7) shows the percentage of projects with the necessary strands for the IoCity project. In this case, only 6% have the three essential subareas.

The bar chart (Fig. 8) shows the number of initiatives created annually. For example, in 2019, six initiatives were created. Due to a lack of documentation, some projects made it impossible to perceive the creation date. Therefore, ten projects appear as ND – not defined in the image. The pie chart is a companion chart showing the percentage of initiatives grouped into three sections, rates of initiatives created before and after 2018 and initiatives that do not have a date. Between 1910 and 2018, 66% of the initiatives were identified.

Finally, Fig. 9 shows the areas where the projects are inserted. The area of mobility, people, sustainability, and governance are the most common projects in Portugal.

Local	Total number of initiatives
North	37
Center	19
South	3
Coast	52
Interior	8
Islands	2

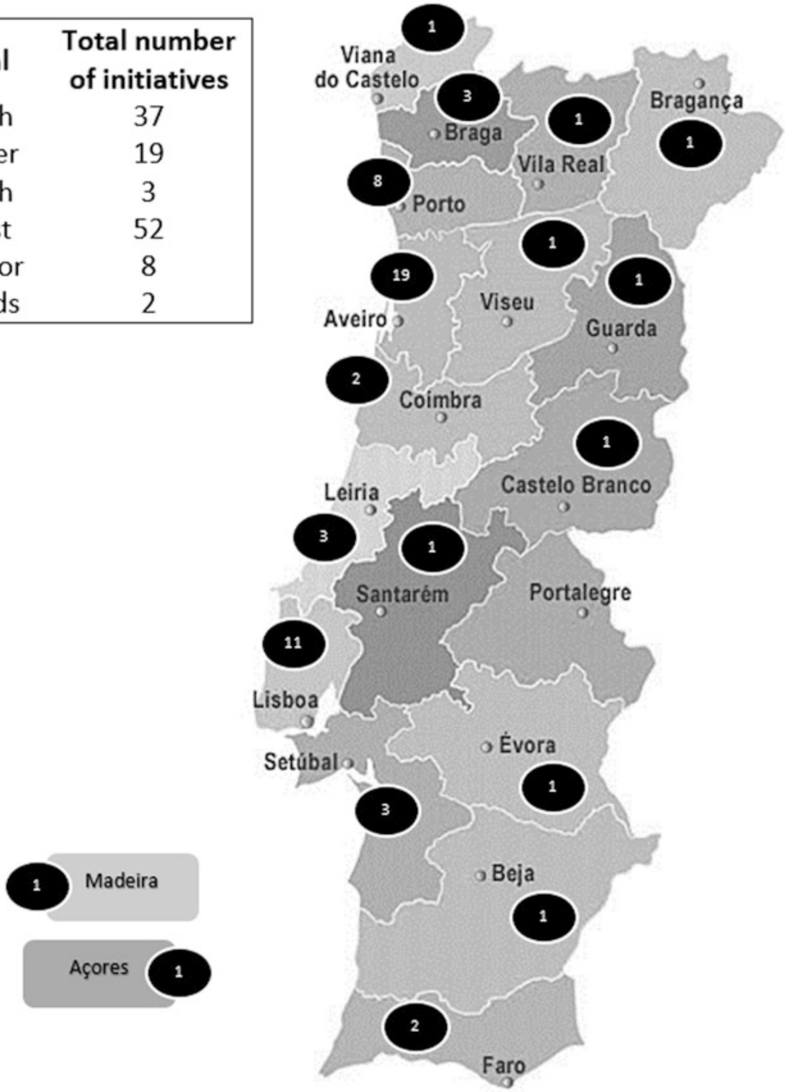

Fig. 5 Projects at the local level

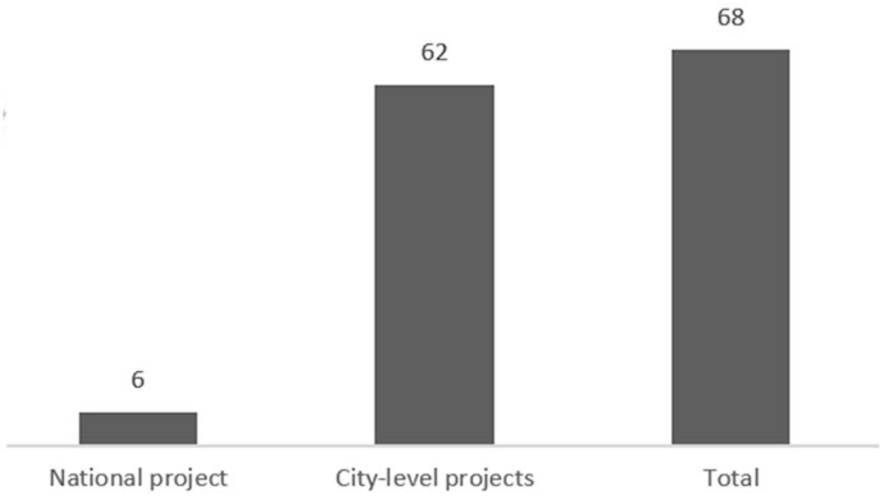

Fig. 6 Number of projects

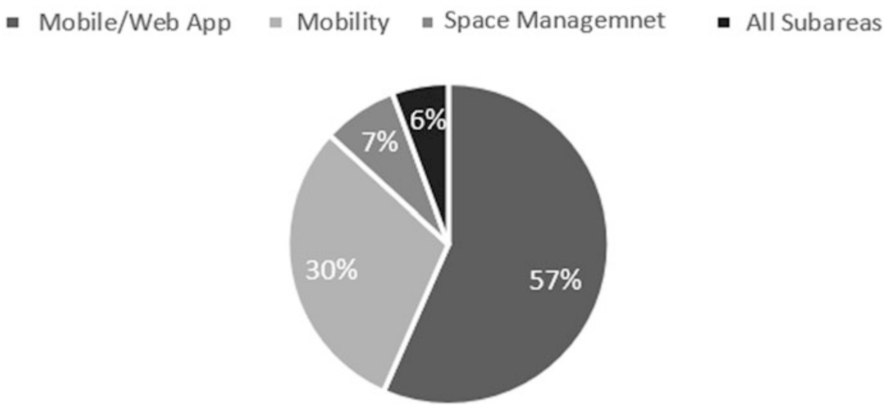

Fig. 7 Percentage of the three subareas

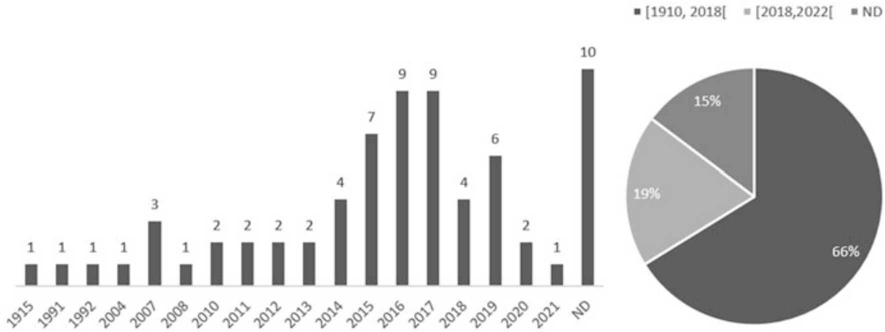

Fig. 8 Count of date of creation/implementation

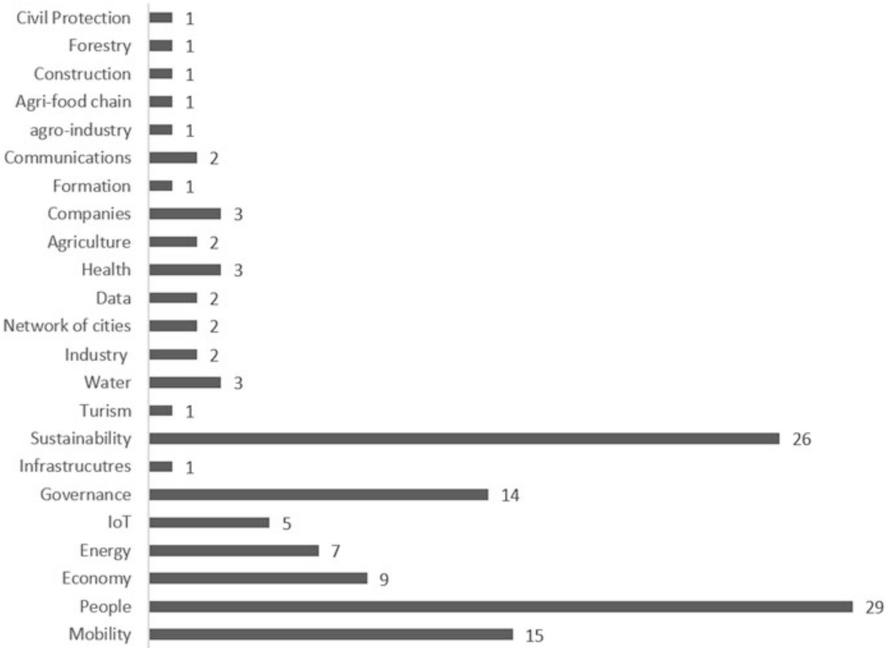

Fig. 9 Count of areas

6 Discussion

The results in Tables 4 and 5 make it possible to conclude and indicate good practices and strategies for smart cities.

Regarding Table 5, the "Via Verde" project stands out. Via Verde is an automatic toll payment system that can be found on highways, parking lots, restaurants, gas stations, and other services. It is one of the country's longest-running and most important projects and has made Portugal the first country in the world to have an integrated network of nonstop electronic tolls. According to the data on the official website [31], it has more than three million users and covers more than 3000 km of highways.

At the local level, the b-smart project aims to develop an urban intelligence platform that combines several intelligent tools in the municipality's management. This project aims to create an innovative city that is both inclusive and modern. Famalicão is in complete transformation, investing in several areas, such as better energy and environmental management. Innovation in infrastructures and mobility are also goals to be developed. For the town to grow in the direction of an innovative, sustainable city, an application called a control center was designed, which processes, cross-references, and analyzes all day-to-day information tow that the territorial management can be more efficient.

It can be observed (Fig. 5) that the cities with more "intelligent" projects are located on the country's coast: Porto, Aveiro, and Lisbon (52 projects were developed). There is a lack of "intelligent" projects and initiatives, especially in the country's interior. Only eight projects were created (Fig. 5). On the islands, only two projects were identified (Fig. 5).

Most projects are related to sustainability (26 projects), people (29 projects), and mobility (15 projects), and there is a notable lack of investment in digitalizing public services (Fig. 9). Projects can be associated with more than one area.

The north of the country demonstrates a more significant initiative in the development of smart cities (37 projects implemented) compared to the center (19 projects created) and the south (only 3 projects developed) (Fig. 5).

It is possible to see that 68 projects were observed in total (Fig. 6). The number of projects and cities is different because some projects take place in more than one city. For example, Braga has three projects (Fig. 5).

Most of the initiatives were created before 2018 (66%). Only 13 of the 68 projects were built after 2018 (19%). In the last year, 2021, only one initiative was identified (Fig. 8). Ten of the identified projects do not have a creation date and are therefore placed in the chart as ND (15%) (Fig. 8).

It can also be noted (Fig. 7) that 30 of the projects acting at the city level, or approximately 57% of the projects submitted, plan to provide a mobile/web application to the public to view/interact with the information provided.

Additionally, 16 projects aim to improve the mobility of citizens, which is about 30% of the projects. It can also be found that only four projects offer, in some way, a tool that helps in the management of occupied space, representing 7% of the listed

Table 6 SWOT analysis of "smart" cities state in Portugal

Strengths	**Weaknesses**
Despite being at an early stage, there are a lot of "smart" initiatives Good support from the government Involvement of the public in some events to take advantage of their opinion Contributes to sustainability	The context of "smart projects" in Portugal is still fragile Uneven distribution of ICT throughout the country's territory Even though there is a need for digitization, its costs are high Individual projects Non-scalable projects
Opportunities	**Threats**
Educate young generations to spread the idea of "smart cities" Numerous areas have not yet been explored The demand to improve people's lives Take advantage of European funds Create a "network" of intelligent cities connected	Resistance from older generations Due to the population's demographic distribution, some areas of the country may be left behind Political options

projects. Only three projects present a solution with these criteria (mobile/web app, mobility, and space management) (6% of the projects).

To summarize the discussion of the results obtained, a SWOT analysis was developed that briefly presents the strengths, weaknesses, opportunities, and threats (Table 6). For example, one of the opportunities mentioned is to improve citizens' quality of life. However, on the other hand, there is a threat of resistance from older generations.

7 Conclusion

This study presents a complete survey of good practices applied in Portugal regarding developing smart cities. As the smart cities industry is constantly evolving, it is essential to follow the progression and explore promising practices that offer several advantages to cities.

The evolution of humanity is atypical. The human being is the only known species that has not evolved to adapt to the environment. Instead, the environment becomes adapted to humans. This "evolution" caused complex problems, on several levels, from the environmental to the political. Thus, it is necessary to start working to solve these problems, seeking solutions through technological innovation.

Like many other nations, Portugal started to develop and implement projects that helped to combat these problems. Identifying intelligent city strategies and promising practices that allow a better quality of life can contribute to a sustainable planet and better city and resource management.

Despite the technological innovation that Portugal has been acquiring and developing recently, it is increasingly necessary to follow the progression and evolution. According to the Smart City Index 2021 [22], Lisbon is the only city in the top 100 smart cities. From 2020 to 2021, it dropped 20 places in the ranking, finding itself in 95th place in 2021. This means that the panorama of "smart" initiatives in Portugal is stagnant and that it is necessary to invest in more "smart" initiatives. It is possible to observe that only one project was created and implemented in 2021. The District of Portalegre does not present any initiative, and the rest of the cities in the interior of Portugal only show one initiative each. The coast stands out with 52 initiatives.

From this research, only six projects were found that operate at a national level. Another 62 are/will be implemented at a regional level. More than half of the initiatives (66%) were created before 2018.

The investment and creation of such initiatives would most likely be an asset to the population's lifestyle. This study presents strategies and initiatives to be adopted in the future for developing smart cities in Portugal. Through state-of-the-art development and with all the initiatives found, it is possible to identify projects that would be an asset to the ioCity project in the field of mobility. In this case, three projects should be analyzed in detail as they present the three crucial subareas for ioCity: mobile/web app, mobility, and space management. These projects are B-Smart Famalicão (Braga), Smart Parking (Guimarães), and Be Águeda (Aveiro). Only 6% of projects have the three subareas required for ioCity.

In addition to the article's contribution to the ioCity project, it is also crucial to understand that Portugal has to follow the evolution and bet on the growth of smart cities, creating better conditions and quality of life for the population. National-level projects should be implemented, and the country's south, interior, and islands should create more initiatives to grow cities. Despite the resistance to the evolution of towns (by older generations and political decisions), the opportunities for better education, a better quality of life, more use of resources, and cities' and environmental sustainability are an asset for development and growth.

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Intelligent Dashboards for Car Parking Flow Monitoring

Francisca Barros, João Oliveira, José Vieira, Carlos Fernandes, and Filipe Portela

1 Introduction

Parking is essential for car drivers, and accessibility is affected by the number of cars and destinations. Parking has two types of problems. The first is regarding the offer, such as the few available spaces. The other is mismanagement and inefficiency in using available facilities [1].

Through the recently emerged technologies with Industry 4.0, the cities innovate, create more intelligent services and offer new products to citizens. The term smart city was born when it used technology to improve citizens' quality of life. Several cities have started to use electronic sensors to collect data, work with it and use it for decision-making [2].

However, a large amount of data appears daily, making data integration more complex, and that valuable information is more difficult to extract. The great challenge is transforming collected data into valuable insights [3].

Consequently, technology allows the analysis of multidimensional data and the viewing of it from different angles. This technology calls OLAP and enables data analysis from multiple and heterogeneous databases. OLAP cubes have many advantages, but the most important is the possibility of aggregating and displaying vast volumes of data with rapid and efficient access. Depending on what users want, the data can be shown sliced, diced and rolled up [3].

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There are three types of OLAP: relational OLAP (ROLAP), multidimensional OLAP (MOLAP) and hybrid online analytical processing (HOLAP). The differences between these models are data storage and technique [4].

This article aims to show that when all combinations for a data cube are developed and predefined, the response time and performance improve substantially, providing a faster and more helpful view of the data for the user. In this case, we will obtain useful data for management parking. This business intelligence project followed the Kimball's methodology. First, a survey of the park's data was carried out to understand what indicators could be obtained, namely, parks, busiest days and hours and parks with higher monthly, daily and annual crowding rates, among others. The data was extracted, transformed and loaded into the data warehouse to build an efficient OLAP engine. In the construction of the cubes, pre-aggregations were carried out to respond to the indicators quickly and objectively.

This chapter is part of the ioCity project and is developed by IOTECH (Innovation on Technology) (a startup that aims to solve social problems by developing intelligent and innovative solutions). This research project is supported by public funds and aims to help solve the challenge caused by transport and traffic. In this way, ioCity proposes, through the analysis of a set of data (sensors, occupancy rate, traffic and parking, among others), to help the customer have a more informed and real-time decision regarding car parks and public transport.

This chapter is organized as follows: the Introduction presents the basis for this work. The second one talks about the background of the article, the most critical aspects and workflow. The third chapter describes the material and methods used. The next one is about a developed study. In the six chapters, the analysis results are presented and then the discussion of these outcomes. The last chapter is a conclusion that launches the basis for further work.

2 Background

This section described relevant elements to the project, like parking management, ETL (extract, transform and load), KPIs (key performance indicators), BI (business intelligence), DW (data warehouse), OLAP (online analytical processing), data analytics and related works. Numerous studies were analysed, and information was taken off from the most relevant topics about each theme. The ioCity project is also presented in more detail.

2.1 Parking Management

Transport and congestion are showing an increasing trend in the most developed economies, which causes an increase in the time spent looking for parking, a more significant expense of fuel and consequently more money [5]. This inefficient parking planning causes several economic, social and environmental problems. It is essential to adopt management strategies that result in more efficient use of resources to solve existing problems without reducing the offer to users [1]. To have a better and more informed management of the park for the user, a study is needed to analyse the data to understand where the change is significant.

2.2 Business Intelligence

The business intelligence (BI) system provides users with historical information for analysis, consultation and reports that support management and decision-making that enable significant changes to improve the efficiency of business processes. BI makes it possible to transform internal and external data into meaningful information that guides the company to become or remain sustainable and competitive. Among many advantages, it is essential to highlight the acquisition of quality information, the ability to analyse opportunities and threats and a better analysis of the information that allows for the growth of organizational knowledge [6].

2.3 Data Analytics

Understanding and analysing the data in detail is essential to get the most out of it and obtain the best indicators for the business. Without this detailed analysis, it is difficult to perceive the opportunities and threats of an organization (for example), which is why data are an asset for companies because without them, it would be impossible to draw basic conclusions about competitiveness and success. Realize the reality and the context and extract valuable insights from the data that help the decision-making process [7].

2.4 Extract, Transform and Load (ETL)

The ETL process is divided into three phases, extract, transform and load. First, the data were analysed to understand how they were organized and what was most important for the final objective. Then, the errors detected were corrected, and the desired columns were loaded for the data warehouse dimensions. Fact tables are usually loaded through associations to dimensions and facts [8].

2.5 KPIs

Key performance indicators (KPIs) are management tools that monitor the performance and success of an organization's objective. Through these indicators, it is possible to quantify the status of the purposes and understand the best strategy to adopt to achieve the success of the established goal [9].

2.6 Data Warehouse

Data warehouses (DW) are central data repositories from one or more sources and can store current and historical data in a unique location. A multidimensional model is a type of modelling used in the design of data warehouses. This type of modelling emphasizes identifying, modelling and implementing critical business processes. A multidimensional model is composed of fact and dimension tables. The fact tables contain the business indicators necessary for the intended analyses, while dimensions control descriptions describe the points [10].

2.7 OLAP

Online analytical processing (OLAP) is a tool that allows users to analyse relevant information from different points of view and in various combinations. By connecting to a database, the system enables the visualization of statistical reports that allow extracting, consulting and retrieving data [4].

2.8 Related Works

This subsection presents a study on the importance of an OLAP system in civil construction and explains ioScience, an approach that is the data science basis of this project.

In civil construction projects, work delays and budget increases during the construction process are recurrent, causing problems between the owners and those responsible for the work. This is due to inadequate management of labour resources. To combat this management problem, a detailed analysis was conducted at the level of industrial construction, and data collection was carried out for a later study. Consequently, a data warehouse was built for further OLAP analysis with the collected data. This way, reports and dynamic graphs of online analytical processing were obtained, where it was possible to extract critical knowledge for better management of the civil construction industry. The results obtained make it possible to get more detailed planning of the work and more real and effective management of resources that reduce delays and potential changes in the value of the work [11].

ioScience is an innovative data science framework that allows synchronizing structured and unstructured repositories [12] and accessing them offline. It is a modular and adaptable solution to process a large amount of data and extract relevant information from it [13] and will be the inference mechanism of the ioCity solution.

2.9 ioCity

IoCity is a project developed by IOTech and aims to solve problems caused by transport and traffic. After analysing various data, it is expected that a prototype demonstrating a decision-making support system that can be useful to the client will be modelled and developed. For this, it will be necessary to analyse the occupancy rate of public transport and the active monitoring of vehicle parking within cities. During the development of this project, two articles have already been prepared: An Analysis of Smart Cities Initiatives in Portugal and Opinion Clustering About Mobility Decisions: A Practical Case Study.

The first article aims to present a case study about most "smart" projects and initiatives among Portuguese cities, analysing the current state of smart cities in Portugal and demonstrating the evolution and impact technology has on cities.

The second article presents a study that aims to show the profile of people about the factors that influence decision-making about public and individual transport.

3 Material and Methods

This section describes the tools and methodology used and provides a clear and brief description of research procedures. A general search was carried out based on predefined keywords "parking management", "values of OLAP service" and "studies with OLAP for decision-making" to identify and select the most important papers to read. Then, the selection was made by name, publication data and abstract. Data did not add quality, or relevant information was excluded. Through the search, ten articles were obtained that helped to understand the impact of OLAP in decision-making and which steps are crucial to this mechanism. Understand all processes, since the data to a dashboard analytical that helps in the decision is the first thing to do for a good output.

Figure 1 presents the workflow of the study. The study started on May 9, 2022, and finished on June 3, 2022. After reading all articles, the dataset with parking data was analysed, and we understood what is possible to extract, transform and load to the data warehouse. Data that fit the needs of the final objective were analysed,

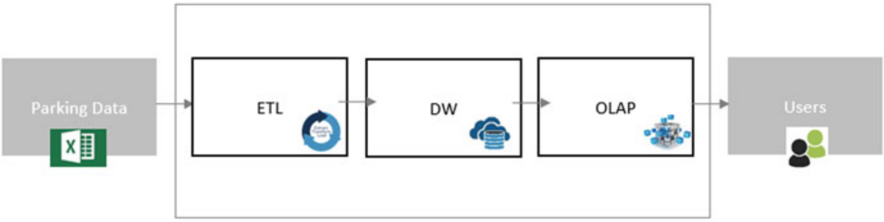


Fig. 1 Workflow of the Study

Table 1 Tools

Functionality	Tools
ETL	Microsoft Office Excel Panda's Library Visual Studio Code
DW	MySQL Workbench
OLAP	Cube.js

selected and verified their quality. At this stage, KPIs were also defined to help in the development process. The data warehouse was created with four dimensions and two fact tables. Consequently, the data was uploaded to the DW, and through cube.js, OLAP analyses were performed to respond to previously defined indicators. Functional analyses were obtained for the user through tables and graphs.

3.1 Tools

For the development of this project, several tools were used to achieve the intended objective and a favourable solution. The tools used before were being chosen to have undergone an analysis considering future needs. In this way, the team tried to ensure that it would use the most effective and coherent tools to develop this project. Table 1 shows the tools selected for each step performed. For example, for the OLAP engine, the tool used was cube.js.

The tools used are the following:

- *ETL* – The panda library is an open-source software that allows data analysis and manipulation [14]. This library and the Visual Studio Code tool allowed the development of open code capable of supporting the necessary operations for ETL development [15]. A spreadsheet, Excel, was also used for support operations and data analysis.
- *DW* – The MySQL Workbench tool was used to construct the multidimensional model, as it allows data modelling, developing queries in SQL, backups and visual database design, among others [16]. After data analysis, a data warehouse was developed to support parking management needs.

- *OLAP* – Cube.js is an open-source headless business intelligence (BI) that allows to pre-calculate and pre-aggregate data, creating an OLAP cube that makes analysis faster. The cube.js enables the connection to several databases, and consequently, the schema is defined for each dimension and fact table in several cubes. For fact tables, the foreign keys and the relationships between the other cubes are defined and the facts to calculate. Through pre-aggregations, we can save the desired combinations for faster analysis. The goal is to get analytical dashboards based on the implemented DW and views materialized that satisfy the information needs for the management of the business [17].

3.2 Kimball's Methodology

As it is a business intelligence work, the methodology adopted was the Kimball Lifecycle. Kimball's methodology focuses on designing a data warehouse by creating fact tables which correspond to business processes. To that end, Kimball developed a method for developing these, called the lifecycle roadmap.

The diagram represents the sequences, dependencies and concurrency of the tasks that must be performed, enabling work development correct within the set time.

In Fig. 2, the scheme that summarizes the methodology is presented by Kimball [18].

The Kimball lifecycle methodology includes several fundamental steps [19], namely:

- **Project planning**: Planning phase (define scope and plan project).
- **Project management**: This phase extends throughout the project to manage the team, resources and expectations.
- **Business requirements definition**: The requirements compression phase of the business with the fundamental objective of linking activities with the life cycle.
- **Technology track: This stage contains two milestones as follows**:

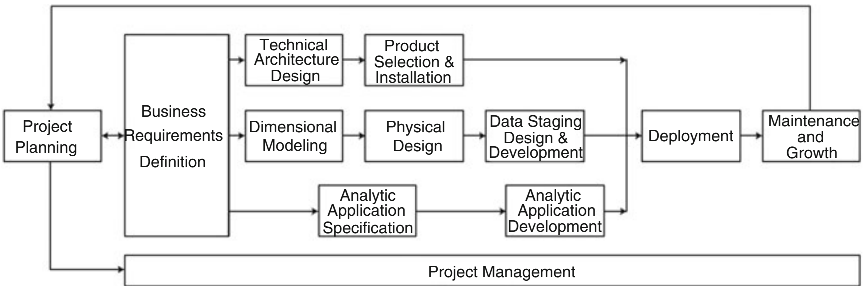


Fig. 2 Kimbal lifecycle methodology

  - *Technical architecture design:* It consists of developing the architecture of the business.
  - *Product selection and installation*: This is a phase in which the architecture is used to complete data warehousing.

- **Data track: This phase contains three milestones as follows:**

  - *Dimensional modelling*: It consists of designing a multidimensional model based on business requirements.
  - *Physical design:* Proceeds to the design of the database.
  - *Data staging, design and development:* It extracts, adapts and provides data and presentation and management of the ETL system.

- **Business intelligence track: This stage contains two milestones as follows:**

  - *Analytic application specification:* This is a phase in which applications are selected to support business requirements.
  - *Analytic application development:* It uses design to develop and validate applications that support business requirements.

- **Deployment**: In the case of data warehousing/business deployment intelligence, data is the primary input. Processing the data in ETL is the most unpredictable task. Unfortunately, even if the data is not fully prepared, implementation proceeds. This phase requires pre-deployment testing, documentation, training and maintenance and support.
- **Maintenance and growth**: After deployment, there must be maintained to control the system's satisfactory performance. If the project needs to grow because of new data or objectives, the life cycle starts again.

4 Study

The workflow described in Fig. 1 was followed for the development study, and the methodology is presented in Sect. 3.2.

The data acquisition process can be done using different sensors (magnetic and acoustic/optical, among others). In this case study, the data was provided by the Camara Municipal de Famalicão from underground sensors containing a partition between the entry and exit locations. For parks that do not have a data collection system, it is expected that this project will also develop sensors that collect information from the car parks.

After data collection, a dataset was obtained. An analysis of the data was carried out to understand the existing attributes better. In this way, in Table 2, it is possible to perceive the attributes obtained, the description, format and possible values. For example, the first attribute, Parking lot id, is the number that corresponds to the parking lot, is in integer format and has values of 1, 2, 3, 4, 5 and 7.

Table 2 Data analytics

Attributes	Description	Format	Possible values
Parking lot id	The number corresponding to the lot of the park	Integer	1, 2, 3, 4, 5 and 7
Latitude	Geographic coordinates	Decimal	For privacy reasons, park latitudes will not be shared.
Longitude	Geographic coordinates	Decimal	For privacy reasons, park longitudes will not be shared.
Name	Park name	String	For privacy reasons, park names will not be shared.
Location	The street where the park is located	String	For privacy reasons, park locations will not be shared.
Total capacity	The capacity of places that the park has	Integer	79, 170, 618, 150, 113 and 98
Observations	Zones and sections that the park has	String	“Zona1, Z1 E6-E | E5-S Z2 E3-E | E4-S”, “Zona2 Z2 E3-E | E4-S”, “Feira Norte: Zona6 Z6 E5-E | E6-S Feira Sul: Zona6 Z6 E3-E | E4-S”, “Zona3 Z3 E3-E | E4-S”, “Zona4 Z4 E4-E | E3-S” and Zona15 – Z15 E5-E | E6-S
Last update	Time and day when data collection started	Date	Hours and days of February and March 2022
Total available places	Total available places that the park had at the time the data was collected	Integer	Array ([52., 160., 633., ..., 3215., −97., 3220.])
Total occupied	Total number of occupied places in the park at the time the data was collected	Integer	Array ([27., 10., −15., ..., −3065., 715., −3070.])
Active	If the park is active	String	Verdadeiro
Update date	Time and date that data collection ended	Date	Hours and days of February and March 2022

4.1 Project Planning

For project management, the SCRUM methodology was used to improve project efficiency and reduce the waste of time and resources. First, it was necessary to define and understand the role in the project and then list the priorities, define and plan the sprints and later weekly and daily meetings [20].

Sprints are a sequence of activities with a defined deadline which must be developed. Thus, there is a biweekly meeting to determine the tasks for the sprint (sprint planning) where the project owner, based on the product backlog (a list of all the desired features of the product), divides the tasks for the sprint in question. During the 2 weeks of work, through daily meetings, each project member shares the activities to develop for the day, what they did the day before and their respective difficulties. At the end of the sprint, there is a meeting to validate all works developed and, consequently, a new meeting for the sprint planning [20].

The sprints in this specific project have 15 days, and 3 sprints were developed. As mentioned earlier, in this section, sprints are based on the product backlog. Consequently, the main tasks to be accomplished were the following:

- Interpreting the problem and reality.
- Extracting, loading and transforming the data.
- Creating the data warehouse (DW).
- Developing KPIs.
- Developing OLAP mechanism.
- Extracting relevant information from the data (data science).

In conclusion, this methodology provides excellent quality, rigour and efficiency to project management, enhancing quality and agility as a team and developing the solution in question.

4.2 Project Management

According to the SCRUM methodology, described in Sect. 4.1, there are three roles as follows:

- *Product owner* (usually, this role is played by stakeholders who define the objectives and direct the team towards achieving the expected results). In this project, Carlos Filipe Portela plays this role.
- *Scrum master* (person responsible for managing the project and the team). In this project, Carlos Fernandes plays this role.
- *Development team* (team members responsible for all the developments of the tasks defined for the sprints). In this project, Francisca Barros, José Vieira and João Oliveira play this role.

It is expected to demonstrate the efficiency and usefulness of the OLAP system and all activities underlying the process.

4.3 Business Requirements Definition

Functional and non-functional requirements must be met to achieve process excellence. In Table 3, these two types of requirements are displayed. For example, in terms of functional requirements, it is intended to demonstrate a multidimensional analysis, real-time updates, interactive models and dashboards.

The activities underlying the realization of these requirements are described in the product backlog in Sect. 4.1. Table 4 presents the KPIs identified to quantify the status of the objectives. These indicators were defined based on the context and analysis of related articles. An indicator is, for example, the areas with the most movement, and the respective KPI is the areas with traffic exceeding 2000 movements per year.

4.4 Technology Track

A BI project requires the storage and analysis of data and the integration of various technologies. The system architecture project is defined in Sect. 3. Technologies were explored and selected that meet the requirements for the expected environment to be successfully developed. These technologies are described in Sect. 2.

Table 3 Requirement

Requirement type	Requirements
Non-functional requirements	Reliability Clarity Efficiency Ease of use
Functional requirements	Multidimensional analysis Real-time updates Interactive models and dashboards

Table 4 KPIs

Number	Indicators	KPIs
1	Areas with the most movement	With traffic exceeding 2000 movements per year
2	Busiest parks	With traffic exceeding 500 movements per month
3	Busiest days	With traffic exceeding 150 movements per day
4	Parks with the highest capacity	Capacity greater than 300 places
5	Stocking rate	Stocking rate greater than 50%
6	Hours with the most affluence	With traffic exceeding 200 movements per hour

4.5 Data Track

According to the data (Table 2), it was possible to perceive that it was necessary to build two fact tables, one relative to the movements and another to the data of each park. Considering that the dataset provides hours and days of each movement, two dimensions, calendar and time, were built. The latitude and longitude attributes allowed the creation of a dimension called location. Furthermore, the attribute with the name of the park's street allowed the creation of the local dimension.

After identifying the fact tables and dimensions, the model was built, and the possible connections between the elements were identified. In this way, it is possible to see in Fig. 3 that the availability management fact table referring to the park's

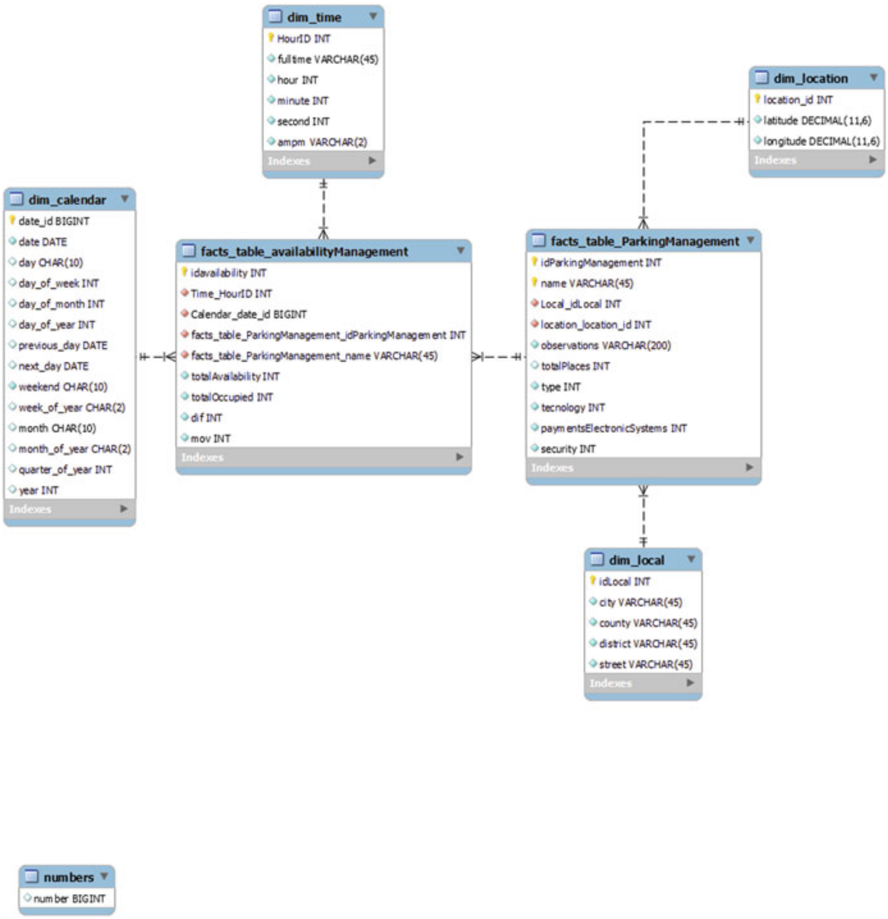


Fig. 3 Datawarehouse

movements is linked to the calendar and time dimensions. Moreover, the fact table relating to park management is connected to the location and location dimension.

In the ETL phase, writing errors, special characters and numbering were found and corrected through Excel (a spreadsheet supporting data analysis operations). Some of the transformations that the data underwent are the following:

- Numbering of parks was 1, 2, 3, 4, 5 and 7. Using Excel's filter and replace function, it changed to 1, 2, 3, 4, 5 and 6.
- One of the locations was written in two ways: Rua Fernando Mesquita and Rua Farnando Mesquita. So the replace function in Excel changed the name to Rua Fernando Mesquita since both streets referred to the exact location.
- Park identifier data, such as park name and street, were anonymized to ensure information privacy.

In this phase, the data warehouse was created with four dimensions, time, calendar, local and location, and two fact tables, availability management and parking management. These dimensions and fact tables were designed and structured according to the data obtained and later analysed. In other words, as we had information on time in the dataset, it was possible to create two dimensions, one related to hours and another related to days. In the time dimension, the attributes are id, full-time, hour, minute, second and whether it is am or pm. In the calendar dimension, features include the id, the complete date, the day of the week, the month and the year, whether it is a weekend or day of the week, month and month number and year, as well as the date of the previous day and the date of the next day.

Through the information of the street name from the dataset, it was possible to conclude the park's county, district and city and therefore created the local dimension.

The location dimension was created with the information of geographic coordinates (latitude and longitude).

The parking management fact table refers to the unique data and information on the existing car parks. As all parks have geographic coordinates and an associated location, there is a one-to-many connection between the location and location dimensions, so the fact table inherits this data from the park. It also has attributes related to the lot, name, observations and total park places.

The availability management fact table refers to the movements that each park has. The table is linked to the time and calendar dimension since each movement is associated with a time and a date. It is also linked to the parking management fact table to identify and inherit the parking associated with the movement.

The columns of interest were filtered, and after the necessary changes, all selected data were loaded for each dimension of the data warehouse. All dimensions were loaded through MySQL Workbench. The time and calendar dimensions were loaded by MySQL scripts, while the location and location were loaded directly with Excel park data. The fact tables were loaded using the panda library (open-source software for data analysis and manipulation). Fact tables were loaded using this library as it was necessary to load data from Excel and aggregate data from the

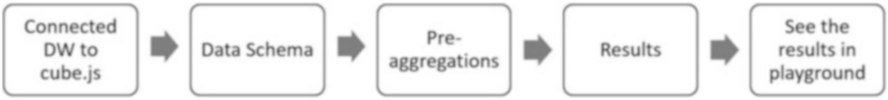


Fig. 4 Cube.js data process

associated dimensions. This was the most viable way to load all the data entered to match each other.

4.6 Business Intelligence Track

After the data warehouse was developed and loaded with data, selecting the application that supported the project's requirements was necessary. Cube.js was the chosen data visualization tool because it has various advantages favouring project development (platform described in Sect. 3.1). This tool allows the creation of an API easily used by other visualization systems and integrated into existing solutions.

4.7 Deployment

Initially, the data warehouse was linked to cube.js. Next, the data schema was developed for each dimension and fact table. The primary key and the respective columns were specified in the dimension's schema. Furthermore, the primary keys, respective columns, foreign keys and facts (measures) were identified for the fact tables schema. After the model's data schema was specified, pre-aggregations were made to respond to the KPIs identified in Sect. 4.3. Finally, the statistical data can be viewed in the playground section of cube.js. In Fig. 4, it is possible to see the workflow in cube.js. Cube.js presents a solution that contains an API that will allow the use of this mechanism in any other system or interface. This API communicates with the cube.js backend, and all requests made to the backend will be presented in the developed front-end.

5 Results

The following statistics were obtained for each indicator and KPIs in the playground at cube.js. The results are indicative only and should not be understood as absolute values. The example presented is easily replicated in other cities and is also one of the features of the ioCity project that will help monitor flows in parks. This data can be crossed with complementary data such as weather and events, making the system even more complete.

5.1 Areas with the Most Movement

In Fig. 5, it is possible to see that local 1 is the most movement area (5385 movements, approximately 35%). In contrast, local 4 is the least busy (1328 movements, around 8.5%).

In Fig. 6, it is possible to see the places with more than 2000 movements per year (only locations 1, 2 and 3 appear).

5.2 Busiest Parks

In Fig. 7, it is possible to see that park 3, both in February and March, is the busiest with approximately 25% of the movements (1554 movements in February and 2270 movements in March).

Moreover, only park 3 in February had more 500,000 movements (Fig. 8).

Dim Local Id	Dim Calendar Year	Facts Table Availabilitymanagement Movimentos
1	2022	5385
3	2022	4982
2	2022	3824
4	2022	1328

Fig. 5 Movements by area

Dim Local Id	Dim Calendar Year	Facts Table Availabilitymanagement Movimentos
1	2022	5385
3	2022	4982
2	2022	3824

Fig. 6 Areas with more than 2000 movements

Fig. 7 Parks movements by month

Fig. 8 Parks with more than 500 movements in February

Fig. 9 Movements by day

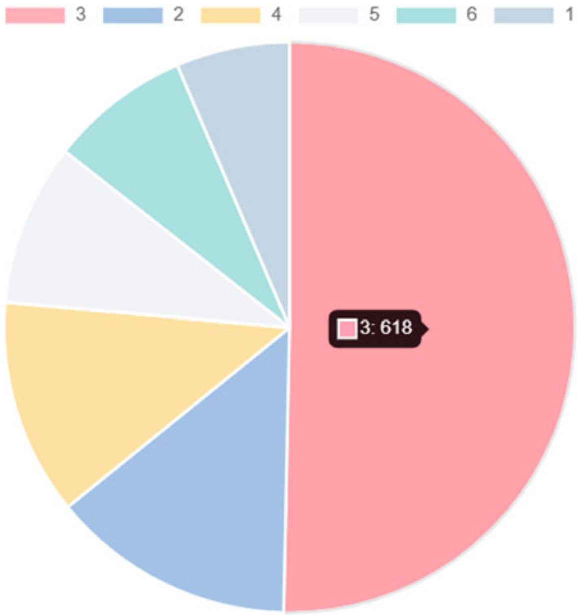
5.3 Busiest Days

In Fig. 9, it is possible to see that the busiest day is March 11, with 535 movements. Furthermore, the day with the minor movement is March 21, with 110 movements.

In Fig. 10, only the days with more than 150 movements appear. Since both February 16 and March 21 do not meet the requirement, they are not shown in the graph.

Fig. 10 Days with more than 150 movements

Fig. 11 Parks capacity (lots)



5.4 Parks with the Highest Capacity

In Fig. 11, it is possible to see the park with the largest capacity, in this case, park 3, with 618 seats (50.3% of the total seats).

In Fig. 12, it is possible to see the parks in more than 300 places. Park 3 is the only one that meets the requirement.

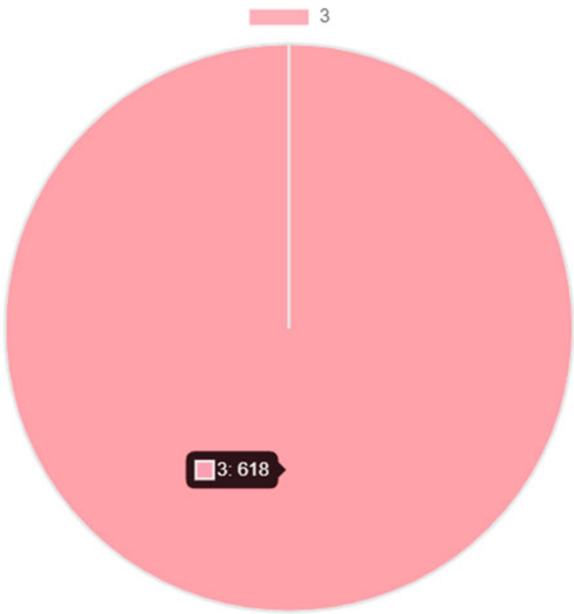


Fig. 12 Parks with more than 300 lots

Facts Table Parkingmanagement Id Parking Management	Facts Table Availabilitymanagement Taxa de lotação do parque
6	61.32%
2	55.56%
5	49.19%
3	37.69%

Fig. 13 Total capacity by parking lots

Facts Table Parkingmanagement Id Parking Management	Facts Table Availabilitymanagement Taxa de lotação do parque
6	61.32%
2	55.56%

Fig. 14 Parks with more than 50% occupation

5.5 Stocking Rate

In Fig. 13, it is possible to see that the park with the highest capacity is park 6, with 61.32%. Parks 1 and 4 do not appear in the image because they do not contain valid data.

Figure 14 shows the parks with more than a 50% stocking rate (parks 6 and 2).

Fig. 15 Movements grouped by hour

Fig. 16 Hours with more than 200 movements

5.6 Hours with the Most Affluence

In Fig. 15, it is possible to visualize the hours with the most significant movement (18 h with 946 movements).

Furthermore, in Fig. 16, only the hours with more than 200 movements are shown.

6 Discussion

Through the OLAP process, it is possible to understand several metrics and indicators useful in decision-making. This analysis of the current context allows better park management, creating more value and usefulness for those who enjoy and manage the parking. Metrics such as crowding rate, movement and busiest hours can be analysed. For example, suppose there is much demand compared to the available spaces on a particular street. In that case, constructing a new car park can be an option to create more parking conditions and reduce traffic flow, allowing for better mobility.

KPIs are fundamental to a perception of parking reality inside cities. Knowing the current context for future assertive decision-making is crucial for an organization's success. After the development of the system, it was possible to measure the previously defined KPIs for this case study:

- Park 3 has the largest capacity, with 618 parking spaces. Consequently, it is the same park with the highest movement per year (3824 movements per year).
- On the other hand, despite being the car park with the fewest spaces (79 spaces), car park 1 is the fourth car park of the six with the most traffic. The busiest street is the first street (5385 movements) because on this street there are two parks (parks 1 and 2).
- It is impossible to conclude the results regarding the stocking rate because the source data is wrong, and therefore, the results are incorrect.
- The busiest hours are rush hours. Check-in is from 8 am to 9 am, check-out is from 5 pm to 7 pm and lunch is from 12 pm to 3 pm. As these are the most common working hours, it is normal for peak hours to be the busiest. Both weekdays and weekend days show constant movement throughout the year.
- The developed system can measure more values in addition to the KPIs, such as the available places in the park by year, month and hour. Just like sections of each park have. For example, park 1 has a "Zone1, Z1 E6-E | E5-S Z2 E3-E | E4-S".

7 Conclusion

This chapter presents a complete study that other cities can follow to aid decision-making. The mentioned indicators are examples of what can be obtained from the data. With another dataset from another city, other KPIs that are useful in the light of the presented data can be identified. Kimball's methodology was followed to show the importance and effectiveness of an OLAP model in the decision-making process. Consequently, a data warehouse was created to store the data, six KPIs, an OLAP model and dashboards to visualize the indicators. Several metrics allow the analysis of the context of the car parks and understanding the streets with the most traffic, hours with more affluence and parking rate, among others. Through the statistics presented, it is possible to make more accurate decisions. For example, if there is a street with much traffic, another park could be created with more places or add more locations to the existing parks. For instance, another park could be created in place 2, given the movement it has and the places it presents.

OLAP is a tool that allows the multidimensional analysis of data and makes decision-making more efficient and effective, developing strategies that meet the needs. The entire workflow, from data collection to OLAP, is crucial to obtain relevant indicators. Building an accurate and complete database is critical. Well-structured data helps to understand its context, which facilitates arriving at a good

OLAP. With all the indicators obtained through cube.js, it was possible to reach all the functional and non-functional requirements defined.

In conclusion, with the development of KPIs and aggregations made in cube.js, it is possible to prove that the response time is reduced and that the obtained indicators are crucial for decision-making. This model created for the ioCity project should be a good guide for execution in business intelligence projects. The model developed is versatile and can be used by other cities. This study presents good practices of a business intelligence process and how an organization can succeed, a contribution to the data warehouse, the OLAP model and the step-by-step process that must be followed.

Regarding future work, it is essential to mention that the model will be integrated into the final artefact of the ioCity project and will be explored/optimized to receive new data.

Acknowledgement This work has also been developed under the scope of the project NORTE-01-0247-FEDER-045397, supported by the Northern Portugal Regional Operational Programme (NORTE 2020), under the Portugal 2020 Partnership Agreement, through the European Regional Development Fund (ERDF).

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Tourist as a Smart Tourist: A Review

Jorge Oliveira e Sá and Ana Margarida Rodrigues Cunha

1 Introduction

We are living in a digital age and people in their day-to-day use a huge number of technologies, implying a volume of information shared on the Internet, with social networks having an important role in this sharing. This technological growth comes along with the increase in the use of smartphones connected to the Internet; in other terms, it comes in a context in which the sharing of information in society has progressed substantially.

One of the areas in which this sharing of information is relevant is tourism. The comments/shares, conducted by peers, that is, by other tourists, are also useful for those who offer tourist services, especially in today's tourism industry which is made up of companies that are purposefully engaged in the joint coordination of their activities to serve tourists. The coordination of activities is the central issue, which points to the importance of an analysis of the stakeholders and their interactions [17]. The sharing of information and communication between tourists for tourism enables the growth of this industry. However, collecting data from tourists is still an arduous task, even though several platforms allow collecting data from tourists, namely, TripAdvisor, Trivago, Momondo, Kayak, YouTube, GoogleMaps, GooglePhotos, Facebook, Instagram, Twitter, and The Fork, among others. However, most of this data is collected because the tourist decides to comment/share an experience, for example, when visiting a restaurant, hotel, local accommodation, or tourist activity, among others. This enables other tourists who take advantage of this knowledge to plan their next tourist visits and then consume these comments/shares. Currently, given the existence of several travel platforms,

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many tourists use them as an aid in their travel decisions and define the places to visit, seeking the opinions of other tourists.

The approach in this chapter aims to see the tourist as an intelligent tourist; for this, throughout the chapter, we will address issues such as the Human-as-a-Sensor. This is one of the many concepts that allows the tourist to be seen as a Smart Tourist since this concept sees the human being as a source of data. Integrating tourism with this concept gives rise to the concept of the Tourist-as-a-Sensor, that is, the tourist as something capable of generating data that will be useful for the sectors related to tourism. Thus, throughout the chapter, we will address issues and technologies that will allow us to propose a solution to better manage the flow of tourists benefiting the entities that benefit from tourism. The goal of this chapter is to propose a solution that will be able to collect dynamic tourist information with a high spatial and temporal resolution, acquiring the necessary data from the human beings themselves and with their consent, allowing any tourist in a city to be considered an intelligent tourist through this solution.

To build the solution, it will be essential to know tourism and understand tourists and what they are looking for when they visit a city. At the same time, it will be necessary to understand what currently exists in the field of Smart Tourism and how tourists can be motivated to share data about their routes when they visit a given city. Thus, in addition to studying technologies such as Gamification, it will be important to understand how Smart Tourism is currently processed and what initiatives exist in this ambit, so that the suggested proposal fits what is expected of these initiatives.

2 Tourist's Behavior

To understand tourism and how to act to provide a better service to tourists, it is important to understand the behavior of tourists. If we know tourists, we will understand what they are looking for when they visit a city, and it will be possible to understand which mechanisms adapt to their needs, allowing better management of the tourists themselves.

However, there is no single, accepted model that explains the behavior of all tourists. There are several types of tourists with very different motivations, and therefore, it is practically impracticable to create a single paradigm capable of understanding the behavior of different tourists [6]. However, some authors have tried to form models that could be useful in this sense, namely, that the decision process to purchase a tourist package has some special characteristics when compared to other types of purchases [13, 14]. One of the characteristics of the tourism sector is that any investment made is to obtain tourist's satisfaction as a return, and on the other hand, it is important to bear in mind that tourists are becoming increasingly experienced and flexible and, with more resources, making them more demanding consumers [7].

To study the behavior of tourists, it is necessary to understand all the factors that affect their satisfaction, such as the motivation of each tourist, the tourists' state of mind, and factors generated by economic and social changes. These latter factors include, for example, the rising price of energy, new communication possibilities, education opportunities, and so on. In addition to these, there are also environmental or social effects, such as the role of the family, the role of other groups of people, the role of social status, and the role of culture.

Based on several existing studies related to tourist's behavior, nine key concepts for tourist's behavior were identified [9] as follows:

- Decision-making: understand how tourists make decisions when choosing what they want to do.
- Marketing: understand how tourists are influenced by product categories, brands, and attributes.
- Motivation: understand how tourists are attracted by marketing in terms of product segmentation, advertising, and positioning.
- Self-concept: understand how the tourist's personality influences the selection of destinations and travel intentions.
- Expectation: understand which tourists' expectations may not be met, be met, or even exceeded; this allows for assessing the tourist experience.
- Attitude: an understanding or measuring the tourist's attitude toward the services, destinations, and trademarks of tourism providers is a challenge, as it is also essential to consider the tourist's mood and emotions at the time of measurement.
- Perception: understand how the tourist perceives risk, and security, including the perception of crime, the perception of terrorism, or epidemics of certain diseases.
- Satisfaction: understand how the tourist evaluates the purchase as a whole or the individual elements of the purchase.
- Trust and loyalty: realize vertical loyalty, that is, tourists can be loyal to suppliers of tourism products from several tourism sectors at the same time; horizontal loyalty, that is, tourists can be loyal to several suppliers of the same tourism products; and experiential loyalty, that is, tourists may be loyal to a particular form of travel.

The study of tourist's behavior around the world is extensive, however inconclusive, in the sense that, as mentioned above, there is no consensus.

Understanding tourist's behavior is a challenge, as there are numerous variants that condition tourists' behavior and, therefore, the design of a single model that allows knowing and classifying tourists based on their behavior becomes considerably arduous.

3 Smart Tourism

The emergence of smart devices connected to the Internet has brought a set of communication mechanisms and sensors capable of collecting positioning, movement, photos, sending messages, etc. and sharing them immediately with other devices. Consequently, it is possible to agree that the conditions exist for everything to be digitally connected, thus allowing, for example, opinions to be shared, to be read, and to be commented on almost immediately.

Smart Cities are a concept emerging with the evolution of technology where communication is centered on the Internet, mobile services, wireless sensory networks, smart technologies, and IoT (Internet of Things). However, the key elements of a Smart City are the proactivity of citizens and the ability to generate new links between them and city administrations. This means that Smart City proposes the integration of advanced tools and technologies in solving social problems, providing solutions that generate a better opportunity to deal with some obstacles [22].

Smart Cities have at their core a highly capable ICT system connected to sensor networks and wireless broadband connectivity and advanced data analytics that lay the foundation for the development of intelligent applications and services applications and services for citizens. However, there is a major obstacle in the use of IoT that is essentially due to the current lack of fully defined standards for IoT architectures. Thus, the key requirements for their use in a Smart Cities scenario become quite difficult to define [16].

The concept of Smart Cities encompasses Smart Tourism, which integrates the sharing of information and communication between tourists, generated by the Internet, and which has a major impact on the tourism industry. Thus, from the combination of ICT and tourism comes Smart Tourism. In other words, Smart Tourism is any service that can be used by tourists to automate tourism-related tasks based on the Internet of Things (IoT).

The adoption of IoT-related technologies by the tourism sector will bring improvements in performance and the way business processes are currently designed. In this way, IoT could provide new ways of doing business for the tourism sector, making it possible for the industry to benefit from investing in this type of technology [22]. Figure 1 illustrates some of the advantages that result from the introduction of the Internet of Things in a city and advantages capable of improving the mobility of tourists, and mobility refers to the activity of tourists within cities:

- Convenience and flexibility: IoT can be used in a way that brings convenience and flexibility to the tourism domain. This technology can integrate and automate various tourism services making it easier and more convenient for tourists to use IoT-related services. In addition, any tourist will be able to communicate through IoT devices. Thus, IoT-based services and applications end up automating tasks and enabling communication sharing and, in this way, bringing new tourism features that facilitate tourism mobility and bring advantages to it.
- Consciousness: With the help of IoT, awareness of tourist mobility in Smart Cities and other tourist places can be improved. For example, information about hotels and tourist places can be integrated into a smart map. This smart map can be quite useful. This map will be able to assist the various stakeholders with

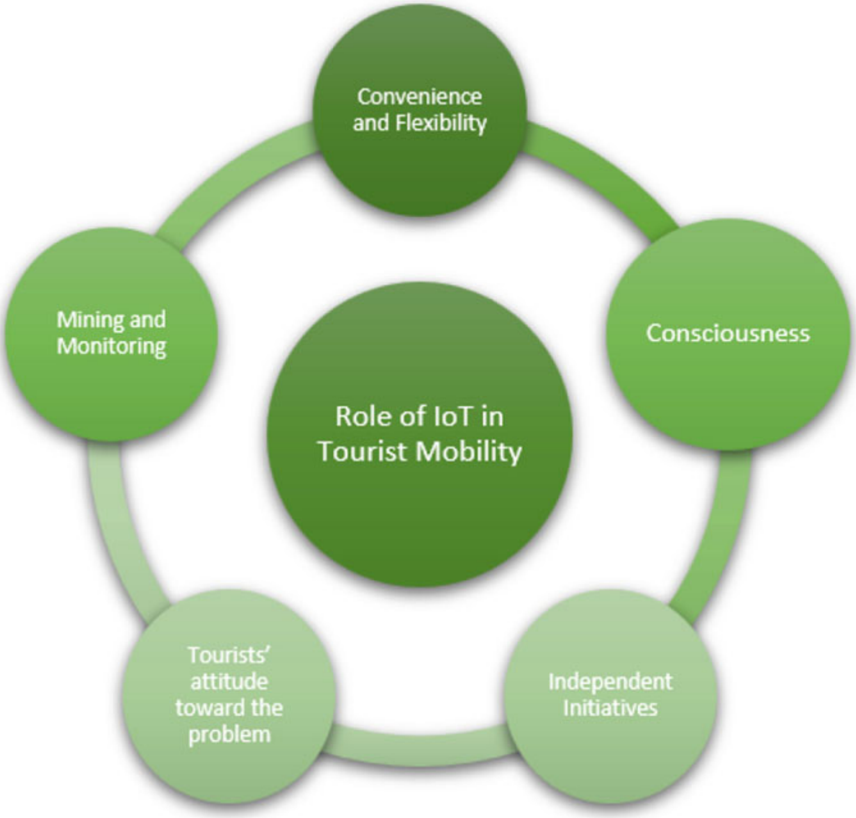

Fig. 1 Role of IoT in tourist mobility

tourism who may have real-time support capable of exploring all likely options as per their needs and thus making more related decisions.

- Independent initiatives: IoT can help different stakeholders in collecting new ideas; it not only facilitates the investigation of initiatives and their adherence but also suggests initiatives to be evaluated.
- Tourists' attitude toward the problem: IoT solutions can help improve tourists' response to problems arising from tourism.
- Mining and monitoring: Government authorities and the entire tourism-related sector can use artificial intelligence and monitoring tools to make the system and their business processes more effective.

With the proliferation of devices such as smartphones and other smart devices, humans have come to be seen as sources of information, that is, the concept arises in which humans are seen and used as sensors – Human-as-a-Sensor (HaaS). This concept opens the door to new ways of solving recurring problems on the part of Smart Cities, allowing them to take advantage of the information produced by these devices. On the other hand, humans can also benefit from the information shared by other humans. This phenomenon can also be seen when humans use social media since when this happens, they are acting as HaaS, providing real-time data and information about entities and events [19].

The concept of HaaS assumes that it is humans who detect or report events. That is, instead of automated sensor systems, we use humans to collect data [19]. The use of technology of this type has increased considerably in recent years [19], and the concept of HaaS has been widely used and successful in detecting threats and adverse conditions in the physical space. Examples of this success include the diagnosis of noise pollution in a city and road traffic anomalies through social networks [8].

The introduction of this idea of HaaS in tourism revolutionizes the entire industry since it is easily perceptible the importance that this real-time generated data has for this sector. Through them, the tourism industry can make improvements in the market based on the collected data, adapting and improving their business processes according to the information obtained about tourists and their behavior. From this interconnection between the concept of Human-as-a-Sensor and the tourism sector, a new concept emerges, the idea of a tourist being seen as a sensor, that is, Tourist-as-a-Sensor (TaaS).

The large amount of data generated by TaaS when using social media, wired networks, and mobile devices has caused the tourism sector to start looking at collecting and analyzing this data. TaaS allow generating more useful information for the tourism sector, an information that allows the emergence of improvements in this sector. Thus, the tourist is now seen as a source of data.

This new vision allows Smart Tourism to collect data through TaaS and using ICT, bringing advantages to entities that provide tourist offers by changing, redesigning their business processes, improving their efficiency and effectiveness, and providing increased profits, cost reduction, and improved functionality, greater productivity, and increased tourist's satisfaction.

However, a question arises, how to convince tourists to be TaaS? A possible solution is the use of Gamification. This concept is analyzed in the next section.

4 Gamification

The concept of Gamification has become a common practice in several businesses [10]. Gamification is an emerging phenomenon, which stems directly from the popularization and popularity of games [18]. Its intrinsic capabilities to motivate action solve problems and enhance learning in the most diverse fields of knowledge and life of individuals [1], and Gamification is as a synonym of rewards, emphasizing that to induce more engagement on tasks, most Gamification systems focus on leader boards, levels, points, or badges [20].

Gamification comes from the word game, and this technique consists of using game dynamics thinking to attract and retain audiences. Considering the power that games have over people and the way they can hold them and capture their attention, it is possible to realize the power that Gamification will have on human beings and how it can be useful in business [2].

Gamification can be seen as progressing through two primary developments [12] as follows:

- Intentional Gamification: Gamification is defined as an intentional process of transforming virtually any activity, system, service, product, or organizational structure into a process that provides positive experiences, skills, and practices similar to those found in games. This process is commonly but optionally done to facilitate changes in behavior or cognitive processes.
- Emergent Gamification: Gamification can be defined as a gradual and emergent, although unintended, cultural and social transformation arising from increased widespread engagement with games and playful interactions. The assumption is that through the increasingly pervasive role of games in human life, cultural and social practices will gradually become and transform into increasingly game-like practices, game communities, and gamer practices.

Associating Gamification with data collection, it is plausible to assume that it is fundamental, in the sense that classical forms of data collection on human behavior are time-consuming, expensive, and subject to a limited number of participants. This is how Gamification emerges, which is a technique capable of generating motivation to participate and provide information. Thus Gamification makes the whole process of data collection more attractive since it involves the existence of rewards and prizes for those who provide information. This technology provokes greater adherence by humans since they will feel more motivated to participate in the process [5]. Many well-known companies have already adopted this technique as a measure to increase customer engagement, gain customer loyalty, improve employee's performance, or gain competitive advantage. Despite the panoply of industries in which Gamification can be useful, the study will target the tourism industry [15].

According to the United Nations World Tourism Organization, the mechanisms involved in Gamification are game mechanisms capable of creating positive experiences in tourism [4] and providing tourists with both information and entertainment [15].

The Gamification market is evolving exponentially; this growth is due to companies becoming more aware of its benefits. This growth represents an important incentive for suppliers of Gamification solutions providers to increase the quality of their products and develop more efficient solutions. The best proof of this is the fact that even if Gamification is less developed in tourism than in other sectors, there are already some producers and platforms in the market. The existence of a new generation of tourists eager to compete in the virtual environment for status recognition and incorporation rewards has generated a decline in the attractiveness of traditional loyalty programs based on the frequency of stay in the hotel chain or of serving dinners in a restaurant. Thus, international hotels and restaurant chains have introduced gaming mechanics in their loyalty programs.

The following examples are some of the most relevant in understanding this phenomenon: InterContinental Hotels and Starbucks [15]:

- InterContinental Hotels Group added a daily online trivia game in 2011 to the group's loyalty program. The game enables participants to earn rewards (free miles) based on quick and correct answers related to travel destinations. Marketers noted that this Win It in a Minute program determined the attractiveness among younger consumers, a group that usually did not loyal to the brand.
- Starbucks recently began implementing quick response codes as part of its mobile Gamification strategy for new product promotions. By scanning a produc's QR code, consumers are directed to the company's website where they can find information about its products, newsletters, coupons, customer service, and other similar benefits. To intensify interaction with consumers, the mobile website is linked to social media outlets. A connection to Facebook is used to create a social platform for consumers to interact and comment on likes and dislikes. From the company's perspective, the accessibility via QR code ensures an analytical database (e.g., time of day, gender, location) that can be taken into consideration in future marketing campaigns.

Through the previously described examples, it is possible to conclude that Gamification, when implemented properly, is effective in building customer loyalty. The fact that there are more loyal customers will generate a greater frequency of consumption by these customers. Consequently, there will be greater brand awareness or the development of new products [15]. In this way, the adoption of Gamification by establishments that benefit from tourism could translate into numerous advantages for these entities. Considering this assumption, the City of Breda uses Gamification as a way for tourists to use the *Breda City App*. In the case of this city, we realize how Gamification can be useful not only in establishments but also in large cities to collect data from tourists visiting the city. Breda is a city in the Netherlands, notable for its accessibility; the city won an award for its accessibility especially because it cares about tourism and the tourists it receives, and for this reason, it creates initiatives that aim to satisfy the needs of any visitor. The platform created by the city *Breda City App* presents interesting upcoming events that the city will have, and it is possible to filter these events by considering the tastes and preferences of each tourist. This application provides hotels, restaurants, and venues to visit, city news, and shopping areas and allows you to easily find the best stores, tourist routes, museums, and theaters, all this in a fast and effective accessible app. The application also provides photos of the city's festivals so that the visitor can see what they look like and feel more intimate with the city. However, what stands out in this application is the use of Gamification to captivate the tourist to use it. The data provided by tourists provide the city with efficient management of tourist flows in certain areas of the city. With this data, they will be able to understand which areas are the busiest and least busy, thus focusing on improving the areas with less demand and making better management of the territory. Thus, it is perceptible the importance that this data has for the city. To ensure that the tourists share this data, the City of Breda introduced Gamification in its application *Breda City App*. The application offers points that are accumulated and can be reversed in discounts on events, museum tickets, and tourist attractions in the city. These points are achieved by completing routes around the city that pass through tourist points, shopping areas, and special places in Breda.

The use of Gamification in the City of Breda encourages tourists to use an application, that is, to become a TaaS, where they share information about their routes; this data sharing allows them to know the flow of tourists. In this way, it will be possible to manage more efficiently tourism, the tourist points, and all the entities that benefit from tourism in the city.

Reinforcing this idea, Gamification was identified in tourism as one of the futures of this industry, since it is appealing to all ages. Currently, as it was possible to see in the previous example, there are already tourism applications that involve Gamification, and these can be divided essentially into two branches [3] as follows:

- Games that prepare the tourist for the visit.
- Location-based mobile games, where the user plays while visiting.

Regarding the first type of game, its main objective is to provide information to the tourist to promote the place of the visit. In turn, the second type of game aims to encourage greater involvement with the place so that the exploration is more immersive [24]. The smartphone games based on location are essentially connected with the principles of the treasure hunt classic, where users must collect context information and at the same simultaneously explore the location in search of points of interest. To increase engagement [11] and the connection between the real and virtual environments [23], location-based games quite often use augmented reality, since it allows one to visualize through the screen virtual content in a real environment. The following are five main patterns in the design of these applications involving Gamification [21]:

- Badges and levels.
- Game design patterns and mechanics such as time constraints, limited resources, and turns.
- Principles of game design and heuristics such as enduring play, well-defined goals, and diverse play styles.
- Game models such as challenge, fantasy, and curiosity.
- Game design methods such as play, test, a game-centered design, and a values-conscious game design.

5 Smart Tourism Cities

Since 2018, the European Commission, based on a preparatory action proposed by the European Parliament, has designed an initiative that rewards European capitals for Smart Tourism. A given city is only rewarded if it considers the various parts of the city, the tourists, and the common well-being between the two; that means the harmony between the city and the tourists in such a way that both benefit. The city

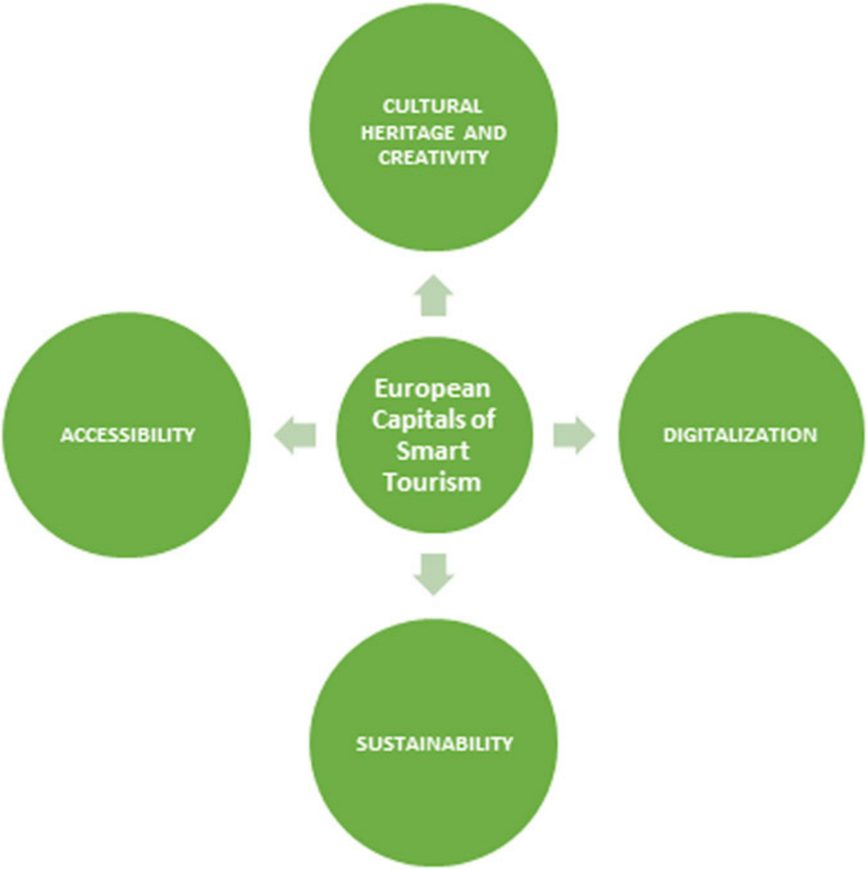

Fig. 2 Fundamental concepts of European Capitals of Smart Tourism

must also fulfill a series of requirements and therefore take into consideration four fundamental concepts that we can see in Fig. 2.

Regarding accessibility, it is important to consider if the city is accessible for everyone and if the streets, the beach, the infrastructure, etc. are accessible. In this context, it is also important to understand if the information about the city is accessible.

Sustainability is important to consider in the fight and adaptation to climate change, if the city preserves the environment and if they try to make good management of tourist flows.

Addressing digitalization, it is fundamental to understand if the information is available for the target groups, if there is a good collection of information for more effective management, and if there is physical and psychological accessibility through innovation.

Regarding cultural heritage and creativity, it is important to understand if the city is reviving traditions and cultural heritage sustainably and if they are using the cultural heritage of the city creatively.

Below it is possible to see some of the awarded cities and the reasons that lead to their recognition in Smart Tourism.

One of the awarded cities was Valencia; this city is the third largest city in Spain and was one of the winning cities in 2022. Valencia receives a certain 2.2 million visitors every year and holds three UNESCO (United Nations Educational, Scientific, and Cultural Organizations) World Heritage declarations. This Spanish city has developed innovative tourism practices and several platforms that involve tourism and require the participation of tourists; these platforms are presented below:

- AppValencia: This platform was developed by the City Council of Valencia and aims to be a communication channel between the citizens/tourists and the administration. AppValencia is dynamic, accessible, and easy to interact with, making it possible to analyze and obtain information about its users. The application has two distinct parts, one for tourists and the other for citizens of the city, so when the user starts using it, he/she is approached to understand if he/she is a tourist or a citizen of the city of Valencia, so that it can be redirected to the corresponding section of the application. In the section directed to the tourist, it is possible to obtain various information that can be useful for the tourist, such as how to get around the city. The application provides explanations regarding available bicycles along with the city, cut-through streets, availability of parking spaces, real-time traffic status, or extension of the bicycle network. In addition to issues related to tourist mobility, the application has other relevant features for tourists in Valencia, such as where to find the nearest libraries and museums or get information about a large monumental area. In this way, it is possible to understand that this application has varied functionalities and concentrates all the necessary and useful information in a single space for a tourist in the city.
- VLCTurism: It is a very intuitive application that gathers in a single space all the information for a tourist in the city. This application has several features and provides diversified information to tourists. Thus, its tourists can, for example, see the main sights of the city, view information about events and activities that will take place, or even have access to maps and guided tours. The application also has a recommendation system in which it suggests restaurants of the most varied tastes to tourists. In addition, it is also possible for the user to analyze various itineraries according to the interests that the user has in the city, that is, the user has access to several itineraries with different purposes and characteristics, so the user can choose an itinerary that best suits the desired trip and the conditions of that trip. This application also offers an area where it is possible to explore the city, where the various museums, hotels, monuments, restaurants, and cabs, among others, are presented. Another feature of the application VLCTurism is the option that tourists have to buy economic cards to

visit various establishments at a more affordable price; in other words, only with the cost of the card the tourist has the opportunity to visit several monuments of the city and may even be included in the transport.

- Touristphone Valencia: This application allows that only with the cell phone the tourist can take guided tours of the city in a personalized way. A Touristphone Valencia has a feature that allows tourists to receive a notification on their smartphone when they pass by a certain place with a brief description of the place and its history. Through this application, it is also possible to see the various establishments, monuments, and museums available.
- Valência Travel Guide: This application presents several features to improve the well-being of tourists. Valencia Travel Guide is completely free and supported in over 14 languages. Through the application, it is possible to plan a trip with the best activities and the most highly rated tours, offered for the user to book immediately. This application presents the main attractions of Valencia and provides street maps and public transport means such as metro and bus views.

In 2020, Malaga was the winner of the European Smart Tourism Capital award, as the city has been bringing together the concepts of sustainability, innovation, and culture to meet the needs of tourists. In addition to the investments made by the city in accessibility issues and the improvement of tourist attractions in recent years, the city offers an application called TurismoMalaga. This application has several pieces of news about the city, through which it is also possible to view the events happening, monuments, hotels, and beaches, among others. The application in question is quite complete since it allows you to analyze all the information about the city, such as the weather. Besides that, it is also possible to see how to get to the city and all the information regarding the city's transport. In this application, tourists have access to different guided tours that integrate the main points to visit in the city; it also has tips on what you can buy in each shopping center, the timetables of the establishments, the traditional foods of the city, and even the most visited restaurants.

Another of the winning cities of the European Smart Tourism Capitals 2020 was Gothenburg; the city tries to stay on top of digital trends in all digital initiatives, to achieve equal access for all, affordable technology, effective long-term planning, and promotion of public-private partnerships. The city stood out as it wanted to give access to innovation and technology; in this way, the city paved the way for abundant 4G coverage, smart grids for traffic and electricity, accessible and open government data, future-oriented public transportation systems optimized for all citizens, and platforms dedicated to environmental protection. Gothenburg, not a major world tourism city, is committed to Smart Tourism to become an expert in building capacity from effective partnerships. The seaside city works together with a wide variety of stakeholders and sectors to implement a truly integrated approach to Smart Tourism. Gothenburg has an app where live news from the city is available, and a variety of tourist guides on what to see in the city, including restaurants, hotels, museums, outdoor spaces, stores to buy, tourist attractions, and events related to culture and entertainment. The application also provides a city map to help the tourist move around the city and important information for those visiting the city about transportation, lodging, Internet, and public bathrooms, among others.

Helsinki was the winner of the award in 2019 and is a modern city with a booming smart tourism industry. Helsinki is a destination that blends high-tech and sustainable design with art and culture. Helsinki Travel Guide is an app for tourists that is very attractive, as it presents information about the city and its hotels. If the user wants more information about a hotel, the app allows to redirect him to the hotel's page. It is possible to see beautiful images of the city, from the perspective of a tourist; the application offers several options of what to do in one day, two days, or even three days in the city. Furthermore, the app provides all the information about the city, such as its history, information on the city's nightlife, what to eat, traditions, what to buy, how to get around the city, information about transportation, and several other points.

Finally, the city discussed will be Copenhagen, the capital of Denmark. This city did not receive the European Smart Tourism Capital Award; however, it was recognized for digitalization. This recognition is due to the Copenhagen Travel Guide application. The Copenhagen Travel Guide offers a complete travel guide for tourists with only your cell phone needed, the travel guide is designed to be used offline without the need for an Internet connection, and it provides an augmented reality view where you can see on the screen in 360 degrees the best points of the city, such as bus stops, how to find the best attractions, restaurants, bars, theater, museums, hotels, and several other points of interest. The application also offers a GPS feature. The application can provide information on various sights and attractions in the city such as information on the history and culture of the city, safety tips in the city, tips and advice to travelers, information on how to get to the city, how to get around, where to shop, busiest nights out in the city, budget hotels and restaurants, popular places, and more.

Some of the examples described above show us how some cities have responded to this technological change in the tourism industry and how they have managed to introduce Smart Tourism in their cities. The study of these cities and their initiatives was fundamental to understanding what exists within the scope of Smart Tourism initiatives, which best practices are implemented, and the main gaps.

6 Discussion

The previously mentioned award-winning cities, referred to as European Smart Tourism Capitals, integrate applications that despite offering benefits to the tourist do not contain a bi-directional relationship between the tourist and the city. That is, the tourist receives information about the city in most of them, but there is no sharing of information with other tourists or provision of opinion from tourists in almost any of the examples provided. There is a lack of interaction between the tourist and the city.

Thus, the proposal that solves this problem would be an application that involves the technologies mentioned above and that involves and interconnects tourists with other tourists and with the city itself, sharing information among all. The solution is based on an application that tourists could install that contains information about the city and the possible touristic routes that could be taken in it. Tourists would select the route they wanted based on their preferences, and after selecting it, they would be redirected to a live view map. This map would have integrated virtual reality tools, and at each point of the routes, the tourists would have to capture an object to signal that they were in that place, and if they wanted, they could also give information about that place. When they captured the virtual object, an explanation about the place where they were would appear, and the tourists would receive points, in the same way, that if they gave their opinion about the place, they would also receive points. These points would translate into achievements that offered discounts in restaurants, hotels, and museums, among others. The opinion provided by the tourists not only provides points but also serves as information for future tourists. Once in the application, there will be a section where tourists can see other tourists' opinions about the places they visit.

In this way, we realize that the application contains information not only provided by the city but also information provided by other tourists; moreover, it will gather in a single space everything that tourists need to visit the city. Besides this issue, due to the introduction of Gamification, tourists will feel motivated to use the application. However, this application will be beneficial not only for tourists. The city itself and the entities that are linked to tourism will benefit as well since they will have information regarding the flow of tourists and their opinions, and in this way, they will be able to make better decisions in that ambit.

7 Conclusions

Tourists can be seen as a source of Smart Tourism. IoT concepts such as HaaS as well as TaaS frame tourists as producers of data as well as consumers. In this way, tourists can be seen as Smart Tourists.

However, there is a difficulty in motivating tourists to share their data; a concept to consider is Gamification. The use of this concept makes it possible for the tourist to be motivated to provide information; in this way, it is possible to introduce the idea of an intelligent tourist as a tourist who voluntarily provides data and benefits from the data that other tourists have shared. This idea revolutionizes the entire industry, as it is easy to see the importance of this real-time generated data for this industry.

Good use of this data by the tourism industry can make improvements in the market based on the data collected, adapting and improving its business processes according to the information obtained about tourists and their behavior.

It was concluded that it is important to integrate these concepts of HaaS and TaaS to reach a level of Smart Tourism, particularly in cities that intend to innovate and become Smart Cities.

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Part II
Attractive, Engaging and Fun

Smart Tourism Design: Take Experience and Resource Integration as the Core

Tao Huang, Yunpeng Li, Yong Li, and Daniel R. Fesenmaier

1 Introduction

Due to the development of information and communication technologies (ICTs), the concept of smart tourism and smart environments has emerged and been viewed as essential for the whole tourism industry [12, 13, 21, 26, 31]. Currently, there are plenty of research conducted to explore smart tourism through the discussion around the application of technology. As argued by Buhalis [10], the application and development of technology in tourism have evolved from information communication technologies to eTourism and from smart tourism to ambient smart tourism. Notably, the iterative performance of technology applied in the tourism industry is not a substitute but the coexistence of old and new forms, producing different effects in the context of big data and information services (Fig. 1). By analyzing the design of smart tourism, Xiang et al. [70] provided insights into the design of smart tourism. However, it remains a problem worthy of discussion to consider smart tourism design from different angles.

Regarding the study of smart tourism, Gretzel et al. [30, 31] proposed that smart tourism entails three basic elements: smart business ecosystem, smart destination, and smart experience. They are reliant on the support from the creation, processing,

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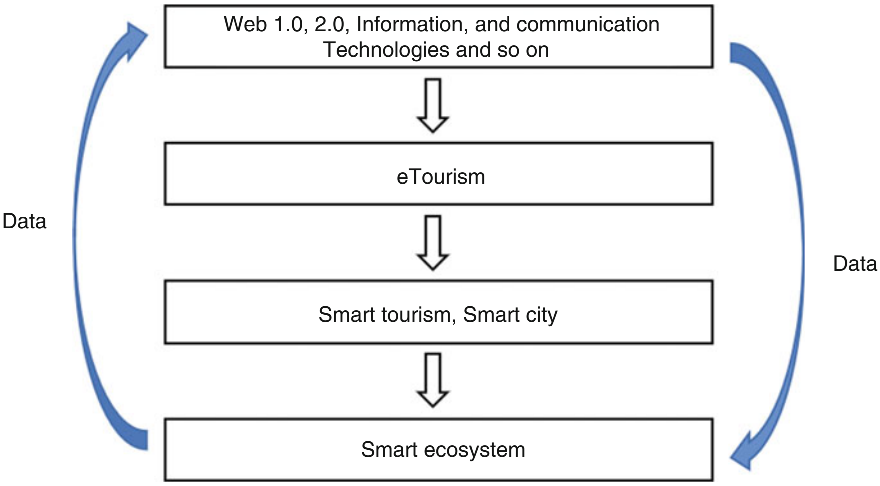

Fig. 1 The application and development of technology in tourism. Notes: ▭ Indicates that the phase persists

and exchange of data. Through a review on the definition of smart tourism, Li et al. [42] defined it as an individual tourism support system with ubiquitous information services as its core. Given the characteristics of information service at all times, this paper integrates the traditional and new forms of tourism data flow and distribution, emphasizing the significance of information individuation. Then, distinct from big data tourism, smart tourism is defined as the process of collecting and aggregating information from the relevant tour operators, infrastructure, and individuals to specific destinations [26]. This directed the attention of scholars to the sustainable development of smart tourism and the capability of information to create value [17, 30, 31, 62, 71].

Whether it is technology research [30, 31], information service research [26, 42], sustainability research [17], or information value creation ability research [62, 71], the research effect of smart tourism is reflected to a large extent in the formation of the feedback on tourist's experience through technology and information [70]. Scholars have explored how tourists gain experience in smart tourism destinations. It has become a research issue worthy of attention to understand how a scene of smart tourism destinations can be designed to influence individual experience.

With the progress made in technology, Geels [24] indicated that these configurations of smart tourism destinations would change constantly over time. In the view of Um and Chung [62], smart tourism plays a key role in elevating tourism resources, supporting tourism management, improving the quality of life, and enhancing communication. As emphasized by Lee et al. [41], smart tourism is a holistic approach where ICTs provide support for the marketing and delivery of tourist products and services at the destinations. With the improvement of digitization levels and the rise in the number of ICT, destinations are made increasingly gridded [26], which leads to a highly complex system. In case of change to some elements, the system will encounter new management problems. Dynamic path design has promoting effects on the sustainable development of smart tourism destinations. Meanwhile, Geels [24] stresses the importance of understanding system inertia. Therefore, the formation of a systematic path contributes to the sustainable development of smart tourism.

On this basis, this study aims to understand smart tourism design through complex system theory, which is required to find a sort of existing smart tourism design elements, build a conceptual framework, and figure out the future development trend, thus promoting the sustainable development of smart tourism destinations. The related research questions are as follows:

Q1: What are the core elements of smart tourism design?
Q2: How to form a conceptual framework based on complex system theory to form a path for tourist's experience and stakeholder resource integration?
Q3: How to form the future development trend of smart tourism from the aspect of design?

It is illustrated in the present study that to make sense of smart tourism destinations necessitates a holistic understanding and scrutinizing of the concept for the understanding of its diverse dimensions [26]. Based on the meta-analysis method, the dimensions and elements of smart tourism design are first identified through an analysis of the existing high-frequency citation papers on "smart tourism" and "design." Then, the decision-making path of smart tourism design is studied from various perspectives: tourists' experience, resource integration, the value creation of stakeholders, and the form of practical effects. Furthermore, the complex system theory is applied to find the dynamic path of smart tourism design by integrating different elements, which provides insights into the future development of smart tourism design.

2 Literature Review

2.1 Smart Tourism and Design

Due to the emergence of new technologies, the notions of smart environments and smart tourism have become familiar to the public [1]. As a theme as well as an interdisciplinary topic of growing academic attention, smart tourism involves the knowledge in relation to sustainability, information technology, and library smart management [3]. There are different ways to incorporate the area of tourism to the definition of smart tourism. In some studies, smart is classified as the interrelationship of technology with offline activities, infrastructure, and online portals [34, 42]. Also, there are several authors suggesting the prevalence and accessibility of digital data based on the dealings between such stakeholders as suppliers and government agencies [8, 30, 31, 42]. Gretzel et al. [30, 31] defined smart tourism by suggesting that it is comprised of three basic elements, smart business ecosystems, smart destinations, and smart experiences, all of which are supported by the creation, processing, and exchange of data. Through a review on the existing definitions of smart tourism, Li et al. [42] defined it as an individual tourism support system with ubiquitous information services as its core. Given the ever-present character of information services, they integrate the traditional and new forms of tourism data flow and distribution, with the emphasis placed on the significance of personalized information. Besides, for other industries linked to smart tourism, Buhalis and Leung [14] suggested an outline form of integrated and connected smart hotel to clarify the significance of such elements as information services, platforms, and data to smart tourism.

Supporting the development of smart tourism and the integration of resources, science and technology are crucial to understanding the decisions made by tourists regarding travel time and routes as well as the influencing factors in tourist's experience [49]. Therefore, it is vital to consider smart tourism design from a dynamic perspective.

2.2 Tourist's Experience

It was in as early as the 1960s that Boorstin introduced the term "experience" to tourism. At that time, experience was viewed as a popular and unique tourist's behavior, a "superficial," "trivial," and "boring" pursuit of "artifice" and "alternative" experiences [19]. Differently, MacCannell defined travel experience as a positive response made to the dilemmas arising from modern life [48]. In the view of Cohen, different tourists may have different needs for travel experiences. Focusing his research on commercial exploitation, Schmitt argued that experiences entail sensory, emotional, intellectual, operational, and cultural experiences.

In addition, Schmitt paid close attention to business development, stating that there are five dimensions of experience: sensory experience, emotional experience, thought experience, operational experience, and related experience [57]. With tourism experience research as the core of tourism research, tourism activities are purposed to gain pleasurable experiences [68]. As the fundamental structural element of tourism phenomenon, tourism experience connects tourism subject, object, and media. In the absence of tourism experience, there is neither basic contradiction nor core of tourism phenomenon, which means tourism demand is closely associated with the product offered. Supported by big data, platforms, and technical systems, smart tourism can tailor its services to particular tourists through the ubiquitous nature of information. In this way, tourist's needs can be better met, and the quality of the experience can be improved, which accounts for the different experiences from the traditional meaning. In comparison to the traditional model of tourism development, the development of experiential tourism with tourism experience as the core is characterized by the respect for human nature, the attention to individuality, the emphasis on tourists' engagement, and the creation of pleasure. With the production and service supply of tourism experience as the starting point, Zhang et al. [72] believed that the value chain of the tourism industry has a modular- and network-like structure, showing such characteristics as the integration of manufacturing and service industries. It is thus imperative to figure out how resource can be integrated with tourist's experience as the core of smart tourism destinations.

3 Research Design

3.1 Meta-Synthesis

In general, qualitative research methods are required for researchers to aggregate, integrate, and interpret the research results obtained from qualitative research samples [46]. As an important research method in literature integration and analysis, meta-synthesis is conducive to interpreting the existing theoretical research results for understanding the new trends of research.

To ensure the accuracy and comprehensiveness of related research results [22], according to a review on the predecessors of advances [58], the seven-step method proposed by Sandelowski and Barroso [55] is adopted in this study for analysis (Fig. 2), to identify research questions, conduct a literature review, retrieve the

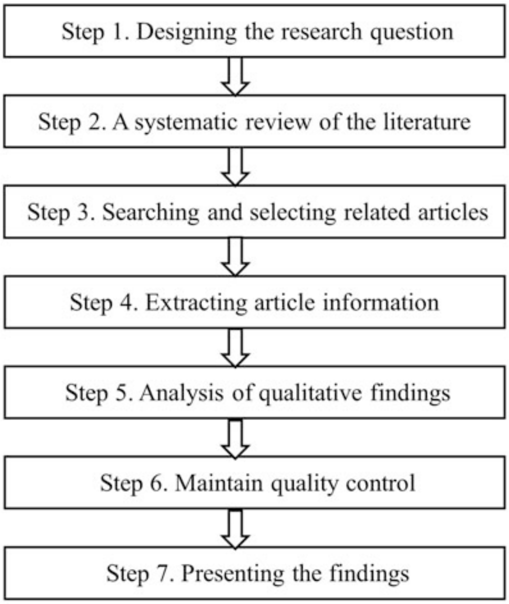

Fig. 2 The seven-step model of meta-synthesis. (Source: Sandelowski and Barroso [55])

relevant literature, extract information from articles, analyze results, apply control, and obtain results.

3.2 Data Collection

Among the most widely used databases in different disciplines, the Web of Science (WoS) database includes multidisciplinary and different types of scientific literature. The core collection of WoS covers the literature data passing the quality tests in this database [53]. Therefore, the WoS core database is used in this study to make the literature used in the analysis as comprehensive and high in quality as possible. The keywords retrieved in this study include "smart tourism" and "design." The papers have been retrieved online by July 1, 2022. One hundred eighteen papers were obtained for analysis.

4 Research Results

4.1 Meta-Synthesis Results

By conducting meta-synthesis, the causal conditions affecting the development of smart tourism destinations are identified as follows (Table 1): the increase in Internet penetration, the application of information and communication technologies, the emergence of smart cities, and the development of social networks. Information technology plays a crucial role in the transformation of sustainable tourism for both developing and developed countries. Applying modern technologies of tourism destinations not only exerts influence on experience but also promotes tourism development by improving the competitiveness of destinations and projects [11, 12]. Similarly, smart city indicates the path of development for smart tourism and its modeling and substructure [8, 11, 18, 39]. In recent years, there are various changes presented to the global travel system, one of which is the emergence of information technology and complete access, such as the increased use of social media [25]. Due to the exchange and cooperation between ICT users, a wide range of interactive and dynamic programs have been launched [38], laying a foundation for the development of smart tourism destinations.

4.2 Tourist's Experience

It has been confirmed in prior research that tourist's experiences rely on the stimuli generated by the scene for the tourist, rather than occurring in isolation (Fig. 3).

Table 1 Meta-synthesis results

Dimension	Element	Scholars
Technological factors	Develop information and communication technology	Arenas et al. [5], Xiang et al. [70], Liburd et al. [43] and Sabou and Maiorescu [54]
	Development of social networks and big data	
	The emergence of the smart city	Gretzel [28]
External factor	Economic and financial factors	Jia et al. [36]
	Technological and infrastructure factors	Arenas et al. [5], Jia et al. [36] and Lim et al. [44]
	Environmental factors	Jia et al. [36] and Lim et al. [44]
	Social and cultural factors	Jia et al. [36], Gretzel [28] and Xiang and Fesenmaier [69]
Intervening conditions	Government support	Johnson et al. [37], Buhalis and Amaranggana [11], Buonincontri and Micera [15], Esteban Curiel et al. [23], Gretzel et al. [30, 31], Huang et al. [35] and Xiang and Fesenmaier [69]
Value co-creation actions/interactions	Resource integration (use of renewable energy sources, increase the attractiveness of natural, reduce environmental pollution, energy efficiency)	Tanguay et al. [60], Torres-Delgado and Palomeque [61], Giffinger et al. [27], Blancas et al. [7], Khan et al. [39], Schianetz and Kavanagh [56], Lombardi et al. [45] and Wan [65]
	Organization (reinforcement entrepreneurship and competitiveness, develop cultural infrastructures)	Gretzel [28]
	Service (level of service quality)	Ali and Frew [2], Buhalis and Amaranggana [11], Huang et al. [35] and Lim et al. [44]
	Marketing (perceived destination image, destination attractiveness)	Boes et al. [8], Buhalis and Amaranggana [11] and Sabou and Maiorescu [54]
	Information resources (ICT infrastructure, use of mobile equipment, use of cloud computing services, use of the internet of things, use of end user internet services, use of data analysis technologies)	Arenas et al. [5], Jia et al. [36] and Xiang and Fesenmaier [69]

(continued)

Table 1 (continued)

Dimension	Element	Scholars
Effect	Improving the quality of life of residents and tourists	Jia et al. [36]
	Management of natural resources through participatory policies	Al-Nasrawi et al. [4], Boes et al. [8], Caragliu et al. [16], Chourabi et al. [18] and Xiang and Fesenmaier [69]
	Convergence of economic, social, political, and environmental goals	Al-Nasrawi et al. [4]
	Improving tourist's experiences	Arenas et al. [5], Jia et al. [36], Johnson et al. [37] and Xiang et al. [70]
Trend	From eTourism to smart tourism	Arenas et al. [5], Jia et al. [36], Gretzel [28], Johnson et al. [37], Xiang and Fesenmaier [69], Wang et al. [66], Gretzel et al. [30, 31, 32] and Gretzel [29]
	Knowledge acquisition and transfer within a destination ecosystem	
	Tourism co-creation in real time and multidirectional supported by smart technologies	

Note: The papers analyzed are not fully presented

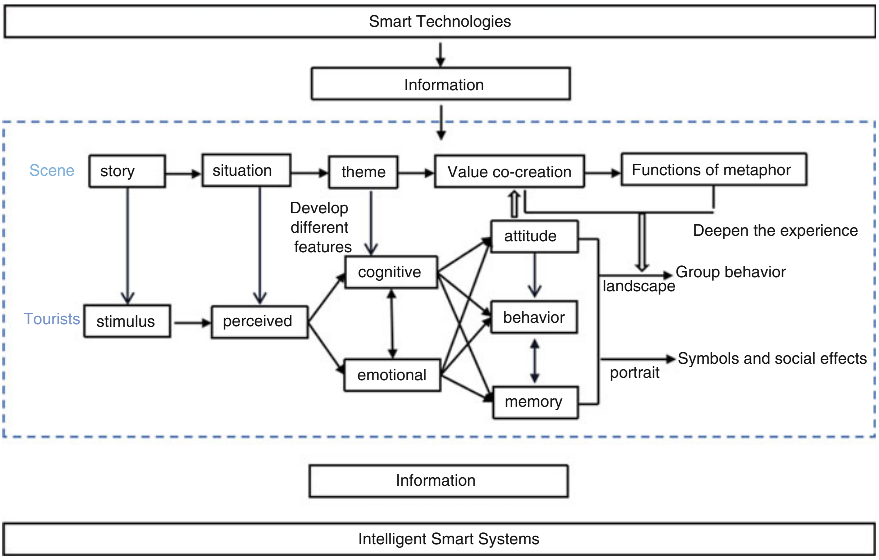

Fig. 3 Tourists' experience based on the scene

According to the study of Xiang et al. [70], tourists derive experiences from environmental stimuli in the first place. In respect of smart tourism destinations, the virtual or real scenarios are constructed through their specificity and inclusion of stimuli to create the environment of tourist's experience, taking the form of information services and information systems. As revealed by earlier research, cognitive and emotional resonance can be triggered by the sharing of tourism experiences through short vlogs and VR technology, from the perspective of information. That is to say, smart tourism destinations can generate tourist's cognitive and emotional feedback through different ways, such as story building, contextual design, and thematic induction. In co-creative value with smart tourism destinations, tourists can perceive the destination in different angles, such as service quality, brand, social responsibility, and others. This leads to the cultivation of individual emotions that increase tourist value and inspire behavior. As the key driver of tourist's participation in the practice of value co-creation as well as the result of co-creative value at the individual level, the cognitive-emotional-behavioral chain reflects the closed-loop nature of the co-creative value ecosystem. Through value co-creation, the tourism experience is deepened by the resulting functional metaphors horizontally and vertically. This contributes to group value, symbolic consumption, and social effects.

This is layer 1 (Fig. 3): the tourist's experience layer. The outcomes of tourist's experience are reflected through several stages [20, 64], including perception, cognition, and emotion in sequence. In turn, they lead to attitude, behavior, and memory [70]. Besides, individual behavior relies on social networks of relationships to exert influence on collective behaviors. Stimulated by the environment, the influences of the tourism experience are contributory to shaping tourist's perceptions through the storyline, situations, and themes constructed by the destination in the context of co-creative value. Also, the experience is reinforced by functional metaphors.

4.3 Stakeholders

Herein, resource-based theory and experience theory are applied to explore the paths of resource integration and tourist's experience for smart tourism destinations. This is crucial to enriching the applied research on resource base theory in the context of big data, digitization, and networking.

In theory, the earliest research on resource-based theory originated from Penrose's view of the enterprise as a collection of resources mentioned in his book titled *Theories of Enterprise Growth* in 1959 [50]. However, Wernerfelt [67] put forward a resource-based view on this basis, arguing that Barney [6] focused attention on the characteristics of resources. It was suggested that companies cannot gain a competitive advantage without having resources with value, scarcity, inimitability, and non-substitutability. Emphasizing the possession of valuable, scarce, inimitable, and non-substitutable resources, Barney's [6] VRIN (valuable, rare, inimitable, and non-substitutable) framework is crucial to gaining a competitive advantage for a firm. It marked the emergence of resource-based theory. However, it is noteworthy that the theoretical studies of this period overlooked the dynamic acquisition of such resources for attributing competitive advantage only to the heterogeneous resources possessed by firms from a static perspective [33]. This resulted in a disconnection between resource-based theory and practice in an increasingly uncertain external environment to cope with these challenges.

To address these challenges, scholars have explored how to address the limitations of resource-based theory through the introduction of dynamic capabilities and the integration of theories of managerial cognition and organizational behavior. The focus is placed on the factors, processes, and outcomes that make difference to the way resource management is practiced in specific contexts [59].

According to the meta-synthesis results, the factors that can affect smart tourism destination design include society, economy, culture, technology, and environment. In line with the complex system theory, the research puts forward layer 2 by integrating the elements (Fig. 4): a multifaceted interactive layer of resource integration for smart tourism construction. Driven by data, smart tourism forms an efficient operation with timeless information services. Technological developments enable the formation of a multi-interactive layer of smart tourism through the interaction of destinations, platforms, and tourists, which is subject to government supervision. In this way, destinations make use of data to form decisions, forecasts, and developments. For platforms, data and information are integrated to perform intermediary, marketing, and feedback functions. For tourists, decisions are made and feedback is given through the information services of destinations and platforms. By following the interactive process, smart tourism plays its role in

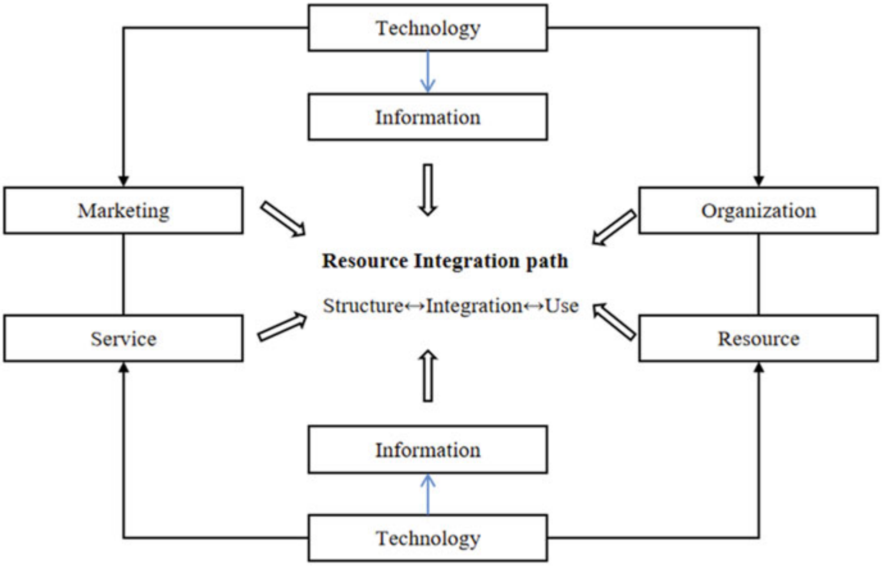

Fig. 4 Resource integration path

optimizing the layout of ecological business, building industrial value networks and pan-community networks, promoting the collective participation in the construction of smart tourism, and integrating the resources requisite to enhance regional competitiveness and meet the demand of tourists instantly.

4.4 Smart Tourism Destination System Path

Originating from Prahalad and Ramaswamy's [51] theory of co-creative value based on tourist's experience, the study of tourist co-creation suggests that the co-creation of tourist's experience is between tourists and companies. Then, Prahalad and Ramaswamy [52] further defined the concept of co-creative value, demonstrating that the source of the co-creative value process is tourist's experience. On the other hand, it is emphasized by the service-led logic based on Vargo and Lusch [63] that interactive experience is the premise of co-creative value between the tourist and the company. From the perspective of service ecosystem, Lusch and Nambisan [47] reiterated that the core of co-creative value lies in the co-creation of experiential value between service providers and beneficiaries. In the research on co-creative value models and processes, the role of co-creative value on the resources and capabilities of firms has been qualitatively explored. Besides, a review of the relevant literature has been conducted to highlight the close association between the two. Considering service innovation, Lusch and Nambisan [47] defined a firm's resources as a dynamic four-component set of capabilities, relationships, knowledge, and information. It was argued that the co-creative value between tourists and firms is a process in which resources are integrated, matched, and reconfigured on a continued basis. In addition, there is some empirical literature identifying the positive impact of co-creative value on the resources/capabilities of a company. It is thus worthwhile to explore how co-creative value would make impact between smart tourism destinations and tourists.

To build a knowledge framework on co-creative value research, the co-creative value research framework is applied to categorize and organize the retrieved literature. The model and process of co-creative value are what co-creative value research is based on. The main line is "connection-interaction-resource integration-reconstruction," the focus of which is placed on the evolutionary trajectory of the subjects, channels, and behaviors in relation to co-creative value.

By revealing the co-creative value mechanism of "tourist co-creation behavior-tourist co-creation experience-result" from the perspective of tourist's experience, the study contributes to deepening the fundamental mechanism of value co-creation. It involves an analysis as to the drivers and outcomes of value co-creation and the dynamics and performance of value co-creation. All the research frameworks in interaction comprise a spiral cycle of evolution.

Based on the resource-based view, experience theory, and co-creative value, the third model framework of this research is constructed.

Firstly, the resource-based theory of smart tourism destinations, which is similar to traditional management theory research, develops progressively with the upgrading of practical needs. This reflects the evolutionary characteristics from static to dynamic and the shift from resource based to resource action, thus providing sufficient support for subsequent research from a theoretical perspective. Secondly, the resource management process of smart tourism destinations entails resource context design, manager cognition, resource strategy, and resource behavior logic. Thirdly, big data and emerging technologies provide an impetus for smart tourism destinations to develop competitive advantages through resource actions. Besides, resource actions are prerequisite for smart tourism destinations to transform the resources possessed by them, allowing the access to organizational capabilities, such as management capabilities and concrete operational execution capabilities. Fourthly, to realize the foundation requires a combination with the feedback of tourist's experience. Through the platform, big data, and system support, tourists will have the information feedback as reflected in experience-related perceptions, cognitive and emotional feedback, attitudes, and behaviors. Smart tourism destinations rely on the data to start a new round of resource integration. Then, tourists improve their experience by providing customized services based on the ubiquity of information.

On this basis, research has developed layer 3 (Fig. 5), with the construction of smart tourism revolving around experience and resource integration. With layers 1 and 2 as the basis, interaction leads to information gain in smart tourism while enriching tourism resource information. Due to the diversification of the business ecological model of smart tourism, the needs of immediate tourists are met by means

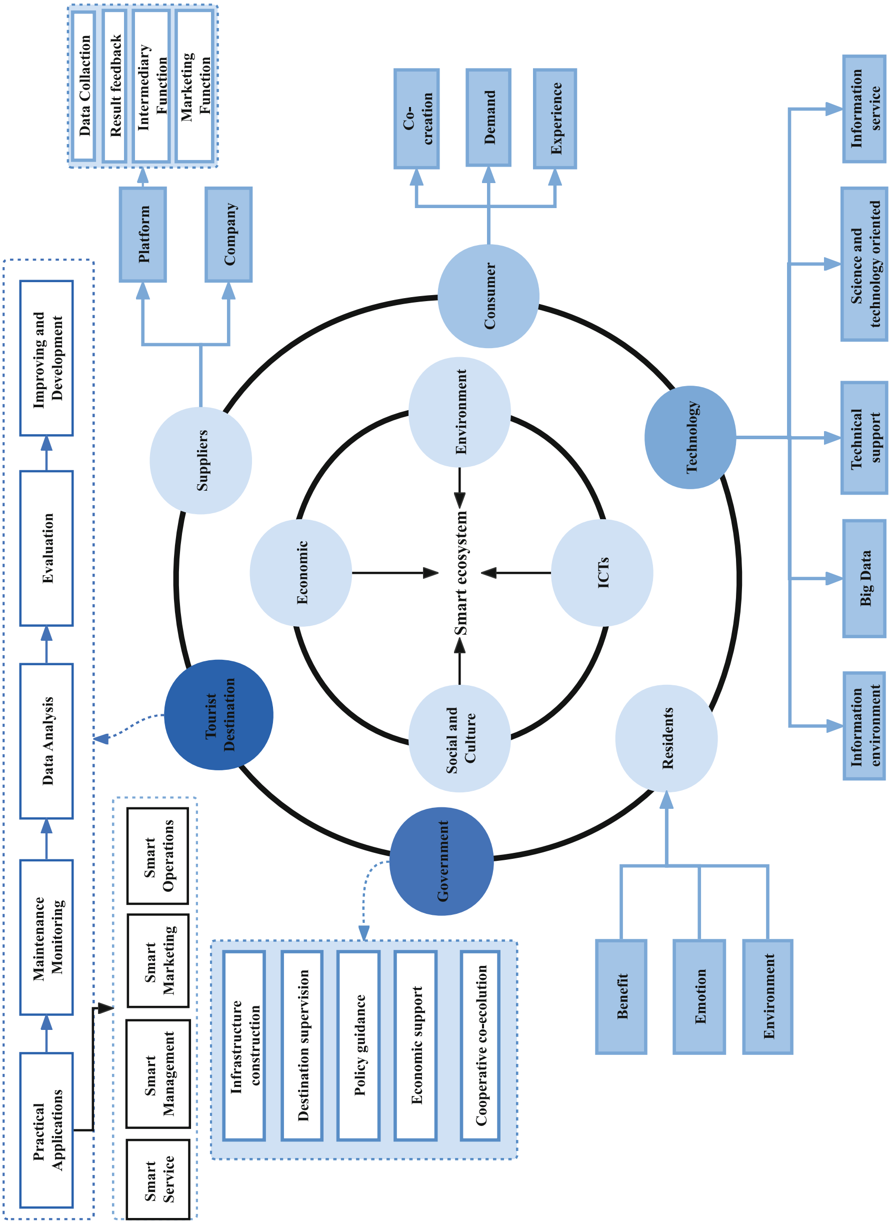

Fig. 5 Smart tourism system path

of information and data analysis, which in turn affects the level of the tourist's experience in the context of value co-creation.

5 Conclusions and Implications

5.1 Conclusions

In the existing research, it is discovered that the existing data-driven paths of smart tourism involve (a) destinations, enabling data prediction, decision-making, and real-time correction; (b) process optimization, service optimization, and technology optimization; and (c) real-time government regulation and guidance of destinations, platforms, and tourist's behavior, as mainly analyzed in terms of data-driven paths. In this study, a theoretical research framework is built for the design of smart tourism destinations with experience theory, resource-based view, and co-creation value. It leads to four pathways: the tourist's experience, the multifaceted resource integration interaction in smart tourism construction, the integration of resource in smart tourism destinations, and the interaction between tourist's experience and destination resource integration as the core. An attempt is made to reveal the dynamic pathways to smart tourism destination design from the perspective of resource integration and in line with experience theory.

Based on the study of Xiang et al. [70] on a review of smart tourism design, this study aims to verify a design path that focuses on the experience of tourists. Based on the stimuli generated by scenarios, a new research perspective is proposed that integrates scenario theory and individual experience to create different states formed by tourists at different stages. Meanwhile, symbolic theory is applied to explore the functional metaphors formed after deepening individual experiences, and an analysis is conducted as to the role of metaphors vertically and horizontally for promoting the development of tourist's experience research.

Secondly, a tourism destination resource integration layer is constructed in this study based on the study of Koo et al. [40]. The roles of information, services, marketing, organization, and resource management in the resource integration process are verified. In addition, the integration of resource into layers is investigated to build a path to the formation of resource integration layers in the design process of smart tourism destinations. This is conducive to the application of resource integration theory in smart tourism destinations.

Thirdly, a systematic framework is constructed in the research for smart tourism. Based on complex system theory, it contributes to the evolution of smart tourism into a smart ecosystem [9].

5.2 *Implications*

5.2.1 Theoretical Implications

Firstly, a new research perspective is proposed in this study based on the design path of scene theory with the experience of tourists as the core. Besides, scene theory is combined with individual experience to create the different states formed by tourists at different stages based on the stimuli generated by the scene. In the meantime, the useful metaphors formed after the deepening of individual experience are explored by using symbolic theory. Moreover, the role of metaphors is analyzed vertically and horizontally, which promotes the development of research on tourist's experience.

Secondly, the role of information, markets, organizations, resource management, and services in resource integration is verified in this study. Through the dissection of resource integration into layers, a pathway is found for the formation of resource integration layers in the design process of smart tourism destinations. This is conducive to applying resource integration theory in smart tourism destinations.

Thirdly, an interactive path is found in this study for the integration of tourists' experiences and destination resources. Then, the dynamic path is constructed through co-creative value, which promotes the development of the theory of smart tourism destination design.

5.2.2 Practical Implications

Firstly, a dynamic path is found in this study for the experience of tourists. From the perspective of smart tourism destination managers, they can seek the improvement of scenario planning and design scenic activities by exercising the factors that affect tourists' experience. In this way, tourists would be willing to engage in continuous consumption, which reinforces consumption experience and produces symbolic effects. This is contributory to the heterogeneity and uniqueness of the scenic area.

Secondly, a resource integration path is developed in this study. There are five perspectives from which smart tourism destination managers can enhance resource integration: information, marketing, organization, resource management, and services. Meanwhile, according to the resource integration path, dynamic resource integration plays a role in completing the dynamic resource effect based on data and information services and in stimulating the potential of resource utilization in the scenic area.

Thirdly, a path of experience and resource integration is developed in this study. By enabling the activities of tourists' participation in co-creation, smart tourism destination managers can improve the matching of resources and tourists' experience. For example, vlogs and feedbacks can be conducted on consumption intentions through social media evaluation, and customized services can be adjusted in due course through feedback information.

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Sustainable Mobility: How to Gamify and Factors to Better Success

Xavier Fonseca

1 Introduction

There is a growing need to make the environmental footprint of present human behaviour more sustainable. Current directions for innovation are intimately aligned with what is no longer sustainable, both to the environment and to the animals and humans living in it.[1] Behaviour change in the mobility sector is one way to fight climate change and reduce the negative and abusive impact that current societies have in the environment. Mobility as a service (MaaS) aims at triggering and sustaining such behaviour change [1].

MaaS is an emerging service that invites citizens to use shared, public and environmentally friendlier transportation in their daily commute and reduce the usage of private polluting means of transportation [2]. The major impact MaaS initiatives aim at is to severely reduce the sources and amount of carbon dioxide (CO_2), nitrogen dioxide (NO_2) and small particle pollution in urban environments, alongside making cities healthier and more manageable to live in [3]. It also addresses problems felt particularly in densely populated urban environments, namely, heavy traffic and congestion, longer commuting periods, parking difficulties, accidents and difficulties for pedestrians and road users [1].[2] With MaaS, citizens are invited to leave their cars and motorbikes at home and enjoy a daily commute by public transportation

[1] https://sdgs.un.org/goals, The 17 goals from the United Nations, last visited on 14 Feb. 23.

[2] https://www.geographynotes.com/articles/7-problems-of-urban-transport-explained-with-diagram/185, Problems of urban transportation, visited on 14 Feb. 23.

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(e.g. bus), shared services (e.g. electrified scooters) or environmentally friendly options (e.g. bicycle). This is done by promoting technological means where citizens can conveniently choose and pay for the desired route and where these routes can be travelled by more sustainable vehicles or through environmentally friendlier business models [4].[3] Mobility policies introduced by cities are costly and liable to fail [5]; therefore, for MaaS services to be capable to invite individuals to have more sustainable commutes over time, they must be coupled with strategies that aim at fostering behaviour change.

Substantial efforts have been developed to better comprehend how interactive technologies can be used to promote individuals' awareness, encourage active participation and promote behaviour change towards a more sustainable way of living [6]. Playful approaches like gamification are one way to explore such behaviour change strategies and have been actively researched in their ability to invite successful behaviour change [5, 7]. To various extents, such approaches take advantage of game components to influence user behaviour in non-game contexts [8], with the objective of providing more effective, efficient, engaging, enduring and entertaining experiences [7, 9–12]. This document aims at covering the state of the art of playful approaches used by digital means to promote behaviour change in the topic of urban mobility. It analyses what has been used to promote more sustainable commute habits, what works and what has not worked as well for MaaS from the gamification perspective and other factors that are not being addressed by the studies done so far and that future research must address for higher future adoption of such applications and mobility services.

The next section regards the methodology followed in this chapter to collect papers on the promotion of sustainable urban mobility through active play-based approaches. The section after presents the background based on the selected papers, organized in the following subsections: (1) gamified solutions for behaviour change towards sustainable urban mobility and (2) gamification frameworks for gamified mobility. The section after presents an analysis of the success of the playful approaches done so far in the MaaS paradigm. The next section discusses what has not been covered by current studies and thus presents gaps that future research should focus on. The section after concludes the chapter.

2 Methodology

This chapter focuses on web and mobile applications for behaviour change towards sustainable urban mobility, which includes all forms of mobility as a service (e.g. the sharing of vehicles owned by a company or private car sharing), physically active modes of transport (bicycle, walking), vehicles of zero small particle emissions and all forms of public transport. These applications must be digital, employ

[3] https://maas-alliance.eu/homepage/what-is-maas/, What is MaaS?, last visited on 14 Feb. 23.

some form of playful approach (e.g. gamification), must work in an actual urban environment (not just concept) and support citizens to commute. As such, an exhaustive Internet-based literature search following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines was carried out in Google Scholar, IEEE Library and ACM Library, with the following search query: ("Digital" [Title/Abstract]) AND (("playful approaches" [Title/Abstract]) OR ("Gamification" [Title/Abstract]) OR ("serious games" [Title/Abstract]) OR ("play-based" [Title/Abstract])) AND (("Urban" [Title/Abstract]) AND (("MaaS" [Title/Abstract]) OR ("mobility" [Title/Abstract]))). This query is used to look for technical approaches to *the actual promotion of sustainable urban mobility through active playful-based approaches*. Criteria used excludes papers on gamification approaches for policy-making, urban freight transport, stakeholder engagement, traffic system education, consumption models, urban decision-making and visualization, educational tools, road education, politically centred topics like neoliberalism, data access, playful approaches not developed for actual urban commute (e.g. education on designing games), gamified approaches to face Covid pandemic isolation, simulation-based approaches, connected vehicles, mobility-pattern analysis, cultural experiences in urban environment, e-participation, training of spatial awareness, participatory approaches to design smart cities, exergames, the use of smartphones to capture data to describe smart cities and the use of ludic practices for civic engagement, urban rehabilitation and social integration. Also excluded are digital playful solutions not directly built to support the daily commute of citizens; even though they may influence such commute (e.g. *Pokémon Go* [13]), solutions found in the literature like location-based games do not change/support mobility behaviour but focus on entertainment [14–18] and the support of several other serious causes [19–30]. They do have a positive effect on inviting citizens to engage in co-located play [21] and discovering cities [31], yet it falls outside the scope of this chapter.

After the initial search on the basis on the inclusion criteria, 9707 articles were identified, after which 9462 were excluded after inspection of title and removal of duplicates. From this process, 245 unique papers were identified, where 211 were excluded after inspection of abstract and 4 excluded due to inaccessibility of full text. From this number, 30 papers were included in this review. This process is shown in Fig. 1.

3 Background

This background section covers the literature on playful approaches for the promotion of behaviour change towards sustainable mobility habits. Based on what was found in the reviewing process, it is organized as follows: (1) gamified solutions for behaviour change towards sustainable urban mobility and (2) gamification frameworks for gamified mobility. These subsections detail what sort of digital

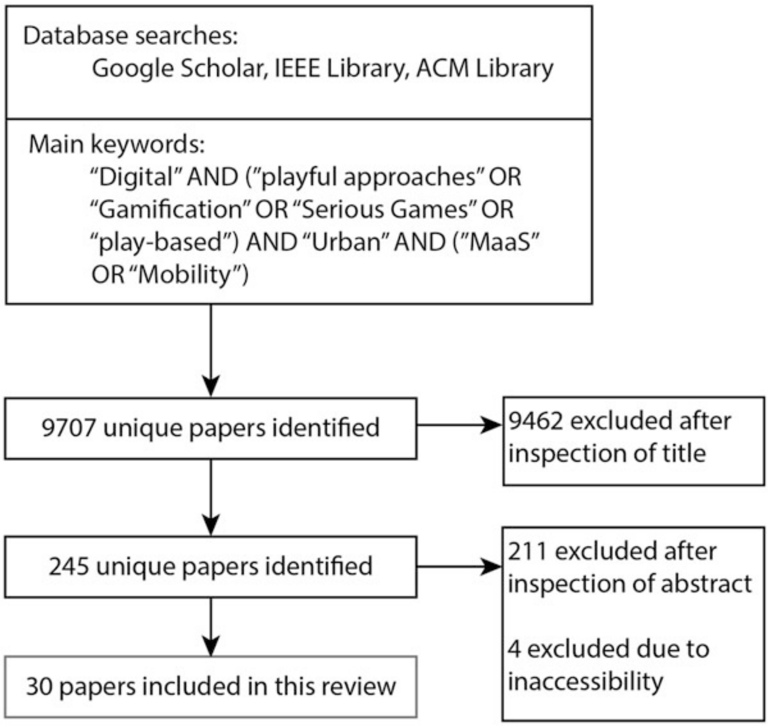

Fig. 1 Overview of the literature review identification process

solutions has been created with gamification imbued for the direct support of daily commute.

Note: In studies on persuasive strategies [32], it is possible to see gamification being implicitly categorized as a reward mechanism. This study does not endorse this perspective. Persuasive strategies like challenges and goal settings, self-monitoring and behaviour feedback, social comparison, personalized suggestions and cooperation are a few examples of persuasive strategies found in the literature that are presented as dissociated from gamification [32–34]. Yet the vast majority of these are also seen in games. This study clarifies that by "gamification," it means the use of components found in games (e.g. elements, mechanics, dynamics [35]) in non-gaming applications. As such, this chapter adopts the perspective of playful approaches, instead of the one used in persuasive strategies.

3.1 Gamified Solutions for Behaviour Change Towards Sustainable Urban Mobility

Gamification has been used to invite behaviour change towards sustainable urban mobility [5, 32, 36–41]. It has shown promising results through basic and more complex elements and techniques such as points, ranks, leader boards, levels, competitions, paths, challenges, missions, rewards, badges, user powers, feedback, social reputation and comparative maps [33, 42]. Gamification is actively being researched in the mobility sector for ever-more-effective persuasive applications [34], and the following table gives an upfront overview of the gamified solutions found in the literature for sustainable urban mobility. They are detailed next in Table 1.

In 2009, the *INSTANT* project illustrated an application to reduce traffic congestion and pollution in Bangalore and reached 14,000 employees of a company [43]. Focusing on bus users, this project proposed *monetary incentives* to individuals acting as "decongestors" instead of charging congestors, while focusing on the spatial offering (same time, different routes) instead of the temporal offering (different times, same routes). At the same time, the *TrueCentive* incentive platform is proposed to offer incentive schemes (*rewards*) for citizens to share information about parking spaces in the city and uses gamification theory to validate the chosen protocols for incentive [45]. Still in 2009, the *EcoIsland* application was also developed to persuade and assist individual families in changing their CO_2-impactful lifestyle, based on mobile sensors and a web platform [46]. Gamification-wise, it used *rewards*: credits and an emission-trading system to acquire objects to decorate the user's island.

Table 1 Overview of gamified applications for behaviour change towards sustainable mobility

Year	Name	References	Year	Name	References
2009	*INSTANT*	[43]	2017	*Bellidea*	[44]
	TrueCentive	[45]	2018	*MUV*	[37]
	EcoIsland	[46]		*SMART*	[47]
2011	*Green Daily Guide*	[32]	2019	*Play&Go*	[6]
2012	*Tripzoom*	[39]		*SaveMyBike*	[48]
2013	*Foursquare*	[17]		*MARGe*	[49]
	MatkaHupi	[50]			
2014	*Peacox*	[51]	2020	*GoEco!*	[52]
	From5To4	[53]			
2015	*Traces*	[3]	2021	Corporate bike/scooter sharing services	[54, 55]
	E-Mission	[56]		*Sharing Lisboa*	[57]
2016	BikeRider	[58]		*The Tracker for Cycling*	[59]
			Ongoing	AYR	Footnote 5

In 2011, the *Green Daily Guide* is an application that uses gamification to motivate people to use public transportation or an option other than private car [32]. Users would use the application to plan their commute and be virtually *rewarded* with scores and presented with *statistics* on their traveling choices [60].

In 2012, the *Tripzoom* platform was used to identify mobility behavioural patterns and invite individuals to improve their CO_2 footprint, health and time through personalized mobility solutions [39, 61, 62]. This mobile sensing platform was used together with an incentive system and social media feedback, to make commute more sustainable and rewarding to individuals. Game elements used were *challenges* and *rewards* (saving time or money and gaining information and social recognition).

In 2013, researchers investigated the particularly successful location-based social network *Foursquare* to understand how gamification elements had been used to turn "life into a game" and used to influence mobility decisions [17]. In *Foursquare*, *digital ownership* and *social prestige* (mayorships) brought dynamics of *competition* and had influence in the places users would choose to go to, especially those they already had been to before. *Rewards* for mobility would be given frequently as well, namely, badges at the first check-in, 10th and 50th check-ins. *Points* and *leader boards* were also originally used but were de-emphasized over time given their lack of effectiveness on users [17]. Also in 2013, the journey planning application *MatkaHupi* was created to automatically capture individuals' commutes and modes of transportation used to inform them on their CO_2 footprint [50]. It used gamification to present a set of mobility *challenges* to the user, centred on environmentally friendlier commute options and based on virtual *rewards* (points) at challenge completion.

In 2014, like *MatkaHupi*, *Peacox* was developed to propose environmentally friendlier routes to users, which was done by taking users' preferences and their context into consideration [51]. Visualization of the CO_2 footprint on the environment was paired with personal and collaborative *challenges*, to invite users to change behaviour towards less environmentally harmful commuting choices. Still in 2014, the *From5To4* web-based game tool was created to incentivize individual or groups of employees to have at least 20% of their daily commute done by sustainable means. Gamification elements used were based on *peer pressure* and *competition*, *team coherence*, *small rewards* and the obligation of having to log in personal travel choices; this achieved a 21% decrease of use of personal car in peak hours in companies of over 1000 employees [53]. During the same period, a gamified model based on the SUPERHUB project was proposed, with the purpose of serving as a reflection mechanism on current travel behaviours and a way of triggering behaviour change [63]. This tool was used by users to track their own travel behaviour, *set goals* and manage progress made towards such goals through *challenges*, *points* and *levels*.

In 2015, the platform *Traces* was used to promote the use of sustainable mobility through game elements and locative features. The application leaves colourful digital traces on a city map based on the different commuting modalities chosen by the users [3, 64]. This pervasive application was enhanced by offline campaigns in urban space, and it implemented a self-regulation mobility behaviour with four possible "mobility stages" to map the mobility choices of users. It used *quizzes* and group *quests* to colour the city map, *game status* based on colours over a map indicating progression and *points* at the discovery of new places. Still in 2015, *E-Mission* motivated users towards the same objective through gamification and data visualization [56]. For gamification, it used *goals and rules*, *feedback*, manageable *challenges* and *game progression* (harder stages).

In 2016, the Street Life project executed several pilots that applied gamification to promote more sustainable mobility behaviour. The *BikeRider* application used gamification not only for higher service uptake from citizens but also to validate actual changes in behaviour through system performance and CO_2 emissions. Together with a comprehensive inter-modal set of routes to users, it proposed a set of bicycle routes and a corresponding safety assessment as unique feature (to inform on the safest options). That was done through public statistics, but game elements were also used to break old commuting habits: *competition* for game credits (*badges* – green leaves) that would turn to *collectable* virtual trees and real *rewards* (merchandizing from Siemens and the Municipality of Berlin) [58]. Throughout the overall project, it was created other two games: the *Zone Hunter*, a city exploring game with *points* and *virtual trophies*, and the *Play&Go* mentioned below.

In 2017, the *Bellidea* application was created to give ecological feedback to users and stimulate them with mobility-related challenges [44]. These would get users some points proportional to the amount of time spent weekly on public transportation/bicycle/walking. *Points* would be redeemable into *real prizes* (discounts on energy bills, store vouchers or public transport tickets) and regular community *challenges* (giving the whole community extra points).

In 2018, the *MUV*[4] platform was created to calculate the average amount of kilometres travelled, calories burned and CO_2 saved throughout the week. With *MUV*, users would get *points* every time they moved in a sustainable way (i.e. walking, biking, through public transportation or car-pooling); they would be invited to get *involved in the community* (e.g. in sports *training sessions*, *challenges* and *team tournaments*), would be *rewarded* for it by sponsors and become aware (through *game statistics*) of how much they contributed to changing the world [11, 37]. Also in 2018, the *SMART* cycling application aimed at offering positive incentives for users to use the bicycle more often. It used *challenges* and *rewards* (points, tradable for services and discounted products), *feedback* (in-app messages) and *game progression* [47].

In 2019, an urban game called *Play&Go* was designed to promote behaviour change for sustainable mobility, by inviting players to plan their journey, share their game status on social media and check out possible weekly prizes [6, 41, 65, 66]. This long-running mobility game managed to sustain behaviour change through standard game mechanics (*competition*, *points*, *badges*, *leader boards* and

[4] https://www.muvgame.com/en/, MUV, last visited on 14 Feb. 23.

real prizes), trip-tracking features and more advanced game mechanics such as personalized *challenges*. Running for three years through different case studies, it argues that even the players that played the game and then quit sustained their change in behaviour [6]. Still in 2019, the *MARGe* mobile application was conceived to use hardware beacons to engage users and persuade them to have more sustainable commutes [49]. The beacons were conceived to offer authentic content about Madeira Portuguese island's history, all the while assisting and locating players throughout their gameplay experience. Focused on tourists and free public transportations (busses), the beacon Bluetooth communication technology was coupled with authentic co-located stories and curiosities to turn the tourist path into an adventure. Gamification technique is used to maintain user engagement: a list of *challenges* (quizzes, tasks, clues, quests) is provided to tourists and the dynamic of progression through *rewards* (points and badges, Easter egg collectables), *narrative* (stage-based stories) and *competition* (levels, achievements, leader boards). In the same year, the platform *SaveMyBike* offered a set of services for the bicycling world that were adaptable to any city and associated with the chronic problem of bike theft: burglar alarm, feedback giving, bike discovery and a gamified *reward* system [48]. This system allowed private bicycle owners to fit IoT-related hardware in their bicycles to identify them, which in turn allowed for more agile recording of thefts, *citizen participation* and at the same time having access to the *statistics* of the use of the bicycle. In terms of gamification, the reward scheme is associated with the statistics collected by the Good_Go application. The rewards (points) can be traded by businesses associated with the platform. Lastly, in the same year, the application *GoEco!* was created to invite car-dependent individuals to use public transportation, and it resorted to automatic mobility tracking, feedback, the mechanic of *social comparison* and gamification elements: *goals* for energy consumption and *progression*, *game statistics*, *rewards* (trophies and badges) and *competition* (leader board) [52].

In 2020, corporate services for bike and scooter sharing widely used points to promote service quality and user loyalty [54, 55]. Throughout the offered services, the companies attributed points to every user reporting broken or badly parked bikes/scooters and retracted points from users violating traffic codes or using bikes/scooters the way they should not. Together with the points system, the *reward* attribution included service/supermarket discounts and prioritized customer support [54].

In 2021, the digital social market *Sharing Lisboa* was developed to enable the exchange of goods and services between citizens for a year. The solution aimed at triggering behaviour change at the time of exchanging such goods/services and used the mechanic of *competition* that could earn players some points. These points would be tradable for a given cause (schools across the city) [57]. *Causes*, *incentives* and *reward mechanisms* served as a guiding thread for individuals to engage with the community and local business, which influenced their commute. On top of this, the schools involved in the game would compete for the most points, which, at the end of that year, would render the winning school real funding for its energy refurbishment.

Also in 2021, the AYR[5] platform begun its development to reward carbon neutral mobility behaviour and accelerate the global transition towards carbon neutral cities. This blockchain-based solution aims at quantifying the CO_2 not produced by a user, which is then taken by the platform as *savings* that are tradable by services. The platform uses a game-related approach based on the quantification of the impact of user's actions (*game statistics*), the *reward* of savings and the exchange of these savings for real-world services. Still in 2021, the "Tracker for Cycling" mobile application [59] was created to incentivize sustainable urban mobility in Austria. That was done by nudging users to explore sustainable tour services and visit points of interest of the city. Overall, the application used *rewards* as "heartbeats" (points), *social comparison* and *challenges/quizzes* to both measure and influence behaviour. Table 2 summarizes all the gamified solutions for behaviour change towards sustainable urban mobility that are presented in this sub-section.

3.2 Gamification Frameworks for Gamified Mobility

In the literature review performed, gamification frameworks stand out as platforms and tool sets that use gamification to promote the actual commute of citizens through more sustainable means. They aim at making the process of creating and supporting gamified applications for mobility and are therefore included in this chapter. The works of Kazhamiakin et al. stand out and are detailed next [5, 41, 67].

One of the first proposals were created within the EU project STREETLIFE:[6] a generic service-based gamification framework to enable the design, deployment and execution of games that could use the panoply of services that cities offer, while at the same time enhancing players' awareness on new and sustainable public mobility policies [5]. The framework enabled gamification strategies within regular applications for smart cities (e.g. regarding sustainable mobility), which would ease the effort and streamline the process of creating gamified-based solutions. In parallel, this framework aimed at being capable of delivering long-term user engagement: it would use players' status and reputation in the game to enable the automatic and personalized challenges generation, together with rewards attribution and the management of the game.

The architecture of the gamification framework (first version in [5], second version in [41]) was built based on the values of openness, generality and extensibility and has three layers: gamification enablers, gamification services and gamification front end [41]. The enablers' layer regards the basic functionality of the gamified component, from design, development and execution of the gamified model within the smart cities ICT overall system (e.g. content generation system, player's profile, game state and game history). The services' layer consists of enabling the creation

[5] https://www.ceiia.com/ayr, CEiiA AYR platform, last visited on 14 Feb. 23.

[6] https://www.fokus.fraunhofer.de/go/en_streetlife, Streetlife, last visited on 14 Feb. 23.

Table 2 Summary of gamification and non-playful techniques explored by the literature for behaviour change towards sustainable urban mobility

Gamification explored	Non-gamified features used
Monetary incentives, real rewards, vouchers, merchandize from brands and discounts for services	Enablement of hardware beacons to track commutes and offer in situ personalized content
Virtual rewards and game credits	Application plans multimodal route
Competition (e.g. scores, leader boards) and peer pressure	Challenges on environmentally friendlier commute options, during peak hours, are included
Visual statistics on travel choices and CO_2 saved	Marking a visual map of the city with colours based on modality used
Feedback	Personalized routes
Challenges, quizzes and quests	Having to log personal travel choices
Digital ownership	Mechanism to reflect on travel choices
Social prestige and game status	Taking citizens' preferences and context as input
Recurrent/planned rewards	Rewards proportional to weekly time spent in public transport
Collaboration and team tournaments	Calories burned is included
Team coherence	Involvement in the local community
Goal setting	Social media feedback, in-app messages
Game progression and progressive challenges	Offline features
Self-regulation of behaviour	Evaluation of system performance and CO_2 emissions
Virtual collectables	Comprehensive intermodal coverage and risk assessment per route
Narratives and stories	Trip-tracking features
Behaviour reinforcement and deterrent	IoT hardware to enable burglar alarm and bike discovery services
	Citizen's participation and neighbourhood feedback
	Points used for privileged customer support
	Target mobility needed to exchange goods/services between citizens
	Trade rewards to contribute to meaningful causes in the community, for example, to refurbish local schools' energy system
	Blockchain features

of new gamified components based on the core components of the framework, which require accessing information about game state, player state and functionality related to notifications of game results to players. The front end layer regards end-user applications for each of the stakeholders: (1) the definitions supporting the gamified module and its deployment, (2) the presentation of game state and (3) the required game analysis panel.

Further work of the researchers led to a new iteration of the gamification framework, focused specifically on individual transport choices [67]. This framework enables mobility managers and decision-makers to create actions for behaviour change and to closely follow their impact. It also enables game designers to explore game elements and mechanics according to the defined urban policies and enables citizens to interact with the gamified applications while getting digital and real rewards. In this framework, there are four different proposed components: gamification engine, game management, gamified application and trip validation. The gamification engine exposes a set of APIs related to the design, deployment and execution of game applications, which include simple elements (points, badges, collections, levels, leader boards), single/multiplayer mechanics (challenges and missions) and advanced features for automatic challenges generation. Regarding the game management module, it oversees the game definition, game supervision and game analytics. The gamified application regards the application with which players interact with the system. Lastly, the trip validation module is a module closely in line with the mobility scenario: it aims at automatic detection of the user's actual mode of transportation and comparison with what is reported by the user. Only validated trips contribute as player-associated actions in the system.

4 Analysis of the Impact of Gamification on Supporting Behaviour Change Towards Sustainable Urban Mobility

Literature defends that gamification is an asset when addressing the key issue of sustainable mobility: the voluntary travel behaviour change. Gamification has shown promising results at promoting sustainable mobility behaviour and enhancing players' awareness on new and sustainable public mobility policies [5]. Yet the body of knowledge is mixed when it comes to efficacy of playful approaches such as gamification, because it can just as well be inefficient or even harmful. From the perspective of gamification, this section discusses both what works and what has been proven to be suboptimal for the MaaS paradigm.

On the one hand, researchers argue that the simple attribution of badges, even though just a digital reward, is often enough reward by itself to encourage certain behaviour [17]. In the mobility scenario, players can be driven by the dynamic of collection and see places across the city as opportunities to get digital collectables, irrespective of the route taken [68]. A known strategy to influence behaviour is branded campaigns. These campaigns promote, for example, the "raiding" of a city for more badges, which are often designed and promoted by a specific company or entity [17]. Researchers [6] ranked basic and more complex game elements that players preferred most and show that challenges ranked first, leader boards second, whereas badges and final prizes ranked last in user preferences (weekly prizes and points ranked mid-table). Weber et al. [69] argue that gamification strategies based on points alone, when combined with properly developed features such as good application connectivity, are effective at generating higher bicycle usage. They argue that points do not seem to encourage more engagement in participation, yet for individuals who already cycle, they tend to cycle at even higher frequencies. Researchers also note that rewards, when coupled with personal accomplishment, are an effective working solution, unlike the use of simple direct incentives. Yet they are dubbed as extrinsic motivators that are effective at amplifying appropriate behaviour, which should not be used when intrinsic motivations are the desired aim [33, 70].

On the other hand, other game dynamics such as competing for ownership of a place do influence players, but these often trigger negative feelings of frustration and cheating, which are best avoided to warrant player satisfaction and flow [6, 17]. This is also valid for feedback mechanisms used to influence users' actions (e.g. measurement of CO_2 footprint), which are reported to trigger feelings of guilt [33] or not engaging enough [71]. Competition has been requested by users, but researchers argue that it works best when users compete within their social network and not with strangers [72]. Furthermore, persuasive strategies through gamification are not widely recognized as capable of sustaining the triggered behaviour changes on traveling habits for long [33]. Studies show that players' motivation is positively influenced at the early stages but tends to fade away over time [9, 59], that a plan is required to keep motivation up [73] and that that is done best by tailoring such plan around the individual skills and performance of each player (often with procedural content generation tools) [6, 64, 65, 74, 75]. Impacts are often transient and diminish over time unless new game elements and mechanics are used to influence motivation [9, 65, 73]. Further insights on what works for users of sustainable mobility applications are: (1) not every citizen is motivated by environmental concerns, (2) individuals prefer real rewards over nominal ones, (3) sharing of data should only be done when clearly meaningful and safe and (4) personalization is key: users want to know their actual impact on the environment and their own health and fitness [38, 71].

Specifically on the effectiveness of longer-term exposure of certain game elements (points, leader boards, badges, badge collections and challenges), researchers show that badges do not score high and that, opposite to that, prizes (material prizes), challenges and competitive elements (points and leader boards) were argued as effective [66]. Of these, personalized challenges scored the highest. In studies assessing citizens' preferences, the reported results are aligned with what is argued in [6].

Literature also defends that (1) personalization and tailoring of challenges, (2) feedback and (3) suggestions are complex gamification approaches that are appreciated by users and are reported as capable of enhancing players' motivations [33]. Particularly on the personalization of gamification, tailoring the approaches around the user is argued as required for a long-term behaviour change, which includes contextual awareness of the player, personalized notifications, different personality types and the proactive and timely delivery of information [34].

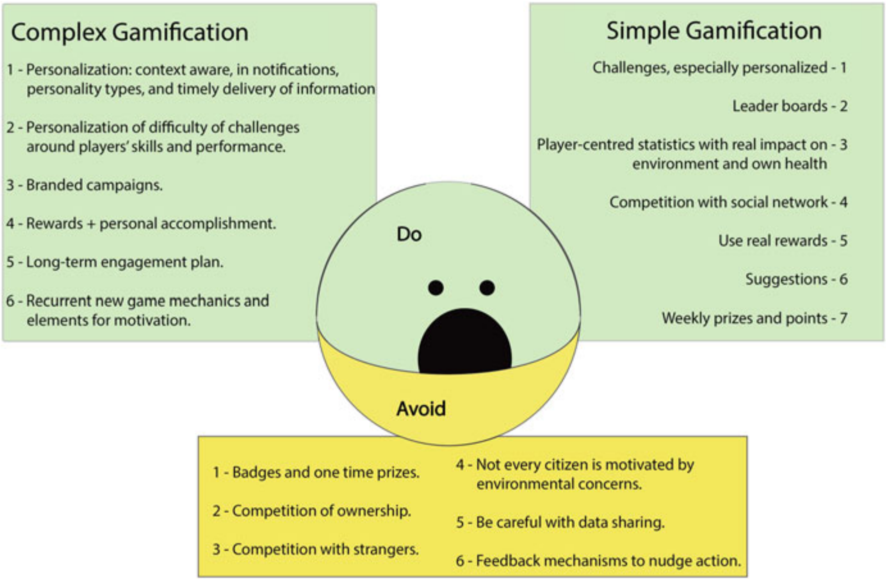

Fig. 2 Recipe for success: sustainable urban mobility gamified

All these results indicate how gamification of future technical solutions should be done to be most successful at inviting citizen behaviour change towards sustainable urban mobility.

As summary, Fig. 2 illustrates the information analysed in this section. The "recipe for success" of Fig. 2 contains the information on the findings of the studies reviewed in this chapter, and that argue about what works and does not work regarding gamification for behavioural change towards sustainable urban mobility. Therefore, it serves as quick guide to designers of future applications to apply gamification for the promotion of sustainable mobility, as it is rooted on the presented studies.

5 Key Aspects That Block Mass Adoption of the Mobility as a Service Paradigm

This section discusses aspects that were found while reviewing the literature and that are considered pivotal to the success of the mobility as a service paradigm. These aspects regard factors that failed to be included in the designed technical solutions for behaviour change towards sustainable mobility and thus hinder the uptake of such applications by citizens. These factors regard the lack of consideration for external aspects to gamification, which play a key role on usage rates and engagement levels over time. That, in turn, effectively inhibits the wide adoption of sustainable modes of transportation through mobile applications and the behaviour change that goes with it.

A few examples of the factors that have been noted as potential influencing factors to a more sustained engagement over time are: ICT literacy [76], weather conditions, ethical and legal implications of the approaches used [59] and health beyond calories burned and heart rate benefits [48, 77]. Particularly regarding the health factor, the play-based technical approaches for sustainable mobility that are reviewed in this chapter fail to provide health indicators, with the exception of calories burned in "Play&Go" [6] and the monitoring of heart rates in "The tracker for cycling" [59]. Even though citizens mentioned wanting to know the impact of such sustainable commute to themselves [38, 71], overall existing solutions do not go beyond these two indicators. This argument is in line with a recently published systematic literature review [59] that argues that sustainable commute patterns should focus on actively improving health and well-being but that no existing smartphone apps for this purpose consider mobility-related health components.

Another type of issues observable from the literature is the lack of integration of built solutions with all the public and private mobility providers at a given region. In line with previous studies [78], projects such as the STREETLIFE[6] were financed by the EU but ended up failing to have any long-term impact on people because they were not adopted by any public or private operators. Failure to have such tech transfer means having cities not advancing towards novel ways of transportation that are integrated into one solution. Things that must still be addressed are the last-minute availability of public transportation, inclusion of last-mile transportation in proposed itineraries (usually the last 5 km) and one unified form of payment that works with all the heterogeneous stakeholders. Such lack of functionalities is likely to have a negative effect on the engagement of citizens in any mobile application over time and does not address the convenience that users currently attribute to their privately owned transports.

Figure 3 summarizes what is discussed in this section in terms of the key factors that are found in the literature, as a recommended-to-consider list of factors in future MaaS applications.

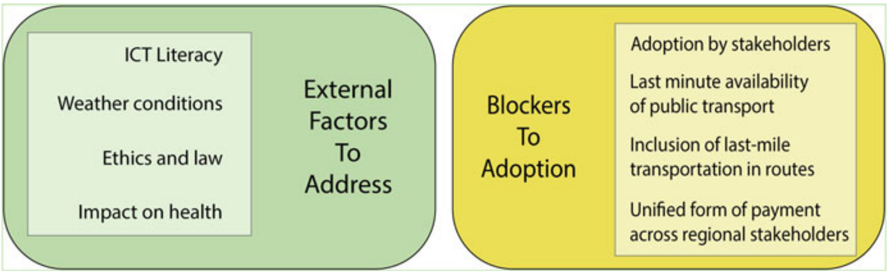

Fig. 3 Factors to further success of MaaS applications

On the left-hand side of Fig. 3, it is summarized the external factors that have largely been missed by the technical artefacts developed so far to support sustainable urban mobility. On the right-hand side of it, it summarizes the blockers for mass adoption of the created technical solutions, which, when not addressed, mean an eventual death of either the technical application or project.

6 Conclusion

Several projects have been carried out in recent years to address the unsustainable commuting habits across the world. This unsustainability refers mainly to the impact of small particle emissions on the environment, but also to the overall health of the population, and other nuisances such as city congestions. Developed projects and technical artefacts have attempted to invite citizens to change their daily commute choices towards physically more active and zero emission modalities. This chapter reviewed the existing literature on projects and applications that actively supported individuals in their daily commute and offered an overview of the successes and shortcomings of the developed studies on sustainable urban mobility. This review is done from the perspective of play-based approaches such as gamification, given not only their potential to influence user adoption but also their ability to mediate behaviour change. Gamification in specific has been explored up to various extents and outcomes, and this chapter covers what has worked or not in the process to creating an application that works in inviting citizens to commute sustainably.

This chapter offers an analysis of the gamification designs developed by such projects and summarizes the findings on a “recipe for success” for sustainable urban mobility. Simple gamification elements used, and that work, are primarily challenges that are personalized, followed by leader boards, statistics that reveal a measurement of the actual impact in the real world, competition with friends, real rewards, suggestions/feedback and recurrent prizes/points. More complex gamification strategies that work are also summed up: personalization is key, one that takes the citizen’s real-world context into account, one that personalizes the notifications that are timely delivered, one that adapts the degree of difficulty around the player’s performance and adapts accomplishments and one that includes branded campaigns and a long-term engagement plan with ever-changing game elements. Gamification choices that should not be used are also mentioned in this chapter’s summary.

On top of the gamification techniques that should be used or not, this chapter also discusses factors mentioned across the reviewed literature that have not been included in the developed application designs and that potentially had a substantial impact on the lack of success of these applications. Not only that, many projects worked from the technical and from the user engagement/gamification perspective but still failed to be massively adopted by the population. These projects had financial support from the EU, lasted years and were validated across multiple countries, yet they ultimately failed to transfer the developed technology to the regional public and private mobility stakeholders. These factors are listed and argued as "recommended-to-consider" in future projects on sustainable urban mobility and remain as gaps that future research on the topic needs to address.

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How Do Citizens Want to Participate in Smart City Programs? Some Answers from Greece

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1 Introduction

The development of Smart Cities (SC) is participatory when citizens are highly involved. The participation of citizens in the process of political decision-making is an important pillar of democracy. The change from "government" to "governance," as it is interpreted in the literature, suggests greater participation of various stakeholders in the decision-making process and the implementation of public policy [1]. The broad fields of smart governance, economic models, mobility, environment, education, and security in SC together with active citizens and key stakeholders of the city, cooperating on smart solutions and working for a better quality of life, form a smart community as an interactive organism in a social and technological ecosystem [2]. The engagement of citizens is a fundamental but nontrivial aspect of the development of democratic smart cities. In fact, it is a multidimensional and multifaceted process that requires co-work between many different individuals and communities having different interests, visions, understanding, and expectations of various smart cities' goals. The terms "citizen participation" and "engagement" imply complex interactions between citizens, government, governmental or local organizations, public or private institutions, and nongovernmental organizations as part of decision-making processes, developing policies, and participating in various projects' development affecting public services [3]. To benefit from their ideas and

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ensure that the smart city meets the actual needs of people, citizens must be involved in the design process so that the participation strategy is tailored and reflects the context of the target city [4]. Importantly, the concerns and the aspirations of citizens need to be understood and taken into consideration before decisions being made, since asking for citizens' input after the decisions are made or making them participate in a coercive process that obliges them to agree does not qualify as engagement [5].

Over several decades, researchers have been working on the phenomenon of the "smart city," with extensive reference to cities that have adopted new methods, mainly technological, to solve everyday problems and improve living conditions [6–8]. Improving urban living standards is primarily based on smart development strategies and smart forms of governance adapted to the size and requirements of each community [9]. The 2030 UN Agenda for Sustainable Development promotes the objective of cities being inclusive, safe, resilient, and sustainable [10].

Sustainable development is "the development that meets the needs of the current generations without compromising the possibility of the future generations to do the same" [11]. Technically, sustainable development solutions must consider the systemic view of sustainability, which states that an economic system is a subsystem of a social system, which is itself a subsystem of a natural (biophysical) system [12, 13]. When talking about sustainability, abstractions are involved that are shaped by the observer's perspective. These different perspectives have an impact (a) on what is considered to be the main priorities and on (b) decisions regarding what policies should be put into place and what actions should be taken toward sustainability [12]. Additionally, modern ICT, energy savings, and mobility underpin sustainable urban development and the transition of conventional cities to an integrated smart digital environment [14].

Resilience in terms of cities generally refers to the ability to absorb, adapt, and respond to changes in an urban system [15]. Because new solutions that are planned to be implemented for resilient smart cities tend to face challenges in their acceptance, improvements in active citizen engagement play a key role in city development [16]. The current wisdom is that for cities to become smart cities, it is not only necessary to adopt new technologies but also to actively involve citizens [17]. Participatory development is the development in which citizens are actively involved at all stages of the decision-making process, from planning to the implementation stage of various projects and programs, and constitutes the realistic foundation for efforts addressing many social problems faced by humanity.

The scientific community has shown a great deal of interest and already produced a rich literature on the methods of participation, utilities used, and their results [4, 18, 19]. However, this is an area that still requires continuous exploration; hence, this study attempts to contribute with a particular research angle and importantly in the context of Greece, with the ultimate aim of providing some insights about both enhancing the participatory process and the active role of citizens in Greece and, in perspective, around the world. The study was conducted by using a questionnaire as central (key) tool for conducting the investigative process. The creation of the questionnaire was largely based on known theoretical grounds of the smart city topic. During the bibliography study, no weighted questionnaire was found to satisfy the needs of the current study. Therefore, a novel questionnaire was designed from scratch based on similar questions and hypotheses of other studies [20, 21], and the respondents' answers were evaluated using a Likert scale. Thus, the ever-increasing need for citizen participation in the development of smart cities, as well as the rapid growth of ICT, provided the main research interests, namely, (1) what are the main motivations for citizens to participate in the digital transformation of their city; (2) what potential alternatives could exist in relation to different types of technology used in practice; and (3) what types of participation could be identified as preferred in concrete practice. The contribution of this study is not only aimed toward elucidating the relation between citizen involvement and smart city projects and policies but also toward obtaining insights that can help with the development of adequate research methodologies and tools.

The rest of this chapter is structured as follows: Section 2 presents an overview of the literature related to citizen participation. Section 3 presents the research questions and the research methodology. Section 4 describes and discusses the results, and Sect. 5 summarizes our conclusions.

2 Literature Review

2.1 The Term Engagement

Several researchers in their studies attempted to identify empirical studies and scientific articles on citizen involvement through systematic reviews of the literature [22–24], since the top-down decision-making approach often shows its ineffectiveness in many democracies. Although scientific research on citizen participation and public decision-making began in the late 1960s, during a period that was marked by urban struggles and movements, it managed to lay the foundations for participatory development.

Arnstein, in her article "A Ladder of Citizen Participation," proposed a scale simulating different levels of participation (Table 1), ranging from citizen manipulation to citizen control, with each sublevel corresponding to the extent to which citizens could participate in the governance process. In addition to the eight "steps" of participation, the scale includes a continuous description of participatory power moving, from no participation (no power) to the degree of tokenism (fake power) and finally to the degree of citizen control (real power) [26, 27].

Citizen participation is considered a key challenge for the effective development of smart city projects [28] to improve citizens' quality of life. For a smart city to achieve its goals, it is important to engage its citizens and carry out actions and implement decisions in collaboration with them [29] by utilizing ICT technologies as the main driver for implementing smart city projects [30]. However, in [31], it is criticized the smart city approach based only on the use of ICTs and argued

Table 1 Arnstein's ladder of citizen participation

Form and levels of participation	
Substantial participation (degrees of citizen power)	Citizen control, delegated power, and partnership
Symbolic participation (degree of tokenism)	Placation, consultation, and informing
Nonparticipation	Therapy and manipulation

Source: "A Ladder of Citizen Participation" [26]

that smart cities should aim in the motivation of the human capital of the city. Researchers in [32] point out that since participation is important for democracy, it is also equally important for the development of smart cities. Participation and collaboration between government, citizens, and organizations are considered essential for the development of smart communities [33], while citizens participate by playing the roles of the following:

- Democratic participant in the decision-making process to build sustainable local communities.
- Main source of expertise and skills to develop better solutions and designs.
- Data collectors in an active and integral part of the smart city.

In [34], participation is defined as the expectation that citizens' voices will be heard when needed to reflect the dissatisfaction with the way democracy works. Participation in politics is a mechanism developed by politicians and officials to extend these voices into the decision-making process. However, it is unclear what counts as participation and how to understand the various practices that exist. At this point, it must be noted that although the words citizen involvement and participation are sometimes used interchangeably, they are not synonyms. Although these notions seem to be similar, they have different perspectives on the role that citizens have in each one. The main distinction between citizen engagement and citizen participation is that citizen engagement necessitates an active, intentional discourse between citizens and public decision-makers, whereas citizen participation can only be initiated by citizens. Additionally, the term "engagement" has a different meaning to different people and various levels of engagement and participation [35].

Furthermore, participation can be ambiguous; it can either make it easier to resolve policy issues or through vetoing can, under certain circumstances, prevent the beneficial results of a project. In practice, many times citizen participation takes the form of consultation. Consultation, however, is based on the acceptance by policy-makers that they have the ability not only to comment but also to influence the final decision on a policy proposal. Consultation ensures that many voices are heard but takes no responsibility for the final decision. The most well-known approaches used for consultation are public meetings, discussion papers, etc. New technologies and standards (such as Internet of Things, cloud computing, integrated sensors, etc.) play an important role in transforming cities to smart cities. However, an important aspect is how technology is used for engaging citizens in smart cities.

Researchers in [36] argue that the term SC was adopted in 2005 by various technological companies that offered complex information systems for integration and operation in urban infrastructure. Citizen participation definition in the context of smart cities includes ICT concepts, citizens' involvement in the planning, and administrative processes. Other similar studies related to citizen participation in the context of smart cities, such as [37], propose a mixed approach with appropriate technology and social media for citizen participation. Furthermore, researchers in [38] state that the technologies used are mainly of general purpose and not designed to support online participation. They are suitable for use by older people, while information systems are usually suitable for youth participation. Also, the study in [25] presents more practices that enhance citizen participation such as accessing city services and reporting problems through smart mobile applications and suggests as the best method for developing citizen participation to be co-creators. Additionally, in [4], it was identified that methods which work well are face-to-face communication, open data workshops, and web-based collaborative platforms.

Another dimension that should be taken into consideration is the diversity of the citizens. Differences between citizens should be recognized and well understood before engagement procedures, practices, and policies are established. Some groups of citizens having special needs are children and young people, people with disabilities, and various minorities based on ethnicity, race, religion, etc. Especially for people with disabilities, citizen engagement and participation are interpreted as a redistribution of power that allows them to be involved in public planning, information dissemination, and resource allocation [25].

2.2 Citizen Engagement Toolkits

Recently, various citizen engagement toolkits were developed by several organizations covering different sectors. These toolkits aim to support individuals and organizations to understand the various levels of engagement and provide them with a set of methods and techniques that can help them to be engaged in a meaningful way that will positively affect their lives.

A number of different toolkits found in the literature are presented in Table 2.

According to Economic and Social Commission for Western Asia (ESCWA) toolkit [3], citizen engagement has three levels as follows:

- *Participation* involves government and nongovernment actors in a two-way collaboration but the government set the agenda.
- *Collaboration* involves government and nongovernment actors in a two-way collaboration where both sides can set the agenda, but actions are regulated by the government overall policy framework.

Table 2 Citizen engagement toolkits

No	Toolkit title	Publisher
1.	Open Government Citizen Engagement Toolkit	ESCWA – United Nations, 2021 [3]
2.	Engaging Communities Toolkit. A Practical Guide to Community Engagement	West Lothian – Community Planning Partnership, 2015 [5]
3.	Public Engagement: A New Framework	NHS Lothian [35]
4.	Community Engagement Toolkit	Sparc bc, 2013 [39]
5.	Engagement Toolkit: Methods, Tips and Best Practices to Design Effective Participatory Processes	European Food Safety Authority (efsa), 2021 [40]
6.	Community Engagement Toolkit	Paul Schmitz, 2017 [41]
7.	The Manchester Community Engagement Toolkit	Patrick Hanfling, Susan Majeed and Ed Cox, 2005 [42]
8.	The Engagement Toolkit. Effective Engagement: Building Relationships with Community and other Stakeholders (V.4)	State of Victoria Department of Environment and Primary, 2014 [43]
9.	Community Engagement Toolkit for Planning	Department of Infrastructure, Local Government and Planning, State of Queensland, 2017 [44]
10.	Community Planning Toolkit. Community Engagement	Community Places, 2014 [45]
11.	Community Engagement Toolkit	Community Planning and Inclusion Glenorchy City Council, 2017 [46]
12.	Community Engagement Toolkit. Guidance and Resources for Engaging Community in Planning and Policy Development.	Futurewise, Interim CDA, OneAmerica, El Centro De La Raza, 2014 [47]
13.	Community Engagement Toolkit. Greenways for Pittsburgh	Department of City Planning, City of Pittsburgh, 2017 [48]
14.	Public Engagement Toolkit	SFU Morris J. Wosk Centre for Dialogue, 2019 [49]
15.	Equitable Community Engagement Toolkit 2020–2023	Boston Public Health Commission, 2020 [50]
16.	Community Engagement Toolkit. One Council Approach to Community Engagement	Slough Borough Council, 2018 [51]

- *Full engagement* involves government and nongovernment actors in a two-way collaboration where both sides can set not only the agenda but the overall policy framework in form of "co-governing."

However, in a more granular approach, most toolkits identify five levels of citizen engagement which in turn lead to an increased level of public impact. These are the following:

- *Inform:* Just provide the public with the necessary information to understand an issue.
- *Consult:* Collect information from the public about their opinions and attitudes and provide feedback about how these inputs affected the decision.
- *Involve:* Involve the public to all stages of work to make sure that their concerns and aspirations are well understood and considered.
- *Collaborate:* Treat the public as partners in every aspect of the decision and implementation process.
- *Empower:* The making of final decisions is placed on the hands of the public.

The study of citizen engagement toolkits identifies that the citizen engagement process is very close to stakeholder's management process in a project. Many of the methods and techniques that are described in toolkits are the same with methods and techniques used in stakeholders' management. Specifically, the development of a citizen engagement policy and strategy, the planning of engagement, the identification and prioritization of participants, the communication, and the monitoring and evaluation are identified as common processes, along with a set of common techniques and tools. On the other hand, the massive character of citizen engagement and the diversity of them require the adoption of specific tools that could enable and enhance collaboration and active participation. The main types of such tools are citizen participation platforms, crowdsourcing and co-design tools, mobile apps, communication tools, multi-application software, data collection tools, and data sharing tools. Such tools can be chat platforms, blogs, emails, repositories, social networks, shared bookmarks, wiki, electronic voting, etc.

A set of tools that can be used in each stage are shown in Fig. 1.

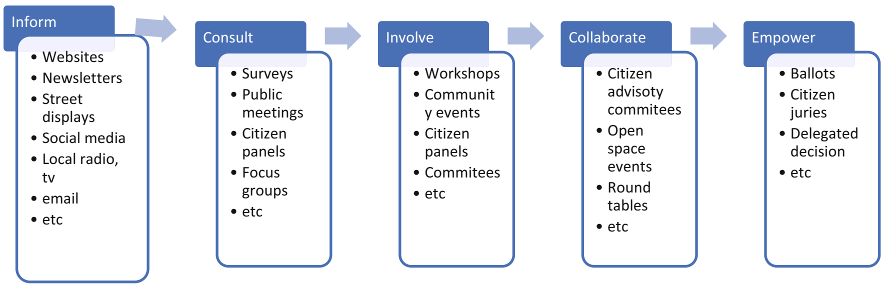

Fig. 1 Stages of citizen engagement and tools that can be used

Factors such as the type of tool, the technical skills required for its installation and usage, the usage of data, and the cost have an important role and influential role in the final selection and therefore to citizen participation. Researchers have investigated perceptions, opportunities, efforts, and toolkits aimed at assisting individuals and organizations to understand the various levels of engagement and provide them with a set of methods and techniques for effectively involved people in meaningful ways that affect their lives; however, it is unclear which methods and incentives will succeed in largely enabling citizens to participate through the use of ICTs.

3 Research Methodology

The main goal of this study is to examine citizens' intention toward participatory development and how they could be motivated by using ICT. Firstly, a literature review necessary for understanding the multifaceted concept of citizen participation for the development of a smart city was conducted. In parallel, a research aiming to ascertain possible ways of enabling citizens to participate in public life and regarding the different citizen engagement toolkits that exist was also conducted. Based on the findings of the literature review, the following research questions were arisen:

RQ1: How do demographic characteristics affect citizen participation?
RQ2: To what extent do they want to participate?
RQ3: By using what technology would they like to get involved?
RQ4: Which method for citizen participation is most representative?
RQ5: What are the motivations for citizens to participate?

Next, based on the literature, a questionnaire consisting of 15 questions divided in 5 sections was created. The first section's questions aimed to explore citizens' intention to participate in terms of participation levels based on Arnstein's conceptual participation scale. Respondents could express their intention by using the five-point Likert scale with the options "not at all, a little, moderate, very, and very much." In the second section, respondents were asked to answer questions related to which technology they intend to use in order to participate. They had to select between general purpose systems and specific information systems. The third section contained questions related to the choice of participation method between participation as democratic participants, as co-creators, and as ICT users. The fourth section concerned factors that affect motivation for participation, aiming to identify the strongest motivating factor, and finally, the fifth section contained questions related to the profile of the respondents of this study. They were asked about their gender, age, level of education, employment status, and place of residence.

The questionnaire was created using Google Forms and distributed to email addresses provided by various city communities. Also, social networks such as Facebook, Instagram, LinkedIn, and Viber were used to distribute the questionnaire.

Although it is difficult to record the exact number of people who received the questionnaire, it is calculated that at least 1500 people received the invitation to answer it. After 2 weeks, 384 responses were collected, providing a response rate of 25.6% that gives a representative number of answers. At that time, the Kaiser-Meyer-Olkin (KMO) test was used to examine the sampling adequacy. KMO value varies between 0 and 1, and recommendations suggest that the accepted values should be greater than 0.5. Specifically, values between 0.5 and 0.69 are mediocre, values between 0.7 and 0.79 are good, values between 0.8 and 0.89 are great, and values between 0.9 and 1 are superb [52]. KMO test gave a result value of 0.932 which was considered extremely satisfactory for further analysis, and at this point, it was decided to close the survey. Furthermore, Cronbach's alpha test was used to verify the reliability of the five-point Likert scale that was used in the questionnaire as it demonstrates how closely a set of items are, as a group. The index takes values in the range [0, 1], with 0 being interpreted as a lack of reliability, while 1 is interpreted as a strong reliable scale. According to [53], it is generally accepted that Cronbach's alpha values that are higher than 0.8 are acceptable. In the present study, Cronbach's alpha index proved to be extremely high (Cronbac's alpha = 0.933), which means that the questionnaire scale has internal consistency. Both Cronbach's alpha and KMO tests were implemented using SPPS v.26 statistical package.[1]

4 Research Findings

4.1 Descriptive Statistics

The descriptive analysis included the frequency distribution of the qualitative variables and estimation of the position and dispersion parameters of the quantitative variables (mean value, standard deviation, minimum and maximum value). Possible correlations were investigated using inductive analysis, which included Spearman correlation coefficient, Mann-Whitney U test for independent samples, and Kruskal-Wallis H test for control of qualitative independent variables with more than two groups and quantitative dependent variables.

According to descriptive statistical analysis concerning the responders' demographic characteristics, approximately 60% of them were female and 40% were male. In terms of educational level, 2.46% of the respondents hold a university degree, 21% of them hold a postgraduate degree, 30.5% are high school graduates, and finally nearly a 2% of responders hold a Ph.D. degree (Fig. 2).

Regarding their employability (Fig. 3), 35.7% are civil servants, 33.6% work in the private sector, and 10.4% are unemployed.

The majority of respondents (Fig. 4) (67.4%) live in urban areas of more than 10,001 inhabitants, 14.8% live in semi-urban areas of up to 10,000 inhabitants, and

[1] https://www.ibm.com/products/spss-statistics

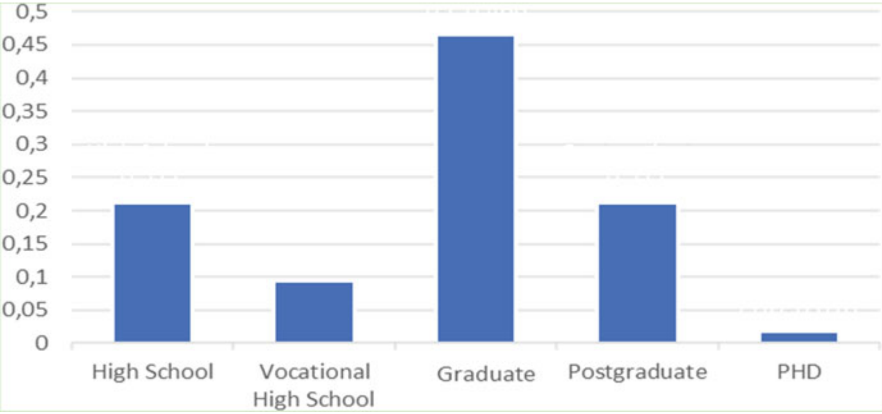

Fig. 2 Educational level

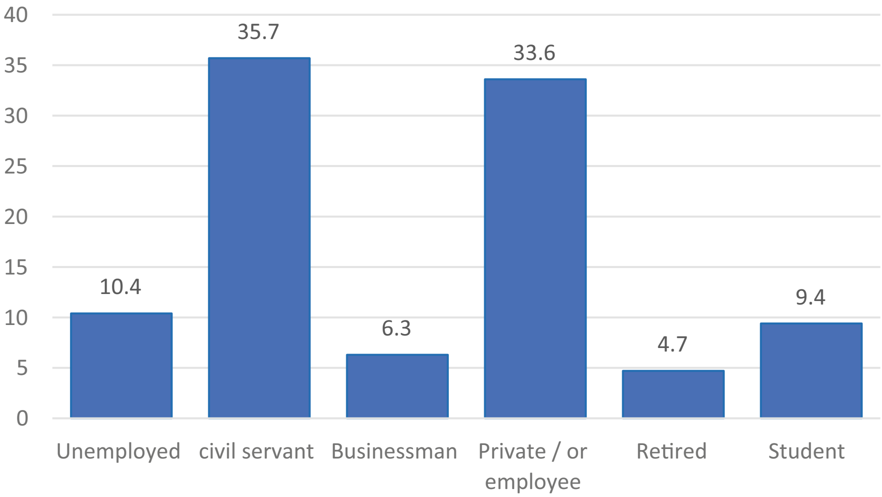

Fig. 3 Working condition

10.9% live in large settlements, while the remaining 6.8% live in settlements with less than 2000 inhabitants.

Regarding the levels of citizen participation concerning RQ2, they were classified from bottom to top based on the Arnstein scale as (a) the level of nonparticipation that includes treating and manipulating citizens; (b) the level of symbolic participation as informing, consulting, and appeasing citizens; and (c) the level of meaningful participation as cooperation, delegation of power, and full control by citizens. Results, as they presented in Table 3, show that about power-level "substantial participation," most of the citizens want to have some kind of control in relation to task planning, decision, and policy-making with no intermediates. Regarding the

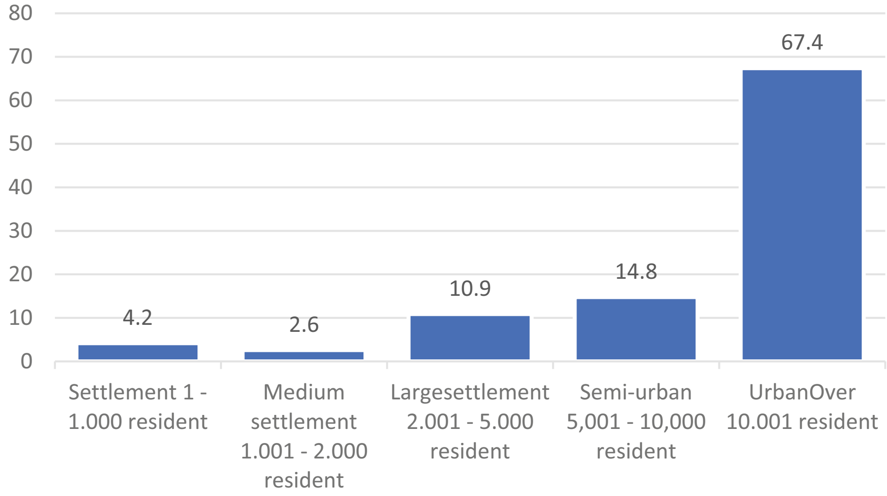

Fig. 4 Place of residence

level of "delegated power," 69% of the respondents support this option in the sense that they want to be assigned with the power to control, manage, and decide about programs rather than just be participating and managed by powerholders. This also enhances accountability. However, there is a noticeable 31% that are not in favor of this approach. Causes of this could be the lack of time, no willingness to take responsibility, different worldviews, fatalism, etc. However, as the causes of this approach are not easy or trivial to be interpreted from the collected data, more research is needed, for deriving safe conclusions. "Partnership" is the preferable choice for more respondents regarding the level "substantial participation" as almost 90% of them want to have the power to negotiate better deals, be able to set veto to decisions, share funding, and set requests that are partially or fully fulfilled. Regarding the level of "placation," more than half of respondents (51.6%) do not want to be granted with limited degree of influence, and their participation is largely or entirely tokenistic, meaning that they do not want their participation to be demonstrated as an alibi for powerholders' decisions. However, there is 29.2% that occasionally can accept this behavior, and almost 20% have no problem to be tokenized. Regarding the level of "consultation," most of the respondents (75.8%) want to be involved in a consultation process. The same holds for level "informing." Regarding "therapy" level, 49.2% of respondents do not want to participate in a way that allows powerholders to hide their responsibilities and accuse citizens in case of failures, while a remarkable 50.8% does not have a problem with this. Finally, concerning "manipulation" level, 69.2% of the participants declared that they do not want to be manipulated. However, there is a significant 21.4% that can accept some degree of manipulation and 9.4% have no problem to be manipulated. It is worth mentioning that in most cases there is almost 20% of the respondents do not

Table 3 Participation levels

		NAA	AL	MOD	VR	VM	Total
Substantial participation	Citizen Control	3.1	17.4	**34.1**	32.0	13.3	100
	Delegated power	8.1	22.9	**33.1**	26.8	9.1	100
	Partnership	1.3	9.4	19.8	**37.2**	32.3	100
Symbolic participation	Placation	22.4	**29.2**	**29.2**	14.3	4.9	100
	Consultation	7.8	16.4	**31.3**	29.9	14.6	100
	Informing	8.1	16.1	24.2	**26.0**	25.5	100
Non-participation	Therapy	22.9	**26.3**	25.5	18.0	7.3	100
	Manipulation	**48.4**	20.8	21.4	7.6	1.8	100
NAA: Not at all, AL: A little, MOD: Moderately, VR: Very, VM: Very much							

NAA not at all, *AL* a little, *MOD* moderately, *VR* very, *VM* very much

Table 4 Participation technologies

		NAA	AL	MOD	VR	VM	Total
General purpose systems	Email	5.5	16.7	**25.5**	**31.5**	20.8	100
	Electronic voting	3.4	15.9	22.1	**35.7**	22.9	100
	Interactive websites	3.1	16.1	27.9	**32.0**	20.8	100
	Video conference	16.4	18.2	**31.0**	19.0	15.4	100
Information systems	Open consultation app	8.1	22.1	26.6	**28.6**	14.6	100
	Web platforms	1.3	17.2	25.8	**36.5**	19.3	100
	Social media	7.0	21.1	18.2	**28.4**	25.3	100
	Troubleshooting app	5.5	20.6	24.5	**32.0**	17.4	100
	Smart mobile app	2.9	16.1	18.8	29.2	**33.1**	100

have any willingness to participate. This is also something that needs to be further analyzed in a future research as it is beyond the scope of this work.

As for RQ3 which concerns the use of participation technologies (Table 4) citizens intend to use, they have identified two types of technology, that is, (a) general purpose systems that include the categories: email, e-voting, interactive websites, and video conferencing and (b) information systems that include the categories: open consultation applications, web platforms, social media, problem reporting applications, and smart mobile applications. Analysis of the responses indicates that citizens are in favor of using ICT to participate and they can easily use applications that are familiar with such as mobile devices and social networks.

Regarding the participation methods (Table 5) which are examined in RQ5, and more specifically "citizens as democratic participants," all three questions of this group gathered most responses in the "very" category. Specifically, "citizens as democratic participants" want in their majority (>80%) to have a moderate or higher degree of participation in decision-making processes, problem-solving, and public administration issues. The same applies for "citizens as co-creators," a category where citizens express their willingness to participate in exchanging ideas with city's management, participate in focus groups with experts, or take part at living

Table 5 Methods of participation

		NAA	AL	MOD	VR	VM	Total
Citizens as democratic participants	In the decision-making process	4.9	14.6	24.2	**39.3**	15.9	100
	Specialization in public administration issues	3.9	15.1	31.0	**38.3**	11.7	100
	Problem solving	1.6	18.2	22.7	**37.5**	20.1	100
Citizens as co-creators	Immediate exchange of ideas with management	2.1	15.4	29.2	**33.1**	20.3	100
	Focus groups with experts	2.3	15.6	29.4	**36.5**	16.1	100
	In living laboratories	9.6	18.2	**30.2**	26.8	15.1	100
Citizens as ICT users	Use of smart infrastructure of the city	1.3	14.6	22.1	**36.2**	25.8	100
	Access to open data	1.6	13.0	27.3	**36.7**	20.8	100
	Feedback	2.1	18.5	24.7	**33.9**	20.8	100

laboratories. Category "citizens as ICT users" also follows the previous status with respondents indicating that they want to use the smart infrastructure of their city, access open data of their city, and be aware of any feedback provided by authorities.

In terms of RQ5 concerning "what are the motivation for citizens to participate," two dimensions were examined, the "personal interest" and "social influence." According to respondents, "personal interest" stems from the fact that they want to contribute, in various degrees of commitment, to smart initiatives (78.4%) because they think that it is important to some extent for their city (91.4%). The factor of "interpersonal communication" has also an important contribution to their motivation to participate (76.6%). Regarding motivation from "social influence," the influence from friends or relatives is a significant factor (71.6%). However, there is a 28.4% declaring that they are not influenced by this factor. Even higher (84.4%) is the motivation sourcing from suggestions coming from other sources without blindly follow, unquestioningly, what others do (59.1%). This demonstrates the importance to inform citizens about their city development and on their personal benefits from their participation according to respondents (Table 6).

Table 6 Motivation to participate

		NAA	AL	MOD	VR	VM
Personal interest	I contribute to smart initiatives	1.8	19.8	**28.6**	**25.3**	**24.5**
	It is important for my city	–	8.6	22.9	**29.7**	**38.8**
	Interpersonal communication	5.2	18.2	28.1	**25.8**	**22.7**
Social influence	Influence from my friends/relatives	6.0	22.4	**35.2**	24.2	12.2
	I hear suggestions from others	1.0	14.6	26.6	**39.8**	**18.0**
	I follow what others do	29.2	29.9	26.8	**9.9**	**4.2**

Table 7 Correlation Mann-Whitney U test and Kruskal-Wallis H test

Correlation Mann-Whitney U test		Substantial Sig.	Symbolic Sig. membership	Nonparticipation Sig.
Sex	Male and woman	0.452	0.730	0.990
Correlation Kruskal-Wallis H test				
Age		0.050	0.339	0.147
Education		**0.001**	**0.016**	0.866
Occupation		0.059	0.084	0.962
Residence		0.739	0.753	0.308

4.2 Correlation for Citizen Participation and Influencing Factors

In this section, the correlation between participation and influencing factors like gender, education, occupation, etc. regarding RQ1 is presented. A confidence interval of 95% was used for the statistical analysis, and the significance level was set to $\alpha = 0.05$. Next, the correlation of participation levels with gender was performed using the Mann-Whitney U test coefficient. For the correlation with other demographic characteristics, the Kruskal-Wallis H test was used. Statistically significant results were obtained only in terms of education level. The level of education positively influenced the intention to participate both at the level of meaningful and symbolic participation since the p-values of p- 0.001 and p- 0.016 < 0.05, respectively (Table 7).

Specifically, as it is depicted in Fig. 5, in terms of substantial participation, the highest degree is presented to those participants who hold a Ph.D. degree. However, since the number of Ph.Ds was rather small in the sample, the results need to be further analyzed in future research.

The correlation between participation levels and the other variables was then tested using Spearman's Rho coefficient.

As it is depicted in Table 8, the results of the correlation for the participation indicate that (a) the control by the citizens, (b) the delegation of power, (c) the cooperation, (d) the placation, (e) the consultation, and (f) the information are positively related to the intention of effective participation. Regarding the intention of symbolic participation, results indicate that (a) control by citizens, (b)

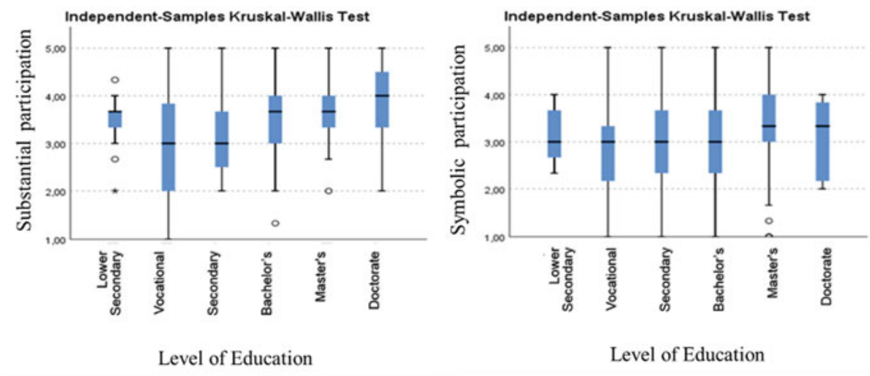

Fig. 5 Level of education in substantial and symbolic participation

cooperation, (c) placation, (d) consultation, (e) information, and (f) treatment and manipulation present a statistically significant correlation.

5 Conclusions

Citizen engagement is a vital factor of success in any project or effort that were undertaken for the development of smart cities. That is because these processes require knowledge, skills, and resources that are not held by any governmental or other organizations alone [3]. The importance of citizen engagement is augmented through the development of various forms of citizen engagement toolkits aiming to enhance citizen participation through the development of personal skills such as communication, collaboration, and teamworking, build confidence, and improve the sense of belonging and ownership in local community. Furthermore, by using such tools, local authorities and government can be more confident that resources are targeted to those that most need them, and cities' infrastructures meet citizens' needs appropriately through the implementation of atomic and composite smart services [54].

According to the results of this research, citizens are interested and want to have meaningful participation, care about the well-being of their city, want to advice, and are willing to participate using smart technologies that they are familiar with. Citizens also recognize that participation has an impact on decisions made about their lives and enhances trust in their city life, and they are willing to support the whole process. Also, based on the results, it seems that the higher the level of education, the higher the level of citizens' willingness to participate, which is a factor that should be taken seriously by the administrations. Based on this, they need to create appropriate conditions from a technological point of view, so other populations could reach and be engaged both at the city and country levels.

Table 8 Correlation coefficient Spearman's Rho

Correlation of levels of participation with rate Spearman's Rho	Substantial participation		Symbolic participation		Nonparticipation		N
	Correlation coefficient	Sig. (two-tailed)	Correlation coefficient	Sig. (two-tailed)	Correlation coefficient	Sig. (two-tailed)	384
Subs participation							
Citizen control	.772**	.000	.325**	.000	.023	.647	384
Delegated power	.743**	.056	.098	.056	−.088	.086	384
Partnership	.820**	.000	.353**	.000	−.004	.938	384
Symbolic participation							
Placation	.180**	.000	.732**	.000	.366**	.000	384
Consultation	.308**	.000	.773**	.000	.270**	.000	384
Informing	.221**	.000	.782**	.000	.354**	.000	384
Nonparticipation							
Therapy	.016	.000	.433**	.000	.875**	.000	384
Manipulation	−.061	.000	.238**	.000	.787**	.000	384
General purpose systems							
Email	.388	.000	.322	.000	.109	.032	384
Electronic voting	.405	.000	.285	.000	−.022	.664	384
For active websites	.399	.000	.254	.000	−.036	482	384
Teleconferencing	.425	.000	.305	.000	.030	.564	384
Information systems							
Open consultation applications	.489	.000	.271	.000	.012	.816	384
Online platforms	.402	.000	.238	.000	.038	.452	384
Social media	.194	.000	.240	.000	.097	.058	384
Troubleshooting applications	.304	.000	.244	.000	.070	.169	384
Smart mobile applications	.285	.000	.241	.000	.104	.042	384

Participation as co-creators							
Exchange of ideas with the management	.482	.000	.262	.000	.023	.649	384
Focus groups with experts	.396	.000	.267	.000	.080	.119	384
Living laboratories	.403	.000	.254	.000	.135	.008	384
Social influence							
Influence from my friends/relatives	.000	.000	.295	.000	.199	.006	384
I hear suggestions from others	.000	.000	.406	.000	.329	.011	384
I follow what others do	.002	.000	.157	.000	.141	.006	384

**The double asterisks (**) in the correlation coefficient column in Table 8, indicate that the correlation coefficient is statistically significant (at the 0.05 level), meaning that there is a very low probability of observing such a strong correlation by chance alone

Moreover, this work also gives us preliminary results about (a) the intention of citizens to participate is greater in urban centers, (b) citizens are interested and want to have meaningful participation, and (c) citizens follow social lines for participation, since they believe that this is beneficial for their city. Using these preliminary results, we plan for a new research to create more technical questions about the type of technology could be used to promote civility and well-being in the interaction of citizens among specific communities and their cities. Given that this research theme is quite open and there are a lot of searches and explorations to identify the best ways to develop the appropriate methods for citizen participation in specific domains, this work will be continued to consolidate the preliminary results and conclusions to develop new research questions that will also include self-assessment of citizens' ability to collaborate and make propositions to their cities through various methods and citizens' training needs to improve their skills [55] for participation in smart cities' development.

Further research to expand the findings could focus on those factors that could enable participation for citizens who do not have the basic ICT knowledge since our research sketches a portrayal of at least a moderate ICT user. Moreover, we plan to thoroughly research and compare the need for implementing citizen engagement toolkits in various smart cities and their foci regarding the different stages of their involvement.

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Sociable Smart Cities

Eleni Christopoulou and Dimitrios Ringas

1 Introduction

Cities are the places where people choose to live, with their population rising three times faster than that of rural areas [1]. They are characterised by permanence, large population size, high population density and social heterogeneity [2], and their appearance can be traced back to a radical change in human evolution. Through the ages, they have undergone several transformations adapting to changing political, economic, social and cultural conditions. It has been the introduction of a novel technology, though, that has catalysed each transformation [3].

Preindustrial cities have left a legacy on modern cities, especially in reference to city planning. The existence of a grid, defining public land and dividing ownerships, an axis, which unites districts, plazas and squares, the living rooms of cities, can be identified in each modern city. Industrial era steam engines brought production into the city centre and vastly enlarged cities trade area. Proliferation of personal mobility and a pursuit for healthier living conditions in the 1950s fractured cities giving rise to suburban residential areas while keeping trade and commerce downtown. The advent of information technology allowed people to work, shop and entertain anywhere; yet people do not choose to move away from cities.

Cities create opportunities for human contact. This is why today we seek to redesign them diffusing ubiquitous computing and smart technologies aiming to explore how this transforms both the place itself and our role in it.

The introduction and diffusion of various computing devices into the urban landscape has given rise to the new field of urban computing which is not constrained into the mere technological issues related to the use of ICT in the urban

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environment but mainly focuses on the effects that this technology has on urban life, the dynamics of the cities and the decisions that inhabitants make based on better information that is available [4, 5]. Several attempts to formulate a concrete definition of this new field have been carried out; common ground is the core elements of urban life that researchers identify and the fact that in all attempts urban computing lies in the intersection of these elements, thus highlighting that it is not merely a technological advance but a radical evolution that shifts the current life paradigm.

Urban computing focuses on the use of technology in public environments such as cities, parks, forests and suburbs [6]. However, it is not merely a technological novelty; it also studies the dialogue between people and urban environments [6] and the effect of embedding ubiquitous computing into the city landscape [4]. It is a multidisciplinary field connected by artists, architects, urban planners, geographers, social scientists and interaction designers [6] that lies in the intersection of three academic areas [7]: social studies, urban planning and computing. It studies and reshapes all the urban areas where users live, work and visit [8].

In this chapter, we present the notion of the sociable smart city, the impact of smart cities in society and how a sociable smart city may empower and engage people, enhance citizens' social interactions and improve cultural life. Via various applications and case studies, which promote our vision, we will present how the notion of sociable smart city can support the sustainable and innovative character of a city. Additionally, we will study how these factors can benefit sensitive populations and demonstrate that smart cities ought to be inclusive and accessible for all.

2 Research Questions

In our research approach, the integration of computing into the urban field is vital, but not our main focus, since we aim to transform the urban space. According to [9], what was regarded as in-between space re-emerges as a new social-technical landscape, which contributes to shape our identity and community. In [10], the concept of third places is introduced in urban computing. The concept of "third places" [11] refers to inclusively sociable places essential to public life and community. Another significant aspect is the heterogeneity of real cities compared to the uniform view of urban computing applications [12]. Although urban computing applications tend to approach every city as simply a setting and a container for action, populated by a rather uniform population of young, well-educated and highly mobile on a global scale, in reality, cities are not alike but the result of diverse historical and cultural activities. The main axes of our research are the concepts of place, community and infrastructure.

In [13], the tension between reactive and responsive that emerges as computational intelligence is introduced in the physical landscape is discussed; simply reactive systems entail a technical manifestation while responsive systems between people and the environment involve mutual learning of activity patterns and adapting to changing intentions. The concept of urban computing is also divided in two distinctive parts. The one part regards urban place a set of sensors and mobile devices, which collect, gather and output data that reveal patterns and flows and satisfy user needs. The other part suggests a more socio-cultural approach, which is not confined to the implementation of mere utility services. Therefore, the city landscape is not a neutral space or just a place where activities occur; it is a populated place and is socio-culturally organised [14]. It is the embeddedness of technology to this space that reveals the public and private qualities and help us to appreciate and understand it [15]. In our perspective, urban computing allows interventions into the city landscape, which smooth the line between familiarity and unfamiliarity; we focus on how people alter their perception, what socio-cultural activities emerge and which is the appropriate degree of intervention.

Inspired by the core topics that emerge on the definition of public space, the transformations that technology brings to the social space and the changing patterns in the use of infrastructure that emerge [4], we research whether technology in city landscape may alter the people's experiences. Our goal is to regard the city as a sociotechnical ensemble and review citizens' spatial and temporal proximity, their perception for the city landscape and their contribution and participation in the city life. We seek to address research questions like the following:

- RQ1: What is a public space and how urban computing alters the perception that people have of it? New layers have been infused in the fabric of modern cities; these layers of digital information enrich the landscape with location-aware content and allow novel views and uses on the city. People can experience a computer-mediated transformation of their city as a setting for learning, gaming, sharing or art performing.
- RQ2: What is our role in the social sphere and how will technology alter it? In a time when public authorities and municipalities invest in applying novel ICT infrastructure into cities, it is worth looking into whether this infrastructure can enhance participation of people on collective matters, their sense of belonging and responsibility or even sustainability in the long run. It is worth evaluating to what extent current tools can relate people and their experiences within the city and how people accept tools that mediate local knowledge sharing.
- RQ3: How does and in what degree public infrastructure affect the adoption of urban computing? People's engagement with the novel applications that are being deployed can be mediated either by personal smart devices or via public infrastructure. It is interesting to evaluate whether the openness of a city's infrastructure or the affordance of public gateways alters public engagement with the novel digital layers or the perception of people for urban computing systems.

These questions guide our research that focuses on how the key aspects of urban life, that is, place, community and infrastructure, are influenced or altered by the introduction of urban computing in everyday life. During our work, we have witnessed how urban spaces can be transformed from in-between spaces in ones effort to traverse a city into places that reflect and affect the identity of people and communities, as well as the role of public infrastructure as a facilitator of such transformations.

3 Is a Smart City a Sociable Smart City?

The early forms of cities determined human evolution, as radical changes came when humans started living in permanent installations. A city, from a demographic perspective, can be characterised by permanence, large population size, high population density and social heterogeneity [2]. It is expected that the 68% of the Earth's population will live in cities by the year of 2050 [16].

A city as a permanent, big, dense and structured settlement creates opportunities for human interactions and cultivate collective and socio-cultural life. Though all cities offer similar services, for example, being political, religious and economical centres, each city has its own character. The city's relation with the physical environment, its structure and its social interactions have evolved and shape the character of each city, which is unique. Through the ages, cities have undergone several transformations adapting to changing political, economic, social and cultural conditions; however, it is the novel technology that has catalysed every transformation in each era.

The embeddedness of ubiquitous computing into modern cities and the increasing number of smart phones led researchers to define the cities of tomorrow; terms such as *smarter cities*, *iphone city*, *sentient city*, *digital cities* and *intelligent cities* were presented. A number of definitions try to depict the dimensions of the concept "smart city" [17].

In [18], a city can be regarded smart when investments in human and social capital as well as to transport and ICT communication infrastructure fuel sustainable economic development and a high quality of life, achieving a wise management of natural resources via participatory governance. A smart city affects all aspects of city life [19]: economy, transportation and ICT infrastructure, resource management and environmental protection, human capital and participation in public life, quality of life and cultural activities and participation in public decision-making. In [20], an intelligent city is the one combining three degrees of intelligence: the individual's intelligence and creativity, the population's collective intelligence and the artificial intelligence embedded into the city.

The concept of smart city differs depending on the challenges that a city has to face, the degree of technological development, the willingness and effort to innovate, the available resources and the commitment of its shareholders, though we cannot say that a city truly claims to have fully mastered intelligence [43]. A smart city has to redefine its character, as both technologies and societies dynamically alter, and find out new ways how technology can be exploited for the common good [43, 44]. Smart cities also focus on human interactions taking into account the infrastructure and governance that play an important role in alleviating or exacerbating their existing issues [44].

An important aspect that can drive innovation in a smart city is the concept of sustainability. The socio-economic and geo-strategic context is transforming at a very rapid pace, and social change and adaptation are required so that a competitive economy may adapt individual way of life in order to preserve natural resources. The transition to sustainability is a social challenge, and cities must bring together both economical growth and environmental change. Smarter and sustainable cities need to combine growing sustainability awareness, urban development and technological innovations [43]. Taking into account also the sustainable development goals defined by the United Nations, as mentioned in [45], a smart sustainable city is an innovative city that uses technology to enhance the quality of life and the efficiency of urban operations and services and competitiveness while at the same time ensures the desires of current and future generations with respect to the economic, social and environmental aspects [46].

We can identify various routes orienting towards smart cities. The first approach is technology oriented; the information and communication technology as well as modern technologies play a key role, and the value of technology is emphasised and promoted. The second approach is human oriented; the human capital is highlighted and socio-cultural aspects are of major importance. Our research follows the human-oriented approach and aims to allow human to shape and decide the future of their sustainable city.

3.1 Defining the Sociable Smart City

Sociable: willing to talk and engage in activities with other people; friendly (Oxford dictionary).

Sociable is a place that is friendly and welcomes people to spend and share their time in it. A sociable place promotes interaction and collaboration among people and cultivates a pleasant mood. In a sociable place, people can be extrovert, sharing and participating in outgoing activities. A sociable place is open, welcome and approachable to all.

According to the sociable space concept in [21], sociable spaces are dependent on physical structure, which creates the arena for various activities and functions. The structure and physical infrastructure of a city determine the connectivity and accessibility, and sociable spaces are safely accessed by people. It is the physical structure's design that enables functions; functions operate as catalysts, attract people, encourage activity and movement and enhance socio-cultural life. Without such functions, a neighbourhood becomes monotonous and grey. The space's functions allow occurring various types of activities, which reveal its sociable character. In a sociable space, humans spend their free time, unexpected activities happen and various events occur.

The uniqueness of each city is defined by the interactions not only among humans but also between humans and the physical space. Cities are not just infrastructure and services; a city is the reflection of its everyday life and culture. The people who inhabit a city and their interaction, stories, concerns and experiences transform its character and advances its culture.

A sociable smart city offers a plethora of infrastructures and services, focusing on people and not on technology. ICT infrastructure should assist people to participate and act collectively. A sociable smart city must promote a shared sense of belonging and shareness and advance feelings of ownership and responsibility targeting a sustainable city. The way that people connect and collaborate each other as well as how they experience their city can be mediated via various digital tools and new media. City's physical and technological infrastructure can support gamification activities, outdoor learning processes and cultural events. We have proposed the following definition of a sociable smart city:

> A sociable smart city is one rich in infrastructure, which combines and exploits both people and artificial intelligence, empowering and engaging people in activities where urban social interactions thrive aiming to advance the quality of life and culture [22].

3.2 Other Approaches

Other researchers and academics have also used the term that [22] coined exploring similar aspects, focusing on people-centred design of technologies deployed in modern cities. [41] focuses on participatory innovation in a city and presents initiatives across Rotterdam and the Netherlands that mix Open Data, Internet of Things and a participatory design process. In a later keynote speech, [42] also calls for design of cities that is citizen-centred; this mix of human experience and information and communication technologies would make cities smart but also humane and sociable.

4 Transforming a City to a Sociable Smart City

Following the definition of sociable smart city, we have worked with peer researchers towards identifying some clear and distinct aspects of it, and then we proposed a methodology that interested researchers could follow in order to approach a city and design interventions that could alter it towards becoming smarter and more sociable.

4.1 Aspects of the Sociable Smart City Concept

In order to identify and decide on the social aspect of a smart city and refine the features and characteristics of the sociable smart city notion, we organised the homonymous workshop [23] in 2013. The workshop's outcome led us to the following routes [24]:

- *Methodologies on city dynamics*: A key aspect to understand the city dynamics is data. Big data collection and analysis may depict local routes and tourist flows; locals prefer to follow accustomed routes, while tourists follow specific directions to popular sights. Big data mining can also reveal interesting points of area for both tourists and locals and highlight the character of each area, like commercial, night-life, leisure, athletic space, etc. Collecting data that people share via their social networks, like local knowledge, people's experiences, reviews and comments, we can identify both social and sustainable districts and neighbourhoods. Knowledge from collected data may provide context-aware services and personalised experiences to tourists, which explore the city, enabling the concept of smart tourism experience. On the other hand, local authorities and municipalities can gain insight from such knowledge.
- *Infrastructure, tools and applications*: A sociable smart city follows a human-oriented approach, but it cannot overlook the indispensable character of the city's infrastructure. Such a city must invest in infrastructure; network infrastructure, like public WiFi network, 5G mobile networks and Internet of Things services, via embedded sensors that sense the city and actuators that take appropriate actions; and public displays and new means that allow people to interact with various applications. The city should also provide and support the development of various smart city applications that assist city life in sectors such as economy, education, health and mobility and promote sustainability and quality of life. All these infrastructures, tools and applications may advance interaction, communication, sharing and participation reforming ordinary city spaces into sociable public spaces.
- *Social engagement in urban areas*: A sociable smart city should not disregard the impact of technology on city's social and cultural life. Humans always found ways to exploit tools and technology to improve social life and communication and create art. Such cities may enable the development of modern artistic installations, attaching digital content to physical objects and buildings, and even give a physical subsistence to digital concepts. Therefore, a sociable smart city is a city that welcomes various cultural activities and events and has a significant impact on cultural life. Additionally, a sociable smart city can be regarded as a playground for outdoor learning experiences and gamification activities enabling the concept of smart people. Finally, in such a city, people must be able to spontaneously collaborate and new social forms of participation in which strangers team up should flourish.

It was revealed that researchers believe that the sociable features of a city are reflected in the urban social interactions that evolve and that rich social interactions strengthen the community. A sociable smart city supports socio-cultural interactions promoting the city's social and cultural life. Offered applications can also enhance the citizen participation, promote their sense of belonging, enable decision-making and organise people into collective goals. Having defined the sociable smart city and revealed its aspects, our next target was to explore how we can transform a city into a sociable smart one. To this target, we propose a city exploration methodology, which supports the research community to identify and propose suitable interventions.

4.2 City Exploration Methodology

We invited researchers to get acquaint with our definition of sociable smart city and follow our methodology. They were engaged in an outdoor city exploration and propose technology-based interventions that could affect how people use and experience the public space. We were inspired by Paulos urban probes [9] and proposed a three-phase methodology; participants were asked to (i) observe and select a public space, (ii) identify the actors that pass by or stay there and (iii) propose an appropriate technology-based intervention [25]:

1. On the first phase, participants stroll around the city, visit various places and locate areas with particular interest and character. Their goal is to find spaces that can be augmented with novel technology aiming to function more efficiently or even to transform their character. One can select from various functions that each city offers, like markets and commercial areas, transportation hubs, social and leisure areas, athletic courts and playgrounds, educational settings, cultural heritage sites and museums, etc.
2. On the second phase, participants have selected a place with a specific function, and they are expected to spend an amount of time in this place aiming to recognise its primary actors and how they perceive this place. The primary actors of a place can be people who are frequent there, people who work there or go for a specific job, others who just traverse it or even people who are idle between other activities.
3. On the third and last phase, participants are invited to work on a brainstorm session and propose and design an appropriate technology-based intervention; such intervention can be of any combination of infrastructure, applications, tools and data. An intervention should confront established habits, routines and activities in the space, aiming, though, to promote its sociable qualities.

Our methodology enabled workshop's participants to propose and design interesting interventions, which could augment or even alter the functions of the city of Corfu [25], relevant to transportation, market and leisure. Since 2018, we have invited graduate students from both the Ionian University in Greece and the Sapienza University of Rome in Italy to follow our methodology and transform their city, Corfu and Rome, respectively. Our experience revealed that such a methodology permits participants to view their city via a different angle and propose interventions, which aim to make their city more friendly and sociable. Students have proposed interventions relevant to transportation, cultural heritage, green areas and parks and market places, integrating elements of gamification, social involvement, sharing, belonging and responsibility.

5 Case Studies

Our research over the years has led to a series of applications that promote the vision of the sociable smart city. In the following section, we present the most prominent ones, which satisfy and address our research questions.

5.1 CLIO (ColLective cIty memOry)

Collecting people's memories and experiences of their city can have a number of positive effects. Memories act as anchors in time, connect diverse generations, reveal views of the city that get hidden or retrieve lost ambience in urban sites caused by the constant change, promote the sense of belonging as well as the formation of identity and transform sites that we routinely traverse to settings of exploration and learning. People's memories are thus an important aspect of the cultural heritage of a city, one that should be captured and preserved for the next generations.

The collective memory, though, is not preserved by the space itself. Individual memories have a short time horizon, as they can be lost along their carriers or altered through time. In the process of preserving collective memory, the most important factor is the interaction among people and memories. We have thus opted in this work for the use of the term collective city memory as it conveys the fact that these are memories that have occurred in the city and the social context is the one that brings a higher value to them and assists in their preservation and perpetuation.

Focusing on collective city memory is a particularly fit use case to study the effect of urban computing in modern cities. Collective city memory is shared in the community of a city, it is related to the place as it is mentally anchored to the physical landscape and since it is not a novel service but something that has always been, it allows us to evaluate what is the effect of modern infrastructure on how people perceive it and contribute to it.

We designed CLIO, an urban computing system, which transforms individual memories into collective ones and attach them to the physical landscape allowing an interaction among memories that simulates the traditional way in society that people share memories via conversations [27]. CLIO allows people to share personal memories, context annotate them and relate them with city landmarks, thus creating the collective city memory. Using CLIO, citizens can remember minor and significant events that occurred in their city, interact with collective city memory and contribute to their city's urban culture. The focus of our research is on the future of the city, and our main goal is to study the impact of an urban computing system on the urban culture and in particular how it alters the city, the perception of people about the city and the communication among people.

CLIO enables people to form and interact with the collective memory via a number of context-aware applications in the urban environment accessed on various personal devices hosting interfaces with different capabilities. The name CLIO, also an acronym for ColLective cIty memOry, was inspired from the Ancient Greek mythology Muse Clio, one of the nine muses whose name derives from the Greek verb *kleo*, meaning to recount, narrate and make famous, and who represents the scholar or researcher who ignites the desire to record, to research and to give an account of events in time.

We identified four research questions, relevant to the research questions presented in previous section, and we evaluated CLIO in various settings in order to answer them [26]; these questions are the following:

- Are citizens willing to share their personal memories and participate in the creation of a collective city memory?
- May an urban computing system enhance social interactions and simulate the traditional process of people sharing their memories in conversations?
- Can collective city memory be embedded into the urban physical landscape?
- How people consider urban computing systems and how the city's computing infrastructure affects their usage?

CLIO has been applied and evaluated in two cities in two different countries: the City of Corfu in Greece, the capital of a popular touristic island, where the Old Town of Corfu is characterised as UNESCO World Heritage Centre, and the City of Oulu in Finland, the most populous city in Northern Finland characterised as a living lab and ubiquitous city.

We set off at 2010 applying CLIO in Corfu, designing and building an initial version of our system, aiming to study how willing people are to share their personal memories, interact with collective city memory and discover the city via it. We developed CLIO system and made it available through various interfaces, like web browsers, smart personal devices and an augmented reality browser (Fig. 1). Firstly, we deployed the web interface, a simple and familiar interface suitable for the general public, via which people could both share their personal memories and browse the collective one. In an attempt to explore whether it is feasible to infuse the collective city memory into the city landscape and attach it to city landmarks in Corfu, we experimented with printed two-dimensional barcodes (QR codes). In order to fully exploit the potential offered by the abundance of mobile devices in the city landscape and provide citizens an interface traversing the city, we developed an Android mobile application and an enriched view of the physical surrounding we offered CLIO via Layar, an augmented reality browser for smart phones.

The CLIO system was deployed in the City of Oulu during the summer of 2011 exploiting the ubiquitous infrastructure of the city. Our goal was to apply and evaluate CLIO in an authentic urban setting enhanced with urban computing as we

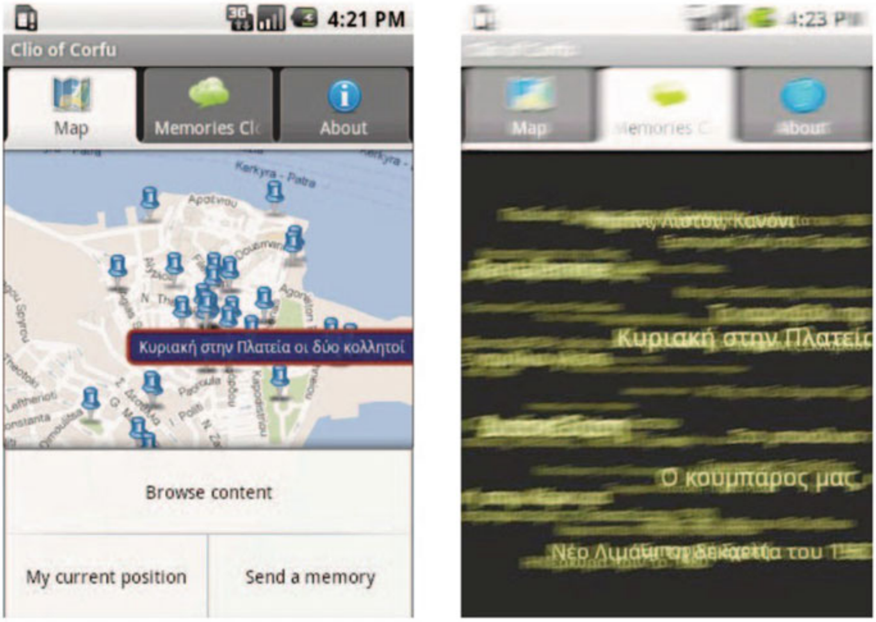

Fig. 1 Android application interface; map view presenting nearby memories and cloud view while shaking device presenting a random memory

Fig. 2 CLIO via UBI-hotspot and Layar in Oulu City Library

could exploit the WiFi city network as well as the 12 UBI-hotspots [28], a network of public interactive displays at indoor and outdoor public spaces. We deployed an interface for the UBI-hotspots, a mobile version for sharing memories, and a view for the augmented reality browser Layar (Fig. 2).

The main findings and lessons learned from our research with the CLIO system are as follows:

1. *Sharing personal memories:* Experience from both cities revealed that people want to share memories, but the collection method affects significantly the result. Given a setting where a user could feel comfortable and able to recollect, student interviewers approaching family members in Corfu exploited such a setting, users are more eager to share, enrich their memories with old photos and co-related events of the past and the present narrating story threads. Although people appreciate the value of sharing and recognise that it adds value to the city, they are hesitant to share not due to privacy reasons but more because of the peer pressure associated with sharing a story to the public. None reported that they do not share in order to protect their privacy, especially since sharing could be anonymous, but quite a few raised concerns that they had nothing interesting to share. An interesting outcome was that when people were asked to share spontaneously a memory in-situ, they usually described a recent experience relevant to the nearby place, whereas during interviews, people shared memories of their childhood and previous years.
2. *Social interactions:* In Corfu, students, who were engaged in the memory collection process, pointed out that they liked the idea and enjoyed talking with their grandparents and people of previous generations about their experiences and memories related to the city. Our study shows that engagement with our system promotes intergenerational dialogue. Via this process, our study engaged users of different generations in a meaningful dialogue, where the cause has been to couple the elders' recollections with the youngers' technical aptitude. The total effect was a deeper contact that both parties appreciated and experienced as a chance to come closer. People, from both cities, were excited with the idea of sharing and capturing personal memories, appreciated the effort of preserving this part of their city culture and considered valuable the knowledge emerged for their hometown. One of the most interesting findings emerged both from our observations and interviews was that CLIO has in all settings stimulated communication among people, as discussions erupted, content commented and similar memories were recalled and shared, and people experienced strong emotions viewing memories, like laughing and even arguing on common experiences perceived in a different way.
3. *Blending memories into the city:* In the City of Corfu, we evaluated CLIO system via various interfaces; users could either use a web browser or a mobile application. Users exploring CLIO system from their desktops at home via a web browser preferred to view random memories, whereas users moving around the city and exploring CLIO via their mobile phones selected memories close to their physical location. In the City of Oulu, we also evaluated CLIO via various interfaces; users could use the public displays, a mobile application and an augmented reality browser. The result from the evaluations in Corfu that people seek memories occurred close to their location was confirmed, but an interesting aspect that we derived is that people seek also memories relevant to

the character of their location, for example, when they are situated in a cultural site, they tend to search memories related to cultural activities. Our key finding in Oulu was that people consider the UBI hotspots as anchors of collective city memory on the physical space, which was considered to have a notable role linking memories and space. Another observation is that people who explore CLIO via the outdoors UBI-hotspots tend to look around the actual surrounding in an effort to try to locate the spots memories mention. The overwhelming majority of people, in both cities, expressed their impression and excitement while interacting CLIO via the Layar augmented reality browser and found this experience truly engaging and attractive.

4. *Experiencing urban computing:* Back in 2010, the City of Corfu was a city with limited computing capabilities; there was not any computing infrastructure, like city WiFi, and the mobile network was fairly unreliable for data-oriented applications. Thus, users who evaluated CLIO in Corfu strolling around the city via mobile phones, which we provided to them, were disappointed due to the fact that the smart phone experience was not as satisfactory as expected. On the other hand, users who explored CLIO via mobile phones in locations with reliable WiFi network expressed very positive remarks. Our experience from the City of Corfu that could not be characterised as a smart city and the City of Oulu that acted as a living lab confirmed our hypotheses that urban computing infrastructure affects and defines people's experience with smart city systems. In the case of Corfu, the unreliable network and the lack of city's infrastructure either discouraged them or broke totally their experience. In the case of Oulu, the city's truly ubiquitous infrastructure brought out the potential of the CLIO system and enabled their vivid experience with collective city memory. In Oulu, several participants reported that interacting with our system was the reason to use for the first time one of the city's public displays; thus, deploying infrastructure is not enough to lure users, and functions that would be useful to them have to be offered alongside. Additionally, the majority of the participants shared that they appreciate and regard public ICT infrastructure vital, but they see it as complementary to the use of personal smart phones. Another key finding from our research is how users appreciate smartness and intelligence of such systems. It revealed that people subconsciously expected the context-awareness nature of our system, since proposed memories were relevant to user's context, like location or previous selections. This was particularly evident from the outdoor users, who searched and selected memories close to their location or relevant thematically to the location's nature. Finally, taking into account users' previous selections and ratings aiming to present them suitable recommendations proved to be approved by the users as they had the chance to view memories close to their profile leading to a more engaging experience.

5.2 Participatory Budgeting

Increased urbanisation in recent years significantly affects the future of cities in various dimensions and forces the municipalities to exploit ICT technologies to interact with their citizens and face challenges relevant to public issues such as environment, health, civil protection, transportation and living space, inviting citizens' participation in city governance and administration [17, 29] to make their cities more intelligent, sustainable and supportive. Cities are now combining the introduction of ICT in a citizen-focused approach, and they pursue citizen's participation in the governance of the city providing digital services to them. A challenge that cities are facing is to strengthen e-Democracy; an interesting approach is via e-governance and participatory budgeting plans.

According to [30], a participatory budget targets to strengthen democracy in the decision-making via citizen's involvement into the budget process, which manages the city's needs and their costs. The idea to invite citizens to participate and co-form the public budget by allocating city's resources [31] and exploit ICT technologies via this process setting an electronic participatory budget [32] is proposed by various researchers [33, 34], and the final outcome is empowering and transforming the citizen as a decision-maker [35]. Via a participatory budget process, the city administration and public authorities may gain a lot; firstly, they can understand the citizens' desires, needs and priorities and be proactive, and secondly, they have the opportunity to transform their government via the citizen's participation to an open democracy. Such a process has also a great impact and benefit to the citizens as they are turned from mere consumers of a service into the producers and designers of it via their participation in the digital governance and the decision-making. Therefore, e-democracy can be strengthened and smart citizenship can be developed.

The following four conditions should be met so that e-democracy and e-government practices lead to valid results:

1. The capability of citizens to participate in policy-making process and its strengthening.
2. The guarantee that citizens follow a learning processes, which permits the discussions of different opinions.
3. The ability to collect innovative and prototype ideas that enable a better governance.
4. The definition of the final outcome of growing political legitimacy and trust.

This is achieved by permitting and enabling citizens to monitor and participate actively in the decision-making process [32]. Citizens' contribution to e-democracy can be made via a variety of tools such as workshops, citizen review committees, electronic forums, polls and participatory budgeting, though the exploitation of ICT technology results to valuable services and tools, with which cities can both operate and communicate the produced result via digital media, like websites and social media, and invite their citizens to participate and contribute to it. However, an effective decision-making and governance via citizen's activation are based on ubiquitous, accurate and timely information; citizens must have access to the correct information wherever and whenever. Thus, a crucial aspect is the open data produced and shared by the city, since their characteristics, quality and quantity can create the suitable conditions for citizens to contribute to decision-making.

Our research focused on presenting a participatory budget system that exploits open data, which invites citizens to engage and participate; we consider this system as a suitable case study of a sociable smart city as its main aim is to enhance citizens' collaboration and engagement in public decisions. The presented application was developed for the Municipality of Agia Paraskevi, Attica, Greece, and its citizens had the opportunity to take part in the process and decide on the city's budget in June 2021 [36]. The "Participatory Budget" system is an online participation and information tool relevant to the preparation of a city budget, which provides the necessary transparency in the allocation of the financial resources spent through open data.

The process of participatory budgeting via our system can be divided in the following four phases:

1. The members of the Municipal Council open the administrative period of the new year and define the budget's amount on which the citizens can decide.
2. The citizens and various city bodies decide to participate in the drafting process and the preparation of the municipality's budget. They create proposals, Fig. 3, which highlight local needs and may refer to various areas of activity, like education, sports, culture, safety, etc.
3. A number of proposals are collected, which reflects the needs of the municipality in various areas of its activity, according to its citizens' opinions. These proposals have to be evaluated and costed, by specialised municipality staff, in collaboration with the citizens who have submitted the proposals; similar

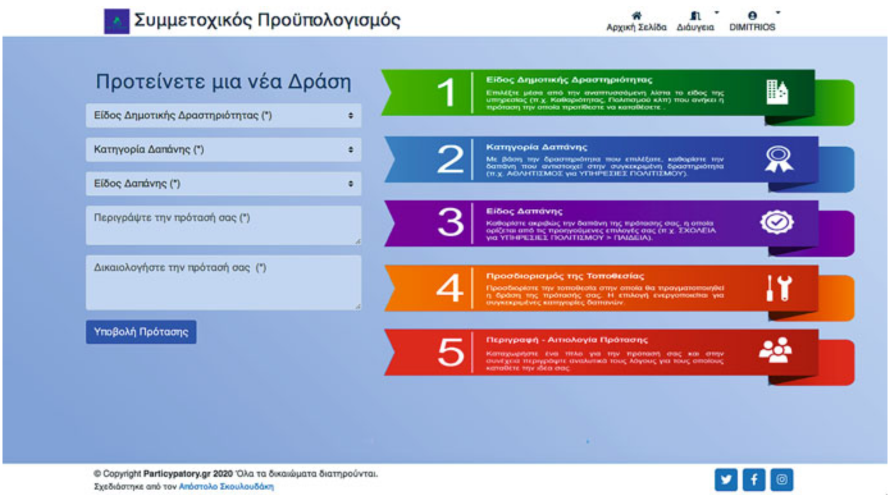

Fig. 3 Citizens' proposals

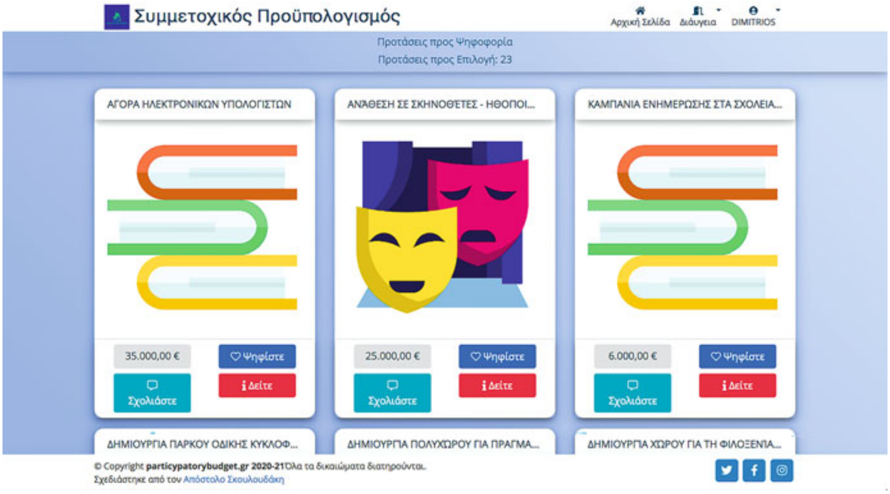

Fig. 4 Voting selected proposals

proposals are unified, and not appropriate ones, for example, due to breaking the law, are excluded.

4. Citizens are invited to participate in the most important phase and vote, Fig. 4. All citizens, regardless of whether they participated in the previous processes, can show, via their vote, their preference for 1–3 proposals concerning their city. In addition, they can comment on each proposal in the context of the advantages or disadvantages it gathers by expressing their opinion. The proposals with the most votes are the ones selected to be included in the overall municipality's budget plan. At the end of the whole process, the final outcome and results are published as open data.

The main activities that citizens can carry out via our "Participatory Budget" are the following:

- Select to join and choose participate in the process of editing part of the budget.
- Make proposals that bring out local needs and priorities, codify them and convey them and their impact via the application.
- Acquire accessible, readable and manageable information, which support their participation.
- Point out, via their votes, their preference for up to three proposals.
- Comment on all proposals, discuss their advantages or disadvantages and express their opinions.

The "Participatory Budget" application was launched in June 2021 at the Municipality of Agia Paraskevi, and citizens became aware of it via various channels, like email, social media and newsletters sent to specific groups of citizens. The application was presented during the drafting period of the 2021 budget, and even in a limited period of time, a large number of citizens attended and participated in the process. This was a significant indication that citizens want and desire to interact with such services, participate in city's decisions and shape the political agenda that defines partially their daily lives.

In the quantitative survey we carried out in order to evaluate our system, citizens, city bodies and associations, employees and elected and municipal parties of the Municipality of Agia Paraskevi participated. The main findings and lessons learned from our research are the following:

1. *Citizens' participation:* Citizens commented positively on the opportunity provided to participate in the process of drafting the budget of the municipality but also to monitor the evolution of the municipality's expenditures through open data. They were eager to participate and share their own proposals via our system in order to form the municipality's budget and they regarded that such system empowers them. Additionally, during the voting phase, they displayed a great sense of responsibility taking into account how important is to be both active and responsible citizens.
2. *Citizens' engagement:* Our system manages to enhance the participation of people on collective matters and alters public engagement. Citizens expressed that via our system the crucial aspect was not only their feeling of responsibility but their sense of belonging, as via this procedure their opinion was vital.
3. *City's sustainability:* All participants, citizens and municipality's employees highlighted that via our system they can collaborate and co-define how they can advance the quality of life in the city and decide upon cultural events that need to be funded. Additionally, the municipality can communicate to citizens the city's sustainability vision and co-define the main dimensions in accordance with them.

5.3 Mapography

As tourism is a social, cultural and economic phenomenon, we focus on the definition of smart tourism presented in [37]; smart tourism can be divided in three main pillars: smart tourism destination, smart experience and smart business ecosystem. Smart tourism is supported by the integrated efforts of a local authority or municipality to collect, aggregate and analyse data relevant to a specific destination; these data can originate from physical infrastructure, like sensors and IoT devices, from social connections, like social media and other mobile applications; from government and organisational sources, like public data, announcements and decisions; and finally data from humans, associations and enterprises. The goal is to use novel technologies, which will combine and transfer these data into smart experiences and added-value business propositions aiming on efficiency and sustainability.

Our belief is that smart tourism applications, which aim to destination management and experience enrichment, are suitable case studies for our vision of sociable smart cities. Mobile crowdsensing (MCS) and crowdsourcing application can benefit both smart tourism and sociable smart cities, as an MCS aims to measure and enumerate mutual interest phenomena, via a data and information sharing process based on human collaboration with sensing and computing devices [38]. So we proposed and developed Mapography, a mobile crowdsensing application, which engages and empowers people in social interactions via data sharing for hidden local spots in a smart city. Our aim is twofold: firstly we want to present an application that facilitates and enhances smart tourism experience and secondly provide an application that can support the concept of smart tourism destination. Regarding smart tourism experience, visitors can interact with a context-aware application, which proposes them personal recommendations, while local citizens' knowledge and experience are taken into account for the recommendation and proposals. In addition, the municipality can exploit such an application in various ways: identify the hot spots in the city and analyse people preferences as well as highlight specific areas and attract people there by organising, for example, various cultural events.

Mapography [39] is accessed via smart phones and anyone who has an interest on finding hidden spots or exploring new tourist locations can use it. It is designed as a mobile crowdsensing tool allowing users to post photos and descriptions of points of their interest and share them with the community; the location of each post is related to the user's actual geographical location, so a user can share a post for a location only when he is on the exact spot. A user can just browse the proposed locations or can also search for specific locations and read posts created by others; users can read and browse posts unrelated to their location. Mapography is an application that may support all aspects of smart tourism and may offer a smart tourism experience to travellers who wish to discover new destinations and share their experience and can support municipalities to provide a smart destination application, which connects local and visitors, and reveal the character and the popularity of various neighbourhoods.

Users can explore and search all posts, and they can choose between a list screen and a map screen in order to view the results. They can also select Explore Nearby and view locations that can be found nearby their current location. In Fig. 5a, the nearby posts are presented and in Fig. 5b the detailed post.

The main findings and lessons learned from the survey carried out in 2021 to evaluate Mapography are the following:

1. *User's data privacy:* It has shown that two out of three users are not familiar with the mobile crowdsensing and they share their concerns that such a system may violate their personal data and privacy.
2. *Highlight a location:* A vast majority reported that Mapography is going to be a very helpful and useful application. *Specifically*, more than 91.7% would use Mapography during their holidays, so they can explore more things about a new location. However, we can see a lessened percentage (70%) reports that they would use it to highlight a location in their hometown. Another encouraging result was that 90% expressed that Mapography can help highlight non-common areas and hidden locations. Almost all the participants expressed that they are

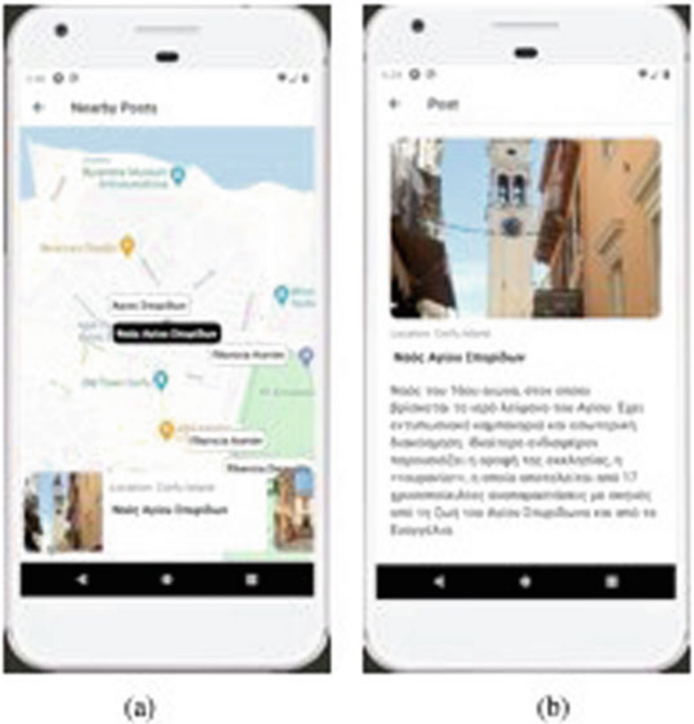

Fig. 5 (**a**) Explore nearby results. (**b**) Explore nearby detailed post

influenced by the opinion of other people and they would like to know what others think about specific locations.

3. *Collective awareness:* Mapography is an MCS application that can advantage the collective awareness of a crowd so that a phenomenon of common interest, like smart tourism experience, can be supported through the information sharing from personal mobile devices.

5.4 Outdoor Museum Experiences

Nowadays, many cities, cultural heritage destinations and museums have created a number of mobile applications to support people's interaction with such sites. In the tourism and culture sector, such applications are especially popular since people travel to discover different places and cultures and are especially interested to cultural heritage. On the other hand, more and more people are interested to learn about the history and culture of their own city and view it from a different perspective. Therefore, the need for awareness of local history and culture guided creators into developing a variety of cultural applications.

Cultural sites, like archaeological museums, can extend their services beyond the borders of a building or space. Thus, we focus to set up a dialogue between a city centre and its archaeological museum, connecting the archaeological exhibits with the location that they were found in the city centre. We designed a mobile application that generates walking cultural paths and presents the archaeological museum exhibits, digitally, in their actual environment in previous year. Our application combines the archaeological exhibits and their actual locations aiming to increase people's awareness and interest both to the museum and the city and to enable a dialogue between city local spots and museum exhibits.

A sociable smart city is a city that supports cultural activities and emphasises its cultural character; we believe that an application that enables the dialogue between a city centre and a museum is a suitable application for a sociable smart city. As a case study for our vision, we proposed a mobile application [40] for the city of Patras, Greece; our goal is to trigger an interaction with the city's archaeological museum. Patras cannot be characterised as a popular touristic destination, and its archaeological museum does not have high visibility, neither from local citizens nor from tourists. Our application targets to engage both travellers to Patras, who spend a few hours or a couple of days, like businessmen, and they do not have the opportunity or time to visit the museum, and locals, like younger and elder citizens, who have free time to wander around the city centre, in an outdoor learning and cultural experience.

A user can select between two modes of functionality. The first mode presents Cultural Routes in the centre of the city, while the second one locates Points of Interest around various city's attractions. At the first mode of functionality, Cultural Routes, the user chooses two points or areas of interest, Fig. 6, which will be the start and end points of the route that includes many points of interest keeping a straightforward route, Fig. 7. As the user approaches the location of a point of interest or selecting it on the map, a pop-up window emerges with exhibit image and information. At the second mode of functionality, Points of Interest, the user either selects an area of interest or its own location, and on the map, he/she can view the museum exhibits based on the excavation coordinates. In both modes, there are photographs and information about the findings in various media. The application is addressed to a wide audience, so it can be used by those who travel to the City of Patras and do not have the opportunity to visit the museum, by people who want to acquaint some information prior to their visit in the museum, by ordinary citizens who are interested in learning more about their city and generally by those who are interested in archaeology, culture and the history of the city. This application was evaluated by all types of users and the outcomes of the survey were very encouraging:

(a) *Advance culture:* Such an application introduces the archaeological museum of Patras to both local citizens and visitors, allowing citizens to acknowledge the history of their city and visitors to learn about the museum, even if they do

Fig. 6 Cultural Routes

not visit it. It can associate the city with the museum and support a number of cultural, touristic, educational and entertainment purposes.

(b) *Raise awareness:* Participants reported that they acquired significant knowledge in a pleasant way and that they recognised and appreciated the city's value, history and cultural heritage. Such an application can definitely involve younger people to creative and educational activities and motivate elders to discover the secrets of the museum by just taking a leisurely stroll in the city centre. Such activities may raise awareness on cultural heritage.

5.5 Addressing Research Questions

These case studies aim to address the research questions that we defined in the beginning of this chapter.

Our first research question concerns how urban computing alters people's perception of the public space. Our research revealed that participants via the CLIO system made connections of the current public space with past and novel views of the city, enriched with digital information that was presented to them. In the

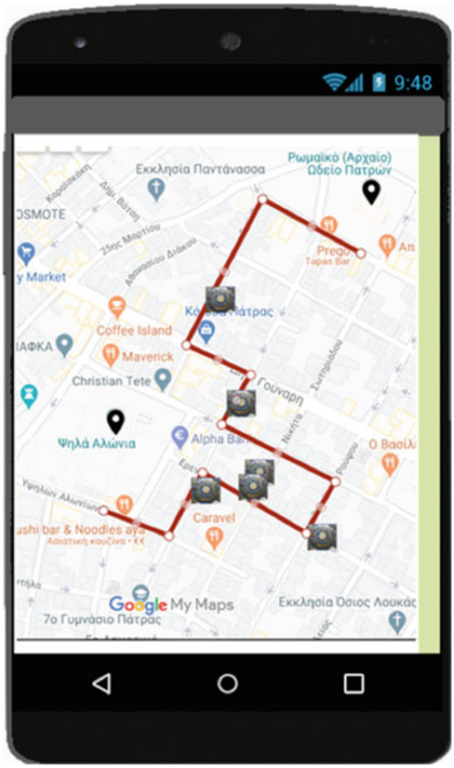

Fig. 7 Creation of Cultural Routes

case of the outdoor museum experience in the City of Patras, participants had also the opportunity to connect their modern city centre with its ancient history and transform their city as a setting for learning. The Mapography application allowed locals and visitors to view a city via each other's eyes, highlighting hidden locations that worth a visit and transforming the city as a sharing canvas.

Our second research question studies our role in the city's social sphere and how technology can alter it. The CLIO system provided users with various tools in order to interact with the collective memory of their city; smart phone applications and augmented reality were quite innovative in 2011. Even though users were not familiar with most of these tools and applications, they embraced the system due to the fact that it allowed them to share their own knowledge and experiences. Similarly, users of Mapography expressed that they would significantly consider using such an application because it gives them the ability to share their experiences. Thus, systems like CLIO and Mapography, which can mediate local knowledge sharing and connect people and their experiences, are systems that citizens can adopt. Additionally, the proposed participatory budgeting system focused on how such a system may empower citizens to participate in local decisions and enhance their participation. The outcomes of its evaluation were very positive, as the citizens expressed great interest, active participation and feelings of belonging and responsibility, and the municipality was impressed from the high participation.

Finally, our third research question evaluates how the public ICT infrastructure affects the adoption of such systems. The CLIO system was launched when the term of smart city was not as popular as today and the majority of cities had not invested in ICT infrastructure; we had the opportunity to evaluate our system in a city poor of ICT infrastructure, like Corfu, Greece, and a pioneer city, like Oulu, Finland. Our research unveiled that ICT infrastructure plays a significant role regarding users' adoption of a novel urban system; thus public authorities have to invest in novel ICT infrastructure. Our research showed that citizens have a strong sense of belonging and responsibility and they embrace tools, which can enhance their participation on collective matters, as in the proposed participatory budgeting system and the CLIO system. Additionally, municipalities and local institutes have to invest on the openness of a city's infrastructure and data, inviting the development of applications that strengthen their communities.

6 Challenges and Conclusions

During our research, we faced a number of challenges aiming to enable the vision of the sociable smart city. The following section, we present our main conclusions based on these challenges:

- *Selection of appropriate use case:* The notion of the sociable smart city is extensive both in broadness and in depth; early in this work, it has become apparent that in order to reach conclusions that would have a substantial contribution, there was a need to select appropriate use cases. We selected to focus on use cases that combine the place, the community and the infrastructure of a modern city; our aim was to enable community to exploit novel infrastructure taking into account the place and anchors to the physical landscape.
- *Exploitation of diverse interfaces:* These days we can exploit a plethora of interfaces to digital services in our cities; we can use our personal smart phones or shared public infrastructure, like public displays, and info kiosks that advertise content and lure users. In our study, it was a challenge to exploit various interfaces aiming to evaluate user's perception for each medium. We had the opportunity to study smart mobile phones and augmented environments a decade ago, when most of the people did not have personal mobile devices and nowadays when everyone is accustomed to them. Additionally, we evaluated one of our applications in a large public infrastructure using public interactive displays. The results of our works conclude that various interfaces have to be evaluated in order to understand how people perceive each medium and its capabilities. Our findings, from observations, interviews and surveys with random users with a variety of characteristics, such as age, sex, expertise and familiarity with computing, who interacted with our applications, demonstrate

differences in the engagement and the feeling that is conveyed when the same content is delivered via these diverse interfaces. Diverse interfaces define how users interact, the degree of engagement and the variety of experienced feelings, even when the same content is presented to them.

- *Blending with the physical landscape:* Related work has revealed a number of approaches that relate content to its location context; this relation takes the form of pinning the context on typical map-based services. This approach however does not promote the anchoring of content to the physical space of the city that this refers to. In our work, we selected technologies that allow blending the borders of the content's digital location with the actual physical landscape. The usage of mobile and augmented reality applications, as well as public displays and QR codes widespread in a city space, revealed how the place defines and plays a determinant role on what content users search and select to view. Additionally, the evaluations of all our case studies revealed that users anchor and relate content to specific places and appreciate more applications that facilitate this process.
- *Emerging social interactions:* An important aspect of our research is to evaluate if and how the urban computing can affect the social and cultural life of a city. We aimed to present applications that permit users to regard their cities via a different perspective and prosper profound social interactions. We managed to develop and evaluate applications and systems, which stimulate and promote social interactions and intergenerational cooperation. Our use cases have succeeded in triggering interactions among people that reflect social processes that usually occurred in tight communities; people using them have experienced strong emotions and have sought to communicate and engage in a dialogue. They, also, allowed the creation of communities and invited citizens to participate, collaborate, discuss, agree and be responsible for the future of their city. Finally, they managed the interaction between diverse groups, like citizens and public authorities as well as local citizens and visitors.
- *Large-scale real-life deployment:* The most crucial challenge is the deployment and evaluation of real-life applications carried out in the wild and not in controlled environments, where users follow certain trials. Our goal was to include novel technology in people's everyday lives and the real world allowing us to rapidly explore ideas with real users in authentic settings. Additionally, another challenge is to evaluate such application not only in outdoor settings but rather in highly heterogeneous places, dynamic and dense in terms of what and who participates in the applications with actors constantly entering and leaving and constantly changing usage patterns. Our research use cases have been deployed in various cities, such as Corfu, Oulu, Agia Paraskevi and Patras, providing valuable insight from real-life and large-scale interactions among the general public of a city and an urban computing system.

Concluding, the concept of sociable smart city focuses on human interactions facilitated by computing infrastructure and applications in the urban landscape and the enhancement of social and cultural life. Designers, developers and public authorities have to orient to provide citizens and visitors with suitable tools and applications, which transform spaces into sociable ones and invite people to participate in local actions. Finally, our research revealed that data, like memories, experiences and even cultural info, that used to be latent in cities can be offered to its inhabitants for exploitation and reuse; so open and shared data can create added value to a modern city.

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Part III
Healthy, Secure and Sustainable

Fostering Healthy Food Habits Through Video Games

Sara Cabascango, Ismael Andrango, and Graciela Guerrero

1 Introduction

Today, undernutrition affects people of all ages and, according to World Health Organization (WHO) [1], is one of the main threats to human health. According to Economic Commission for Latin America and the Caribbean (ECLAC) [2], Latin America and the Caribbean have been facing the problem of child undernutrition in the first years of life for more than two decades, but today, this problem has been aggravated by overweight and obesity in all age groups. The United Nations High Commissioner for Refugees (UNCHR) charity institution shows that 155 million children are stunted, 59 million children are too thin for their height, and 340 million children are deficient in essential vitamins and nutrients, all signs of malnutrition [3]. In Ecuador, according to Instituto Nacional de Estadística y Censos (INEC) [3], 35 out of every 100 children between 5 and 11 years old are overweight and obese; similarly, chronic malnutrition for children under 5 years old represents 23.0% in 2018. United Nations International Children's Emergency Fund (UNICEF) [4, 5] estimates that the percentage of chronic child malnutrition affects 27.2% of children under 2 years old in Ecuador, and in Latin America, 3 out of 10 infants and adolescents, between 5 and 19 years old, live with overweight.

On the other hand, UNICEF [6] specifies that inadequate nutrition in childhood causes difficulties in school and professional performance and increases the risk of developing chronic diseases in adulthood. In addition, UNCHR [7] describes

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mortality, reduced physical capacity and economic productivity, reduced intellectual and learning capacity, stunted growth and physical development, and metabolic deficiencies can even trigger cardiovascular diseases. Likewise, there are economic consequences; ECLAC [8] points out that obesity has an impact on higher health treatment costs, costs due to environmental effects, and costs due to lower productivity, among which are work absenteeism and mortality; likewise, the impact of undernutrition on productivity is equivalent to the loss of human capital it generates for a society; it also generates lower productivity due to the low educational level attained by people with undernutrition and the loss of productive capacity of the population due to mortality associated with undernutrition. ECLAC [2] and UNCHR [7] summarize some of the strategies to combat obesity and malnutrition, among which are the improvement of food knowledge and practices and quality education for guardians, since it has been shown that more educated parents are less likely to have children with malnutrition. Therefore, the promotion of good eating habits is a priority issue, for which it is necessary to seek innovative strategies that contribute to the learning of nutritious foods.

The objective of this study is to measure the food preferences of schoolchildren. For this purpose, information was extracted from related articles in order to obtain characteristics that support this research and to propose a practical and viable solution. For this purpose, a video game prototype will be developed, and two groups will be evaluated as follows:

(i) The control group is formed by 10 children between 6 and 10 years old who will fill out a questionnaire at the beginning of the experiment to determine their preference for certain foods; after receiving the same contents of the video game, but through audiovisual tools and playful activities such as crossword puzzles and word searches, the evaluation will be applied again to check whether these preferences have changed or are maintained.

(ii) The experimental group consists of 10 school-age children who, like the control group, will fill out two questionnaires, one at the beginning of the experiment and another one four days after using the video game called Healthy Gamers for 30 minutes a day, to check if the results have changed.

This article is structured as follows: Section 1 contains the introduction where the problem that gave rise to the proposal already presented is explained. Section 2 describes the characteristics of the work related to video games oriented to child nutrition. Section 3 describes the method and implementation of the video game prototype using the GAMED development methodology. Section 4 describes the evaluation design and the analysis of the results obtained. Finally, Section 5 presents the conclusions and lines of future work.

2 Related Works

Most studies have been devoted to measuring the effectiveness of serious games and gamification in promoting learning about nutritious foods and healthy diets. Such is the case of the study conducted by Froome et al. [9], which aimed to determine whether the game Foodbot Factory improves children's knowledge of the Canadian Food Guide; research conducted by Das et al. [10] also developed and evaluated a new educational game, called FoodCalorie, which aims to teach the caloric values of various traditional Bangladeshi foods and the standard of calorie intake that varies with age and gender. Another video game called NutritionRush, developed by Baranyi et al. [11], aims to educate about healthy nutrition through a nutrition library and encourage users to actively employ the acquired knowledge about nutritional values and daily energy intake while trying to accomplish the missions in the video game. Similarly, Belghali et al. [12] proposed a serious virtual reality game based on enjoyment, movement, education, and EF or executive functioning training that could help address childhood obesity. And finally, Wickham et al. [13] proposed FuelUp & Go!, a technology-driven food literacy program consisting of six face-to-face skill-building sessions, as well as physical activity trackers, text messaging, and a companion website.

Al-Sager et al.[14] and Angkasa et al. [15] emphasize the importance of eating breakfast regularly; for this purpose, they propose two video games, the first is an interactive multimedia-based game that encourages children in an elementary school to eat breakfast regularly everyday before going to school in addition to promoting physical activity and healthy eating; the second proposes a nutritional education tool "Makan Pagi Bergizi" (MAPAGI) or "Nutritious Breakfast" consisting of ten levels, in which the user through challenges, puzzles, and sorting challenges learned to prepare healthy dishes and identify nutritious foods, thus significantly improving the knowledge and attitude of schoolchildren about the importance of eating breakfast.

On the other hand, some researchers conducted studies to determine the effectiveness of serious games to promote and educate children about nutrition; Lee and Lau [16], Holzmann et al. [17], and Schäfer et al. [18] evaluated two video games to see if they were effective as educational tools; in the first one, a nutritional detective game was evaluated, obtaining positive results regarding the learning of the children who participated in the experiment; Holzmann et al. [17] evaluated the short-term effectiveness of the game on nutritional knowledge in seventh and eighth grade students obtaining adverse results in terms of effectiveness for teaching nutrition; finally, Schäfer et al. [18] conducted a pilot study to demonstrate how knowledge acquisition and behavior change can be increased through persuasive and positive elements of the game.

Other articles examined the effects of video game on children's eating behavior, such as the research by Folkvord et al. [19] and Alblas et al. [20]; the former examined the effect of a health video game on young children's eating behavior and attitudes toward healthy and unhealthy foods, using the serious game Garfield vs. Hotdog. Hotdog, with which a group of children played, while others received lessons on a healthy lifestyle, but the results obtained were negative in terms of the application's effectiveness in stimulating healthy food intake; likewise, the second article investigated the effects of a health game on the IAsTF, aiming to associate negative feelings with the choice of chocolate snacks and positive feelings with the choice of fruits, and the results were positive as a slight preference for healthy foods was observed after playing the game.

Since the success of video games is based on user enjoyment and satisfaction, it is important to know the usability parameters that guarantee a good acceptance, as is the case of the studies by Espinosa et al. [21], Marquez et al. [22], Bailey et al. [23], and KatoLin et al. [24], whose objective was to study the learning and user experience satisfaction of children when playing different video games. Espinosa et al. [21] studied the user experience of 8–10-year-old children when playing a nutrition education game. Marquez et al. [22] designed a serious game as a tool to support nutrition education in 7–8-year-old children based on sensors, so two components were implemented: a motion control based on CSC sensor fusion, which was subjected to usability tests to evaluate the impact it would have, and a user application based on a PC interface. Bailey et al. [23] propose FoodKnight, an application to help overcome childhood obesity and whose most important usability element is the player's avatar, as it also gets wider or thinner as the child does, reflecting his or her weight gain or loss, which can be grotesque. Kato-Lin et al. [24] developed a serious game called "Fooya!" with implicit learning components, in food choice, designed as an epic action game with an avatar fighting robots representing unhealthy food, making it more fun, thus enhancing the user experience.

Finally, it is important to show how parents value serious nutrition education games, and Ugalde et al. [25] proposed a study indicating that including a recipe selection and preparation component in a food education video game could be attractive and can improve nutritional efficacy in children. In the results, a group of mothers reported that involving their children in recipe preparation influences their children's willingness to eat vegetables.

3 Method

This section describes the development process, for which the architecture, the technological tools, and the design, development, and implementation process for the development of the serious game Healthy Gamers are presented.

The development and implementation of the proposed serious game were based on the GAMED development methodology, proposed by Aslan and Balci [26], which consists of a set of methods, rules, and postulates integrated in a life cycle for developing digital educational games. This methodology was chosen because the article by Albán [27] studied the various procedures used for the creation of serious

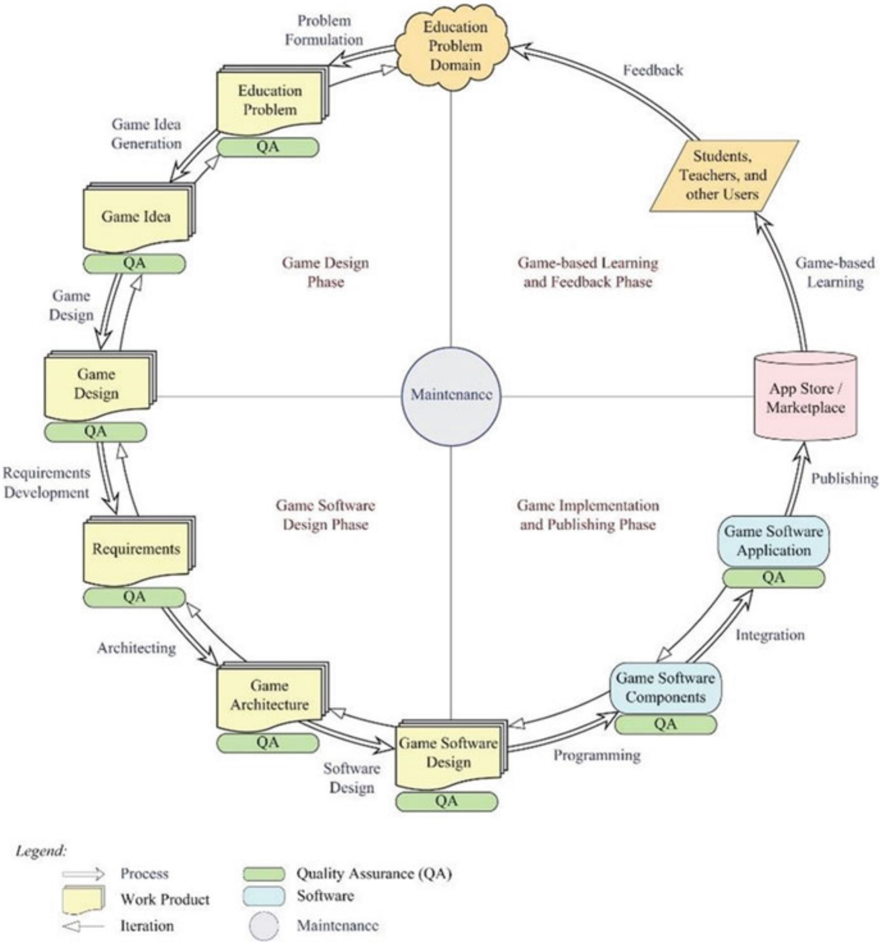

Fig. 1 Digital educational game life cycle [26]

games, from which four main phases were obtained, each with substages, analysis, design, development, and evaluation, where GAMED applies approximately 90% of the substages considered in each of them, in addition to being flexible with the use of technological tools and describing integration techniques.

GAMED requires the employment of the Digital Educational Game (DEG) life cycle presented in Fig. 1 and is embedded within that life cycle. The DEG life cycle provides the foundation of GAMED.

3.1 Problem Definition and Archetype of Solution Proposed

The problem identified in this study was childhood undernutrition and the possible negative consequences it could have, such as problems in school performance, stunted physical growth, and increased risk of developing chronic diseases in adulthood.

The idea that was proposed was the development of a video game where children can make a healthy recipe of their choice; unlike other video games, this one has a dual approach where both children and parents participate and will receive a message where the recipe that the children have made is reflected. In this way, parents can prepare these recipes for their children, and this will help to have a better control of the food that children consume everyday and also to generate greater awareness in children to eat healthily with the help of this video game.

3.2 Archetype Workflow: The Game Design

The video game starts with a form with two fields, in which a username and a phone number with the country code must be entered to enable the game menu. In case the player skips this step, the game starts, but the score will be temporarily saved (Fig. 2).

On the other hand, if the user enters these fields correctly, the user accesses the game menu which has three options: the first one starts the game; the second one shows the accumulated score; and finally, some basic instructions are shown to

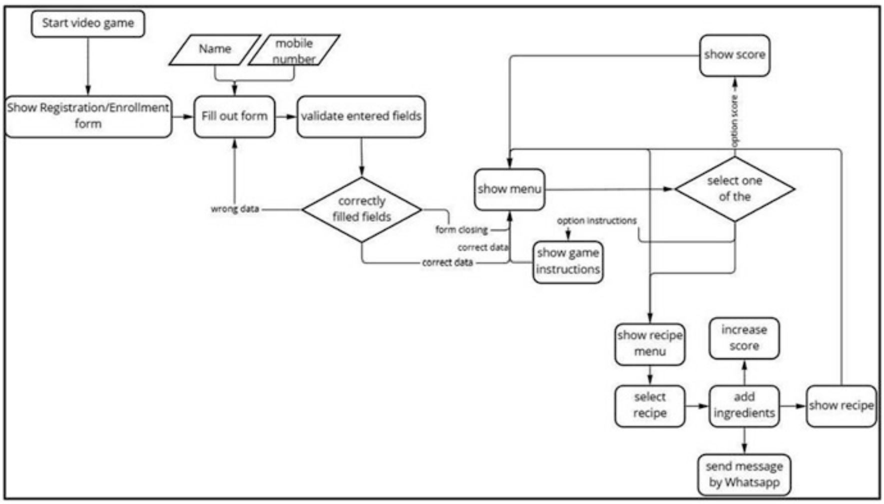

Fig. 2 Flowchart of the video game Healthy Gamers

manipulate the game controls and the menu. Once the video game is started, five buttons are displayed leading to five different recipes. Each recipe has a free choice of ingredients; however, for it to appear in a final dish, it must meet a minimum number of ingredients that will depend on each recipe. If these minimum ingredients are met, the recipe will be sent to the registered or predetermined mobile number, and the player's score will increase as he/she adds ingredients.

3.3 Requirements Development

As part of the requirements gathering phase, it was determined that five recipes should be established so that children could recreate or renew them. For the selection of these dishes, a recipe book from the California Department of Public Health [28] was used, which showed the nutritional information, ingredients, and preparation of various dishes, so the selection of those that would be in the video game was based on the nutritional value, the diversity of ingredients, and the fact that they were accessible in Ecuador.

For the video game, we considered the idea of Kato-Lin et al. [24] that proposed a science fiction context as an interactive part of the video game, so the scenario where the game takes place is a space station, which is attractive to children. In addition, a robotic character called Cookbot was contemplated, which accompanies the child throughout the game and fits perfectly with the space theme. However, the kitchen utensils and appliances were kept in the traditional style so that the children relate the game to real life and get involved in the kitchen with their tutors. No game levels were set, but as a motivator, a scoring system was implemented where the player can accumulate points as he/she adds ingredients to the preparation, and there is also a control as to the minimum amount of ingredients, so that the recipes are as complete as possible.

Finally, the functionality of sending a text message through the WhatsApp Web application to the user's registered cell phone number, which must be that of a guardian, was added; the message contains the ingredients of the recipe selected by the child and its preparation, to involve the people in charge of the guardianship of the infants and thus implement healthy foods in their diets.

3.4 System Architecture

According to Mizutani et al. [29], 55% of studios that connect their video games with third-party applications choose a layered architecture, as it is compatible with the general software architecture that the industry employs in large-scale games and allows code reuse, so Healthy Gamers is built based on a three-layer model shown in Fig 3.

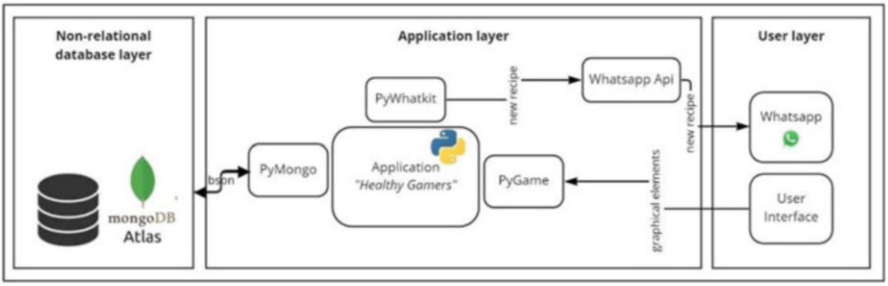

Fig. 3 Layered architecture of the educational video game Healthy Gamers

In the database layer is the connection to Mongodb Atlas, a non-relational database that is hosted in the cloud for free where information about the player, recipes, and ingredients is stored; because this game uses Python as programming language, this layer uses the pymongo library that facilitates the linking and administration of Mongodb Atlas. The user layer includes the user interface, which is built with the Python pygame module that aids in the creation of 2D video games, and the WhatsApp application, as the game sends messages to a registered phone number along with the player's data. The application layer contains all the .py scripts that control the game, which make use of the pymongo, pygame, and pywhatkit libraries that have some functions to handle the WhatsApp API and facilitate sending messages from the game.

3.5 Software Design

The video game is organized in layers, so the scripts that compose them are: (i) Application layer. - main.py, which is the starting point for the execution of the video game; mouse.py, which handles the user interaction when using the computer mouse; game.py, where all the classes and methods that control the video game are located; recipes.py, which contains the functions of each recipe, and menu.py, which controls the game menu since from here you can start the game (Fig. 4) and retrieve the score and the instructions. In the database layer, there is user.py, which contains the CRUD of the user for the database, and finally, in the user layer, there are the following files: character.py, which controls the actions of the character that accompanies the game; register.py, which manages the initial view for the user registration; and whatsapp.py, where the class that operates the API that connects the game with the messaging system Whatsapp is located.

Fig. 4 Design of the application developed (Healthy Gamers)

4 Evaluation and Results

This section focuses on the design of the evaluation with the different scenarios that were proposed and their results in terms of the effectiveness of the video game in changing the food preferences of children versus the use of audiovisual tools and play activities, all based on questionnaires and suggestions from previous research.

4.1 Evaluation Design

The evaluation of the proposed prototype was carried out with 20 school-age children of both genders between 6 and 10 years old, belonging to the Vicente Aguirre school located in Rumiñahui – Ecuador. The children in the evaluation group had basic computer skills and no previous experience with educational video games. The study was organized in seven sessions divided into two scenarios. The methodology used for the evaluation consisted of the following steps:

(i) Implementation of a total of seven sessions in two scenarios. These sessions included two questionnaires measuring children's preferences for certain foods and a usability test to users who used the prototype.
(ii) Analysis of the results obtained.

4.1.1 Scenarios and Sessions

There are two scenarios in which Healthy Gamers will be evaluated to measure their efficiency against the audiovisual tools and recreational activities. The general activities for each scenario are training, two food preference questionnaires, 30 minutes interacting with audiovisual material, and playful activities or testing the video game, depending on the scenario.

Scenario I. To measure the food preferences of the control group after interacting with the audiovisual tools and play activities that teach the same recipes found in the video game. The participants will be ten children of both sexes of school age.

Table 1 Results of the first questionnaire to the ten members of the control group

Questions	Healthy option (%)	Unhealthy option (%)
Circle the foods you prefer to eat: fruits or snacks.	70	30
Circle the foods you prefer to eat: vegetables or chips.	70	30
Circle the foods you prefer to eat: water or soda.	40	60
Circle the foods you prefer to eat: bread or chocolates.	50	50
Circle the foods you prefer to eat: yogurt or sugary juices.	30	70
Average	**52**	**48**

First session. Conduct an introduction to healthy eating with the help of a video obtained from the YouTube platform, to start with a controlled prior knowledge. Unlike the other sessions, in this one, the participants will be from both scenarios. The duration of the session is 30 minutes, and a questionnaire will be applied to determine the degree of satisfaction of the infants with the initial instruction.

Second session. Apply a questionnaire (see Table 1) before the third session and another one after the third session to the control group to evaluate the children's predilection for healthy and unhealthy foods. The final questionnaire will have an extra question to find out if the users remember the recipes or ingredients.

Third session. Videos and playful activities such as word searches and crossword puzzles are used for children to learn the five healthy recipes that were selected for the video game. The duration of the session is 30 minutes a day for four days.

Scenario II. To measure the food preferences of the experimental group after interacting with the video game. The participants will be ten children of both sexes of school age.

First session. In this session, the ten participants belonging to the second scenario complement the first session of the first scenario with a training on the use of the video game, and a questionnaire is applied to determine the degree of satisfaction of the children with the initial instruction and training.

Second session. Apply a questionnaire to the experimental group (see Table 4) before starting the third session and another one after the third session to assess the children's preference for healthy and unhealthy foods. The final questionnaire will have an extra question to find out if the users remember the recipes or ingredients.

Third session. Generate an interaction between the user and the video game for 30 minutes a day for four days, so that the children learn the healthy recipes and send them to their tutors.

Fourth session. Evaluate the usability of the prototype by means of a five-question questionnaire developed by García et al. [30] just to know the defects of the prototype and propose improvements.

Table 2 Results of the second questionnaire to the ten members of the control group

Questions	Healthy option (%)	Unhealthy option (%)	Average number of recipes remembered per child
Circle the foods you prefer to eat: fruits or snacks.	70	30	
Circle the foods you prefer to eat: vegetables or chips. Circle the foods you prefer to eat: water or soda.	70 60	30 40	0.9
Circle the foods you prefer to eat: bread or chocolates.	60	40	
Circle the foods you prefer to eat: yogurt or sugary juices.	60	40	
Average	**64**	**36**	**18%**

4.2 Results of the Food Preference Questionnaire

Results were obtained for the different scenarios, each of which is detailed below.

In scenario I, a questionnaire was applied twice, once at the beginning of the experiment and once at the end of the third session to the control group of ten school-age children, and the responses of each child were reviewed in detail.

Table 1 shows the questions from the questionnaire applied in the second session of the first scenario. The questions were obtained from a nutrition questionnaire of the Division of Supplemental Nutrition of the Department of Health Services [31]. The results corresponding to the control group obtained in the first data collection of the second session are shown. Fifty-two percent of the responses show that children prefer healthy foods, while 48% prefer unhealthy foods.

According to the values obtained, it can be concluded that in the first questionnaire, 52% of the respondents are attracted to healthy food instead of nonnutritious food, and 48% are inclined to the latter.

Table 2 shows the same questions posed by the Division of Supplemental Nutrition, Department of Health Services [31]; however, for the second questionnaire after the third session, a question was added to find out if the children remembered some of the recipes that had been taught. The results for the control group reflect that 64% of the children preferred healthy foods while 36% preferred unhealthy foods. The average number of recipes remembered by the children is 0.9 recipes per participant.

In the second questionnaire applied, 64% of the respondents chose healthy foods and 48% preferred unhealthy foods, with a difference of 12% of children preferring nutritious and nonnutritious foods compared to the first questionnaire, so it can be said that there was a slight improvement in terms of children's preference for nutritious foods.

On the other hand, in scenario II, as in scenario I, a questionnaire was administered twice to the experimental group, once at the beginning of the experiment

Table 3 Results of the first questionnaire to the 10 members of the experimental group

Questions	Healthy option (%)	Unhealthy option (%)
Circle the foods you prefer to eat: fruits or snacks.	70	30
Circle the foods you prefer to eat: vegetables or chips.	20	80
Circle the foods you prefer to eat: water or soda.	30	70
Circle the foods you prefer to eat: bread or chocolates.	40	60
Circle the foods you prefer to eat: yogurt or sugary juices.	30	70
Average	**38**	**62**

and once at the end of the third session. The experimental group consisted of ten school-age children whose responses were thoroughly examined.

Table 3 shows the questions of the questionnaire applied in the second session of the first scenario. The questions were obtained from a nutrition questionnaire of the Division of Supplemental Nutrition of the Department of Health Services [31]. The results corresponding to the control group obtained in the first data collection of the second session are shown. Fifty-two percent of the responses show that children prefer healthy foods while 48% prefer unhealthy foods.

With these results, it is possible to determine that in the experimental group, there is a clear preference of 62% for unhealthy foods versus 38% of responses with an inclination toward nutritious foods.

Table 4 shows the results obtained in the second application of the questionnaire in the experimental group; it should be noted that, as in the control group, a question was added to find out if the users remembered some recipes from the video game. The results show that 64% of the children prefer healthy foods while 36% prefer unhealthy foods. The average number of recipes remembered by the children is 3.3 recipes per participant.

In the second questionnaire applied, 74% of the respondents chose healthy foods and 26% preferred unhealthy foods, there being a difference of 36% of children who preferred nutritious and nonnutritious foods with the first questionnaire, so it can be said that there was a great improvement in terms of children's predilection for nutritious foods.

Finally, when comparing the average number of recipes remembered by each of the members in both scenarios, it can be observed that the proposed prototype is highly effective since the infants were able to remember 66% of the recipes compared to 18% of the control group that only used videos and play activities.

Table 4 Results of the second questionnaire to the ten members of the control group

Questions	Healthy option (%)	Unhealthy option (%)	Average number of recipes remembered per child
Circle the foods you prefer to eat: fruits or snacks.	90	10	
Circle the foods you prefer to eat: vegetables or chips. Circle the foods you prefer to eat: water or soda.	90 60	10 40	3.3
Circle the foods you prefer to eat: bread or chocolates.	50	50	
Circle the foods you prefer to eat: yogurt or sugary juices.	80	20	
Average	**74**	**26**	**66%**

4.3 Usability Test Results

The usability test developed by Garcia et al. [30] was applied, which consists of five questions structured on a scale of 0–4, which measures by means of the Usability Scale System – SUS; this test consists of eight statements; the users, by means of scores, express their level of agreement or disagreement with these statements, with the score zero, strongly disagree, and four, strongly agree. The test was applied to 10 school-age users (see results in Table 5); these users found that the prototype has a usability of 62.5%, which is relatively low, and shows that several corrections should be made.

Table 5 shows the results obtained in the usability test applied to the ten members of the experimental group that used the Healthy Gamers prototype. Each question was evaluated on a scale of 0–4, then a sum was obtained by columns; this value is multiplied by 2.5 and a percentage is obtained that represents the usability of the game for each user. The average of these percentages represents the overall usability of the application, which in this case is 62.5%.

The usability of the video game is 62.5% which on the SUS scale [32] is in the marginal range, indicating that it is not very acceptable and needs improvements and corrections.

5 Discussion

Children need to learn from a young age good eating habits so that they can develop; however, nutrition education can be taught in different ways and use various tools to reinforce knowledge; this is an opportunity to test the effectiveness of video games as a support in nutrition education to change children's preference for unhealthy foods; to respond to this hypothesis, two scenarios were proposed (see Table 6).

Table 5 Results of the usability test applied to the experimental group

Questions	User 1	User 2	User 3	User 4	User 5	User 6	User 7	User 8	User 9	User 10
I think I would like to visit this game many times.	4	4	4	4	4	2	4	4	4	4
I found this video game very complicated.	0	4	0	4	4	2	4	4	4	4
I think this game is easy to use.	4	4	3	4	4	1	4	4	4	4
I think I would need the help of an adult to use the game.	0	2	0	4	3	4	4	4	3	3
I imagine that other children would quickly learn to use this video game.	4	4	4	4	4	0	4	4	4	4
I found this video game to be very challenging to use.	0	4	2	4	4	2	0	4	3	2
I felt very confident in the handling of this video game.	2	3	4	4	4	0	4	4	4	4
I needed to learn a lot of things before using this video game.	0	4	0	4	4	0	0	4	4	4
Sum	14	29	17	32	31	11	24	32	30	29
Sum* 2.5	35	72.5	42.5	80	77.5	27.5	60	80	75	72.5
Percentage	35%	73%	43%	80%	78%	28%	60%	80%	75%	73%

Table 6 shows a comparison of the results regarding the tendency for unhealthy foods of the scenarios formed by the control and experimental group, before and after interacting with the designated tools and technologies, which in the case of the control group were videos and playful activities and for the experimental group was

Table 6 Comparison of the scenarios

Questionnaire description	Scenario I Control group (unhealthy food option)	Scenario II Experimental group (unhealthy food option)
Questionnaire applied prior to the interaction with the tool corresponding to the scenario.	48%	62%
Questionnaire applied after interaction with the tool corresponding to the scenario.	36%	26%
Average number of recipes remembered per child.	0.9	3.3

the video game developed in Sect. 3, showing that in the first scenario in the initial questionnaire, 48% choose unhealthy foods, and in the second scenario, 62% also did so. In the second questionnaire, after the 30-minute daily interaction, 36% of the control group still chose unhealthy foods, and 26% of the experimental group chose unhealthy foods.

These results reflect that on average taking scenario I and scenario II, 55% of the children preferred unhealthy food; after applying the audiovisual material and play activities to scenario I, the predilection for unhealthy food decreased by 12% being then a short success compared to scenario II that after the interaction with the video game decreased by 36%, which shows the effectiveness of the prototype to combat the children's preference for unhealthy food. On the other hand, the effectiveness in terms of the infants being able to remember the recipes learned is very low in the control group since on average 0.9 recipes are remembered, which may show that the tools used for this scenario do not have an impact on long-term memory, while in the experimental group, positive results were achieved since the rate of recipes mentioned is 3.3 out of five recipes, which confirms the efficiency of the video game in influencing medium-term memory. Probably this percentage, both in the tendency to eat healthy food and to remember more recipes, was affected by the usability problems of the video game, which was 62.5%, so that, with improvements, the effectiveness of the prototype could be increased.

6 Conclusions and Future Work

As a result of the research, it can be concluded that it was observed that the children changed their food choices especially the experimental group that used the video game developed in this research, while the control group, although they did opt for healthy foods after the experiment, it was not as significant as with the experimental group. In terms of usability, it can be said that the members of the second scenario had problems when using Healthy Gamers.

The prototype, as such, is an application that could support nutrition education for schoolchildren. About the evaluation tools used, (i) the first questionnaire showed that the control group preferred unhealthy food by 48% and the experimental group preferred it by 62%. (ii) After the evaluation of the three proposed scenarios and by conducting a second questionnaire, it is observed that 36% of the participants of the control group still selected unhealthy food, compared to 26% of the experimental group. It is recommended to encourage and create mechanisms to promote the use of this technological tool as an option to improve learning and nutritional education.

In addition, it is important to consider the time factor in the use of the application by children, since it can be assumed that the novelty in the use of the application may influence the results obtained.

As a possible line of work for the future, it is proposed to increase the number of users to have a greater validation of the application; it is also suggested to apply the study to users of other ages to corroborate its effectiveness with preadolescents. In addition, to provide more entertainment and better capture the player's attention, it is recommended to expand the proposal to incorporate more didactic game levels and mini games. Another possible future work is to improve the Healthy Gamers application environment to allow a customized configuration by the user; the elements that could be modified by the user are the textures and colors of the animations, to provide a better visual experience.

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Smart Solutions for Sustainability: RDI for Urban and Societal Transitions Requires Cross-Sectoral Experimentation Platforms

Ioan M. Ciumasu

1 Moving Beyond Pioneering Initiatives

1.1 The Challenge of Sustainability Transitions Comes to Age

Transformative innovation was urgent a decade ago and still is today, just more so. The unsustainability crisis, mostly visible with climate changes and resource shortages, is already forcing us to reconfigure our economy and society – hopefully opening a new techno-economic cycle after 250 years of modern industrial dynamics [1]. However, this era of profound human impact on the Earth, that is, the Anthropocene, is still driven by unsustainable methods even though our thinking about it has evolved somewhat [2]. In the young twenty-first century,

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a heterogenous set of pioneering projects (seeking ways to achieve an effective transition to sustainable development) have tested the relations between innovation in the private sector and policies in the public sector. Typically, this happened inside complex, university-business-government and multi-sectoral industrial settings. Some valuable hard lessons were learned by a small set of participants, but unsurprisingly at history's scale, real systemic socioeconomic breakthroughs have not been reached yet. The question that many of us were asking a decade ago remains actual: *How to achieve those breakthroughs?* [3].

Here I take a human and technological systems (HTS) perspective, and I rely on work experiences in several countries (a) to trace some of the main historical premises of the European RDI (Research, Development, and Innovation) for smart and sustainable development and (b) to describe a science-based, practice-tested method to do so.

Human Systems Include Different Scales from Individuals to Entire Communities The largest is the whole of humanity on Earth (and in perspective, on other planets and in the outer space). While decisions ultimately rest with the individuals (based on the human rights recognized by the UN), humanity can only become sustainable as a whole, because there is a common biophysical system that sustains it: planet Earth. The unsustainability crisis is a type of problem known as "tragedy of the commons": collective destruction of a common good through individual overuses until it loses its capacity to recover (and collapses) through the nonlinear dynamics of the coupled human and natural systems (CHANS) – a category of complex dynamic systems (CDS) [4–7]. This "race to the bottom" is caused by carelessness, ignorance, and short-term thinking.

To date, we are still relying predominantly on the twentieth-century technologies, and most business models are based on neoclassic economics which considers nature to be external to economic processes, that is, our life quality still depends on the old socioeconomic premises that generated the unsustainability crisis. If we were to judge after the geopolitical-economic-environmental tensions that are piling up and spilling over around the world, the so-called perfect storm that has been looming for 10–15 years [8–10] may have just started out with a "mild shower." Back then, experts from virtually all sectors were talking about reinventing whole industries through "green business," "green jobs," and "sustainable growth," in a socially (and politically) desirable logic of sustainability and competitiveness going hand in hand. This desiderate was for a long time, and still is, reflected by the UN's Sustainable Development Goals [11–13] but remains easier said than done, by and large because of many unresolved grand issues relating to skills, technologies, markets, physical resources, institutions, and policies [14].

Conditionally positive signs can be cited. On 30 May 2022, the European Investment Bank (EIB) released a report addressing the issue of hydrogen in the energy and sustainability transitions [15]; on 14 September 2022, the European Commission (EC) proposed a new financial institution to help sustain a strong market pull matching the European technology push in hydrogen-based energy: the European Hydrogen Bank [16]. Nevertheless, since the key role of hydrogen is that of an integrator of various technologies and solutions, and because the development of hydrogen-based or hydrogen-related solutions requires systemic experimentation platforms (large-scale demonstration projects), this sector is bound (a) to integrate numerous "smart city and society" ideas and methods and (b) to reflect systemic and context complexities.

However, great potentials never remove the risk of overconfidence. Some preliminary data allow some cautious hopes that socioeconomic development may have started to decouple from environmental degradation, but the hard confirmation requires proofs of a systemic transformation – a long journey awaits us, with numerous pulls and tensions that can easily cause failure.

To succeed in the transition to climatic neutrality and overall sustainability of human activity, some necessary conditions must be met. First and foremost, we need to understand well what blocks. A good place to start is the recognition (or lack thereof) that knowledge is distributed across global networks of experts relying on unique professional experiences and embedded in local contexts (i.e., not centralized). In this sense, we know that cognitive and behavioral biases lead to project failures [17]. Most notably, the usual preference of individuals for short-term benefits is a form of long-term blindness. At the scale of society, this creates cycles of hype and disappointment which results in investment discrepancies that hurt long-term developments of technology-based enterprises, goods, and services – not a basis for "smart" solutions [18–21].

Moreover, conjunctions of biases are almost inevitable in large megaprojects, that is, "large-scale, complex ventures that typically cost US$1 billion or more, take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people" [22, 23]. But these kinds of projects are necessary in the transition to sustainability, which requires large-scale, system-level experimentation. Because megaprojects are characterized by "extreme complexity, substantial risks, long duration and extensive impact on the community, economy, technological development, and environment of the region or even the whole country" [24] and because they are "projects which transform landscapes rapidly, intentionally, and profoundly in very visible ways, and require coordinated applications of capital and state power" [25], one can convincingly argue that "looking at society through its megaprojects would reveal its ambitions, problems, as well as its future outlooks" [23]. So another major stumbling block beside short-termism is the sheer scale and complexity of the projects that are necessary for society to transform itself. Concretely, this means that if we want to avoid major mistakes, the issue of knowledge organization and management must be properly understood and addressed. For instance, one old and popular but naive idea (and not unrelated to power grabbing temptations) is that knowledge can be centralized in a person or a small group of individuals. Related to it is the cognitive and behavioral bias known as the illusion of planning (based on the illusion of perfect control) and the illusion of simple ("silver bullet") solutions to complex problems. Such biases undermine all projects. Left unaddressed, they can stump any project.

As a society, we must reach the point where the great majority of actors and stakeholder can face and understand in practical terms the reality that knowledge in general (and science itself) is (a) distributed throughout society across networks of interacting individuals and (b) parceled between many academic disciplines and areas (and between industrial fields and professional traditions), as well as between sectors of academia, business, and the government. So knowledge can only be mobilized, not "centralized." Relatedly, the myth that there is an ideal and coherent corpus of knowledge to which one can just add or take from "automatically" must be actively dispelled through pragmatic projects that target the hardest problems, that is, not by playing around with easy games that bring what appear to be more immediate and spectacular benefits but which actually aggravate the core problems.

Additionally, innovation doesn't just happen: end-value is created through hard work in complex dynamic interactions between relevant actors. Another blocker is the fact that (a) too many people outside RDI ignore the reality that scientific research is (hard but remains) just the beginning of the process of problem resolution and that (b) the amount of financial investment that is necessary to translate scientific discoveries into final products or services is about one order of magnitude larger. This might be due to a superficial understanding of science as an easy work of genius that solves everything (instead of science being the product of a long history of efforts): people seem to want to hear about that 1% genius and simply prefer to ignore the part about 99% transpiration. To be fair, there are also some myths that are popular among scientists and may create subtle frictions in RDI. One is the idea that "we (scientists) are doing the work and businesses are reaping the benefits." This comes from a combination of individual and group biases and undermines collaboration between science and the rest of the society. Still, dismissing such aspects without trying to understand their cause is equally wrong, because, as we know from industrial and organizational psychology, this would disregard conditionalities that are encoded in the respective professional cultures. Such "how we do things around here" background details (taken for granted by insiders but unseen by outsiders) tend to be ignored by everyone until catastrophic misunderstandings and surprises break in [26]. In fact, professional cultures are collective identities that reflect long-term features in the respective contexts and operations and must therefore be regarded as an integral part of the human resource. In this sense, harmless collegial jests like "engineers have built the world and economists have ruined it" (which I first heard in Romania during the 1990s when many factories were scrapped as obsolete) actually hint at the creative tension between the two principal forces driving progress at history's scales – technology push and market pull – and encapsulate the need to understand RDI as a perpetual exercise of equilibrium-finding between those forces [27].

With These Challenges in Mind, I Argue in Favor of Disciplined Experimentation Starting from the idea of "experience as horizon" [28] and taking the professional perspective of a "privileged observer contributor" [29], I describe a structured approach to managing pioneering holistic projects aiming at generating transformative innovation.

In complex multidisciplinary projects (unlike in monodisciplinary works), common denominators require dedicated efforts, often by preparatory projects. Practice

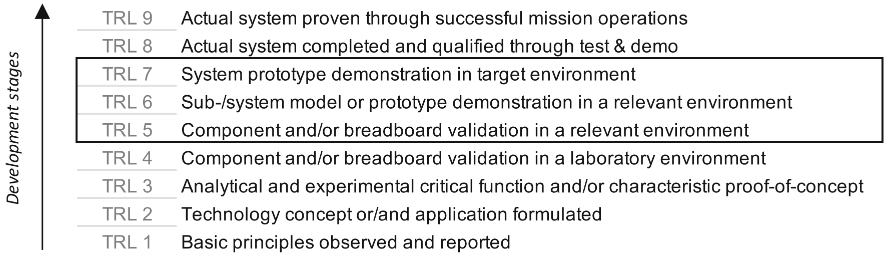

Fig. 1 Generalized list of original technology readiness levels

indicates that a project team must start from the basic idea known from the wall of the prehistoric temple of Apollo in Delphi: γνῶθι σεαυτόν (gnōthi seautón) – know thyself. Instead of undue extrapolations or overplanning toward their common goal, experts must follow scientific principles and build a shared mental representation of their work.

I propose that a logical place to start from is the technology readiness level (TRL) framework (Fig. 1) which was established by NASA in the 1970s and has become popular in industry and RDI around the world [30, 31]. Specifically, I address the main challenge that characterizes the upper half of the TRL scale: a growing need for effective experimentation at relevant system levels, especially at TRLs 5–7. To fulfill this necessity, I argue that we need to build large-scale experimentation platforms, and I describe a method: an iterative, process-oriented stepwise-integration model. In so doing, I also highlight the operational importance of distinct perspectives offered by disciplines, professions, institutions, contexts, and scales, in complex dynamic systems.

1.2 A Decades-Long Exploration of Potential Futures: Examples from Europe

About 10–20 years ago, there was a surge in pioneering science and technologies. These took the form of pilot projects studying the relations between technological innovation, business models and strategy in the private sector, and public policies – the well-known triple helix approach [32]. The Lisbon Strategy, a document adopted at the European Council in March 2000 in Lisbon (a historic city that spearhead the European Age of Discovery 600 years ago), proposed a vision for the twenty-first century, where the EU would become by 2010 "the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion." This was driven by the Schumpeterian idea of transformative innovation led by science and entrepreneurship. (See [33, 34] on Joseph Schumpeter's theory about innovation and the related notions of "bioeconomy" and "ecological economics' pioneered by his student, Nicolas Georgescu-Roegen.) Although most of the technical objectives of this vision were not attained by 2010 (the economic turbulences following the 2008–2010 financial crisis did not help either), its aspirations pervaded Europe and elicited a new European spirit of experimentation which continued with “Europe 2020,” an RDI funding strategy that pursued “smart, sustainable, inclusive growth,” and the “European Green Deal” [35], a broader EU strategy focused on sustainability transitions and related crisis management. Experimentation is also explicit in the “New European Bauhaus” (NEB), a program dedicated to building public traction for sustainability transitions: “Change will not happen from one day to another. The New European Bauhaus will create the space to explore and test policy, funding and other tools for designing and building a better everyday life for all generations.” This expresses “the EU’s ambition of creating beautiful, sustainable, and inclusive places, products and ways of living ... (especially in) construction, furniture, fashion and (...) daily life” [36].

On the Upside of This EU Dynamics, a Big Wave of Bottom-Up Industry-University Initiatives Developed Across Europe Much of it was directly concerned with environmental and social issues of our society (in addition to the economic issues that were always present, especially in the aftermath of the financial crisis started in 2007–2008). Many of those initiatives also benefitted from or were elicited through the top-down funding programs by the European Commission, some of the most well-known being the Research Framework Programs FP6 (2002–2006) [37] and FP7 (2007–2013) [38], which, in order to facilitate lab-to-market processes, asked for a strong participation of small- and medium-sized enterprises (SMEs) and (since 2014) the use of TRLs in the funded research projects [31, 39–41]. They also included a type of projects called “Network of Excellence” (NoE), which saw participation from at least six countries (three EU member countries required) and the Joint Technology Initiatives (JTIs) in partnership with industry.

Another major development is the European Institute of Innovation and Technology (EIT), officially established in 2008 [42], and its first three “Knowledge and Innovation Communities” (KICs, established in 2010), namely, Climate KIC [43], InnoEnergy [44], and EIT Digital [45], which were followed more recently by similar networks for food, health, raw materials, manufacturing, and urban mobility. On behalf of the University of Versailles (UVSQ), I participated in the initial internal work organization of climate KIC, which was an opportunity to compare it with works in our own eco-innovation cluster in the Paris Region (details in Sect. 3.2).

A typical manifestation of this European innovation Zeitgeist was also the first and second European Innovation Conventions organized by the EC on 5–6 December 2011 and 10–11 March 2014 in Brussels [46]. Alongside other 2000 people, I attended each of these events, I welcomed the priority given to learning from the entrepreneurial experience coming from the USA, and I enjoyed the related technology exhibition. I also attended the World Summit of Regions for Climate, 10–11 October 2014, in Paris, France, which was focused on the involvement of cities and regions in the 2015 Paris Climate Agreement, and I witnessed intense EU-USA convergences (see also [47–49] and Sect. 3.2).

On the Downside, Such Top-Down Programs Also Had a Big Bureaucratic Burden They have been criticized for being so complicated as to hurt science itself and fundamentally undermine industrial and economic competitiveness of the EU [50]. The idea is that state actors (governments and intergovernmental organizations) can and should act as catalyzers but then let society/people take ownership and drive the process, precisely because knowledge is distributed (not centralized) and the existence of common interests is not equal to "one size fits all." Governmental overreach causes exponentially growing complications, with a double negative result: bureaucratic burden and administrative inefficiency. In democratic countries, public administration rests on (1) the fundamental principle called "the consent of the governed" which first appeared in the European cultural space during a long historical process, is adopted in the second paragraph of the US' Declaration of Independence ("... Governments are instituted among Men, deriving their just powers from the consent of the governed"), and is stated in Article 21 of the UN's 1948 Universal Declaration of Human Rights ("The will of the people shall be the basis of the authority of government") and (2) on the "whole-of-government" approach: functional coordination across public administration departments [51].

These being said, the EC did meet with professionals and collected feedback for post- FP7 improvements, for example, at roundtables organized in Brussels by Science|Business (a network of leading universities and companies [52]) in which I participated as institutional contact. The following FP, Horizon 2020, was indeed less bureaucratic than the previous FPs [53], although far from perfect. But there is yet another major issue: the very low application success rates (ca. 1/10) is unfair and represents a discouraging result-per-effort balance for many excellent-but-rejected projects. Consequently, most well-qualified applicants see EU funding as a lottery and rationally prefer to ignore it. Worse, this situation created an entire "industry" of consulting and paper-filling intermediation that (1) diverts resources away from real RDI and (2) keeps many of the best and brightest minds away – exactly when society needs RDI the most. In the vocabulary of investment economics, these funding schemes have excessive opportunity costs for the intended beneficiaries and a low/diminishing public return of investment (ROI).

In Horizon 2020, the EC also began promoting "open access" to scientific publications, which (as of October 2022) is still a promising idea and an ongoing experiment with yet-uncertain effects on how science works and how it relates to society. Interestingly, the US President has just endorsed open access for all scientific publications of research [54] – another point of convergence between the USA and the EU.

Other Initiatives Since the Year 2000 Were Funded Through National Programs Three examples have been chosen here (because I was involved in those and can testify based on my own experience): the German program FONA (short for "Forschung fur Nachhaltichkeit," that is, "research for sustainability") [55], the

French program PRES ("Pôles de Recherche et d'Enseignement Supérieur") seeking to develop large research and education clusters [56], and the Romanian CEEX ("Cercetare de Excelență") program promoting research excellence – infrastructure, people, and complex projects [57].

Numerous bilateral institutional initiatives between countries were also commonplace and boosted peer-to-peer relations, for example, the Swiss-Romanian environmental research program ESTROM, 2005–2008 [58], the Romanian-French series of conferences "University in Society" (UNISO) where the concept of "brain networking" was first proposed and debated [59–61], and the efforts by the above-mentioned German FONA program to reach out and connect with RDI actors across Europe, a process strongly energized by the conference "Sustainable Neighbourhood – from Lisbon to Leipzig through Research (L2L)" 8–10 May 2007, during the German Presidency of the European Council [62–64] in Leipzig, a symbol city for German and European reunifications, and the "Innovation Union" flagship initiative of Horizon 2020 [65].

This Tide of Enthusiasm Followed, and Has Built Upon, the Success of Previous European Arrangements and Academic Exchanges Students and teachers benefitted from the *Erasmus Program* (since 1987; *Erasmus Plus* since 2014) and the *Socrates Program* (since 1994; then *Erasmus II* between 1999 and 2007, and the *Lifelong Learning Program* since 2007), plus numerous bilateral exchange agreements. As a master student of Alexandru Ioan Cuza University (UAIC) in the historic city of Jassy (Iași), Romania, I benefited from an Erasmus studentship at the University of Groningen, the Netherlands (February–July 2000). As an undergraduate at UAIC, I received a bilateral university exchange studentship (and the support of dedicated teachers) and attended a four-week summer school at the Aristotle University of Thessaloniki, in Greece (1997). Across the EU, there are tens of thousands of such examples of personal development opportunities, which remind us that there is a grassroots dynamics of reunification of Europe after the fall of communism in Central Europe (eastern EU). It is also important to remember that this period overlapped with the emergence of the Internet as a popular medium of exchanges in the late 1990s, which catalyzed interaction between people and institutions, and generated some complex dynamics that were later on described as "brain drain" (massive emigration of the highly skilled). Internet is also how, like my entire generation, I have found research opportunities and earned my PhD at the Technical University Munich (TUM) in a German cluster focused on technology prototype developments (semiautonomous biosensors for field screening of pollutants [66]). Internet is also how my generation reconnected back across geographies: distance collaborations with home and other countries. In other words, mission-driven expert networks (like the EIT's KICs themselves) are de facto applications of "brain networking" thinking, but its advantages for universities and RDI are far from being fully used [61, 67, 68].

Since recently, the idea of networks of experts advising policy development in real-time is embodied by the European Scientific Advisory Board on Climate

Change, even though this appears to be more a compromise between the need to rely on the wider community of experts and the outdated tendency of public institutions to rely on a small number of expert advisors (in this case, only 15) [69]. At national levels, expert networking initiatives have a longer history and are closely related to RDI clusters. For example, in France, this included the establishment of numerous industrial chairs (at least compared to the previous periods), that is, public-private partnerships (PPPs) with 50:50 financial contributions that aimed at stimulating innovation and collateral research and business through crossovers between academic and business sectors. In Germany, this idea was already being used in the Fraunhofer Gesellschaft, a network of institutes covering topics from miniaturization technology to solar energy and the sociocultural aspects of bilateral cooperation between nations [70–73]. In Romania, the concept of problem solving-oriented “brain networks” was picked up by the country’s Academy of Medical Sciences [74, 75] and by the Working Group for Climate Changes, an international group of 40+ scientists and administrators convened by the President of Romania to propose an integrated set of national policy measures that would use current science and technology to address current challenges (a first report of this group was launched in public debate on 8 September 2022) [76].

All these social, institutional, and cultural developments are nevertheless accompanied by the fundamental economic interest of having a united economic block (EU and EU-US partners), the development of which I had the privilege to witness at all scales (person, city, country, continent) and which partly motivated my interest in sustainable development and the management of innovation. In 1997, I first saw Euro banknote and coin designs shown in the civic center of Thessaloniki and enthusiastic Greek citizens seeing them. In 2002, TUM started paying my salary in Euros instead of Deutschmarks, and I heard German citizens worry about economy. In 2007, I saw my country Romania surfing on a tide of greenfield foreign domestic investments (FDI) that generated a powerful economic convergence with Western EU: according to Eurostat [77], its GDP in purchasing power standard (PPS) climbed from 26% of the EU average in 2000 to ca. 76% (expected) in 2022 (on average 2.3% per year, the fastest in Central Europe).

But these kinds of positive aspects call for intelligent uses of knowledge to advance private and public interests by stimulating convergent dynamics (rather than giving in to myopic fragmentation) while also protecting the progresses achieved so far.

1.3 Between Pasts and Futures

The crossovers and networking evoked here, together with the naturally interactive characters of science and business, have created a formidable potential, which, to date, remains largely unmaterialized. This has been recognized in professional conversations across Europe, including the already mentioned first European Innovation Conference – an event which undertook to address this issue at the highest policy and business level. Given the ambition of Europe to lead developments in sustainability as encapsulated in the policy goals like the European Green Deal, the transposition of research into effective solutions remains a great and growing necessity. Indeed, this takes the logic of TRL to a whole new level. Be it in Europe, North America, or elsewhere, the challenge is much more than developing a top-level spaceship technology (the original purpose of the TRL framework at NASA): it is about transforming entire socioeconomic systems.

Since decades, stakeholders and experts continue to agree that in order to deal with the complexity and challenges of profound change, individual technological advances are not enough: a systems-level approach is needed, starting with fundamental sectors like energy, infrastructure, water, and raw materials. So we talk about an already-old problem, but with more urgency and with the conditional benefit of more knowledge that has accumulated and now awaits being effectively integrated and put to use. A lingering problem is that, unlike the USA, where science finds its way easier into business, Europe appears to be stuck in a period that is characterized by an imbalance between science and business [52].

In terms of technology readiness levels, this can be described as an immense volume of work being already done at TRLs 1–5, but not nearly as much at TRLs 5–7. However, local underachievement in TRLs 1–5 can be turned around as a lower-cost environment for boosting TRLs 5–9. Such a strategy would amount to "smart specialization". (This is yet another and complementary European venue of policy experimentation, one that is integrated in the EU's reformed cohesion policy for 2014–2020 aiming at stimulating economic dynamics by local action [29, 78, 79].) This implies using local peculiarities to gain competitive advantage and thus attract resources for future "smart diversification" [80–82]. If well conceived and executed, such a TRL-based strategy (and national policy) comes as a logical (smart) solution for those EU countries that are now suffering from the effects of chronic underfunding of scientific research: any country running a stable coherent program with projects focused on TRLs 5–7 would naturally attract both private investments (domestic and foreign) and experts from their diaspora – converting brain drain into brain networking as evoked in the previous subsection [61, 67]. Within the EU, all else being equal, this competition will be won by those nations that can start with the greatest relative cost advantage and have the largest skilled diasporas (and this will be beneficial for the EU as a whole).

2 Transformative Projects Must Braid Science and Business

2.1 How to Achieve Systemic Change While Avoiding System Failures?

Unsurprisingly, actors from the sectors of energy production and distribution emerged as leaders and facilitators of the conversations between science and business, promptly warning (again, since decades) that change must be obtained in ways that do not disrupt the daily necessary system-level functions [3, 49, 83]. This means that (a) real-life operations must inform the process of development-experimentation and vice versa, and (b) ad hoc decisions that are only based on a superficial understanding of a situation (which may look familiar to specialists but are actually embedded in broader system dynamics) should not be presumed "harmless" at whole system scales (such presumptions can cause catastrophic consequences, from large-scale blackouts to various environmental, social, and economic losses, and the collapse of living standards) [4, 5, 84]. These being said, all scales of study/action are important, but ultimately the most consequential one is the scale of the project, as it collects all dynamics of interest toward a desired goal.

This is a major-but-usual challenge, because all projects tend to have latent disagreements on values and knowledge [85, 86]. One can illustrate with real life: public administration units around the world have designed and deployed a diversity of measures aiming at mitigation of and adaptation to climate change, only to realize belatedly that many of those department- or sector-driven measures were contradictory, with unexpected and mostly undesired effects that often cancel each other due to various systemic effects across scales [87]. One naturally wonders how "smart" were those solutions? In its sixth assessment report, the International Panel for Climate Change (IPCC; working group WGII, impacts, adaptation, and vulnerability, and WGIII, mitigation) points out an array of situations where mitigation and adaptation actions can be synergistic, antagonistic, or neutral to each other and to the global United Nation's Sustainable Development Goals (SDGs) [88–90]. Current assessments of effectiveness of climate change mitigation (and adaptation) are still based on the study of ex ante potentials. Because of the relative novelty of "climate actions" and the behavioral/cognitive biases summarized in the introduction (Sect. 1.1), the pressure of high expectations [91] can easily result in unwarranted and overly optimistic estimations – and usually it does [49].

The literature abounds with case studies and details, but such challenges boil down to one question: *How to achieve systemic change while avoiding system failures?* This chapter proposes an answer: through disciplined experimentation. However, the deeper question underlying it is *How to make it work (more than fail)?*

At this point, one can observe that we tend to expect that sustainable development will emerge as a new historical paradigm of human development. Still, no technology has yet emerged to be as profoundly transformative as the those that are usually thought of as defining various techno-economic paradigms or "industrial revolutions" [1, 7], and it is in fact not necessary that some particular technology comes to hallmark sustainability. Moreover, this "conspicuous absence" is not surprising for a simple reason: major events in RDI and business may not be easily detected as such while happening, and we are now living through a period of many innovations and changes. In this sense, all known historical techno-economic cycles can be understood through the lens of the theory of disruptive innovation [92, 93]. None of those revolutions was triggered by some glorious breakthroughs. Instead, certain ideas were retrospectively recognized as "very influential" ("central" or "key") – basically, just practice-driven solutions resulted from successive technical optimizations and socioeconomic changes that were dependent on an evolving context (identifiable eras).

This understanding has also been theorized in the multilevel framework of transition management [94]: new and less influential “niche” solutions (startup companies) compete for dominance, that is, a place in the “regime” of incumbents that cooperate based on a common interest to collectively determine the rules of competition (and often act to deliberately or inadvertently inhibit innovation) but also compete among themselves to become part of the quasi-immutable long-term features of the society (the general “landscape” in which everybody operates). Such metaphors serve to convey a general idea across disciplines and society but do not fulfill the operational needs of complex projects (unless they help to inspire experimentation arenas and networks) [94–96].

2.2 A Knowledge-Action Framework Model

While there is a broad agreement that new types of expertise are needed, it all starts with the ability to connect knowledge and action. The idea that modern life is embedded in a knowledge-based economy and society has become a commonplace, but achieving integration of fast-advancing knowledge (usually specialized) and connecting it with real-life action (usually holistic) remains a first-rank challenge. Figure 2 synthesizes this reality. Further, Fig. 3 places knowledge integration in the context of RDI and shows the critical role that experimentation plays along the process of development of technological solutions (products and/or services) as reflected by the TRL framework [30, 31] along the S-curve model of technology maturation [1, 92].

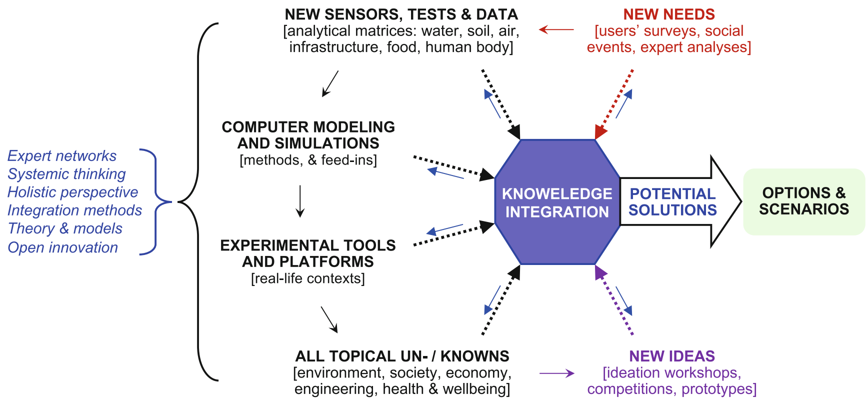

Fig. 2 General representation of the process around knowledge integration toward potential solutions as depicted by the upper TRLs and then options and scenarios for sustainable cities and societies. (Modified after [86])

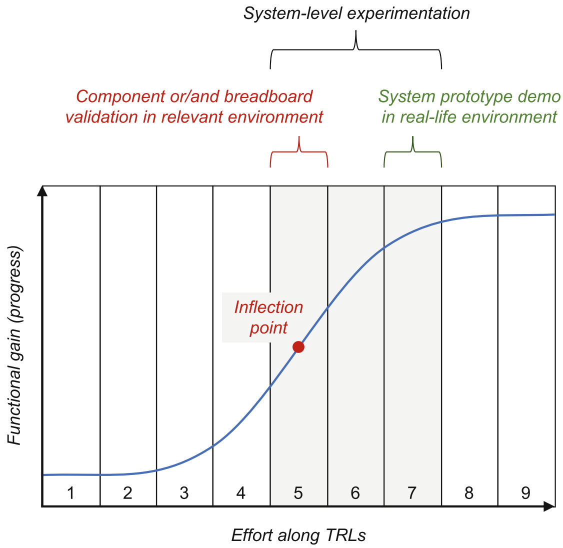

Fig. 3 The key role of systemic experimentation along the idealized S-curve model of technology maturation superimposed on the known nine technology readiness levels. The inflection point is the target of the earlier stages of development and the basis for committing resources to the later stages

In a minimal sense, experimentation only refers to the system-level experimentation captured by TRLs 5–7. Experimentation platforms are explicitly needed for this definition. In a maximal (complete) sense, experimentation involves the entire process (TRLs 1–9).

Given all difficulties related to pioneer and large projects and their root causes, from the semantic, methodologic, and historic-cultural fragmentations to the spread of expertise across contexts, I locate this discussion within the knowledge-action model called DIKAR_*process* (Fig. 4), which was developed based on experience in transdisciplinary projects and the extant literature [86], and I propose that all large and complex projects can substantially increase success rates and ROIs by following a logic of experimentation and disciplined project management as described in this model.

In a narrow sense of the term, experimentation involves only the direct generation, test, and deployment of potential solutions. In a wide sense, experimentation involves the entire in-project work process connecting scientific research and real life. This full set of roles and relations are captured here by iterative cycles within a lattice that combines the DIKAR framework in information science with the steps of problem solving in project management. Each step, depicted as a vertex ("box") in the 12 series, constitutes a "negotiation room," that is, a moment in the process when participants "sit together" to test shared understanding and agree on terminology, objectives, and methods, so that the latent disagreements evoked in Sect. 2.1 are being identified and addressed early on [85, 86] and collaboratively identify gaps, define their space of options, and articulate action scenarios. Thus, the model is a practice-borne universal project organizer, a logical tool for what has been called "fail-safe experimentation" toward sustainability [97].

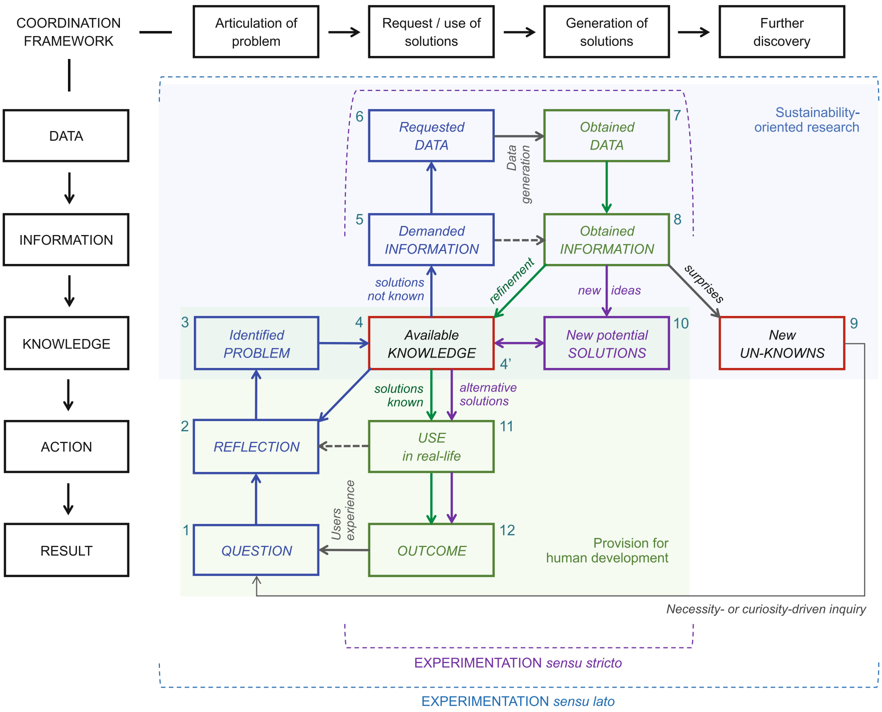

Fig. 4 Proposed understanding of experimentation (as per TRLs 5–7) within a general knowledge-action model ("DIKAR_*process*") for generating new, eco-innovative solutions. (Modified after [86])

3 Discussions

3.1 Further Insights from the Literature on Test and Experimentation Platforms

A particularly interesting trend observable in practice and the literature is the notion of living laboratory (or living lab), which is a user-centered research approach. This term had gained a certain notoriety, arguably under the influence of the popularity of other concepts connecting science and business, like "open innovation" and "product (or service) customization." While certain advantages are obvious, notably the stimulation of crossovers, this approach leaves some basic problems unaddressed, notably the issue of knowledge fragmentation. In fact, in fields directly related to knowledge organization itself, commercial breakthroughs were determined by inputs dealing not with the subjectivity of end users but with how knowledge is generated in knowledge communities (not the least because, in this case, end users rarely are the main contributor) [98].

The model in Fig. 4 above can help make the right distinctions by mapping these relations within the general process and thus assist in making good use of living labs: the notion of living lab is covered by the pink arrows between vertices {4′;11;12}, but the content of those relations is much more dependent on neighboring vertices (and the whole dynamics) than what that implies; for instance, user inputs are determinant for initiating the reflection process that leads to problem articulation, but an efficient articulation of the problem is only possible by mobilizing existing knowledge, and then the generation of potential solutions is based on a research cycle that, once the problem has been defined, is independent from the end user – until these alternative (potential) solutions are being tested in real life and users can say something about the outcome of old and new solutions in their life. Without the visual support (and the intrinsic logic) of the DIKAR_*process* model, this dynamic would be rather hard to grasp.

Other experiences show that political and institutional barriers tend to be obstacles to the adoption of living labs for nature-based solutions (NBS) for improving urban resilience with respect to climate changes, while knowledge brokers, various kinds of intermediaries, and cross-sectoral collaborations tend to facilitate their adoption [99]. In fact, such intermediaries can facilitate all these cross-sectoral cognitive and operational interactions and are wanted by policy makers because they are seen as boosters of eco-innovation "ecosystems," notably through functions like "knowledge creation and diffusion," "guidance of the search," "entrepreneurial experimentation," "market formation," "development of positive externalities," "legitimation," and "resource mobilization" [100]. The model above helps explain this empirical finding: intermediaries simply fulfill the function of information finding and processing by trial and error – but that does not mean that any set of intermediaries that happens to be around is efficient (or even justifiable) in terms of allocations and management of scarce resources.

In a Broad Perspective on Systemic Transitions, Cities Have a Particular Role to Play Cities have a natural capacity to connect local and global scales, because every city is simultaneously (a) embedded in its local biophysical and socioeconomic context and (b) a participant in the global network of cities from which it derives opportunities and value [3, 7, 27, 101–103]. From a system analytics perspective, a city is sufficiently large to be representative for human systems (in their complexity) but also small enough to make system-level project management possible and to allow (in projects or daily life) for a small-world effect, that is, high concentration of disparate elements coming in close contact, thus occasioning productive "shortcuts" (in the overall fluxes of people, information, and materials). This enables a city to be both a development engine for its hinterlands [104] and a unique participant in wider regional-to-global arenas [101, 105].

Especially with regard to climate and environmental changes, cities tend to demonstrate a great sense of agency and capacity to experiment, readily questioning national inertia or "one-size-fits-all" measures, because local communities are more impacted by (hence more sensitive to) situations and events occurring in their life environments and immediate hinterlands [103, 106, 107]. Universities have a particularly important role in these local dynamics, particularly in the countries from eastern half of the EU where the hopes and hardships of the transition from command to market economy overlapped a lot with the transition to sustainable development [102, 108–116].

In a nutshell, cities are "places where things happen" and represent the ideal scale for the systemic experimentation for the transition to sustainability [7, 27, 102], but they also require a conscious effort to protect that beneficial "fluid" network dynamics between cities against the rigid approaches of local/national network administrators [103]. Ignorance of complex network dynamics, or feelings of being overwhelmed, may lead administrators to inadvertently seek excessive control, which is the very antithesis of experimentation. The DIKAR_*process* model above suggests that cities are places where (through which) the full process {1; ...;12} can happen efficiently enough and thus represent a best unit for systemic analysis and action on the path toward smart and sustainable societies.

3.2 Insights from Past Projects

One Pioneering Project in Which I Participated Was Econoving This was a science-business cluster (2010–2013), aimed at developing solutions and scenarios for re-developing Versailles-Chantiers (VC), a main railway station in the City of Versailles [3, 86]. Its main challenge was the organization of interaction between universities (and research institutes) in the region of Paris (University of Versailles Saint-Quentin-en-Yvelines (UVSQ), University of Paris 11, Ecole Centrale Paris (ECP), SUPELEC), private companies (main partners, ALSTOM Grid, GDF SUEZ (now ENGIE), SNCF, SAUR, and ITALCEMENTI Group, and numerous other partners in multiple sectors, from chemical appliances to financial intermediation), and governmental agencies, that is, the so-called triple-helix configuration, for the purpose of generating eco-innovation [3, 117].

The model in Fig. 4 emerged directly from that experience, as the author hereby was the director of the Econoving cluster's graduate program *International Professional Master Program in Management of Eco-Innovation*, where academic and business experts worked alongside students, with the double goal of reimagining the railway station (and eco-city) of the future and the development of the new types of skills and expertise that are needed for generating these new solutions [27]. This master program was the driving force in developing clarity on the big picture and helping all project participants (from graduate students to senior experts) understand that true systemic solutions (a) must, indeed, be as simple as possible to be efficient but (b) must also factor-in all effects (unexpected side and network effects too), starting with ecological footprints, social acceptance/acceptability, and economic viability as a prior condition for scenarios and operationalization.

A first lesson learned by all in the Econoving cluster concerned the scope of systemic solutions: once we looked at energy consumption and costs in the main building and infrastructure of the train station itself, the issue naturally extended to include the whole city neighborhood and the city itself. It quickly became clear that the station was not “just a place where you take the train” but a point of convergence of urban socioeconomic exchanges and life, a true node of multimodal communications. Aside from technical conclusions and reports, the central benefit of the project was about a community of experts moving up the learning curve: (a) developing and testing a modus operandi and (b) a set of generalizable insights and scenarios. Now, these can also serve as a start basis for the iterative use of the framework model summarized in Fig. 4.

The first (yearlong) part of the in-cluster foresight exercise has already followed the coordination framework logic of the DIKAR_*process* above and has led to this list of conclusions about the premises of this type of projects:

- It is very difficult to collect reliable, coherent information – indeed, a worldwide known challenge.
- Trans-sectorial understanding of a city is a heavy task, due to traditional divisions between disciplines (with different vocabularies and methods).
- New types of knowledge management are needed, which requires sustained effort and learning by all, to insure a productive set of common denominators.
- The historical heritage of the City of Versailles and the broader context of the Greater Paris region represented sources of both opportunities and challenges.
- Scenario sets (and methods) can address: technology choices, social acceptability, environmental concerns, costs, and risks.
- Higher spatial scales are more important than usually thought of: a train station can only function as embedded in its city context (and many details matter).

Based on these premises and the available knowledge (both in the form of expertise available in the Econoving cluster and network and in the form of available literature and insights from other projects), the second yearlong part of the forecasting exercise established three generalizable directions for the future. In the DIKAR_*process* model, these are broad categories describing the content coded by vertices {9;10;4′;11;12}:

(a) Urban renewal: Integrative planning for radical progress in VC as key activity hub within the City of Versailles (which is also the seat of Yvelines county).
(b) Urban resilience: Smart adaptation to and mitigation of climate changes in VC as driver of urban capacity to deal with disturbances.
(c) Urban technology: Integrative (systemic) solutions for augmenting the City of Versailles as a whole to the status of all-times international hub of innovation.

In addition to valuable technical results, the cluster also generated successful developments of startups, in some cases going from TRL 1 to TRL 9. This was facilitated (in its critical demonstration phase from TRL5 to TRL7) just by the existence of this VC hub of multimodal communications as a real-world test bed for new smart solution for optimizing energy uses (in domestic, public, and industrial settings) based on the NIALM (Non-Intrusive Appliance Load Monitoring) technology. By the end of the project, we already counted a European prize–winning enterprise with a growing network of clients [118, 119]. In contexts of high energy bills, this is a useful ready-to-use solution.

At the same time, VC served as a platform that generated new questions, which were then explored (from TRL 1 up) – notably on energy flow, viability, and cost models of different technologies/products/services in the train station. The project also generated a process of building system-level models and scenarios of urban sustainability and highlighted the importance of cities as experimentation units and of the organization of knowledge in knowledge-action models that were then refined in follow-up projects.

Insights from these works converge with the broader literature on innovation management and show that experimentation plays a critical role in the development of technologies, especially at the front end of eco-innovation when "product parameters are still flexible" [120] (or, as per Fig. 4, when new ways are still "alternative solutions," that is, modifiable in interaction with the users, before becoming "known solutions"). More broadly, the idea above closes the loop with decades-old signals about the imperative of building versatility into our energy and urban systems [3, 83, 102]. Today, geopolitics show again that indulging in long-term "blindness" for the sake of short-term ease logically leads to a rude awakening. The DIKAR_*process* explains and addresses this reality and supports efficient mobilization of knowledge across "brain networks."

Another Project Provided Complementary Experience: The EIT's Climate KIC There, the main challenge was the organization of the interactions across a network of experts and institutional partners (universities/research institutes and private companies) scattered across several European countries: France, Germany, Switzerland, the Netherlands, and the UK. The "easy-to-say, hard-to-do" solution was finding operational common denominators across institutional, sectoral, and national-cultural contexts.

But a most important insight is perhaps the fact that in both Econoving and Climate KIC, the challenges of bringing partners on the same page were truly formidable at the beginning (as centrifugal forces appeared unstoppable). However, each project had an education program at the core and that proved to be the axis around which discussions kept going and the source of the first successes on which later works could gather and build. And, in both cases, the key to that success was coherent knowledge reorganization based on direct conversations between involved experts and stakeholders.

Climate KIC was also a supplementary learning opportunity at hand. My students participated in its main action: an intensive six-week graduate summer school called "the Journey!," a joint program covering at least three country contexts, fully funded by the EIT. (And I participated in planning, teaching, and management.) Its philosophy was similar to that of the Econoving master program with two differences: ours dug deeper into problems and technicalities (which included but was not limited to climate) while EIT's expanded horizons across Europe (and prioritized climate). This experience (1) enabled us new tests for relevant hypotheses, (2) obliged me to regard the multidimensional RDI space of options as a stand-alone problem to solve (which led me to develop the above model), and (3) confronted RDI dynamics in clusters-by-design vs. networks-by-design: the Econoving cluster grasped better the local community/cities, while Climate KIC was better placed for testing solutions for general use (with some conditions). This observation suggests a strategy of complementarity: initiating smart city projects by a local cluster of experts structuring a target city/problem (disciplined iterations of the model above), as a solid start basis for subsequent high-value interactions across international networks. On the contrary, generating broader (commodifiable) solutions for a smart society would require first an efficient network to distill the core specifications of a minimal product/service, and then its further development (for high market value) can benefit from the work capacity of large innovation clusters.

Also Interesting for Institutional Experimentation Is the EU's "Erasmus Mundus" Since 2004, this funding scheme provided scholarships for students in master programs involving three or more EU countries (or, since 2009, associated partner countries from around the world), with students spending at least two semesters at locations other than the institution than enrolled them. In 2011–2012, I had been solicited and I developed an initial concept based on the experience we already had at Econoving and Climate KIC, but soon I had to prioritize all resources to existing programs instead. Still, those initial works provided some insights into a growing human resource in Europe: generations of networked experts to be mobilized through disciplined experimentation [121–123]. The literature provides interesting insights on opportunities and challenges, for example, "uneasy belonging in the (student) mobility capsule" vs. the "super-mobile student" [124, 125], digital libraries [126], and smart and sustainable university campuses.

Some Other Projects Helped Me to Distill Experiences into Formal/Abstract Models Beginning with 2014, INTRAS (Institute of Innovation for Transition to Sustainability), an RDI start-up (private enterprise of public utility or "fonds de dotation," enabled by a new French policy of administrative flexibility toward innovation as inspired by classic endowment funds of American universities), focused on "big picture" modeling of the unique experience and (yet unprocessed information) from Econoving. The latter had ended in 2013, but its insights have been picked up (as intended) by SNCF and used in a new, state-led PPP of urban regeneration (2014–2019). While at INTRAS, we physically visited and we analyzed a series of urban regeneration projects in the Paris region, and we compared them with our works in Versailles, using the conceptual lenses given by the field of knowledge organization (KO) [98]. One was the experimental smart eco-district of Fort d'Issy inaugurated in 2013 (first in France; 1620 high-end apartments and common (utilities) infrastructures inside the former ruins of a military fortification abandoned after the Franco-Prussian war of 1870–1871) in Issy-les-Moulineaux near Paris and Versailles [127–129]. Another was SenseCity, an experimental research platform dedicated to the development of smart sensor networks in a university campus ("Descartes") in Marne-la-Vallée, an eastern suburb of Paris [130, 131]). In this triangle, SenseCity was the most academic and a source of technical questions linked with (a) my prior experience and the latest literature on sensor prototypes, sensor networks, and environmental analytical strategies and (b) other technical, systemic, and managerial questions from Econoving. Our basic approach was to add all those pieces together and solve the pile as an "eco-city puzzle" according to the principles of scientific modeling and knowledge organization. In it, DIKAR_*process* above first helped us to develop a set of other models (see below) and then included them as part of its knowledge vertex.

This triangle of projects helped us distill a problem solving-oriented theoretical core: success/failure is closely tied to having/lacking more explicit-but-versatile operational representations of the problem of interest. This led to the conclusion that this kind of work requires a commitment to persistent experimentation with conceptual/mathematical models being tested against ever broader experiences. For us, this resulted in a new general type of urban metabolism model called Eco-City Reference Model (ECRM), a multistep knowledge aggregator for tailoring holistic eco-city projects. This uses the systems' perspective on sustainability [7, 115, 132, 133] and a map of topics (obtained by combining empirical and literature insights with bibliometric and graph analyses) called urban sustainability nexus (USN), in which complex interdependencies between priority topics (security, demographics, buildings, climate changes, waste, health, leisure, and food) constitute a crown of issues that are gravitating around an even more central core of interdependent topics (landscape, water, energy, and transport) [7, 134–137]. Then, a daughter project (an Internet platform concept) called Interactive Knowledge Maps for Brain Networking (IKM-BN) emerged and is currently being developed for the general community of users in science, education, business, and policy [67, 68].

In terms of urban system complexity, the VC project in Versailles stayed "unbeaten": a modern multimodal transportation hub with a huge diversity of urban functions. For example, the electricity grid in Fort d'Issy eco-district included mainly residential consumption [129] while VC requirements covered industrial, commercial, and residential aspects related to the train station itself (which then served 50,000 passengers per day and growing) and the surrounding urban districts, including potentialities for onsite renewable energy sources [138, 139–141], electrical cars [142, 143], and the railway network per se [144]. By the time IssyGrid started to require technological updates, VC was in the midst of an urban renewal program that affected the entire city (e.g., it became a major hub for now-reorganized bus networks, a strong commercial and business center). By 2019, VC was the main transportation hub in the western part of the Paris region and a national eco−/smart renewal showcase for train stations and for cities.

The Formulation in Fig. 4 Was Speeded Up by Yet Another Project: ACE-ICSEN This project (2017–2020, UVSQ, CEARC) was a typical example of holistic endeavors where the number of variables of interest increases exponentially (with the number of questions asked) and quickly touches an "invisible ceiling" of feasibility. The model formulation shown in this book chapter is a direct response to the practical question "How to connect extremely different topical work packages of a complex project?" Specifically, it addressed the need for transdisciplinary methods in a so-called transversal work package (WP-TR) that was meant to link knowledge and action in three topical WPs that addressed a set of problems (characterizing the transition to sustainability) that were very different but were known to occur simultaneously: biodiversity loss at local and regional scales (WP1), health impacts of air and water pollution (WP2), and impacts of short-lived pollutants on climate change scenarios (WP3). Thus, the model is both as an example of and a means for problem structuring [85, 115, 145].

3.3 *Mapping Specific Issues and Experiences with RDI in Smart City Projects*

Here I locate project activities according to both TRL and DIKAR_*process* (Table 1) and discuss a few issues to help visualize the interactions and draw additional insights.

One Aspect Is the Social Learning That Happens Naturally Inside a Running Project This is a natural resource for formal education programs and the development of human capital in general. In the Econoving cluster, the two fortunately overlapped because (1) many teachers in the master program were also experts in the cluster's industrial component and in the train station program (all industry partners contributed teaching) and (2) all students participated directly in the cluster's train station program. The master program's module called "Integration Seminar" counted (by design and strategy) as activity in the project's Work Package WP3-Anticipation (see Sect. 3.2). Also, most students found internships with the cluster's main partners or network of collaborators. We also carried out cross-deliberations between this master program and one dedicated to architects ("Construction durable et éco-quartier"/sustainable construction and eco-districts) jointly organized by UVSQ and ENSAV (Ecole Nationale d'Architecture de Versailles). The overall experience of all participants in this pioneering project featured many issues that were known from existing expertise and literature on cultural theory (related to social learning) [149] and project management (related to cognitive and behavioral biases) [17; Sect. 1.1] but which "had to" be learned by doing, as summarized during an end-of-project meeting by one main partner (citing from memory): "it is only now, after three years, that we really learned how to work with each other."

Another Is a Fundamental Need of Strategic Data Acquisition This is true for RDI in general and for "data-driven business analytics" [150, 151] in particular. The latter is coded by the second half (vertices 7–12) of the model circuit and should be managed in the integrative context of the full model. This would help current data-driven approaches [152, 153] gain a useful sight on problems, that is, become operationally "smarter".

Concretely, the so-called knowledge discovery (inferring basic patterns from large amounts of data) was not applicable in VC because data did not exist or was not easily available. In fact, even the basic information (with any degree of

Table 1 A general taxonomy of activity types in university-business projects (PPPs), generated as a Cartesian product of technology readiness levels (TRLs) and the steps of the DIKAR_*process* model of project management

			TRLs								
			Basic science (principles)	Technology concept or application formulated	Analytical /functional proof of concept	Component validation in the laboratory	Component validation in a relevant context	Subsystem /prototype demo in relevant context	System /prototype demo in target context	System completed and qualified by test & demo	System proven through successful operation
			1	2	3	4	5	6	7	8	9
DIKAR _*process* steps	1	Question	A11	A21	A31	A41	A51, B51	A61, B61	A71, B71	B81	B91
	2	Reflection	A12	A22	A32	A42	A52, B52	A62, B62	A72, B72	B82	B92
	3	Identified problem	A13	A23	A33	A43	A53, B53	A63, B63	A73, B73	B83	B93
	4	Available knowledge	A14	A24	A34	A44	A54, B54	A64, B64	A74, B74	B84	B94
	5	Demanded information	A15	A25	A35	A45	A55, B55	A65, B65	A75, B75	B85	B95
	6	Requested data	A16	A26	A36	A46	A56, B56	A66, B66	A76, B76	B86	B96
	7	Obtained data	A17	A27	A37	A47	A57, B57	A67, B67	A77, B77	B87	B97
	8	Obtained information	A18	A28	A38	A48	A58, B58	A68, B68	A78, B78	B88	B98

	9	New unknowns	A19	A29	A39	A49	A59, B59	A69, B69	A79, B79	B89	B99
	10	New potential solutions	A110	A210	A310	A410	A510, B510	A610, B610	A710, B710	B810	B910
	4’	New/updated knowledge	A14’	A24’	A34’	A44’	A54’, B54’	A64’, B64’	A74’, B74’	B84’	B94’
	11	Use in real life	A111	A211	A311	A411	A511, B511	A611, B611	A711, B711	B811	B911
	12	Outcome (of each action)	A112	A212	A312	A412	A512, B512	A612, B612	A712, B712	B812	B912
Actions in a medium-size train station: Versailles Chantiers	*A. Academic-led activities, along these themes:* • Project writing (constitution of initial set of participants in an eco-innovation cluster/PPP: 6 universities +6 private companies); development of human capital and further networking: An international master program (fully dedicated to the management of eco-innovation – The first of the kind worldwide) as central collaboration point for the cluster; and participation in international professional networks, notably the European Institute of Technology’s Climate KIC and the elite universities-businesses network Science|Business [3, 116] • Research: Diagnosis of energy performance of the train station, including the use of and refining market solutions (new algorithms) based on NIALM technology [146, 147], energy modeling of the train station [140] and the exploration of complex engineered systems/smart grids [138, 139, 141], and the use of EV batteries plugged into the grid in 24 h patterns [142] • Development of scenarios for the redevelopment of the VC train station and its neighborhood (city district) *B. Business-led activities:* • Wide-scale real-life development of the public project for refurbishing VC and remaking the VC: Details available online, by the City of Versailles [148]										

reliability) was hard to come by (unavailable/lost original plans of the building, various later modifications, legal issues related to information sharing, and technical issues and costs of generating large new data). Consequently, the initial project objective, which was the generation of an energy model of VC based on an array of sensors (the number of which had to be predefined-budgeted in the early stages of the project), has stumbled because those sensors were too few (only 100), were later discovered to be located rather suboptimally, and were non-relocatable (all that in spite of people doing their best in the initial planning phases of the project – activities A51 to B74 in Table 1). In this situation, the foresight exercise (one among the project's work packages) redoubled efforts, gathered every bit of information available anywhere, and succeeded in providing SNCF with work options for the urban regeneration program that was carried out afterward.

This case study also illustrates the earlier-mentioned need to find the right interplay between RDI clusters and networks according to purpose: general use solutions (e.g., NIALM) and/or localities (e.g., VC). On the one hand, the aim of this foresight exercise concerned a locality: to find a best possible minimal set of realistic scenarios/potential futures for the train station in its urban context, that is, district, the City of Versailles, and the Greater Paris Region (especially within its Grand Paris program of development of communications) [154, 155], the country, and the EU. On the other hand, the purpose of the company deploying a given technology was to gain market shares anywhere, so it used the Econoving project as a platform for experimenting better solutions for meeting general market demands (e.g., monitoring/optimization of electricity consumption or a replicable train station model). The generated competing/complementary scenarios were critiqued and improved in weekly, monthly, and yearly cycles by mixed teams. Other topics included inter alia energy fluxes [139], complex engineered systems and smart microgrids [138, 139, 141], and time optimization of electrical vehicle uses [142].

The Method Also Entails some Risks to Be Accepted and Addressed as Appropriate Notably, the method requires a high-and-constant level of reflexivity and dedicated resources. By the way, the model is also relevant for robotic process automation (RPA) tools, within known limitations: task repetitiveness normally correlates inversely with project complexity and high context dependency of unsupervised/supervised choices in machine learning (ML).

The experience from the projects evoked in this book chapter suggests that some people will quickly grasp the method (especially if they have already practiced disciplined experimentation) and most will understand its logic after due explanation but will not use it unless two conditions are met (each, being potentially sufficient). Firstly, the project needs to be designed with this logic in mind from the beginning; otherwise there will be too many centrifugal "business-as-usual" forces and the project will switch on "automated pilot" (based on previous lowest common denominators). Here, I contend that given the high stakes of complex projects and the fact that the model emerged from practice, designing a project (or program or policy) with this model in mind is not too much to ask. To put it differently, the model is already distilled as a product of "human-executed RPA" so to speak. Secondly, a small team must be assigned from the start for interfacing all project participants according to the framework model described here. At a minimum, this can be just the project manager. For example, I did it in the Econoving cluster and master by resolving on the spot (thinking on the go) the paired operational requirements of Structured Problem Resolution x DIKAR (the model axes in Fig. 4), using a simple two-dimensional managerial mental model structured as a 5 × 4 matrix, that is, $Spot\ Model = \{\mathcal{M}_{i,j}\}$, $i = \{Data, Information, Knowledge, Action, Result\}$, $j = \{Problem, SolutionDemand/Use, SolutionGeneration, FurtherDiscovery\}$. But in projects above a certain size, the manager needs dedicated support to fill and manage the content of model components. This team must not add on top of existing structures (this would result in administrative conflicts and clutter); instead, it would be part of it from the beginning. Its role would not be to centralize knowledge (except for some very specific issues) but to insure workflow efficiency across relevant knowledge networks.

Retrospectively, I noticed that, in its logic, the basic mental model behind the more detailed DIKAR_*process* is convergent with the 3D Smart Grid Architecture Model (SGAM) co-developed by the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunication Standards Institute (ETSI) in response to the standardization mandate M/490 by the European Commission [156, 157]. Essentially, the DIKAR_*process* model is complementary to SGAM and informs its "interoperability dimension" (with five layers from business to physical components) and/or vice versa: SGAM can organize content details of the projects that are structured according to DIKAR_*process*, for example, to generate eco-innovation for energy transition and/or to address current energy-security-climate/sustainability challenges. Similarly, the model can help interactions between the domains of NIST smart grid concepts by the USA's National Institute of Standards and Technology [158]. In all cases, the taxonomy in Table 1 can serve as a map and operational connector for superior work efficiency and versatility.

Another Common Highlight Is the Need of Digital Systems for Efficient Operations To materialize the proposed model's potential for assuring and testing project validity and for aiding all managerial decisions, a project must not involve (substantial) "paper work". If that is not possible, my own and others' experiences suggest that the project manager(s) will soon have to choose to either "stay and fight" (if there is something worth fighting for and if winning appears to be possible) or quit (i.e., accept the sunken costs and render her/his skills and capacities available for a new and better conceived project). This also applies to public administrations: effectiveness of policies and programs for smart and sustainable society is in fact conditioned by digitalization. Otherwise, nice visions will remain costly exercises in "public relations" or worse: systematic failure will leave a trail of public distrust and social conflicts that will exacerbate crises.

The Model Can Also Help Experts Sort Out the Security-Energy-Climate Conundrum In the context of the Russia-Ukraine conflict, the European Commissioner for research and innovation launched a public debate on Horizon Europe, to see "if we are still doing the right things and if our priorities are still the relevant ones" [159]. To such purposes, DIKAR_*process* can operationally codify virtually all other concepts, approaches, and methods, starting with the multi-level model of transition management [160] and the problem of uncoordinated climate/energy/other policies between scales [87] (Sect. 2.1). In a study comparing smart city developments in Amsterdam (Netherlands), Hamburg (Germany), and Lingbo (China), Raven et al. [161] show tables which exemplify exactly the kinds of work outcomes that I envisioned for the negotiation rooms in the model. They also observe that PPPs are at the heart of meaningful urban experimentation, and cities can lead. For instance, Amsterdam adopted PPP because private funding was needed in their urban projects during the 2008–2010 financial crisis. Similarly, the unique (UNESCO) patrimony of Versailles is not an obstacle but an asset – if relevant expertise is mobilized. Cities that reinvent themselves as eco-cities [102] can play the inspirational role that Glasgow and London played in the first industrial revolution. At larger scales, the model can support, for example, the New European Interoperability Framework (EIF) seeking "seamless services and data flows" for European public administrations and their modernization through "eGovernment solutions" [162].

The Method Could Also Apply to Analyze and Reuse Results from Past Mission-Oriented Projects, for Example, those Focused on Non-/Formal Environmental Education (EE) To date, I have good feedbacks from a past project funded through the EU's *Leonardo da Vinci Community Vocational Training Action Programme* (2006–2008), which was led from a pilot center at UAIC in Romania; involved a network of experts from historic cities in Germany, France, Spain, and other EU countries; and made important first steps toward a European Curriculum for EE and education for sustainable development (ESD) [107, 114, 163–165]). And this is just one example among intellectual resources spreading out across Europe and worldwide, which can be used and extended by cycles of expert reconnection that would also muster other RDI and education capacities [114].

4 Conclusion

The joint crises of today grew from past collective complacencies, which is yet another reason why they should not be wasted. However, competent action requires preparation. Given the overwhelming volumes of scientific outputs and heterogeneity of technological state of the art, the challenge we face is not a lack of specialized expertise but a lack of successful integration of available knowledge in novel solutions that are compatible with a sustainable development and are resource- and time-efficient. In this book chapter, I made the case that now, more than ever, we need to develop large-scale platforms for disciplined experimentation at system scales, and I proposed a method whereby any type and size of relevant professional experience called into a project can be described by 1-*n* iterations of graph sub-/components representing steps, paths, and cycles of the co-work process. The method relies on classifying project activities along the joint lines of project management dynamics and technology readiness levels, with the ultimate goal of obtaining the best trade-off between efficiency and versatility in any given work context (and, ideally, professional equanimity for project managers). Technically, any user of this model can exercise coding her/his own experiences (as briefly illustrated with the details shown in this book chapter) as iterative paths in the mathematical graph represented by the proposed model. Those who are familiar with category theory and graph analysis can see additional uses of the model, for example, by comparing path length and centrality of different types of activity, so as to identify gaps, prioritize tasks, and decide resource allocations or as a general framework for different other methods. This intrinsic versatility allows this model to serve as a common coder of actions and courses of action. In principle, the model also informs and can guide workflow automation and robotic process automation, via either software or users (or both, as interface).

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Protecting Organizations from Cyber Attacks: An Implemented Solution Based on CyberArk

J. M. Pinheiro and P. Carvalho

1 Introduction

As the world is becoming more and more connected, so do the threats of malicious attackers rise, attempting to gain access to information that is, and should be, confidential. These attackers focus on gaining access to privileged accounts, commonly designated as administrator accounts, and moving laterally within a company's infrastructure [11, 12, 18]. BMW (Bavarian Motor Works) is aware of these threats, and that is how this project was initiated.

Considering PAM solutions, there are many solutions available, namely CyberArk, One Identity SafeGuard, and ARCON PAM. However, since they come as a password vault for basic operating systems, they need further improvements to make them a possible choice for production work. Improvements such as creating a connection between the solution and software used by the companies, for example, an RMB (Remote Management Board). Since these improvements are an addition to the solution offered by the specified vendors, tests need to be developed to assure a working state [1, 3, 8, 17, 18, 22].

As mentioned, the way companies handle accounts is not able to withstand the attacks of malicious individuals, causing confidential information to be released to these untrusted parties, designated as a data breach. These occurrences have a very negative impact on societies' perception of the affected company, possibly reducing sales, losing market value, or even major lawsuits against them [11, 18, 19, 21]. These attacks also affect users, compromising their accounts and their

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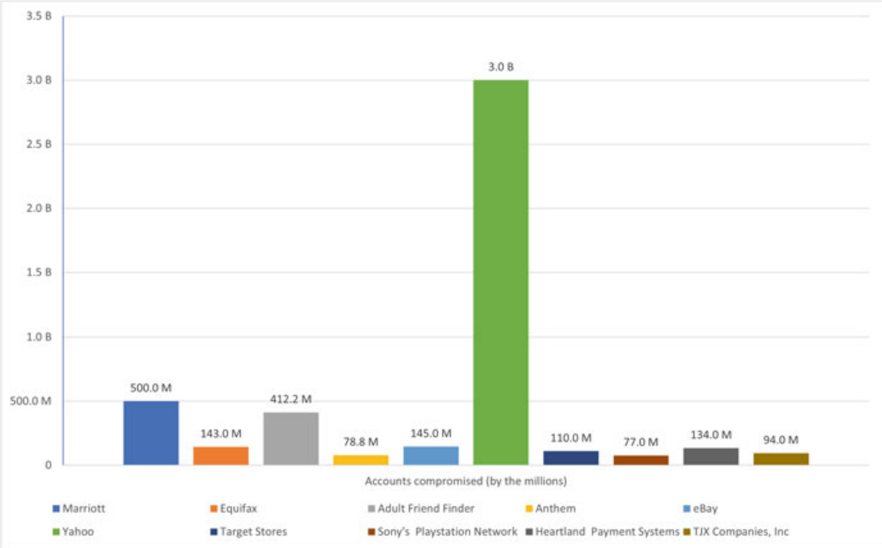

Fig. 1 Accounts compromised on the biggest data breaches of the twenty-first century [10]

personal information, as shown in Fig. 1, Accounts compromised on the biggest data breaches of the twenty-first century. After these breaches, the users, even if not affected, lose trust in these companies and decide not to use the companies' product anymore [10, 18]. EBay is one of the companies that is visible in Fig. 1, Accounts compromised on the biggest data breaches of the twenty-first century. EBay's data breach compromised the information of 146 million users, which led to the company urging users to change their passwords. As a result, eBay experienced a decrease in user activity that quarter [9, 10].

This attack was performed by using employees' log-in credentials, to gain access to rights the outsiders do not have permission to access, allowing them to move freely inside the organization's infrastructure and retrieving the customer's confidential information. The attackers had completed inside access for 229 days, which shows how dangerous and hard to track these attacks with privileged accounts are [9, 18, 19]. The financial information of the customers was securely encrypted and stored on a different network, and the breach was detected before the attackers could gain access to this information. Had those attackers gained access to this information, it would mean eBay had released 145 million customers' worth of financial information [9].

Due to these dangers, organizations are under immense pressure to remove attackers that have managed to breach their infrastructure, and "I think this pressure complicates the already considerable challenge of confidently drawing a box around what was compromised and confirming the attacker's access and influence has been eliminated, making sure they will not return." [9]. Peterson alludes to the fact that, even when a breach is detected, it is a very hard task to understand the reach of the breach, which was previously evidenced on the eBay breach, where attackers had complete access for 229 days after the breach was detected.

The purpose of this work is to transition BMW's privileged accounts into the CyberArk platform. Due to the scale of the organization, this work focuses on two specific improvements to the CyberArk platform. The first improvement that this project documents is the automation of tests for the platform: improvement that is in place to make evident the functionalities/limitations of the platform. These tests are not testing the work that was developed by the internal team but the work developed by CyberArk and should show the development team what can be leveraged later. This does not mean that development work is not tested. The opposite is very much the case since, according to the DoD (Definition of Done), development work is only accepted as complete when there are tests in place that state it works as intended. The second improvement that is realized in this project is the creation of different connection components that CyberArk does not natively support. BMW as a company uses many different technologies to manage their work, such as Windows, Oracle SQL developer, RMB's, just to name some. From the previously named technologies, only Windows is natively supported by BMW, so there is a need to create these connection components to connect to the other technologies, allowing all the BMW employees to connect to their respective workstation through CyberArk, isolating them from their privileged accounts, and as a result making a malicious attacker's job harder. To use this solution, employees need to connect to their software of use, making this a crucial improvement to the initiative, taking up most of the development teams' time [22, 23].

The automated tests are developed using java, and mainly focus on using Selenium for web-based tests, and API (Application Programming Interface) calls for API tests. The tests are fully automated, using Cucumber as the framework to automate these tests. Cucumber is supported natively by Jira and Xray, where the Gherkin, language used by Cucumber, is placed. These tests are created whenever the development team wants to test the functionality of a specific CyberArk utility. In terms of connection components, CyberArk allows developers to create and deploy universal components that can be used on the teams CyberArk environment. They also have multiple connection components available on the marketplace that do not come by default with CyberArk. The deployment of custom connection components is documented in CyberArk's documentation and requires the team to create the component itself, using AutoIt, the coding language that is advised by CyberArk, and the one the team is using currently. After this component is created, it should be placed in the components folder that exists within the PSM (Privileged Session Manager). The PSM is the server that allows CyberArk to initiate, monitor and record the privileged sessions, as well as the usage of administrative tools. When the new component is placed in its proper folder, the developer must adapt the AppLocker to tell CyberArk the new component is trusted and can be used. After the AppLocker configuration is done, now the developer needs to enter the PVWA (Password Vault Web Access–CyberArk's Web Interface) and configure CyberArk to use the newly added configuration component [22–24].

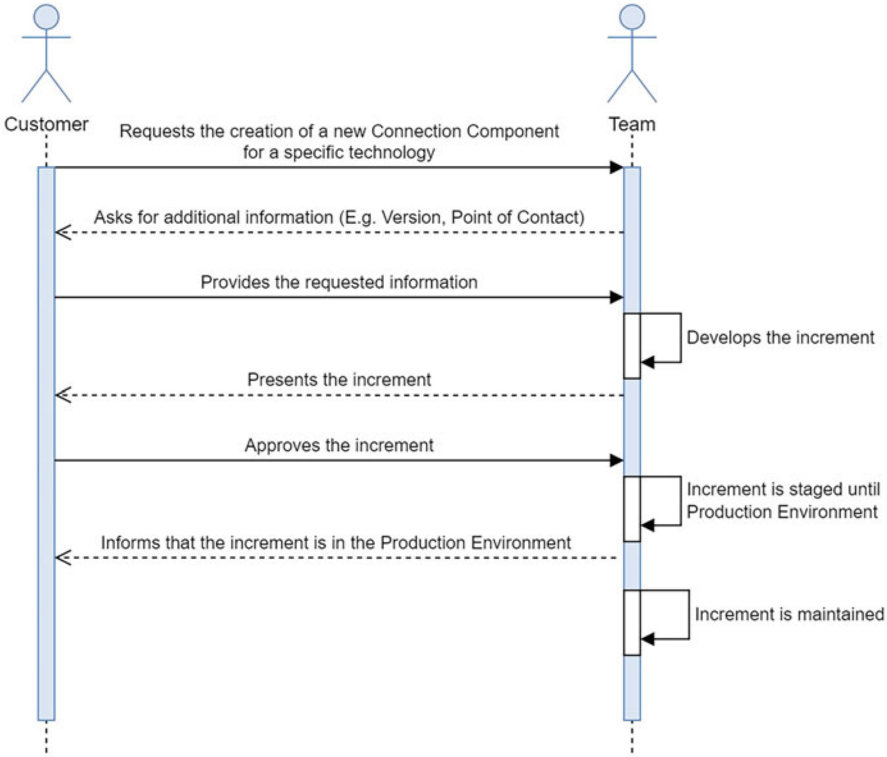

Fig. 2 Diagram of a possible request process

With this process in mind, the development team needs to create a process where BMW infrastructure team members can contact them and request the creation of these connection components. Figure 2 represents the diagram of a suggested request process, where the customer would contact the development team with information required to complete the development. Once the development is complete, the team reaches out to the customer to get the approval on the increment, staging it to the production environment afterward. Once the increment reaches the production environment, the customer is informed and the development team maintains the increment healthy.

2 State of the Art

Most of the research done in this field of security focuses on the importance of securing privileged accounts, as well as the risks involved with not properly securing those accounts. The research available on implementation solutions is very limited, especially when it comes to technical implementations and the best practices for securing these accounts. This research investigates a PAM (privileged access management) solution implemented in a corporate scenario, the benefits and difficulties of such an implementation, and the additions that were necessary for such a solution to work [12, 17, 18, 20, 21].

Protecting privileged accounts and actively responding to potential breaches have become a vital initiative for many corporations. Stolen credentials are the main avenue that attackers use when performing their attacks and breaches, and privileged accounts are the most sought-after accounts when it comes to breaching an enterprise. Compromise a system administrator and an attacker would rule over a companies' system and all connected applications and devices [15–17, 19–21].

However, privileged accounts are not limited to administration accounts. Often executives possess highly sensitive information within their own devices, and these accounts are also target for these attackers, as they would have access to confidential company secrets. These executives are often not tech-savvy, which leads to poor quality of the passwords they use, making them vulnerable to malicious attackers. Even worse, they might not realize that they are being targeted [15, 16, 18–21].

The most straight forward answer to vulnerable privileged accounts is to downgrade their permissions. However, as mentioned above, privileged accounts are much more than accounts that can cause system damage. Companies need a solution where all their secrets and privileged administration accounts are safely stored and monitored. Here is where privileged access management tools such as CyberArk and BeyondTrust are involved. These solutions add a security layer between the users and the privileged accounts that they access [13–16, 19, 20].

Both solutions offer enterprises with a mechanism to safely store privileged accounts and monitor their usage. The solutions operate in similar fashion, utilizing proxy servers as a connection point to target systems, to detach users from the targets systems, and monitoring the actions that users perform on these servers. The secrets are also stored in a secure vault server that injects the credentials when requested, however the communication between the components is where these solutions differ. BeyondTrust's components all communicate between each other, and the secret injection is done by the vault via API requests [13, 17, 21].

In contrast, CyberArk's vault is isolated and outside the domain of the enterprise, only being accessible on premise, or via a remote management board, and only able to communicate with other components via its own proprietary port. The other components themselves only communicate with the vault, as the vault is the center of all actions that occur in CyberArk, as shown in Fig. 3 [14].

Figure 4 depicts a sample connection executed by a user, and the steps performed by CyberArk to provide the protected session. Initially, the user connects to the PVWA, which is the web graphical interface where he can select which privileged account and target systems he wishes to connect to. Afterward, the user is provided with an RDP file, which allows him to establish a connection to his selected target application [24, 25].

This process is seamless to the user, as he is already connected to the selected target application; however, there are some steps behind the scenes that CyberArk

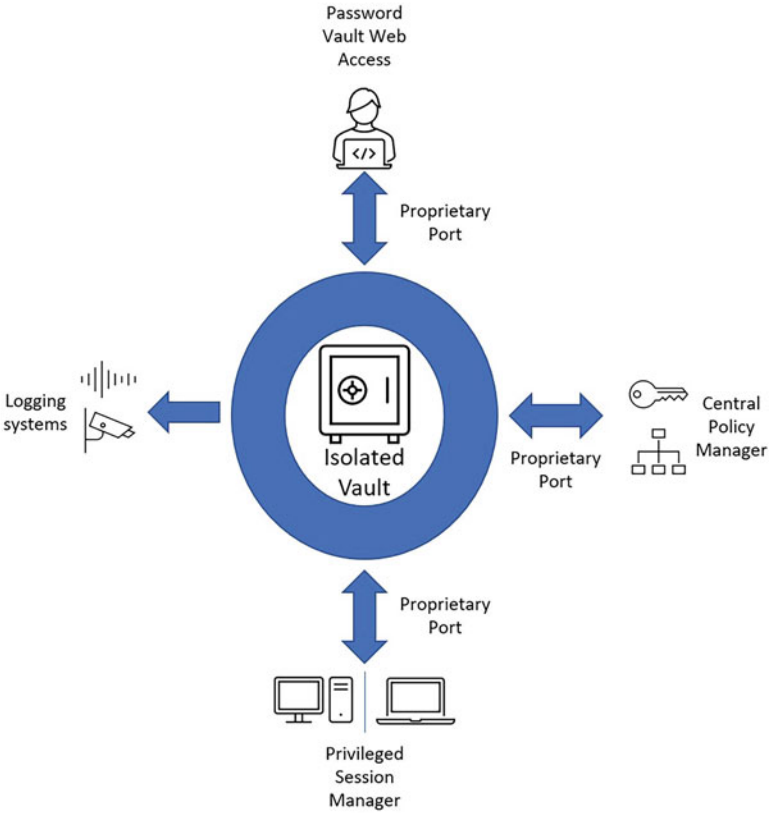

Fig. 3 CyberArk **v**ault as the center of all actions [14]

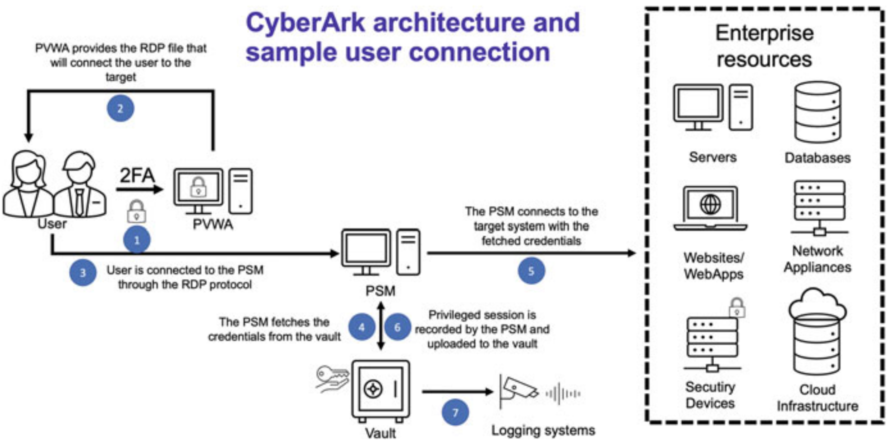

Fig. 4 CyberArk architecture and sample user connection [14]

must perform to ensure a protected session. When the user executes the RDP file in step 3, the PSM, which is the server that is running the selected application and functioning as a jump server, fetches the credential secrets from the Vault. With the credential information, the PSM is able to authenticate to the target system and provide the application process id to the Vault, ensuring that the customer only has access to the selected application and not to the entire system. All these steps are recorded by the PSM and uploaded to the Vault server, which is then integrated with BMW's proprietary monitoring solution [14, 23, 24].

This added layer of security is what caused BMW (Bavarian Motor Works) to select CyberArk as its privileged access management solution, as its features answered the companies' needs for secure usage of privileged accounts. This chapter delves into extensions developed to enhance the direct connection feature offered by CyberArk, as only a few applications are supported by the vendor.

3 Solution Description

For the purposes of this chapter, the version of CyberArk currently used by BMW is version 11.1, having the default installation alongside with the companies' rules. CyberArk itself already restricts access and power that each server component has, however having the companies GPO (Group Policy Objects) and rules restrict the components even more, making it harder for developers to perform work on these servers. Due to these issues, there is no local environment that can be used as test, which is why the test environment is used. This leads to difficulties replicating the productive environment, which causes the test environment to not behave as expected. After a feature is tested using the test environment, it will be implemented in the integration environment, which is an environment that closely resembles the production environment. In this environment, the real capabilities of the added feature can be tested, as well as the efficiency.

All the previously mentioned environments are separate. The test environment consists of servers that are only used in that environment, as is the integration and the production. The servers vary depending on the environment, with the test environment having significantly less servers at its disposal, and the production environment having most of the servers, since it is the crucial environment, and requires the highest up-time and consistency.

3.1 Existing Connection Components

Since the environments come with the base version of CyberArk installed, this also entails some connection components that CyberArk supports by default. This section presents some of these connection components, as well as their uses, and enhances the purpose of this work and why there was a business need to create more connection components for other applications. Along with presenting the connection components that are integrated by default with CyberArk, this section also explains how each connection component works and analyses of the upsides and downsides of each. These connection components are used to access the environments where the BMW employees perform their work. This asserts a higher level of security, along with tracking the actions each employee takes. It also makes it harder for outsiders to damage the company's information, since multiple steps for authentication must be performed.

SSH Protocol The first connection that CyberArk allows by default is the SSH Protocol connection. This protocol is also referred to as Secure Shell and is a method that allows secure remote login from one computer to another, protecting the communications between them with strong encryption [2]. The SSH connection allows a user to access the target server, with the protocol's dependencies, and having full access to the server, independently of the purpose the login was made with. Since the user would have one account to login, this account would be used to perform the actions the user needs. These actions cannot be tracked since the user has access to the entire server, after the server's rules are in place [4]. This solution is feasible for a user that must perform generic actions to the server itself, for example, a server administrator; however, when considering any other employee, this user does not need access to the entire server to perform his work [4].

Considering the protocol behavior, below are some upsides to the usage of the SSH Protocol connection component:

- It gives server administrators the access they need to perform their work, with the traceability the company requires.
- The tools within the server are usable, which gives users the access to their respective tools.
- Different accounts per target server allow for the application of the least privilege principle, while also minimizing lateral movement.

Some downsides to the usage of the SSH Protocol connection component are present below:

- Most users have access to tools/controls they do not require.
- Users can retrieve information that is not relevant for their work.
- Giving unrestricted access is a security breach that cannot be allowed in the company.

RDP CyberArk also has RDP as a default connection component. It works similarly to the previously mentioned SSH Protocol; however, it provides the user with a graphical interface version of the target computer. This connection is made over a network connection, allowing a user access to have total control over the target computer [7]. This connection is preferred for users such as a server administrator, since these would have access to all the required components on the target server, however, when thinking of a database user, he does not need to have access to the entire server to perform his database actions. The goal for the latter user would be to have a connection directly to the database application, and this is also the goal on the auditing side. This solution gives more traceability and removes the possibility for users to cause harm to the companies, since they only have access to the resources, they require to perform their work [4].

Considering the protocol behavior, below are some upsides to the usage of the RDP connection component:

- Gives server administrators the access they need to perform their work, with the traceability the company requires.
- Allows access to local windows administrative accounts, as a last line of defense in case all other avenues of connection get compromised.
- Different accounts per target server allow for the application of the least privilege principle, while also minimizing lateral movement.

Some downsides to the usage of the RDP connection component are present below.

- Difficult to regulate access on target systems.
- Malicious users can attempt to exploit the operating system's vulnerabilities, with the intent to move laterally in the domain.
- Giving unrestricted access to the server's software/services increases the vectors that can be exploited.
- Not possible to log inputs directly to the monitoring database.

SQL-Plus SQL-Plus is an application used by database administrators to manage BMW's database information. This application is already available by default with the current CyberArk version and is integrated in all environments [5]. SQL Plus is the application's supported Oracle database management application. This connection is the preferred solution for the initiative since it isolates the server from the application. Using this connection, the user only has access to the database he selected, and not the server where this application was started. This means that the user has access to all the tools necessary to perform his work, while not having access to any of the server's information. This is an improvement to the previous connections, the SSH and the RDP connections [5]. The SQL-Plus connection component initiates the SQL-Plus application, with the account selected in the PVWA, with the address defined in that account as the target address. This means that only one database connection can be open at a time (in the same application). Improvements to this issue are currently under discussion; however, CyberArk does not support multiple database connections at once.

Below are some upsides to the usage of the SQL-Plus connection component:

- It gives database administrators the access to the required databases.
- The tools are isolated from the server.
- Full traceability of all actions performed on the application.

Some downsides to the usage of the SQL-Plus connection component are present below:

- Only one connection can be made at a time, which changes the usual workflow for the database admins. These users are accustomed to opening connections to all the known databases and swapping addresses within one singular application.
- Not intended for complex/multi-line queries, as SQL-Plus is used for simple single line queries.

Toad Similarly, to SQL-Plus, Toad is a tool that allows its user to manage the corporations' databases. This application is also integrated by CyberArk; however, it does not work with the configurations made on BMW's servers. Due to this reason, the team had to make some changes to have this connection component operational [6]. Like the former, this method of work is the preferred solution for the initiative since it isolates the server from the application, which means the user only has access to the information present in the application and not any other internal information that does not relate to his line of duty. The Toad connection component initiates the Toad application, with the account selected in the PVWA, with the address defined in that account as the target address. This means that only one database connection can be open at a time (in the same application). Improvements to this issue are currently under discussion; however, CyberArk does not support multiple database connections at once. This connection component was changed to have a secondary RDP connection that would connect to the application. This is not the native application that the users desire; however, the connection was not working properly due to an RDP issue.

The issue was caused by a known RDP dependency, where the execution that is occurring within the RDP window stops whenever this window loses focus. This meant that when users would change to another window to perform other actions while the connection component loads, as sending an e-mail, the connection script would stop execution, since the focus was lost. This was fixed by having another RDP window encapsulate the Toad application.

Below are some upsides to the usage of the Toad connection component:

- It gives database administrators the access to the required databases.
- The tools are isolated from the server.
- Full traceability of all actions performed on the application.
- Query sheet allows for the creation of more complex queries.

Some downsides to the usage of the Toad connection component are present below.

- Only one connection can be made at a time, which changes the usual workflow for the database admins. These users are accustomed to opening connections to all the known databases and swapping addresses within one singular application.
- The connection component opens an RDP window to the application, which is not the native application that the Oracle users are accustomed to.

Table 1 Connection components current state

Product	Integrated by CyberArk	Required improvement	Developed by team
SSH	✓		
RDP	✓		
SQL-Plus	✓	✓	
Toad	✓	✓	
SQL-Dev			✓
OEM			✓
RMB			✓

3.2 Current State after Development

As mentioned on the previous section, some of the connection component had to be altered to be usable by the clients. This adaptation is the objective of this initiative and the focal point of this report.

This section presents a summary of the previous section, with a table that shows which connection components are integrated by CyberArk, which had to be updated to work on BMW's infrastructure and which had to be completely developed from scratch.

In Table 1, it is visible that even the components that were available through the base version of CyberArk encountered issues when attempting to on-board them into BMW's infrastructure. These applications required some further investigation made by the development team on possible ways to integrate them with the current environment and even improve some details on how the connection is performed. Even though this still has not forced a connection component to be created from scratch, a lot of the base process of the script had to be re-imagined. Are also illustrated, some connection components that the team developed from scratch, either because there was no product available on CyberArk or the marketplace, such as the OEM (Oracle Enterprise Manager) and the RMB, or because the request made by the client had some specific details that could not be answered by the components available, for example, SQL-Developer and RMB connection components.

4 Implementation

The team releases a working product on a two-week-based sprint rotation, which is planned just before the sprint begins. This product is based on a sprint goal, and the team follows this goal to deliver the best iteration possible. This sprint rotation also gives an overview of the developed work, which is the reason this section displays the implementation description using a sprint-by-sprint basis. Each subsection contains information regarding the sprint's goal, along with the product(s) increment(s) that was developed during that time box. The sprint separation also

Table 2 Sprint timeline

Sprint	Start date	End date	Goal
1	4th of March	18th of March	Automate the bank auditor test
2	18th of March	1st of April	Creation of procedures that stakeholders would follow to request a connection component
3	1st of April	15th of April	Creation of a roll-out procedure Preparation for the creation of connection components
4	15th of April	29th of April	OEM connection component creation
5	29th of April	13th of May	Creation of the RMB configuration file
6	13th of May	27th of May	Creation of the RMB connection component

Fig. 5 Sprint 1 timeline

Fig. 6 Sprint 2 timeline

Fig. 7 Sprint 3 timeline

Fig. 8 Sprint 4 timeline

gives a complete view over the issues found within the development and how they were resolved (see Table 2).

After each sprint section there is a timeline graph, Figs. 5, 6, 7, 8, 9 and 10, to depict the work that was performed during that sprint.

Fig. 9 Sprint 5 timeline

Fig. 10 Sprint 6 timeline

Sprint 1 This sprint's goal was to automate manual tests found in the Jira test repository. This chapter focuses on the test that automates the verification of user permissions, namely, the bank auditor. The bank auditor is a user that only has access to specific safes, determined by the safe's name. For auditing reasons, there is a need to create tests that confirm that a bank auditor cannot access safes that do not respect their safes' naming convention. Due to this, the first step was creating the minimal requirements to implement the test. Under this category fall creating a test user that mimics a bank auditor as a CyberArk local user and rewriting the manual test as a Cucumber test using Selenium.

This test would initially log into the PVWA using the test user and verify the user only had access to safes that match the bank auditor safes' naming convention. This proved to be insufficient since the user having access to a safe does not co-relate to him having access to that safes' recordings. Due to this impediment, the test was changed to check the auditor page for the safes the auditor can access. With this approach, Selenium would need to click each audit and verify what safe it corresponds to, which is not feasible for the current scale of the project since thousands of audits would need to be checked. To counteract this issue, an investigation of CyberArk's API was initiated, which came back with possible solutions.

The API can be leveraged to return a list of safes that correspond to the audit safe the user has access to: solution that proved to be more efficient than the previously designed one. The API required an authentication token that corresponds to the user's session key, therefore the API was also used to authenticate this user. The session key was returning a JSON file, JavaScript Object Notation, without any attributes, which made it difficult to process the response dynamically. To proceed, the response was directly stored in a variable, which would contain the session key. This variable needed to be treated, since the response came with extra quotation marks that had to be removed. After the session key was properly implemented, and the API call to retrieve the recordings was complete, it was evident that the API call did not return the safe the user has access to, instead showing the safe where the recordings are stored. To complement this issue, the recordings were stored in safe that was not respecting the naming convention. All recordings were being saved to a global safe, which is the default by CyberArk, making it impossible to filter what safes the auditor has access to. Due to this issue, recording configurations had to be changed, assigning a recording safe that respects the naming convention to all bank safes. With this change, it was possible to filter what safe recordings the user has access to. After this information was altered, the test would filter all the recording safes' names and verify they only belong to the bank auditor group, by using the safe naming conventions. This allows the test to assert the user can only audit bank safes and cannot access recordings from other safes. If the previous assertion is true, then the test would pass, failing otherwise.

Sprint 2 The goal for this sprint was to create procedures the stakeholders could follow when they required a connection component to be altered or created. These procedures are described in the solution design section of this chapter; however, this section displays the methods used, alongside the investigation that took place to create the procedures. The intent of these procedures is to facilitate the interaction between the development team and the stakeholder, by reducing the amount of meetings required to start the work process. This benefits the development team by speeding up the requirement gathering process, and it also benefits the stakeholder, since the reduced traction in gathering information leads to a smoother start and development. The first target of investigation was customer support solutions, namely, automated ones, as well as the requested minimum requirements necessary to start the support process. From this investigation surged the creation of a database that contains all the current on-boarded connection components, to automate the process for the stakeholder. Furthermore, the procedures that BMW already has in place were investigated to adjust the team's needs with what the stakeholder is accustomed to, namely, to request a server, such as windows or Linux, and to request the on-boarding of a new employee. Since the stakeholders would be other BMW employees, it was considered that they are aware of BMW procedures, therefore leveraging this seemed a plausible solution. This investigation resulted in the necessity to request the project ID (Identification number) of the requester, to understand their product needs for such request. This project ID can also be used to order the requests in terms of urgency.

Lastly, the necessary requirements to upgrade or develop a connection component were investigated. For this investigation, potential stakeholders were contacted with the intent of gathering the preferred ways of contact, which became e-mail in the short term, having the self-service portal as the end goal for all future requests. With the knowledge of previous work developed on the topic of connection components, it was decided that the product version, both current and requested to update, requested version for new connection components, and a test account would need to be provided as necessary requirements for the development.

After this draft was complete, the team held a meeting to discuss the minimum required information to create/update a connection component, from which resulted the final document that can be found in the Solution Description section, Sect. 3.1 Existing Connection Components.

Another topic worked on this sprint was the setup of a Jenkins server that would run the tests developed by the team. Some barriers rose due to the server being isolated within BMW's environment, not able to download dependencies from anywhere outside this environment. This was solved by re-configuring the proxy settings found in the Linux server. Once the Jenkins was up and running, hooks with bitbucket were set up, so the tests are run automatically on every merge from pull requests, to validate the functionality of the development that was merged. Plugins necessary to run the already developed automated tests were also installed, namely, Cucumber for Jenkins. With Jenkins and Bitbucket connected, the credentials used for the tests were added to Jenkins' credential database, and the Jenkins file was edited to use these credentials as environment variables.

Test accounts for all tests were created locally in CyberArk and the necessary BMW servers, namely, Jira and Bitbucket. Afterward, the feature files for the Cucumber tests were not being stored properly, causing issues when running the tests via Jenkins. Since the feature file is dynamically downloaded from Jira whenever Jenkins starts the execution of the tests, the folder that would contain this file did not exist, since Git deletes empty folders. This was causing an issue that was not directly spotted since there are different types of feature files, the ones located in the source code that are used for development testing and the ones outside the source code that would be downloaded into the folder and are used for automated testing. A dummy file was created to prevent Git from deleting the feature files folder.

Lastly, when the Jenkins configuration was complete, it was demonstrated and explained to the entire team.

Sprint 3 Sprint 3 focused on researching procedures that have to be followed by the development team. This report details the roll-out process of connection components, the discussion about new connection components that are necessary, and the code conventions that the team follows. To create the process for connection components, roll-out, an investigation of possible ways to roll-out the connection components was initiated. After a connection component is developed, it needs to be rolled-out into the multiple existing environments, and minimum requirements need to be met to start this process. Multiple BMW procedures that were already in place were investigated to create these requirements.

After the BMW procedures were investigated, the team focused on the roll-out method that CyberArk recommends. This is found in CyberArk's documentation, documenting the process that should be followed to roll-out a created connection component onto various CyberArk components. The team adapted this documentation, using it as a skeleton for future roll-out procedures. Each connection component has to be created, tested, and documented. Part of this document guides the stakeholder on how to rollout the connection component onto the necessary environments, as well as the changes that need to be made. This document is custom made for each connection component and is part of the acceptance criteria of each connection component user story.

The team had a meeting to discuss the requirements mentioned above, resulting in the final document, which can be found in the Solution Description section, in Sect. 3.1 Existing Connection Components.

During the sprint, the team had multiple meetings with possible stakeholders that required a connection component for their solution. The first stakeholder was the OEM (Oracle Enterprise Manager) database team, which requested that the OEM was integrated with CyberArk. CyberArk's environment was already configured with all the databases found in OEM, therefore only the OEM had to be integrated. The OEM team conducted a short demo, showing what their workflow was at the time of the meeting. OEM is based on a web application; therefore, the connection component would need to open a browser and navigate to the login page to authenticate the user. This would show the user the main screen where all the databases can be found. If the user decided to authenticate into a database, he would need to click on the specific database, which would require another authentication to that database. The team refined this request after the meeting, creating multiple user stories for this issue, namely the creation of the OEM Login, a form detector to detect when the database form is visible and the authentication to the previously mentioned database, when the form detector is triggered.

Another request was made by the administration team regarding the creation of a mRemoteNG connection component. The normal process of the stakeholder's work is making multiple RDP (Remote Desktop Protocol) connections to multiple servers, for which they use the tool mRemoteNG (multi-protocol remote connections manager). A presentation of the current usage of the PAM tool was made, to which they requested the integration of the tool mentioned above, to preserve their regular flow of work. This request was also refined, leading to some spikes to understand the feasibility of adding mRemoteNG to the environment, as well as how the integration would be made. Two topics that were discussed as possible solutions were the usage of the RDP Proxy, which would only affect the URL (Uniform Resource Locators) the stakeholder would use on his RDP connection or integrating the application onto CyberArk. Both solutions required more information, since the first would have great effect on the current structure, while the latter led to some concerns with how the user would keep his personal customizations on the application. The last issue developed within this Sprint was the creation of the AutoIt code convention. This was based on the conventions suggested by the AutoIt team and was adapted to fit the team's needs. Any AutoIt code present in a pull request has to follow these conventions, and it is the team's responsibility that this is the case. The document was reviewed and presented to the team.

Lastly, the team investigated linters to integrate onto Jenkins to speed up the review process; however, no linter met the team's requirements.

Sprint 4 This sprint's goal was the creation of connection components for the stakeholders that requested them in the previous sprint. This report highlights the work developed on the OEM login connection component, as well as the issues that arose with its configuration. Lastly, this connection component had to be tested, which was the team's first Robot Framework application. Initially, the AutoIt script was developed locally, navigating to a web page, the OEM address, and inputting the credentials of the user onto the login form. After the forms are populated, the script submits and performs the authentication. Furthermore, the script must be exported to the PSM, to use CyberArk's components, so it can be used as a connection component. The DLLs (Dynamic Link Library) provided by CyberArk for connection component creation were used, retrieving the credentials from a connection request and using these for the authentication. At this point, the script was tested locally on the PSM and was working as intended. The code was then formatted to respect the team's code conventions, and the script itself was complete. With the script complete, the team followed the roll-out procedures to allow CyberArk to use this new script as a connection component. For this, the PVWA had to be configured to accommodate for these changes. The on-boarding process was followed to on-board this connection component onto the test environment. The script was compiled with administration privileges; the hardening process was executed with the executable file's hash, so it is an allowed application.

The connection component was also created in the PVWA settings and associated with the correct platform, Oracle Enterprise Manager. After these steps were followed, the user has access to the new connection component, however, the application, Internet Explorer, was not starting whenever the script was executing. After investigation of the error events, they demonstrated the user did not have permission to execute Internet Explorer. The user that runs this application on the PSM is a user called shadow user, whose password is only available to CyberArk.

From the previous conclusions, the next step was to use the admin account to reset the local shadow user's password, to verify its permissions on the PSM server. All the permissions were correct, and he was able to successfully run the AutoIt script locally. Due to these discoveries, the error would need to be the AppLocker not considering Internet Explorer an allowed application. This assumption was correct, however, the error persisted. The new errors were investigated in CyberArk's error page to no avail; therefore, the event logs were verified. The event logs displayed some errors loading DLLs when the shadow user attempted to initialize Internet Explorer. Adding these DLLs to the allowed applications in the AppLocker file, and executing the hardening process fixed the errors, allowing the connection component to be executed successfully. The Internet Explorer itself was also hardened, with minimal customization, only a single tab available, and removing the ability for the user to change the URL. With the connection component complete and entirely integrated on the test environment, the tests were the next step to finish the user story.

The robot framework test used an API call to retrieve the RDP file that would use the OEM Login connection component. This RDP file was properly obtained; however, when executing the file, the test would wait until the entire execution would end. During the execution, a prompt would appear asking if the user would want to proceed with the connection to the end point, hence blocking the execution.

Since the test was being blocked, it was not possible to click connect to proceed. Multiple robot framework keywords were tested to run the RDP file, but to no avail. A command prompt keyword was also run to start the RDP connection but with similar outcomes. Since robot framework is based on python, functions created in python can be used in robot framework as a keyword. Due to this, a python script was created to run a command that executes the RDP file. Since this script did not wait for the execution to be over, the test was not paused and the button to connect could be interacted with, but it had to be dynamic, which led to the use of image recognition libraries. Image recognition library Sikuli was installed and used to click the connect button; however, it was unsuccessful. The connection keyboard shortcut was used to connect (Alt+n), however, an image recognition library was still necessary to assert the connection component executed properly. Multiple image recognition libraries were experimented with, the final choice being the Image Horizon robot framework library, that compared screenshots to assert the result was as expected. With the integration of the library, the test was complete and assertion was successful. The integration of this library also allowed the test to be dynamic, by waiting until an image appears on the screen to execute a step, removing hard coded waits. Lastly, the complete connection component and respective tests were demonstrated to the team, and a discussion on the next required steps to complete the OEM database issue took place.

Sprint 5 The goal for sprint 5 was to initiate the roll-out process for the connection components. To reach this sprint's goal, this report presents the work developed to create the RMB connection component, namely, the configuration file that will be used by it. Due to the design the team agreed on, a singular connection component needs to dynamically authenticate a user independently of what vendor the RMB belongs to. The authentication pages vary from vendor to vendor, therefore the team decided that having a configuration file, with all the information required to perform the authentication, is the best solution. The connection component needs to travel to the target address, a web page, and needs to retrieve the vendor that page is from. With this information, the configuration file is used to retrieve the form information relative to the specific vendor. The RMB configuration file layout was discussed, with the objective being a XML (Extensible Mark-up Language) file that allows the connection component to dynamically access the username and password fields of the RMB web login form. This configuration file was developed, displaying the username and password fields for each of the RMB versions/vendors. Most of the vendors' fields could be obtained by searching for a unique id, except for iDrac version 9 that could only be obtained by using the name parameter. The name parameter used is unique for all the iDrac version 9 iterations. Once the configuration file was finished, a robot framework test was created using the Selenium library to access each RMB's endpoint. This test initially retrieves the expected element from the XML configuration file and asserts that the attributes for each vendor is correct. Afterward, the test launches a browser that navigates to the vendor's endpoint and searches for the fields, username and password, configured in the XML file. The test does this for every vendor, asserting that the configuration file is properly storing each of the RMB's login properties.

After running the tests, only the HP RMB was failing. This issue was investigated and it was discovered that Selenium could not find the login properties since they were inside a frame. The Hp node was changed to contemplate this discovery, adding information regarding this frame, allowing the test to first navigate to the frame and then search for the login attributes, making the test a success. With the test finished, it was refactored to meet the team's code convention, and later presented to the team.

With the file configuration approved and closed, the next step of the sprint was to integrate the CCP (Central Credential Provider) with the previously created OEM connection component. The latter part of the OEM connection component that performs the login to a database will need to access credentials from other accounts on-boarded onto the CyberArk environment. To do this, CyberArk possesses a feature named CCP that allows an application, in this case a connection component executing on the PSM, to request access to an account. To use this feature, the application performs an API call requesting the credentials of an account, stored in a safe, that will be processed by a specific CCP instance. The API is authenticated using the operating system's credentials; therefore, it can only be performed by a server that is within CyberArk's components.

Based on the investigation results, to test the CCP, an application would need to perform the API call. To do this, a custom connection component was created to perform this experiment. The experiment output was successful; however, the output was a file that could not be used to retrieve login credentials. After further investigating the CCP configuration on the PVWA, it was detected that there were no trusted hosts configured. This was causing the API call to return an untrusted host error. Once the host that calls the API and the servers where the CCP is configured were properly setup as trusted, the application was able to return the account's information, including the credential that was required. While working on the OEM connection component that uses the CCP application, a bug on another feature was found. The team had previously developed a script that travels to an environment, namely to a specific component, retrieving the configuration files from that server. It does this for two different environments, for example, test and integration. Most of these files are either XML or in configuration. Once these files are retrieved from both the environments, the script would initiate the comparison section, comparing each file and outputting the differences between the files. The issue occurs with the comparison of XML files. The script checks each node individually, storing the nodes' names and comparing the parameter of each node with the respective node found in the other file.

When there were duplicated parents or nodes with attributes that were different, the script would fail to confirm the difference. Below is a replication of this error:

```
File 1
<Object Name="Server 1" System="Windows"/>
<Object Name="Server 2" System="Linux"/>
File 2
<Object Name="Server 1" System="Windows1"/>
<Object Name="Server 2" System="Linux1"/>
```

This example should return that the system attribute is different between the files; however, it would not output any error, since the script would only check if the node "Object" appeared twice, and that the name attribute is the same for each object. The fix that was issued was to use the entire Xpath of the XML nodes, since they are unique to the information that they contain. This makes it evident where the differences are, and the user is able to clearly navigate to the files and perform the necessary changes.

Sprint 6 This sprint's goal was to complete the creation of the RMB connection component requested in the previous sprint. This report highlights the work developed on the webpage identifier for the connection component, as well as the issues that arose with its development. Lastly, this connection component had to be tested, which was based on the previous Robot Framework application.

Initially, the AutoIt script was developed locally, navigating to a web page, the RMB address, but was blocked by a certificate error page. To bypass this, a function was created that would check if the page were a certificate error page, by checking the text that is found on the page. If this function is triggered, the script clicks the "Proceed to the next page (not recommended)" link, bypassing the error page and entering the target web page. This is not the intended workflow; however, to complete development with the current state of the RMBs, this was the approach taken. Once the certificate error was bypassed, the login page for the vendor would open. Since there are five different vendors, HP/Lenovo/iDrac7/iDrac8/iDrac9, and the connection component was designed to be dynamic and work with any vendor, it would need to retrieve which vendor the login form belongs to. To retrieve this information, the title of the page was used. On every vendor, the title would show the vendor's name, except for Lenovo that would not have a vendor name. Since there is only one exception, this method was valid. With this approach, the page would need to be loaded to retrieve the proper title. This causes issues when looking at previous connection components, where the load times were higher than normal, due to how the proxy communicates with the target system. This was mitigated by using an AutoIt function, IELoadWait, that waits until a page is loaded. It is only a mitigation because most of the webpages for the RMBs also have JS scripts running after the page is loaded, which causes changes to occur after the loading, for example, title changes. Even though this is an issue that impacts how the script acquires the page information, and the JS scripts execution vary between vendors and connections, a listener was added to the connection component that would wait until the script reached timeout, about 60 seconds, or until the title information was populated. When this field was populated, it meant the JS script had finished executing. It also allows the script to retrieve the page's title, to acquire the vendor type, using the developed method. Up to this point, the script can open the browser, navigate to the target address, skip any certificate errors that might appear, load the login page, and retrieve the RMB vendor using the title. The issues now arise when looking at specific vendors.

Starting with HP, it is the only web page that has a frame covering the login elements. Since the login is dynamic and does not change depending on vendor, a solution would need to be found to keep the same login style for all vendors. This is still feasible since AutoIt uses objects to make calls to the Internet Explorer library, and instead of sending the browser object that does not have visibility over the login elements, the frame object can be sent, which gives the script visibility over the desired elements. The only change that had to be done was a verification of what information the previously developed config file contained. If this configuration file populated the script with information related to a frame, then the object to be sent would be the frame object, otherwise the browser object would be used to perform the login.

Following Lenovo, when the page is loaded, the server runs a JS script, which blocks the login fields. This causes a problem when attempting to set the values for the login; however, since the parameters had a state of "disabled," it was possible to halt the connection component execution until the JS script is terminated. This wait also helps all the other vendors, since it makes sure that the parameters are enabled and can be populated. Once this verification is complete, the parameters can be populated, and the login can be performed.

Considering the vendor iDrac, there are three different versions, iDrac7, iDrac8, and iDrac9. Starting with iDrac7 and iDrac8, these have the same base framework but have small intricacies, causing some minor issues that need extra attention. They function on the same base script as the previously mentioned vendors; however, iDrac8 has a longer connection time, which forced the team to increase the timeout of the execution. Apart from this minor issue, the current script responds to both iDrac7 and iDrac8 necessities. With iDrac9, there are quite a few differences. Initially, the parameters cannot be accessed through identifier, therefore the configuration file has information regarding the names of these parameters. The button is also disabled until there is input on the login fields. Normally, the script sets the value for the field, which does not count as inputting the values on these login forms. To unlock the button, the values must be written in both the username and password field. A loop was created that writes values onto these fields, until the disabled value of the button returns false, meaning the button is enabled and the login can be performed.

Similarly, to other previously developed connection components, the AutoIt script was developed locally, navigates to a web page, detects which vendor the page corresponds to, and inputs the credentials of the user onto the login forms according to the configuration file. After the forms are populated, the script would submit and perform the authentication. The local script was then configured to work via the PSM, with the necessary hardening and PVWA configurations. The script ran with minimal bugs, caused by very specific and hard to recreate circumstances. After these bugs were dealt with, the connection component was considered complete.

5 Results

At the end of every development process, the team has a procedure in place to evaluate the quality of the solution. The stakeholder's needs must be considered when evaluating the increment created, and this feedback is crucial when the product is reviewed.

There is also a company internal tool that evaluates if an increment opens a vulnerability; however, it was not mentioned in this chapter due to how CyberArk extensions are created. From a technical standpoint, CyberArk extensions are an automation of operating system calls, and the end user only has access to the exact process that the application is running on. This means that the custom code does not add any vulnerability if following the recommended standard of only giving access to the target application process.

As end users only have access to the target application, it limits the avenues of attack vectors that attackers can exploit. It is therefore of utmost importance that the applications are patched as they are the ones that can be exploited. Target servers should also be kept as isolated as possible, as to avoid lateral movements from possible attackers; therefore, it is recommended that each account only has access to one server.

Accounts should also be configured to be used exclusively, which means that only one user can use a specific account at one time. This would require more accounts per server so multiple users can work on a server at once; however, if this configuration follows the standard mentioned previously of each account only accessing one server, then the system is still secure.

Automation of platform tests, it was discontinued due to business reasons, but some tests were automated. These tests are displayed earlier in this document, and progress towards this objective assisted the team with the tests they currently create for their work, such as for the Connection Components.

The OEM connection component and the RMB connection component are both fully developed, tested, and integrated on the test environment, as well as in the process of being integrated on the other environments. They are also approved by the responsible parties. Technical information regarding these issues is present in the developed work section of this document.

During development of these objectives, some issues were found that could not be fixed. Starting with the connection components, due to the connection between the PSM and the proxy, the load times of the connection components is not consistent, which leads to using more computing power, since the script stalls until an event occurs, which is not the most efficient method of developing the script. This is a connection limitation and is in place, so the product always works. Due to its nature, this limitation will always be present.

Considering the RMB connection component, the certificate error page is currently being skipped, due to the certificates not being ready to be implemented following BMW standards, and therefore the proper workflow cannot be obtained. The connection component should not skip the certificate error page, it should stop the connection whenever the certificate is invalid. This is considered as future work for this connection component, although it will only proceed once the RMB team has the proper certificates configured, following BMW's standards.

There are also some test limitations, since end-to-end tests use graphical interface recognition technology, no movement can be made while these tests are being executed. This should not present an issue since they are run on a dedicated server, however, if this server must be updated or a windows pop-up appears, it might cause the test to fail. This is a very specific error case, and running the test again will make it have the desired outcome, be it a pass or a failure. This limitation might be revisited in the future, however, it is not currently considered in the scope of work.

With the implementation of CyberArk on BMW, and with all the increments presented on this chapter, 1500 additional teams are now using the privileged access management solution, which results in over 300,000 privileged accounts currently managed by CyberArk. All the accounts are now properly secured, following BMW password health policies and respecting German regulation in terms of financial accounts. The monitoring that CyberArk has brought to the company has also allowed BMW to pass the internal and external security audits.

6 Conclusions

The automation of tests is valuable for the development team, allowing them to understand possible weak points of the CyberArk infrastructure and how to improve these. It is also of value to the other teams in the initiative, giving them the same understanding and speeding up the testing processes.

The major contribution of this project to the company is the creation of connection components for the usage of the privileged users, keeping their accounts safe, without major changes to the environment they are accustomed to. This improvement will greatly increase the cyber security within BMW and lower the possibilities for data breaches.

During development, some issues were found. Due to the connection between the PSM and the proxy, the load times of the connection components is inconsistent, which leads to using more computing power, since the script stalls until an event occurs, which is not the most efficient method of developing the script. This is a connection limitation and is in place, so the product always works. Due to its nature, this limitation will always be present. Also, some test limitations, due to that end-to-end tests use graphical interface recognition technology; no movement can be made while these tests are being executed. If the server has to be updated or a windows pop-up appears, it might cause the test to fail. This is a very specific error case and might be revisited in the future.

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A Sustainable Framework to Manage Plastic Waste in Urban Environments Using Open Data

Navjot Sidhu, Fernando Terroso-Sáenz, Guadalupe Ortiz, and Andrés Muñoz

1 Introduction

1.1 Motivation

Plastics are now polluting most of our urban and natural ecosystems. As stated in [1], the first evidence of plastic accumulation was found through the examination of the gut content of seabirds in the 1960s. Up until today, little progress has been made in reducing plastics but large progress in knowing the effects they have on the environment [2].

According to [3], the continuous increase of plastic waste in our cities can be harmful not only physically but also mentally, for example, with cases related to depression, anorexia, and restlessness, among others. Moreover, plastics are not usually controlled in some Eastern countries such as India and the Philippines. Thus, in India, 90% of solid waste including plastics is usually dumped in the open, but reusing plastics has been known as a positive reinforcement in order to lessen plastic waste in a community [4]. Recycling plastics through melting them and making a reusable product or using it for roads or as fuel is also a big help. However, it can lead to complications because of the incompatibility of the plastic polymers and their different melting points. There are solutions made available to help fix the problem of the accumulation of plastics. For example, as stated by [5], it is better if we throw our plastics in a landfill. On the contrary, [6] stated that landfill is the least

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favoured option for a public or private initiative. This author also stated that there are many other ways to reuse plastics, such as using plastics for road constructions, mixed with cement, or turning plastic into fuel.

Recently, due to the COVID-19 pandemic, the production and distribution of plastics have increased significantly. During this time, every individual needs face masks, face shields, or personal protective equipment to protect against the transmission of the disease [7]. Therefore, with the growth of plastics as seen in today's time, efficient plastic waste management is necessary. However, because incineration or landfill is the most common way of eliminating plastic waste, finding an efficient way to manage plastic waste, without mistreating the environment additionally, is indispensable [8].

In this context, our proposal aims to provide a collaborative framework to manage plastic waste in a sustainable manner in urban environments using open data, especially for Eastern cities in countries such as India and the Philippines where policies to control this type of waste are scarce. Next, we briefly overview the impact of Information Technology (IT) on the plastics management process and introduce our proposal as an alternative for the design of a smart framework for dealing with plastic waste in urban environments. Thus, the main contribution of this work is to provide a starting point to help cities struggling with plastic waste management through a smart framework for urban planning.

1.2 Background

In this section, sensors, open data, and machine learning are briefly reviewed through related studies that have used these technologies for plastic waste management.

1.2.1 Sensors

Sensor technologies are normally used in medical applications, environmental systems, traffic and parking monitoring, agriculture, and many more to detect different types of characteristics such as temperature, motion, location, etc. and convert them into readable outputs [9]. An example of the use of sensors in waste management is in segregating waste. Thus, in [10], a sensor system was used to separate waste into five different types: paper, plastics, metal, glass, and the rest. Two capacitive sensors were utilized to separate paper from plastic, while glass waste was separated through an infrared sensor.

The efficacy of these sensors for waste monitoring has been proven, especially through the integration of information and communications technology and the Internet of Things (IoT) [11, 12]. However, certain communities such as developing cities are still hesitant to put this type of proposal into action as the number of sensors and other hardware components being used in this process is not cost-efficient and difficult to maintain. As a result, low-cost proposals are a paramount necessity in these communities.

1.2.2 Open Data

Open data is the paradigm of how data, within different contexts and domains such as scientific, administrative, and demographics, among others, can be published and reused without permission barriers. This important concept of reuse without permission is essential for further studies. In scientific research, the rate of discovery can be accelerated by better access to data [13]. Open data in smart cities means not only the global data collected and made accessible by the government but also it should include the sharing of data among individuals and industries [14]. Furthermore, as stated in [13], open knowledge amounts to data for everyone that is free to use, reuse, and redistribute without legal, social, or technological restrictions. As a result, public data in smart cities can be used as comprehensive datasets that are integrated into technological processes related to waste management. An example of this is the use of country-level municipal waste data, population, and gross domestic product to predict future municipal waste generation in a country [15].

1.2.3 Machine Learning

Machine learning (ML) is a foremost branch within the Artificial Intelligence discipline. The key goal of ML is the use and development of data mining techniques and algorithms able to learn a particular task in a gradual manner as humans do. It helps improve decision-making systems based on predefined and static rules into more dynamic and statistically oriented settled systems that can adapt to new data [16]. Machine learning can be classified into three approaches: supervised learning, the most widely used type that uses training data with labels to be able to predict future outputs, unsupervised learning, which uses training data without labels to be able to recognize, group, or cluster similar data, and reinforcement learning, which uses sequences and observational data to interact for further augmentation [17]. As an example of the application of ML in waste management, in [18], some ML techniques were used to forecast the fill level of the bins and to cluster data to differentiate between biodegradable and non-biodegradable waste.

1.3 Towards the Design of an Intelligent Framework for Plastic Waste Management

Due to plastic waste increasing day by day, the use of IT elements as an alternative to manage the amount of plastic generated in the context of smart cities will be an essential solution. Thus, the design of an intelligent framework based on the aforementioned IT components may represent a compelling solution for this task. For instance, developing a smart bin with low-cost sensors for households would be an important tool to accurately check and analyse plastic generation and management in urban areas. Likewise, open data such as the population, the number of bins, their distribution in the streets, etc. of cities such as New York or Madrid can be reused to design new urban plans for other developing cities lacking waste management infrastructures, for example, to distribute an optimal number of plastic waste containers in the streets.

To achieve this desirable solution, our approach proposes a starting point consisting in designing a method for deploying municipal waste bins in developing countries or countries with no waste containers in the streets. The designated number of bins will be generated by applying different techniques coming from the fields of statistical analysis and machine learning on open data collected in several Western cities with previous successful experience in waste management. Then, services such as the generation of collection routes for waste pickers and volunteers for household waste and for stakeholders to collect municipal waste will be offered to provide these actors with optimal directions. The integration of these processes will result in the development of a framework for the holistic and intelligent management of plastic waste in urban areas of developing countries by using heterogeneous and open data sources, promoting at the same time the use of sustainable means of transport for the collection routes.

As a result, all of these services can be integrated into a general framework offered to help the community, especially in Asia where the waste management policies and technologies have not been updated while solid and plastic waste production has increased [19, 20].

Figure 1 shows a general overview of our proposed intelligent framework for managing plastic waste in smart cities. It focuses on actors such as the households, local authorities, and the waste pickers interacting with the system in order to give or receive outputs for their own purpose such as collecting, disposing, and planning plastic waste-related elements. The system consists of different processes such as intelligent modules, open data connectors, dashboards, and data storage that all revolve around smart bins which are responsible for the input and output of data. The low-cost household bins equipped with sensors will monitor plastic waste, whereas a web/mobile application will be used to manage the collection of household plastic waste within the communities with the help of volunteers or waste pickers.

The rest of the chapter is structured as follows. Section 2 provides an overview of the current studies focusing on the integration of ICT solutions for plastic management with urban development. Section 3 is devoted to the description of the reference and target cities involved in the proposed framework, including the analysis on the estimation of the number of bins needed in the target cities. Section 4 shows the main results and evaluation of the simulation scenario in a neighbourhood in the Philippines. Lastly, a summary of the conclusions and future work is included in Sect. 5.

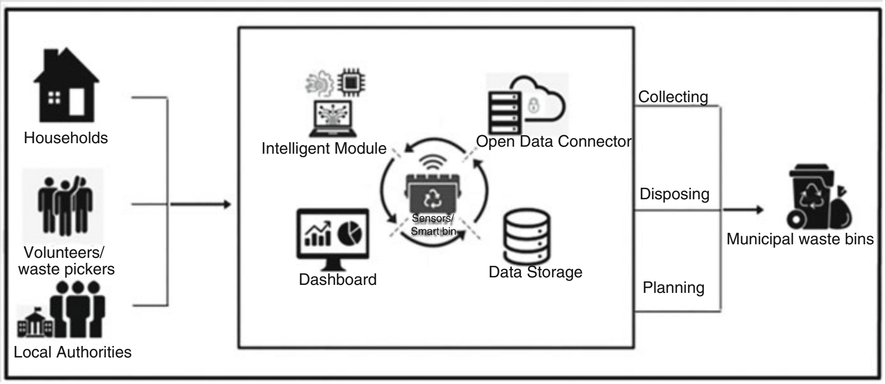

Fig. 1 General overview of the proposal of an intelligent framework for managing plastic waste in smart cities

2 Related Work

The integration of Information and Communication Technology (ICT) solutions with urban development planning is one of the paramount points for the achievement of smart cities. Indeed, the concept of the Internet of Things (IoT) fosters the connection and transmission of data among any type of device in a city, allowing citizens and organizations to exchange these data and create collaborative services on top of these IoT systems.

A survey published in [21] presented the different models of waste management opportunities in IoT-enabled smart cities. Thirty-six case studies involving different models which use different types of sensors such as capacity, weight, temperature, humidity, chemical, and pressure sensors were studied. The characterization and process of the survey were three-tiered: physical infrastructures, IoT technology, and software analytics. Physical infrastructure focuses on the waste bins, pipes, depots, dumpsites, types of waste, and other things that pertain to the hardware or physical properties that are associated with the bin and waste. IoT technology includes the recording and transferring of information through sensors, and actuators, with the use of GPS, WSNs, RFID tags, and Near-Field Communication (NFC) to measure the quantities of waste such as humidity, temperature, weight, capacity, and other attributes. Lastly, software analytics involves the analysis of data such as decision support systems, dynamic scheduling, and dynamic routing, among others.

The work in [22] proposed an IoT waste management system that used a bin-level monitoring unit and a wireless access point unit. The level monitoring unit included an ultrasonic sensor, a network processor, and a power management unit. On the other hand, the wireless access point unit consisted of a wireless router deployed at several points close to the bins, to provide data connectivity to users. As it was self-powered due to its low dropout regulator, the entire unit could last up to 434 days based on the experiments. The unfilled levels could also be monitored precisely from a distance of 119 m or less.

The study in [23] included the use of proximity and humidity sensors, load cells, a lever-activated switch, GPS, and microcontroller. A mobile application was also used by rubbish vehicle drivers to schedule bin collection and the location of the routes. In a similar study [24], Near Infrared Spectroscopy was used to classify five different types of plastics. Based on this technology, an automatic wireless sorting system was successfully created. The system included an automated device able to detect 4 plastic items per second and to sort 5 different polymers through pattern recognition. The accuracy reported for sorting was at 96–98% for materials like polyvinyl chloride, polyethylene, polypropylene, and polystyrene and 99% accuracy for polyethylene terephthalate. The monitoring of the system was done with a remote wireless interface.

Another IoT-based plastic waste management system [25] included ultrasonic sensors that were able to measure bin fill levels, RFID tags for easy tracking, load cells for identifying the weight of the bins, image sensors for capturing the image of the bin from the inside, and temperature, humidity, and gas sensors, which were used for classifying the materials inside the bin. Each bin was also equipped with a bin controller, which transferred all the data to the server, and later accessed by the users and by garbage collectors. The database in the server stored data such as the number of filled, empty and under-filled trash bins, bins that needed immediate service, total weight of the bins, route information, and communication status information of each bin.

Segregation, collection, and transportation are the purposes of a study in [26]. The types of waste bins are biodegradable, plastics, glass, and paper where each bin is equipped with an ultrasonic sensor that can detect fill level and hand movements to open the lid of the bin. The bin is also equipped with a Raspberry Pi Zero W development board that can automatically lock the bin lid when it is full. Text messages are also sent to the administrators of the system to notify them when the bin is full. With the data acquired through the different sensors, a calculation or algorithm was also developed to forecast the different types of garbage levels in the coming months for all types of waste.

In [27], different types of waste which need proper waste management are presented. Among the types included, it can be found organic, hospital, electronic, nuclear, green, recyclable, and industrial waste. The study suggests an in-depth analysis of the features that should be included in a smart waste management system such as waste bin fill status notifications, automated vehicles to collect waste, modernization of landfills, converting waste to energy, and waste collection vehicles running on natural gases. The proposed smart bins include ultrasonic sensors to measure fill level, RFID tags to help with bin location tracking, load cell to determine the weight of the bins, image sensors to see the contents of the bin, temperature and humidity sensor to detect industrial waste, and gas sensors for chemicals deposited in the bin. Additionally, the study suggests that waste collection vehicles are one of the most crucial parts of the smart waste management system. Some features that make an efficient vehicle include a robotic arm for the automation of collection, sites where solid and wet waste can be stored, accelerometer, air quality sensor, camera and wireless signals placed in the vehicles, and a GPS and real-time communication system with the server.

In comparison to the aforementioned studies, this work focuses on an approach that integrates open data from countries with a well-developed waste planning to infer the number of bins in countries with limited to no bins. An initial evaluation of the collaboration of waste pickers to collect and dispose plastic waste has also been integrated in this bin allocation approach.

3 An Urban Plastic Waste Planning Approach Based on Open Data

This section introduces our proposal to address the plastic waste problem from the urban planning perspective in cities with limited or non-existent plastic management policies. The basic idea is to design customized urban planning for such cities based on efficient strategies already implemented in some Western cities. To do so, our proposal relies on the use of open data related to the plastic management available from such Western cities along with other relevant data such as population density, venue distribution, and even shape of the cities regarding the distribution of the streets.

Next sections explain the retrieval of open data in order to statistically analyse the distribution and placement of municipal plastic waste bins in a city. As Fig. 2 shows, the urban features of four specific Western cities related to plastic management were explored where results are applied to three different city areas suffering from dumpsite problems in the two Eastern countries, namely India and the Philippines. Through statistical and machine learning methods in mapping the target and reference cities, this urban planning method may help develop countries to devise a custom-built low-cost strategy to deal with plastic waste management by adapting successful experiences in other countries.

3.1 Description of the Reference Cities

As mentioned above, there are four reference cities namely Madrid, Malaga, Stavanger, and New York City. These four reference cities were chosen due to their distinct urban topology, social life, and variation in demographic profiles. Different features that might impact the generation of plastic waste in the area were taken into consideration. These features are as follows:

1. Each city's demographics and their distribution within each of its districts. This dimension allows calculating the amount of human activity in each of the areas in the city.

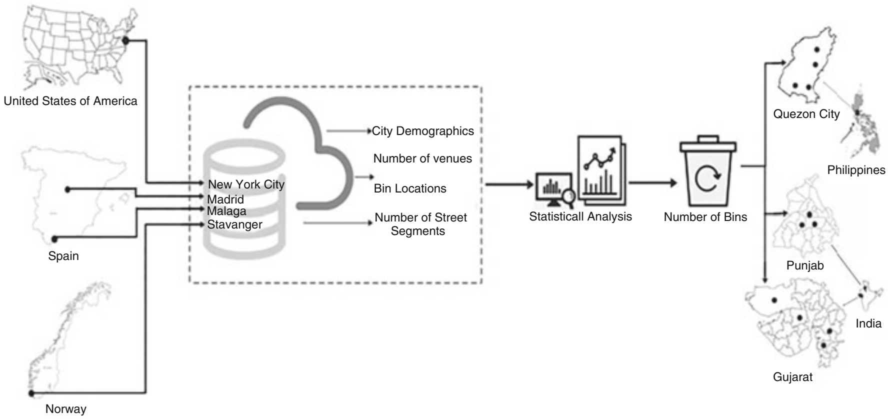

Fig. 2 Overview of an urban planning approach for deploying plastic waste bins based on open data

2. The number of venues in each city that caters to various categories, as well as their distribution by district. This distribution enables us to capture the underlying types of human activities.
3. Each district's number of street segments. This data is a hidden feature of intrinsic urban topology. Such a topology could be a crucial aspect in determining an appropriate bin allocation policy. Districts with varying number of street segments are likely to have varying patterns of movement and, as a result, highly varied activity behaviours. In this sense, a region with many recreational places and large building blocks would have fewer segments than a residential neighbourhood with single-family houses, and therefore the waste generation patterns in both regions could be drastically different.
4. We have also gathered information on where the bins are located in each of these cities. This enables us to calculate data such as the total number of bins and the average distance between bins in each of the four cities' districts.

Data on the number of venues and street segments have been extracted from Open Street Map (OSM) taking into account the geographical polygons that outline the area of each city stored into the OSM repository. Then, the venues (established as point-based features) and street segments (defined as line-based features) that spatially match such polygons are retrieved from the platform. For this purpose, we use the Overpass Application Programming Interface (API). This is a built-in interface provided by OSM to get spatial objects from its repository easily and programmatically.

Table 1 Overview of the demographics and number of bins in Malaga

Malaga	Population	Area (km^2)	Population density	Number of bins	Average distance of bins (kms)	No. of street segments
Centro	84,988	5.87	14,478	20	0.36	3502
Este	67,289	126.63	531	285	3.42	2860
Ciudad-Jardin	37,769	76.21	495	2	0.07	2693
Bailen-Miraflores	62,834	6.39	9066	31	0.51	1429
Palma-Palmilla	29,862	25.37	1177	6	0.33	967
Cruz de Humilladero	93,955	9.91	9480	142	1.81	3383
Carretera de Cadiz	113,424	5.6	20,254	265	2.62	3743
Churriana	20,449	37.32	547	409	3.97	3223
Campanillas	17,472	59.77	292	202	1.03	1335
Puerto de la Torre	49,442	42.26	1169	233	1.14	1556
Teatinos-Universidad	34,405	–	–	100	2.43	2191

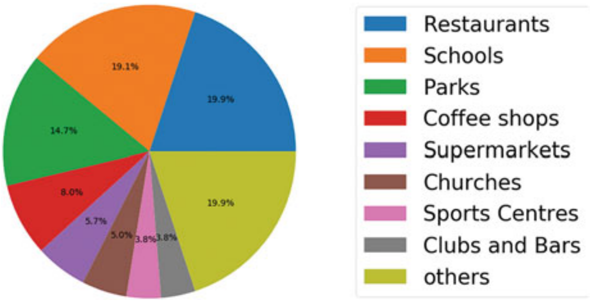

Fig. 3 Number of establishments in terms of percentage in Malaga

3.1.1 Reference City #1: Malaga

The first reference city is Malaga located in the Andalucia region of Southern Spain. This city has 11 districts, as listed in Table 1. As shown in this table, the district Carretera de Cadiz has the highest population and is the only district with over 100,000 people. It is also the densest district with 20,254 people per km^2, while Este is the district with the largest area (126 km^2) in the entire city. Churriana is the district with the greatest number of bins with an average distance of bins at 3.96 km.

Figure 3 shows the distribution of venues in the city of Malaga. The highest percentage are other venues which consist of sports centres, clubs and bars, government offices, hotels, convenience stores, etc. They are followed by restaurants and schools. This shows that unlike NYC and Madrid, the catering and education sectors are almost equally important even though the other establishments are higher in total collectively.

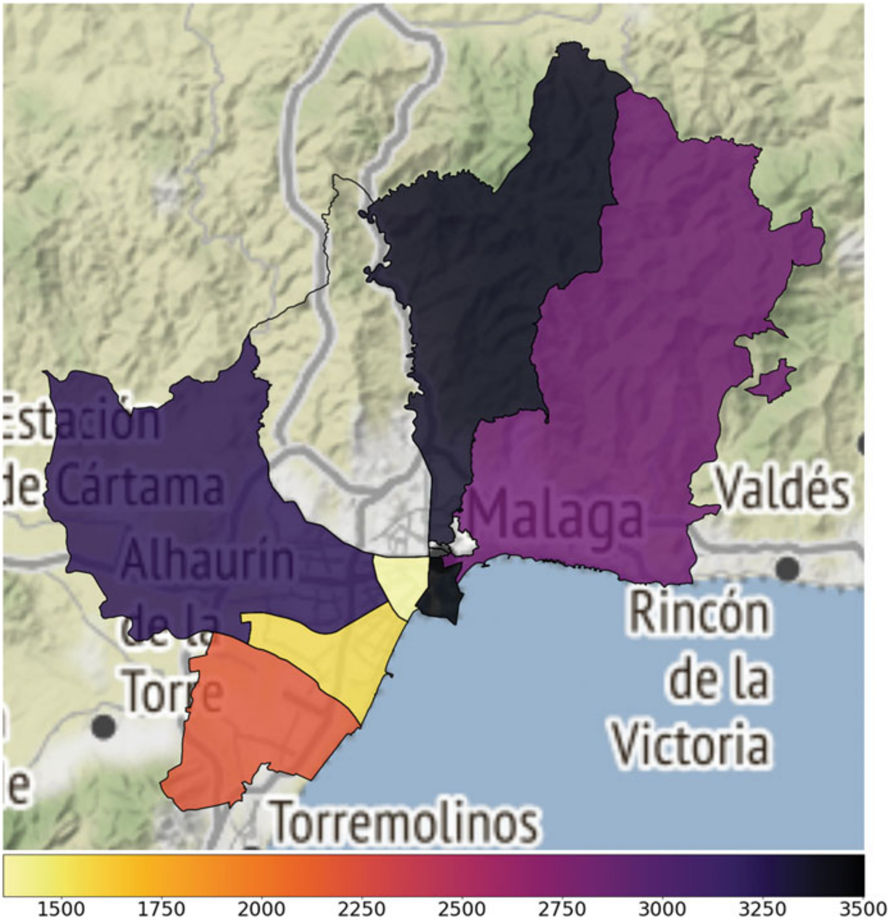

Fig. 4 Distribution of number of streets in Malaga

Indeed, in 2018, with a total of 301,000 tons of waste collected in Malaga city, 8700 tons were plastic waste.[1] Although catering is an evident industry that generates tons of waste, the education industry should not be disregarded when it comes to plastic waste generation, as it is also shown elsewhere [28].

Regarding the number of streets, as shown in Fig. 4, Malaga has a total of 26,882 roads with the district of Carretera de Cadiz with 3743 roads, Centro with 3502, Cruz de Humilladero with 3383, Churriana with 3223, and other districts, Bailen Miraflores, Campanillas, Ciudad Jardin, Este, Palma-Palmilla, Puerto de la Torre, and Teatinos Universidad with less than 3000 roads.

[1] www.juntadeandalucia.es/.

Table 2 Overview of the demographics and number of bins in Madrid City

Madrid	Population	Area (km^2)	Population density	Number of bins	Average distance of bins (kms)	No. of street segments
Salamanca	145,344	5.41	26,865	736	1.22	2050
Chamartin	141,527	9.19	15,400	1095	1.83	2935
Moratalaz	92,958	6.34	14,662	1933	1.08	1728
Ciudad-Lineal	212,565	11.36	18,711	2258	2.02	4201
Hortaleza	185,738	28	6633	2838	1.9	7294
Vicalvaro	72,213	32.7	2208	1547	1.32	3498
San Blas-Canillejas	155,825	21.81	7144	2218	2.12	4545
Barajas	48,315	42.66	1132	1003	495	1.13
Retiro	118,252	5.37	22,020	495	1.13	2493

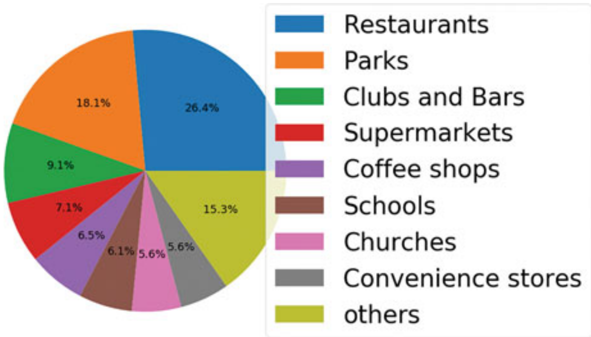

Fig. 5 Number of establishments in terms of percentage in Madrid

3.1.2 Reference City #2: Madrid

The second reference city is Madrid, the capital of Spain. It has a total of 21 districts, and this study focuses on only 9 representing the downtown, namely Salamanca, Chamartin, Moratalaza, Ciudad-Lineal, Hortaleza, Vicalvaro, San Blas-Canillejas, Barajas, and Retiro.

Table 2 shows the different population, with Ciudad-Lineal as the city with the highest population. The densest district with 26,865 people per km^2 is Salamanca. As the district with the highest population, Ciudad-Lineal also has the highest number of bins, with an average distance between the bins at 2.02 km^2. The other districts namely San Blas-Canillejas and Moratalaza also have a significantly high amount of bins, while the district with the lowest amount of bins is Retiro even though it has a population of more than 100,000.

Additionally, Fig. 5 shows the percentage of different venues in Madrid. The highest number of venues are restaurants followed by parks and others, which consist of museums, libraries, and gas stations, among others. This stipulates that Madrid has a large percentage belonging to the catering sector. Indeed, from 2010

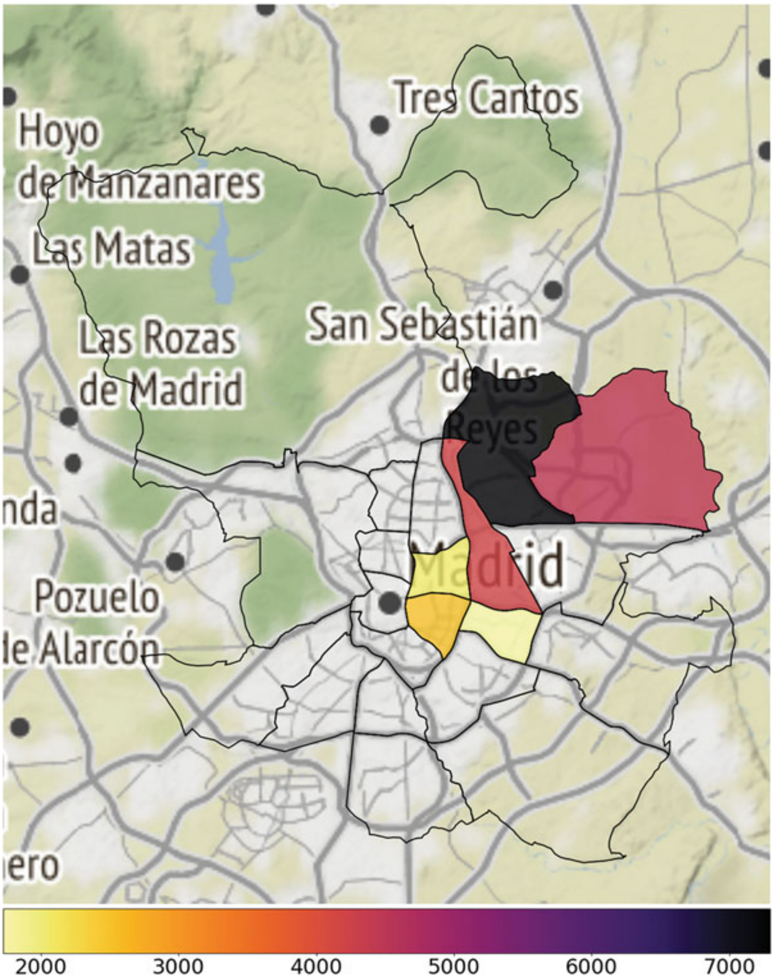

Fig. 6 Distribution of number of streets in Madrid

to 2018, municipal waste generated in Madrid ranged from 20,000 to 23,000 tons.[2] It was also reported that 21.8 kg per capita of plastic waste was effectively recycled in 2017.

Lastly, in the 9 districts, the total number of street segments is 33,222 as is shown in Fig. 6. Hortaleza has the most roads with 7294, followed by San Blas-Canillejas with 4545 and Barajas with 4478. The number of streets can show a significant relation to the area or population of the district. But in the case of Madrid, Ciudad-

[2] appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do.

Table 3 Overview of the demographics and number of bins in Stavanger

Stavanger	Population	Area (km^2)	Population density	Number of bins	Average distance of bins (kms)	No. of street segments
Madla	21,236	13.87	1530	136	2.35	2118
Hundvåg	13,217	6.41	2061	74	1.40	2026
Hillevåg	19,681	8.08	2435	212	1.45	3892
Storhaug	16,544	6.43	2571	188	0.86	1793
Hinna	22,581	15	1505	187	1.65	777
Eiganes og Våland	23,616	7.01	3368	181	1.39	3443
Tasta	15,319	10.87	1409	98	0.74	1943
Rennesoy	4755	65.51	72.58	27	3.12	38

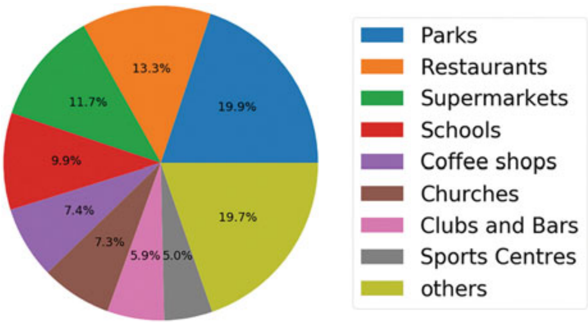

Fig. 7 Number of establishments in terms of percentage in Stavanger

Lineal, which has the highest population, has the fourth highest number of street segments, while Barajas, which has the largest area, has the least number of streets.

3.1.3 Reference City #3: Stavanger

The third reference city is Stavanger, located in the Southwestern part of Norway. This city has 6 districts which are listed in Table 3. Almost all the districts, except for Rennesoy, have a population of over 10,000. Not only does the district of Eiganes og Valand have the highest population of 23,616 but also it is the densest one with 3368 people per km^2. Furthermore, even though Rennesoy has the lowest population, it is the district with the largest area in Stavanger. Hillevag, a district with 19,681 people and an area of 8.08 km^2, has the greatest number of bins with an average distance of 1.45 between the bins.

Figure 7 shows the distribution of venues which indicates that the highest percentage of venues are parks, followed by other venues such as gas stations, museums, government offices, convenience stores, shopping centres, and hotels, among others, and restaurants. This indicates that the generation of plastic waste might be from these venues as these are established more in the city. In one of

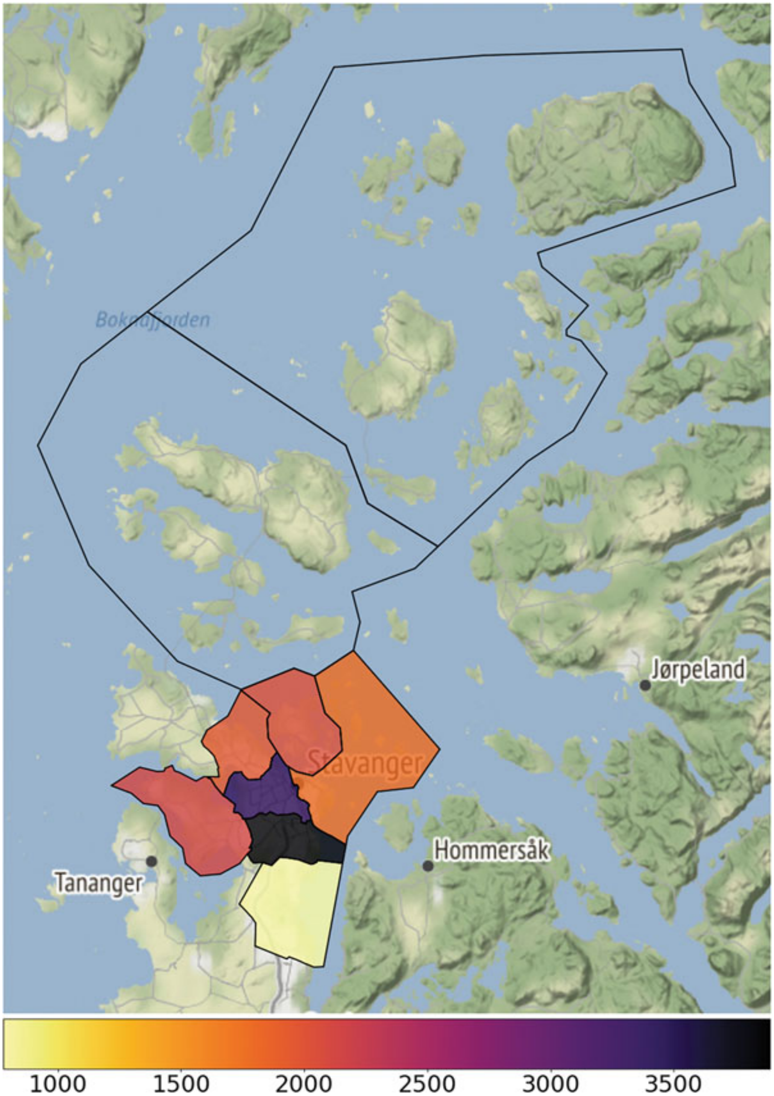

Fig. 8 Distribution of number of streets in Stavanger

the main waste facilities in Stavanger in 2019, it was noted the arrival of waste from households, parks, shopping centres, offices, and other stores containing 15,973 tons of plastics out of 66,250 total tons of waste.[3] Finally, as shown in Fig. 8, Stavanger has a total of 15,992 streets. The rest of the districts have less than 3000 streets.

[3] https://www.ivar.no/english/.

3.1.4 Reference City #4: New York City

The last reference city is New York City (NYC), in the United States of America. This city has five boroughs, namely Manhattan, Brooklyn, the Bronx, Queens, and Staten Island.

According to Table 4, all the NYC districts, but Staten Island, comprise very large populations above 2 million people. In terms of population density, Manhattan is the densest one, with more than 52,000 people per km^2. Besides, it is possible to observe meaningful differences in the distribution of bins in each district. More in detail, Queens exhibits a much less dense distribution of bins, as its average pairwise distance between bins is 8.63 km. This is a much larger distance than the ones observed in the other four districts, with distances ranging from 4 to 6 km.

Regarding the venue data, Fig. 9 shows its distribution in NYC. As observed, a high percentage of venues are restaurants, followed by places of worship and park areas. All of them are above the 10% of the total venues of the cities. This indicates that NYC has a quite important catering sector. This is an important detail as this economic sector might be an important factor in the total generation of plastics within the city. A report by the Department of Environmental Conservation mentioned that 20% of waste generation (the second highest in terms of waste generation) came from restaurants and the catering industry. In a study elsewhere [29], it was noted that collection of waste was more efficient for paper waste rather than for solid waste. While separation efficiencies were still relatively low, paper was still noted as the largest percentage of waste, as well as glass.

Finally, the number of streets is depicted in Fig. 10. It is important to note that this figure indicates the number of street segments in each district. In that sense, a street might be split into different segments if it is crossed, for example, by other streets. Thus, Queens is the district with the densest network with 124,001 street segments. This is a volume of segments much larger than in other districts like Queens (55,192 streets), Brooklyn (22,709), The Bronx (17,338), or Staten Island (16,060). Finally, the Manhattan district is the only one comprising less than 10,000 roads. Unsurprisingly, there is a strong correlation between the total geographical area of a district and its total number of streets.

Table 4 Overview of the demographics and number of bins in New York City

New York	Population	Area (km^2)	Population density	Number of bins	Average distance of bins (kms)	No. of street segments
Bronx	2,717,758	110	24,707	108	4.78	17,338
Manhattan	3,123,068	59.1	52,844	184	5.82	9702
Queens	4,460,101	280	15,929	117	8.63	55,192
Brooklyn	4,970,026	180	27,611	94	6.35	22,709
Staten Island	912,458	152	6003	42	6.71	16,060

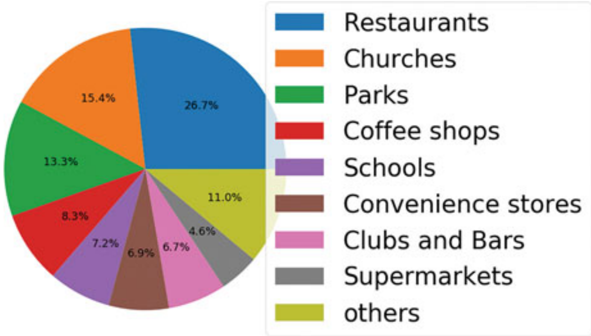

Fig. 9 Number of establishments in terms of percentage in NYC

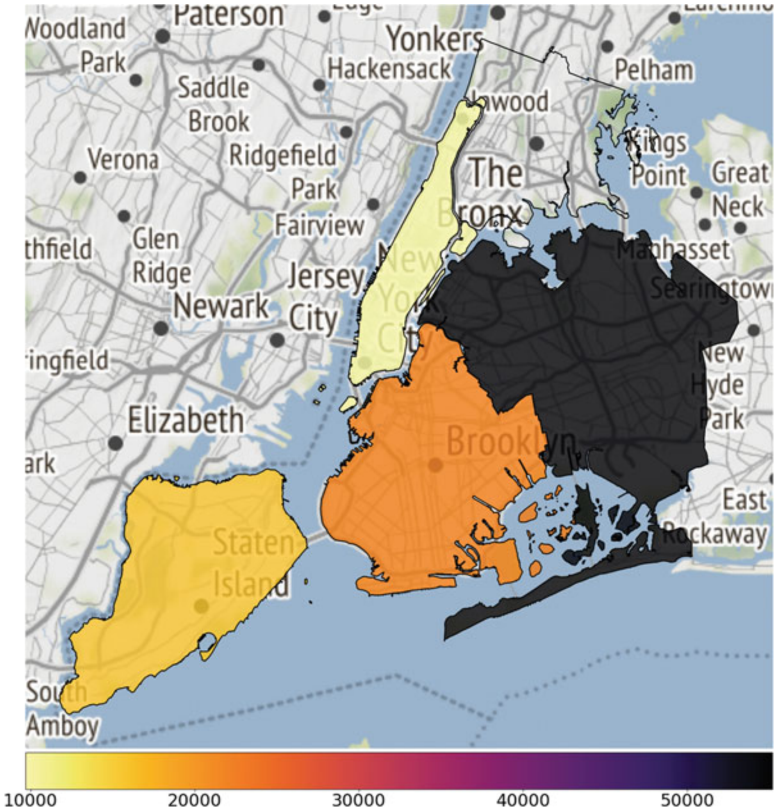

Fig. 10 Distribution of number of streets in each of the five NYC boroughs

3.2 Description of the Target Cities: Quezon City, Punjab, and Gujarat

This section describes the target areas of the developing countries, namely the Philippines and India, where we will apply our method to estimate the number of plastic recycling bins. These areas are selected based on their different urban features with respect to the size of the areas, population density, and venue distribution, as explained below.

3.2.1 Target City #1: Quezon City, Philippines

For many years, the Philippines has been a centre of natural disasters such as floods due to the blockage of drainage because of plastic waste. According to [30], the Philippines produced approximately 2.7 million metric tonnes of waste each year, as of June 2020. Not only do they handle the waste people of the Philippines produce, but also for many years, it has been reported that countries such as Canada, Hong Kong, South Korea, and Australia have dumped their trash in the Philippines [31].

For the above reasons and due to the lack of plastic waste management policy, we have chosen Quezon City as one of the target cities for this study, divided into two groups: group 1, which is located at the border of the city of Manila and Quezon City (4th district), and group 2 located close to the Payatas dumpsite (5th district). The reason for choosing these 2 areas is because of the difference in population and policies of collecting waste (see Fig. 11).

Quezon City group 1 or the 4th district of Quezon City has 32 neighbourhoods, but for the purpose of the study only seven were chosen. The total population of these seven neighbourhoods is 92,283, Tatalon with the highest population. Note that the areas of all these seven places are less than a square kilometre, and thus for the purpose of computing the population density, the area has been converted to hectares (Table 5).

Figure 12 shows the distribution of venues in this first group of Quezon City. Restaurants have the highest percentage, followed by a group of other venues such as hospitals, shopping centres, cinemas, parks, and coffee shops, whereas the third highest are private clinics.

In Quezon City group 2, out of 14 neighbourhoods under the 5th district, for this study only seven of them were chosen. The neighbourhood of Kaligayahan has the greatest population, while Pasong Putik Proper has the biggest area. Moreover, Santa Lucia has the smallest population and also the least area (see Table 6).

Figure 13 shows that the highest percentage distribution of venues are those grouped as “Others,” which is the total of the venues less than 5% such as supermarkets, hospitals, train and bus stations, private clinics, and sports centres, among others. It is followed by restaurants, schools, and gas stations.

Lastly, Fig. 14 shows the distribution of streets in the selected groups in Quezon City. The map further indicates that group 1, with a total of 878 streets, has fewer

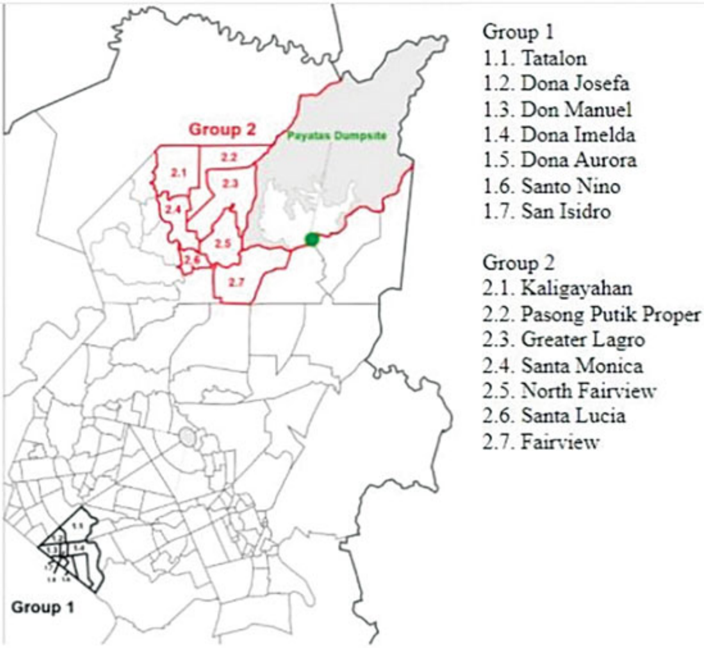

Fig. 11 Maps of areas in Quezon City. Quezon City is included in a bounding box with lat–long coordinates ((14.60, 121.00); (14.78, 121.12))

Table 5 Overview of the demographics in Quezon City group 1

Group 1	Population	Area (km^2)	Population density (hectares)	No. of street segments
Don Manuel	3753	0.238	157.689	33
Dona Josefa	2909	0.282	103.15	46
Dona Aurora	5636	0.128	440	37
Dona Imelda	16, 915	0.929	182.07	138
San Isidro	8578	0.132	649	173
Santo Nino	10, 278	0.193	532.5	299
Tatalon	63, 129	0.925	682.4	152

than group 2, which has a total of 2212 streets. Furthermore, while in group 2 the neighbourhood with the highest number of roads is Fairview which is also the 3rd largest area, in group 1 the neighbourhood of Santo Nino has the greatest number of streets, even though it is one of the smallest in terms of area.

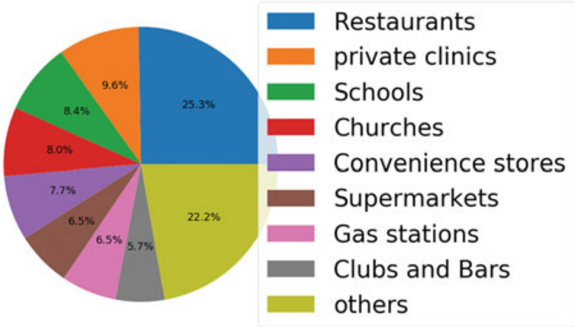

Fig. 12 Number of establishments in terms of percentage in Quezon City group 1

Table 6 Overview of the demographics in Quezon City group 2

Group 2	Population	Area (km^2)	Population density (hectares)	No. of street segments
Fairview	53,151	3.12	17,035	430
North Fairview	41,154	2.01	20,474	200
Greater Lagro	22,764	4.24	5368.86	427
Pasong Putik Proper	35,135	27.5	1278.29	325
Kaligayahan	54,576	2.46	22,185	415
Santa Monica	46,553	1.65	28,214	309
Santa Lucia	25,577	0.642	39,839	106

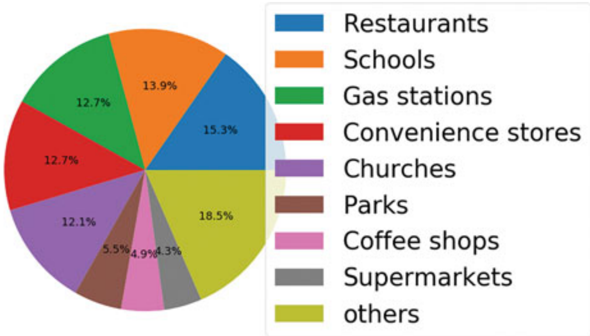

Fig. 13 Number of establishments in terms of percentage in Quezon City group 2

3.2.2 Target City #2: Punjab and Gujarat, India

Similar to the Philippines, we have divided the study of Indian cities into two groups: group 1 located in the state of Punjab, where most of the cities still follow an open-air dumping policy, and group 2 located in the state of Gujarat (see Fig. 15), where they have already started with the trials of the waste management policy and where they have the Pirana dumpsite, one of the main open dumping sites controlled by the state government.

Fig. 14 Distribution of number of streets in the two groups in Quezon City, Philippines

Fig. 15 Left: map of the cities in the state of Punjab and right: map of the cities in the state of Gujarat. Punjab's cities (left) are included in the bounding box with lat–long coordinates ((29.63, 74.12); (32.34, 76,94)) and Gujarat cities (right) with lat–long coordinates ((20.63, 68.55); (24.61, 74.46))

Table 7 Overview of the demographics in India group 1

Group 1	Population	Area (km^2)	Population density	No. of street segments
Barnala	190, 619	11	17, 329	134
Dhaner	2140	10.09	212	4
Ludhiana	1, 618, 879	159	10, 182	5145
Moga	298, 432	2230	134	156

Table 7 shows the data for the four selected cities in the state of Punjab. The city with the largest population is Ludhiana, followed by Moga. The biggest city in terms of area is Moga. However, Barnala has the highest population density. Also, there is insufficient data for the venues in Dhaner.

The distribution of venues in this group can be seen in Fig. 16. The highest percentage of venues are hospitals followed by parks and by a group of other venues such as gas stations, restaurants, sports centres, cinemas, supermarkets, and private clinics, among others.

Group 2 is in the state of Gujarat, India. Out of 18 cities in this state, we have chosen the capital of the state, Gandhinagar, and three of the biggest cities in the state, Ahmedabad, Surat, and Jamnagar. Table 8 shows that the city with the greatest population and area is Ahmedabad, while Surat is the densest city.

Figure 17 shows the distribution of venues in the second Indian group. Hospitals have the highest percentage of venues (more than 50%), followed by parks and other venues such as restaurants, gas stations, schools, supermarkets, and coffee shops, being similar to the first group in the rank of venues.

Fig. 16 Number of establishments in terms of percentage in India group 1

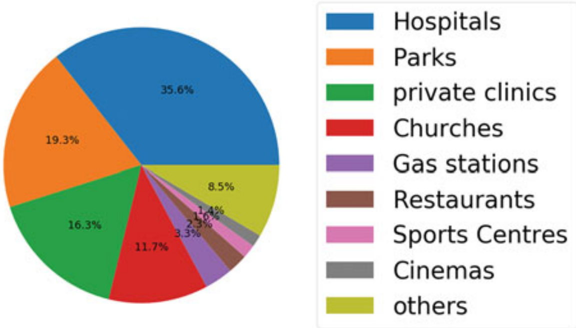

Table 8 Overview of the demographics in India group 2

Group 2	Population	Area (km^2)	Population density	No. of street segments
Gandhinagar	1,391,753	2140	650	3760
Ahmedabad	7,045,313	6968	1011	17, 275
Surat	6,081,322	4549	1336	4472
Jamnagar	1,047,635	6607	159	1060

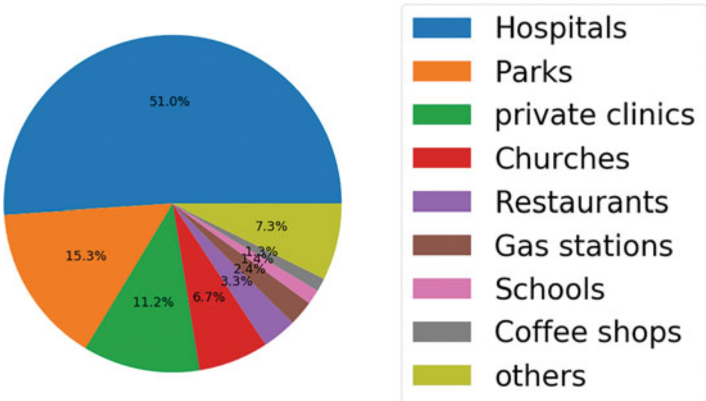

Fig. 17 Number of establishments in terms of percentage in India group 2

3.3 *Statistical Methods Used in the Analysis of the Urban Planning Approach*

This subsection discusses the methodological and statistical models used to infer the number of bins in the above-mentioned target cities.

Regression analysis focuses on modelling techniques for the relationship between one or more independent variables and a dependent variable. Dependent variables are response variables that are a function of the independent variable while independent variables are predictors. In linear regression, parameters are often set and estimated to give the model the best fit and the dependent variable is used to set regression parameters and a random error. The dependent variable in this study is the number of bins in the target city's neighbourhood while the independent variables are some of the urban features of the target cities. In this study, weighted least squares (WLS) was used to calculate the actual values of the intercept and slope parameters of the linear regression formula. Weights are necessary in order to make sure that the acquired or used data fit the model and it is used when there is a higher chance of uncertainty of values due to the fact that there are a larger number of experiments, or the distribution is wider but datasets are lesser.

The principal component analysis (PCA), which finds linear combinations of independent variables in order to prove the variations of the variables, was also used in this study [32]. The collection of different urban features from the reference cities is not efficient to fit the linear regression model with all features. Thus, for the reduction of the dimensionality of these independent features, PCA was used.

3.4 Analysis for the Estimation of the Number of Bins

This section explains the statistical analysis performed to infer the number of bins in target cities (see Sect. 3.2) from the data of the reference cities (see Sect. 3.1). The number of bins was identified as the output variable, whereas the other variables were identified as the independent variables.

To identify the most relevant variables to estimate the number of bins, a linear regression analysis was performed. Through this analysis, the most relevant variables along with coefficient of determination (R^2) were obtained. The R^2 measures the strength of correlation of the obtained model, noting that while the coefficient ranges from 0 to 1, the higher the value, the better the model predicts new values. Next, the SPSS automatic linear modelling was applied in order to improve the model accuracy. The results provided a model with an R^2 value of 0.45 which identifies the population density and the number of street segments (NSS) as the significant variables (see Fig. 18). It is worth mentioning that the importance of the population and area size for calculating the number of bins is captured thanks to the population density variable.

We then focused on enriching the model with venue data from the reference cities. Since there were 27 categories from OSM, they could not be directly integrated into the regression model as a variable, as it would be a too large expansion of the input dimension of the model. Therefore, we performed a feature screening process to filter the most relevant type of venues. On the basis of the variable coefficients on the uncovered axis, the Principal Component Analysis (PCA) can be used for feature selection. As a result, we used a binary format to represent the venues, and then we created a new matrix V (from venues) with 27 columns and rows reflecting the reference neighbourhoods (each one representing a type of venue). Depending on whether the latent type of venue is present in the neighbourhood or not, a feature was assigned a value of 0 or 1. The top four features

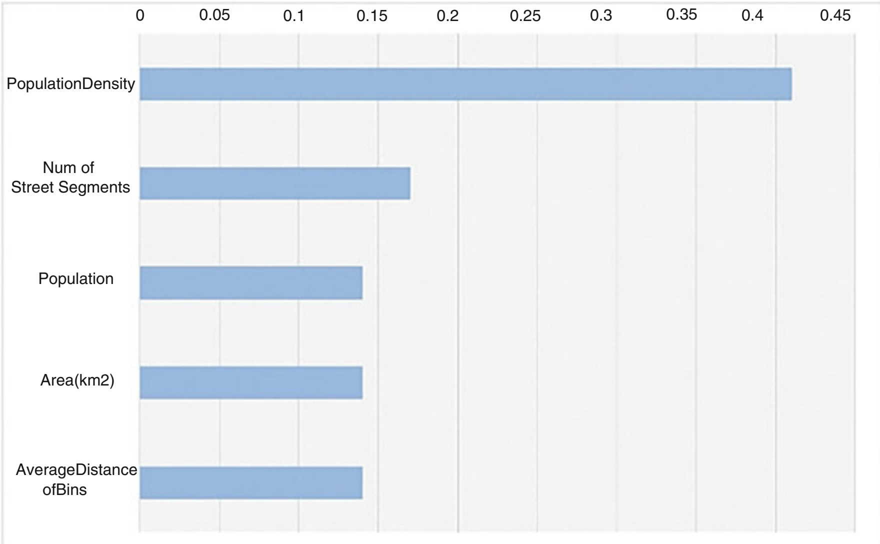

Fig. 18 Relevance of the input variables in the linear regression model for estimating the number of bins

with the highest coefficients in the first PCA axis were then kept. By just keeping 4 dimensions, we do not enlarge too much the dimensionality for the final dataset which is an important issue due the limited number of instances of such a feed. More in detail, these features correspond to the following activity/venues:

- Amenity/restaurants (coeff. 0.2479)
- Leisure/parks (coeff. 0.2442)
- Buildings/schools (coeff. 0.2439)
- Shop/supermarkets (coeff. 0.2438)

Figure 19 depicts the weights of each of the venues based on the PCA four components. The venues in the x-axis are sorted in descending order by their weight in the first component. From the perspective of bin allocation, this set of relevant venues can be viewed as dimensions of a region's latent predominant land use. Finally, the matrix $V' \subset V$, which included the columns of these four features, was added to the original dataset as new independent variables to feed and evaluate the models. This way, we were able to augment the analysis with a simplified perspective of venue distribution of venues in each of the regions.

Finally, applying the Weighted Least Square (WLS) analysis to the variables obtained in the two previous steps (i.e., population density, NSS, and the four predominant land use categories represented as binary values 0/1), we obtained an R^2 value of 0.721 using NSS as the weight variable. The coefficients for the rest of the variables were weighted with the NSS, obtaining the following formula:

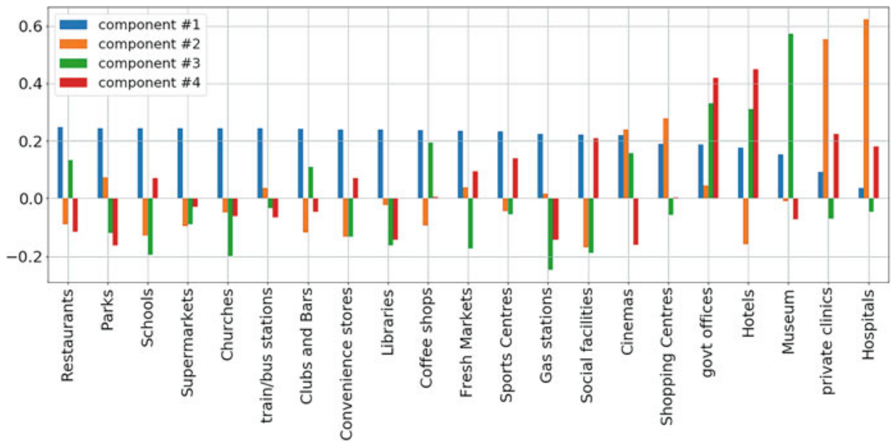

Fig. 19 Venues' weights given the first four components of the PCA

Table 9 Weighted least squares equation results for target cities

City/state	Neighbourhoods	Predominant land use	Proposed number of bins
Quezon City, Philippines	Don Manuel	Amenity/restaurants	26.34
	Dona Josefa	Amenity/restaurants	26.88
	Dona Aurora	Building/schools	146.41
	Dona Imelda	Amenity/restaurants	26.10
	San Isidro	Building/schools	114.32
	Santo Nino	Amenity/restaurants	22.59
	Tatalon	Building/schools	143.99
	Fairview	Leisure/parks	748.90
	North Fairview	Amenity/fuel	1251.18
	Greater Lagro	Leisure/parks	865.56
	Pasong Putik Proper	Amenity/restaurants	15.13
	Kaligayahan	Amenity/placeofworship	1235.07
	Santa Monica	Amenity/placeofworship	1174.78
	Santa Lucia	Shop/convenience	1058.53
Gujarat, India	Gandhinagar	Leisure/parks	912.75
	Ahmedabad	Amenity/hospitals	1446.81
	Surat	Amenity/hospitals	1443.56
	Jamnagar	Amenity/hospitals	1455.33
Punjab, India	Barnala	Amenity/hospital	1283.63
	Dhaner	–	1454.80
	Ludhiana	Leisure/parks	817.43
	Moga	Amenity/place of worship	1455.58

$$Number\_of\_Bins = 1456.921 - (0.010X_0) - (1429X_1) - \quad (1)$$

$$-(537.667X_2) - (1306.106X_3) - 1344.143X_4) \quad (2)$$

Table 9 shows the numbers of bins estimated for the target areas after applying this result (the predominant land use for each target area indicates which of the four dimensions identified by PCA algorithm takes value 1 in the area). As can be seen, for areas in Quezon City group 1 and India group 2, the number of bins corresponds with their population density and the number of street segments as for similar reference cities. However, some values are unexpectedly high for some specific areas, as for example in Dhaner, with an area of 10 square kilometres but with a small population of 2140, has a number of bins of 1454. These values could be due to the lack of information about the predominant land use or due to an imbalance of data in terms of population or area.

4 Evaluation of the Proposal as an Enabler for Sustainable Plastic Waste Collection

To assess the impact of our intelligent framework for plastic management in urban environments, we proposed a simulation of the effect of deploying the number of municipal bins recommended by our system in one of the target city neighbourhoods. In this manner, we perform a comparison at the level of household plastic waste collection rate in a scenario where only dumpsites are used as usual with a scenario where the municipal bins and collection routes proposed by our system are introduced.

It is worth mentioning that we have previously developed a low-cost smart household bin elsewhere [33] for our intelligent framework devised in Fig. 1. This smart bin allows real-time monitoring of the container's current capacity, as well as predicting when its maximum capacity will be reached. The smart bin has been integrated into this simulation scenario so as to evaluate our urban planning approach for plastic waste.

4.1 Evaluation Setting

The evaluation of our proposed intelligent framework for plastic waste was performed through as a simulation in Don Manuel neighbourhood at Quezon City in the Philippines (see Sect. 3.2.1). Figure 20 shows the proposed locations for the 26 municipal bins estimated through the urban planning module of our framework (see Table 5), including 3 households with smart bins and 1 waste picker.

Since the urban planning module does not specify the location of the 26 bins, we manually set the location of each bin. In that sense, all bins are equally distributed

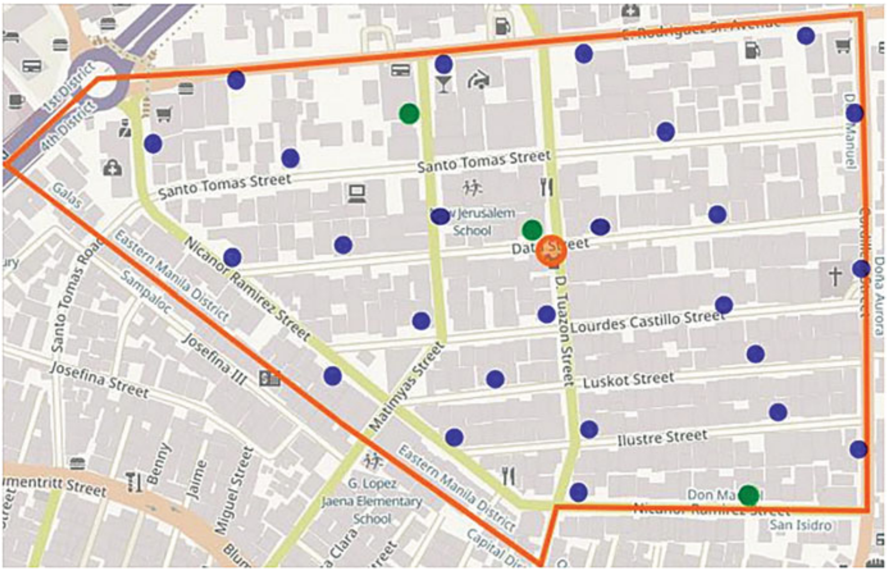

Fig. 20 Visual representation of the municipal waste bin (in blue dots) and household smart bin (in green dots) locations

Table 10 Location of the smart bin and waste pickers in Don Manuel Quezon City

Don Manuel	Address
Smart bin 1	21 Matimyas street
Smart bin 2	89 Nicanor Ramirez street
Smart bin 3	27 Data street
Waste picker 1	51 Cordillera street

in the geographical map of Don Manuel. The locations of these bins are within the range of 100–250 m from each other, which is estimated by computing the minimum distance of bins by dividing the area in hectares (23.8 hectares) with the proposed number of bins (26). These bins are going to be used by the waste pickers to throw the plastic bags collected from the household bins.

For the sake of completeness, Table 10 shows the exact location of the household smart bins and the waste picker in the neighbourhood.

Regarding the data about the plastic waste generated in the households, they were obtained from the low-cost smart bin described in [33]. Briefly, these 3 households are located in the neighbourhood of Don Manuel, which is one of the smallest areas in Quezon City with 0.238 km^2. This neighbourhood also has a higher age group percentage of 12.5% for 20–24 years old and the generation of plastic waste is significantly low compared to the other neighbourhoods in the city because of the small area and population.

The next subsection shows the results for the collection rate of plastic waste in this simulated scenario.

4.2 Simulation Results

Figure 21 shows that the solution achieved an average collection rate of over 80% for bikes, cars, and on foot as a means of transport. The rate of collection for bikes and on foot collection is greater than 60%, which suggests that the proposed system with the use of waste pickers and municipal plastic bins may help to develop a sustainable system that supports the use of bicycles and going from one place to another on foot rather than by car. An additional interesting finding is that when the predictions are based on more items, the collection rate also increases. This is contrary to the findings included in our previous work [33], which achieved a collection rate of 0.8 with bikes or cars as means of transport, whereas on foot the rate significantly dropped.

Furthermore, Fig. 22 also shows the collection rate for each of the different days of the study. The rate of fluctuations for the routes covered on foot is higher than the routes covered by car and by bike. It is worth mentioning that, in evaluations of former versions of our proposal [33], car-based routes showed a higher stability having rates above 70% most of the days and foot-based routes having a rate of 0 on normal days. However, in this new scenario involving the estimated municipal waste bins, walking, and biking routes never reach this 0 rate, as depicted in Fig. 22.

This evaluation comprises the comparison among the existing dumpsite locations in the neighbourhood of Don Manuel (see Sect. 3.2.1) and the 26 on-street containers estimated through the urban planning module of our framework, as presented in Sect. 4.1. This differentiation also involves the waste pickers and household smart bins presented in our previous work [33]. The waste pickers from each cluster will be able to put collected plastic waste from the household to the municipal waste bins instead of the dumpsites closest to them. The most significant change seen in Fig. 23 is the average rate of collection on foot, which is less than 20% and more than 80%, respectively.

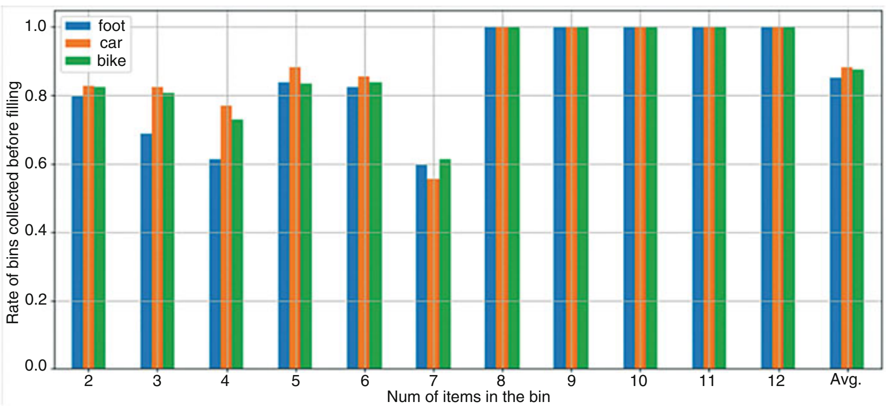

Fig. 21 Collection rate per means of transport and number of items in the bin

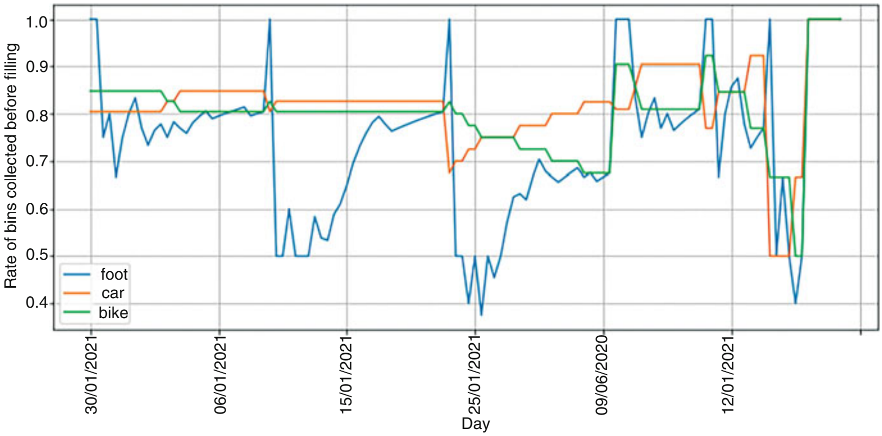

Fig. 22 Collection rate per means of transport and day

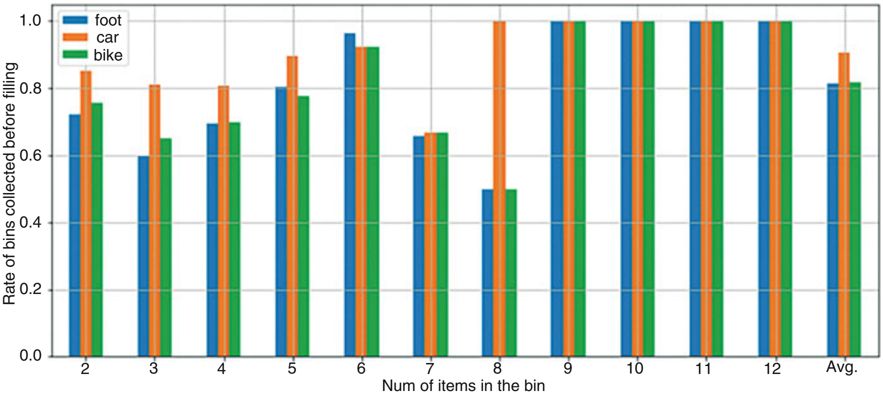

Fig. 23 Collection rate of bins per means of transport with the inclusion of municipal bins and dumpsites

The inclusion of dumpsites in the matrices and collection time series can make a huge difference in terms of the collection rate of the more sustainable means of transport, such as by bike and on foot (Fig. 23). Collection rates by car have increased since the dumpsite is farther from the household bins, waste pickers, and the location of municipal bins. This proves that the concept of municipal plastic bins will gradually help the environment not only with the proper disposal of plastics but also with the environmental friendliness of the means of transport collection.

Additionally, unlike Fig. 22, the rate of fluctuation for the transport of bikes and on foot is higher than Fig. 24 where the rate actually reaches zero during some days which indicates that it was not possible to compose a route able to visit any of the bins. With the dumpsites, the rate of fluctuations of the routes covered by a car is higher or more stable than the other two.

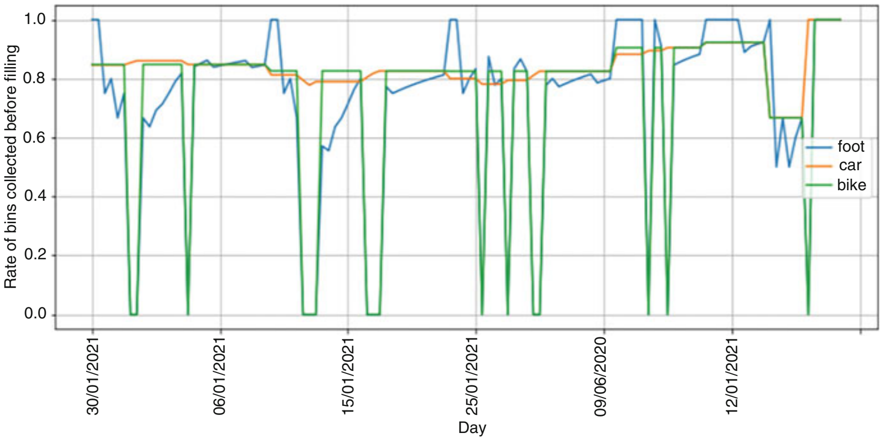

Fig. 24 Collection rate per means of transport and day for route composition

4.3 Evaluation Discussion

With the integration of the household smart bin system which includes the route composition mechanism and the urban plastic waste planning approach, the combination of having waste pickers and municipal plastic waste bins in one neighbourhood is sustainable and efficient in terms of collecting plastic waste and management of plastic waste in a municipal level. The best and most efficient collection showed an average rate of 80% for bikes, on foot, and cars as means of transport based on the number of items in the bins. In conclusion, the waste pickers' collection rate from household bins to the municipal bins implemented by the urban plastic waste planning module is more competent than having waste pickers' routes from household bins to dumpsites.

5 Conclusions and Future Work

The control of plastic waste in urban settlements represents a major challenge in many Eastern countries. As stated elsewhere [34], the impact of visual pollution of plastic waste could eventually damage the residents' abilities to enjoy a view, which can further lead to a negative perception regarding comfort, psychologically and visually. Improper disposal of plastics resulting in microplastics is also harmful to the environment, wildlife ecosystem, and also human health [35]. Furthermore, plastic production has significantly increased during the COVID-19 pandemic. Disposable products such as masks, PPE kits, and gloves have doubled the plastic waste, which makes communities and countries in need of new and creative waste management solutions including the installation of plastic bins in urban areas.

Additionally, citizens with disabilities, seniors, and those in COVID-19 quarantine may have difficulties throwing the plastic waste on a daily basis.

This work has proposed a preliminary analysis for an urban planning method based on the use of open data to estimate the number of plastic bins in developing cities that are struggling with plastic waste management. Thus, a set of variables and data related to the management of plastic bins in several Western cities available in their open-data web portals were collected, with the aim to infer the number of necessary bins in the cities of two Eastern countries. The results of this proposal have been integrated with a low-cost smart household bin, previously introduced in a study elsewhere [33], in order to develop a collaborative and sustainable solution for plastic waste collection. The complete framework has been evaluated in a simulation scenario in Quezon City, Philippines, showing that our proposal allows increasing the collection rate of the collaborative solution up to 80% where sustainable means of transport are promoted to achieve collection rates quite similar to the ones obtained by other more polluting solutions.

The results of this work could serve as a basis for the development of new applications and services related to plastic waste management in cities with limited resources. For example, the use of maps to monitor the status of plastic waste bins could be integrated into the proposed framework. It will make it easier for garbage services or waste pickers to deliver garbage as the map can help determine the nearest bin. Another application may be developed to give out incentives to the users of the household smart bins for plastic recycling.

Future research lines include the use of open data as an alternative of sharing analysed data to the stakeholders and the local community and augmenting knowledge about the accumulation and generation of plastic waste. The collected data from the smart bin can be used to analyse user behaviour such as the number of times they throw plastic waste, the total amount of plastic waste accumulated in a specific interval, and other related research fields such as analysing consumer and recycling behaviour of different types of households. In addition to studying the behavior of different households, it can be essential for future research if we include the difference in climate and temperature of the cities included in the study. Because this solution offers a stepping stone to a complete initiative to control plastic waste in an area in terms of efficient management of plastic waste from the urban planning perspective, future work can focus on enlarging the framework by dealing with the proper disposal of collected plastic waste or repositioning plastic waste in the municipal bins. This would result in a holistic management of the whole plastic waste "pipeline" which would become a valuable resource especially in Western countries such as India and the Philippines.

Another future line of work to be explored would be the application of the techniques presented here to other smart city application domains, such as issues related to water supply networks. A study could be made of the areas of the city with more leaks or more maintenance needs to predict when the renovation of water management facilities will be necessary or study water consumption by zones, to assess the areas whose real (non-census) population is growing or decreasing to predict the needs of other municipal services such as, for example, plastic waste collection addressed in this chapter.

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Mapping Industry 4.0 onto Eco-city Transitions: A Knowledge–Action Matrix

Ioan M. Ciumasu

1 History Shows, But Learning Is Up to Us

To understand the place of Industry 4.0 in the transition to sustainability, we must first examine its premises and clarify what matters for concrete operations. This sub-chapter reviews the grounds for subsequent methodological choices and conclusions.

1.1 Human Society Evolved Between Technology Push and Market Pull

The seeds of technology and industrialization are as old as humanity itself: we trace the evolution of *Homo sapience* through tools, i.e., objects our ancestors created to change their environment and improve their lives. To classify assemblages of Stone Age artifacts, archaeologists use terms such as "industry" and "technocomplex," defined according to basic elements of lithic production used by unrelated human groups over tens or even hundreds of thousands of years across wide geographical areas. These two categories are ranked higher than "culture," which is defined based on a range of artifact types that are thought to be related to a distinct tradition [1,

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2]. These concepts already reflect the recognition by the students of humanity that technology intermediates the relation between us and the rest of nature.

We now live in times that are profoundly marked by planetary impacts of human activity, notably climate changes—an era that geologists started to call "Anthropocene" [3–5]. In fact, we have created a technosphere, i.e., "a globe-girdling web of human artifacts, including buildings, machines, roads, and electronic devices," that fuses with the Earth's biosphere, the result being a "Technobiosphere" [6]. This notion incapsulates the objective reality that all interactions between us and nature are now occurring within interdependencies known as "coupled human and natural systems" (CHANS) [7–9].

The first main leap toward this situation was the Neolithic revolution that started about 10,000 years BCE and marked the shift from the nomadic hunter-gatherers to sedentary agriculturalists [1, 2, 10], an important factor in this change being the climate warming that happened after the last glaciations [11]. This new way of life resulted in large settlements and cities, as more sophisticated forms of socio-economic organization (based on division of labor, notably in the manufacture of exchangeable goods, as well as trade and political power [12]) have favored a succession of long-term cultural cycles that were driven both by local environments and intrinsic social dynamics [13]. During this transformation, the human intellect expanded through coding of individual thoughts and interindividual interactions in ideograms and then in writing systems, and also by transmission of ideas through traditions and arts. This continued with the emergence of consciousness of human values (in the Axial era which saw the emergence of religion and philosophy between the eighth and the sixth centuries BCE, as embodied by Socrates and Aristotle), then the flourishing of knowledge and engineering of the classic antiquity (facilitated by intensive physical and cultural interactions across unprecedentedly large empires) and the era of long-range travels and geographic discoveries that triggered globalization and the emergence of modern science during late Renaissance.

The Scientific Revolution was a series of key discoveries that occurred during the seventeenth and eighteenth centuries on top of knowledge "recovered" from classic antiquity and stimulated the socio-economic developments called Enlightenment and Industrialization. From the standpoint of current innovation studies, this societal transformation traces as a succession of technological revolutions and development cycles (or "techno-economic paradigms"): (1) the first began in 1771 when Richard Arkwright's mechanical (cotton carding and) spinning machine, a water-powered mill opened in Cromford, England; and with James Watt's new steam engine (1765–1776) in Glasgow and Bo'ness, Scotland; (2) the age of railways started in 1829 when the "rocket" steam engine was tested for the Liverpool–Manchester railway, from where it spread to Europe; (3) the age of steel, electricity, and heavy engineering commenced in 1875 with the mass production of low-cost steel at Andrew Carnegie's Edgar Thomson Steel Works plant in Pittsburgh, Pennsylvania, based on the Bessemer process (an era that was particularly powerful in the United States and Germany); (4) the age of oil, automobile, and mass production emerged in 1908 with the serial Model-T, the world's first affordable car, at Ford Motor

Company in Detroit, Michigan; and (5) the age of information and telecommunication initiated in 1971 with the announcement of the Intel microprocessor in Santa Clara, California, and is epitomized by the geographic cluster known as "The Silicon Valley," the world's main engine of computer-based innovation. Each of these was revolutionary because of two key features: a strong technical and commercial interdependence between the participating systems and subsystems and a capacity of certain technologies to transform the rest of the economy and society itself because of their high connectivity with the rest of interdependent sub-systems [14]. The views of historians on this phenomenon may vary. For instance, the presumed role of railways ranges from being as just one of "a multiplicity of innovations that were applied to a broad spectrum of economic processes" to strong statements that "not all innovations had equal effect on economic growth. Railways, however, were undoubtedly one of the most influential during the nineteenth century ... the innovation of the railroads was important in the United States, and this is even more true of Germany, where the industrial revolution cannot be explained without it" [15].

This range of scholar perspectives is particularly reflective of the historical grounds behind the idea of Industry 4.0. But before discussing that in more detail, some other research perspectives need to be mentioned.

Importantly, the correct representation of historical development cycles is through system dynamics, i.e., there is no "determinism" carried by one technology or another, even though some technologies may have a disproportionate influence in certain eras. Instead, we talk about complex effects of novelty and knowledge across networks of interacting actors, no single component being more important than the emergent properties of the system as a whole. Standard statistical mechanics applied to modern economic growth theory shows that when the number of agents in a free market exceeds a threshold value, an income distribution pattern emerges that is similar to a Boltzmann machine, where the entropy intermediates "swarm intelligence" and quantifies the cumulative technological progress of human societies [16]. This provides a basis for considering industrial revolutions as natural leaps occurring right after certain sets of conditions (critical thresholds) are met in their internal functioning.

In the study of systems based on social network analysis and agent-based modeling (ABM) and its engineering counterpart multi-agent systems (MAS) [17–19], the industrial revolutions described above are coherent with the "small-world" effect that is well-known from both natural and man-made systems, from supply chains to road networks, electric power grids and the Internet. Accordingly, the overall efficiency of a network of components making up a system increases when there are some components that are directly linked to many (if not most) other components (in network analysis terms, this means that they have a high centrality) and therefore can act as "facilitators", i.e., provide shortcuts that diminish the functional path between any two components participating in that network. However, growing connectivity may increase creativity and success of a particular node only up to a point/optimum, after which it decreases it, because of increasing homogenization in long-established clusters, which lowers the overall value of exchanges (an inverted-U pattern) [20]. The value of such interactions is even higher when many diverse components co-occur (i.e., there is an expanded space of options). This was the case both in the Mediterranean world during classical antiquity, and the metropoles of sea-faring empires during the colonial era, and is the case now with all major cities. Mathematically, in all such systems, there are optimal tradeoffs between network efficiency and resilience, whereby the structure of the network consists in a core of hub nodes (that insure efficiency) and a periphery of lesser connected nodes (that insure robustness of the whole network, e.g., stability against random removal of nodes or/and resilience to external shocks affecting network functionality) [21–26].

In standard economic growth models, the small-world effect helps connect historic insights with current policy for innovation and development: the small-world effect influences "how increasing economic integration affects firm size and efficiency, norm enforcement, and aggregate economic performance." Specifically, when economic integration is low but local connectivity is high, entrepreneurial behavior is controlled by informal norms that promote cooperation as increasing integration improves investment opportunities. But when economic integration reaches higher levels, cooperation deteriorates and formal institutions are needed, i.e., there is an increasing systemic (societal) demand for strong institutions. An economic boom in that network of actors "is explained by a feedback effect from investment to the formation of long-distance links and the diffusion of knowledge", with the condition that formal institutions are strong enough. If institutions are weak, economy stagnates in a middle-income trap: it remains composed of many low-productivity small firms [25].

1.2 Where to from Here?

Our future depends on society-as-a-whole understanding what science has already established, namely, (a) that we live in complex dynamic systems (CDS) no matter what we want and how we interact with each other; (b) that even if hugely impactful, humans are not separate from nature but are part of it; and (c) that planning is a legitimate aspiration but is limited in practice by the normal misalignments between goals, actions, and action impacts of different types of actors, by different contexts, and by basic properties of CDS, starting with their intrinsic non-linear dynamics and the inevitable uncertainties associated to it [8, 27–29]. This systemic perspective guides our analysis of various professional standpoints from academia, industry, and public administration.

Insights from the study of innovation, management, and world development also add to the conversation. Most importantly, progress is always the product of the interactions between some forms of technology push (e.g., even stone tools enabled humans to try something new) and some forms of market pull (i.e., all demand for whatever works to improve survivability and human life). The results of this interplay are cumulative, so that later techno-economic cycles built on and benefited from (and extended or/and improved) earlier advances. For example, towards the end of the nineteenth century, when the third industrial revolution brought about massive and fast production of steel, the rail industry (specifically, Pennsylvania Railroad) saw an opportunity and funded the Bessemer steel plants in the United States (thus matching technology availability with economic interests) and switched to the new material (coming in great volumes and cheaper: 50 USD/ton in 1875 vs 100 USD/ton 2 years earlier; was readily available, and made rails last 10 times longer). This provided a growing bulk market that helped drive the price even lower (to 18 USD/ton in 1890) and encouraged further innovations. This made possible large-scale engineering works: the United States united its vast territory by means of a well-established and now improved technology [30], while Great Britain achieved its ambition to unite all its empire by undersea telegraph cables [31, 32].

What made the first industrial revolution in Great Britain special was the sheer scale of its market, expanded via colonies (collections of very different territories interacting with each other based on a common set of rules). This favored high-throughput methods for ever-cheaper manufacture of goods, which further allowed commoditization and mass production, hence faster accumulation of reinvestable resources. In the second industrial revolution, the advent of a series of innovations around 1820, e.g., the railway and the telegraph, further amplified this virtuous cycle of progress fueling itself [25]. Nowadays, the European Union itself harbors "convergence clubs" but can also show divergence dynamics [33]. Southern Europe converged until the financial crisis of 2008 and diverged thereafter [34, 35]. Central-eastern Europe is in a process of economic convergence that now overlaps with the transition to sustainable development, which is a unique and creative context that can benefit innovation and investments [36].

From a sustainability studies perspective, Industry 4.0 holds great potentials but has important shortcoming that holds it back. In the remainder of the chapter, I confront Industry 4.0 with the theoretical framework of the systems perspective on sustainability and make a practical critique of it in terms of action options. In brief, this analysis shows that, regardless of chosen historical divisions by different authors, the notion of Industry 4.0 (and related concepts) as originally formulated is not tenable and must be either (i) re-conceptualized to cohere with current knowledge about innovation for sustainability or (ii) discarded to avoid confusion, serious opportunity costs, and unnecessary self-made obstacles to real progress. Finally, I conclude that the most useful way for Industry 4.0 to contribute to the transition to sustainability is to have its conceptual propositions critiqued and absorbed into the systemic perspective on sustainability. It is understandable and desirable that experts from industry or/and public administration try to articulate their experience in terms that can be understood outside of their own work contexts, but these contributions require grounding in modern science. This is not to imply that semantic pluralism is undesirable—quite on the contrary. It simply means that coherent operations across a network of actors and stakeholders require the existence of a valid basis of common denominators, because nobody can indulge in ignoring what other professional constituencies and walks of life have to say about shared societal problems. The fact that politicians and/or administrators and/or business people (and for that matter, the wider public) are not usually trained in science is not an excuse for sloppy policy that escapes scientific and public scrutiny, but a hard argument in favor of serious triple helix science–industry–government dialogues.

2 Potential Utility of Industry 4.0 for Sustainable Development

2.1 The Knowledge Basis Provided by Science

Science is first and foremost characterized by the scientific method, which is a set of principles (necessary conditions) that must be met in the search for truth, usually in a sequence of actions. This boils down to the idea that whatever is proposed to be true (a) must be coherent with known facts and (b) must pass the empirical test of reality (observing and hypothesizing; experimenting and analyzing; confirming-or-rejecting). In a broader sense, science is the core source and main beholder of human knowledge. As for what is knowledge, current philosophy defines it as "justified true belief" (JTB) with some caveats that are still being debated in epistemology. Another more clear-cut definition is through the statement "knowledge tracks the truth" grounding an "epistemological practice of reason justification" [37], involving the addition of a sensitivity condition covering the situations escaping the JTB definition, thus resulting in JTB plus a Justification Condition that is needed to prevent lucky guesses in the analysis of knowledge, i.e., JTB+ [38]. In a practical sense, knowledge is our best set of representations about reality (a consolidated set of models, together with the reasons behind them) and a ground for prediction-based action, e.g., choices and planning for crises response and management [39]. In mundane vocabulary, we talk about modern life being embedded in a knowledge-based economy and society.

In brief, the purpose of knowledge in general and science in particular is prediction, technology being the direct application of this capacity to anticipate. However, prediction is not enough. Knowledge also needs to be operational. This is usually not an issue at small scales (very specific matters only requiring very narrow expertise) but becomes one when we talk about all knowledge across different fields, as required by complex matters like sustainability. To this end, the field of Knowledge Organization (KO) deals with indexing, classifying, and representing (knowledge captured in) documents for information retrieval (IR), electronic or physical browsing, and related processes performed by humans or computers. While IR is dominated by computers executing programs for "match techniques, popularity measures or personalization principles, KO attempts to reflect knowledge as reflected by science and contemporary scholarship" [40]. What matters in practice is explanatory power with respect to evidence. The scientific method originates in philosophical argumentation but is grounded in empirical observation, i.e., it uses induction in spite of its philosophical problems. Induction may have been dubbed as "the glory of science and the scandal of philosophy" [41], but once a "what" empirical pattern has been identified, that philosophical unease is actually useful because it helps clarify the "why" (current theory), and generate the "how" (i.e., current technology and method), which then feeds back additional insights into iterative science advancement. Karl Popper's critical rationalism proposed that science relies on a procedure consisting in conjecturing hypotheses, deducing their potential consequences and then empirically trying to falsify them. Thomas S. Kuhn theorized that, as some representations (abstract models) attain acceptance in a group of people through social (not only psychological) phenomena, commonly held views become normalized as dominant paradigms that unify generations and eras and change with them [42].

In other words, social network dynamics characterizes the history of science too, not only the history of industrialization—for good or bad. In fact, the disconnects signaled in the previous sub-chapter to exist between science and some commercial/public policies are recognizable as lesser desirable effects within such dynamics: "absence of the epistemic justification of reason defaults to the use of an unjustified form of reason that runs the play of an unrecognized and unchecked dialectic between epistemology and science" [37]. This dark side of network dynamics is a cause for concern and a reason for studying how different propositions made in the Agora apply (or not) to the desired transition to sustainability. Nonetheless, science remains our best practical set of representations of reality: a set of reasoned predictive models grounded within communities of actors with complementary expertise [39]. This means that the organization of knowledge in concrete projects aiming at smart and sustainable cities and societies (1) must recognize the limits of cognition and (2) should be derived from the collective representations of relevant communities that keep updating what they know [43].

2.2 The Contribution of Policy: Making the Right Distinctions

In spite of the inherent limits to knowing and the inherent uncertainties characterizing complex dynamic systems, it belongs to us to distill and clarify the big picture so that we can take the best decisions in professional and personal lives. In other words, we must strive for objectivity "to the best of our knowledge." While devising efficient policies for promoting own national interests is legitimate and useful, ideology cannot reinvent reality. A sound policy can have good catch phrases to carry out its message but a catch-phrase cannot replace evidence. Inadvertent subordination of science to rhetoric is not only a self-evident misallocation of resources. Innocent or deliberate, confusions have consequences. Project management and organization studies have already established that (cognitive and) behavioral biases distort resource allocation away from objectively (demonstrably/−ted) best projects and toward those which just look best on paper [44] and from key long-term investments to short-term investments that ignore essential information even when that is right in front of our eyes [45]. Therefore, we need realistic operational frameworks for “understanding how the actions and properties of groups emerge from the way individuals generate and share information” [46].

In other words, policy must be evidence based. As science is the hard core of modern knowledge and the fundament of modern life, one cannot politically or administratively disconnect science from policy-making and then naively believe or pretend that science would just “catch-up” and would come to rescue. In fact, this is one of the lessons learned from the experience of Central European countries (former eastern German lands included) with ideology-driven economic thought, central planning, and forced industrialization imposed by the occupying Soviet Union—a political entity that placed ideology above scientific evidence, with catastrophic consequences on both science and society as a whole [47, 48]. A third of a century after the fall of communism in the region, judging after the enthusiasm with which policy propositions disconnected from objective research are being proposed and pushed in various places across the developed West, it would appear that this lesson is being forgotten for some reasons (I limit myself to making this signal. I leave the readers choose their own examples of denigration of science and related political and commercial manipulations). It is therefore practical and—in line with the United Nation’s Sustainable Development Goals [49] —a moral duty for present and future generations to keep our memory fresh and to cultivate our critical spirit through logical analysis and methodological consistency.

Industry 4.0 is not a concept that emerged bottom-up from science or practical experience (although it was indirectly informed by those, via its proposers who worked in business, policy, and science). It is a policy catch-phrase devised to promote German industrial know-how and trade output based on the brand “Made in Germany” that is normally associated with high quality and reliability. Thus, the features incorporated in the made-up notion “Industry 4.0” are essentially a list of attributes that German companies and policy-makers thought of as key selling points on potential new markets (notably, when the notion emerged in 2015, in very large countries and world regions like China, Russia, and others). Put differently, German policy-makers were fully aware of the great technology push potential of their country’s industry (also supported by massive capacity in its universities and research institutes) and, logically, wanted to channel it toward markets that could exert substantial pull. In this sense, the term Industry 4.0 was a useful unifying reference to backup and open political discussions and to inspire government-to-government negotiations.

Obviously, the relevance of discussions about Industry 4.0 extends beyond Germany and the other industrialized or industrializing and export-oriented economies, because of the high inter-connectedness of modern supply chains, but the issue of shared values like free markets, open societies, and scientific truth (or disregard thereof) is key. In this sense, it is useful to remember the original motivation for the proposition of Industry 4.0: keeping German industry competitive in manufacturing in spite of its high wages [50]. The relation with industrial competitiveness has a particular ring in eastern EU countries, because post-communist transitions came with massive deindustrialization (obsolete factories became scrap metal).

Regardless of the reasons behind this phenomenon (it essentially boils down to chronic underinvestment and the well-known shortcomings of planned economies), this industrial-economic breakdown remained in the public consciousness as a deep loss, an element of collective identity and pride to be recovered by new means in a new era, e.g., by green re-industrialization. It is interesting to note the differences in the impacts of Internet across different contexts within Central Europe. In the prosperous western Germany, Internet has brought to prominence the notions of Internet-of-Things (IoT) and Internet-of-Services (IoS) and policy propositions like Industry 4.0 to make use of those [50]. In lower-income Central Europe (eastern Germany and the other former communist countries), which had suffered from economic crash and a large drop in professional opportunities, Internet facilitated "brain drain", i.e., the emigration of the highly skilled into the more developed West (the author of this chapter included), via online advertisement and online application for jobs and graduate studentships. But then it also generated policy propositions like "brain networking", i.e., internet-based involvement of skilled diasporas in advanced high-value projects across geographies and the local contexts from which they left [51], i.e., ultimately the Internet of People (IoP) [52]. Equally interesting is the question of how to combine these two dynamics through online platforms for generating solutions for sustainable development, notably through Research, Development, and Innovation (RDI).

These being said, we need to clarify what Industry 4.0 actually is. Current evidence shows in a straightforward way that, although it is not a phenomenon observed through scientific research but a policy strategy, it can nevertheless be studied because we must understand the underlying process of policy-making and draw lessons for future policy-making. The right tools for understanding Industry 4.0 are therefore analytical and pertain to objective scientific investigation of innovation, organizations, and all complex dynamic systems. Any other approaches (e.g., ideological or rhetorical) inevitably carry subjective loads and would yield wrong conclusions: at best, naive-therefore-irrelevant, at worse, manipulatory, and would incur unnecessary costs upon us.

2.3 Mapping Industry 4.0 onto Sustainability Transitions: Focus on Cities

The aim of policy studies, themselves a part of the study of organizations and project management, is to understand the phenomenon of policy-making and to distill the aspects and dynamics (including those having impacts on science–business relations) that can serve, in light of extant knowledge, as relevant information for a given topic—in occurrence, the transition to sustainability. For concreteness, this chapter relies on experience and literature to facilitate more in-depth analyses and illustrates its rationale with examples that are focused on cities. Thus, according to the systemic perspective on sustainability [53, 54], any economic system is a

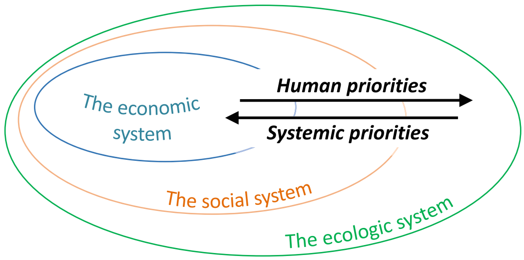

Fig. 1 The nested inclusion relation between economy, society, and nature. The two arrows indicate the conflict between priorities according to people's needs vs. systemic reality. Adapted after [53–55]

subsystem of a social system (i.e., a social system can exist without an economic system but an economic system cannot exist outside a social system), which is itself a subsystem of an ecologic/biophysical system, i.e., a natural system like an ecosystem or the entire biosphere can exist without humans, but humanity cannot exist outside the natural system supporting it (Fig. 1).

This relationship has two operational consequences. First, it allows us to understand, from a systems standpoint, that the main difficulty on the path to sustainability is a conflict of priorities: people act according to a certain order of priorities (first they want to solve their economic problems, then the social problems and lastly the environmental problems) while science says that sustainable solutions require the opposite (and somewhat counter-intuitive) order: because people depend on the carrying capacity of their natural environment, in order to be systemically sustainable (and therefore durable on long term), any solutions to those fundamental problems of people must first integrate environment aspects, then social and then economic. Second, the nested inclusion relation between economy, society, and biosphere can be operationalized based on all available knowledge in the form of Sustainability Filters (Ecologic, Social, and, respectively, Economic): lists of specific requirements that need to be met ("passed") by any potential solution proposition [55]. By combining these two logical consequences, one notices that finding solutions to problems on the path to sustainability involves two phases: the definition of the problem according to what matters for people (i.e., starting with the economic issue and then developing it to include the social and environmental aspects underlying that economic problem experienced by people) and then the articulation of potential solutions according to what the systems need in order to be sustainable (i.e., starting with the environmental details defining the context of interest, then the social grounds and then the economic aspect of ultimate interest that motivates the adoption or not of a proposed solution).

Figure 2 maps this full cycle of sustainable problem resolution, i.e., the series of 3+3 steps, against the stages that describe the development of technologies from an idea to a finite product, i.e., the technology readiness levels [56, 57], under the constraint of thermodynamic efficiency of scientific representation, namely, the Maximum Entropy Principle (MEP), according to which a statistical model (or a concept) agrees with data but is otherwise as "structureless" as possible, implying "maximally noncommittal with regard to missing information" [58–61].

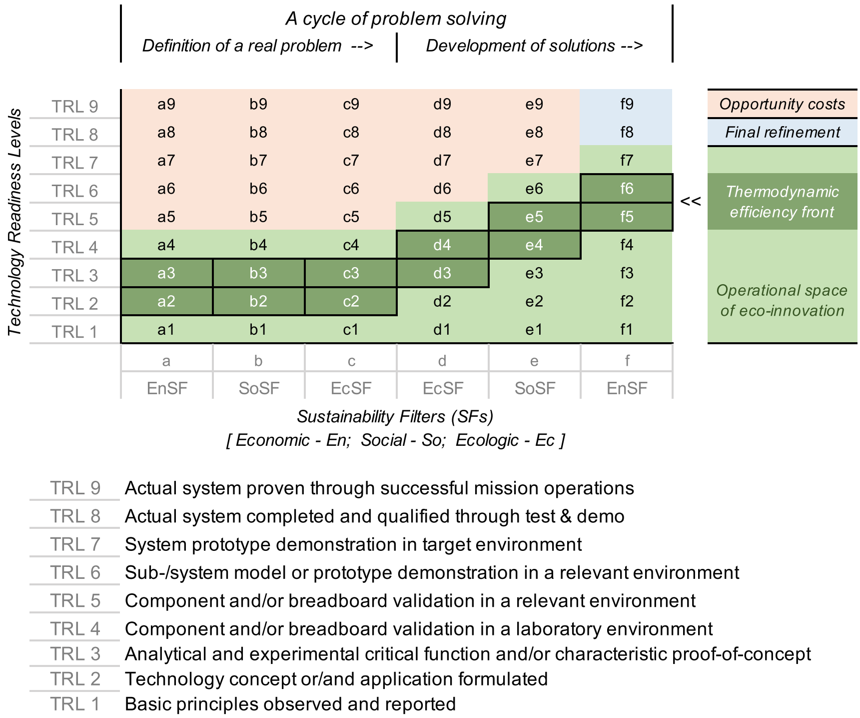

Fig. 2 RDI knowledge–action matrix: correspondence between the problem–resolution process along sustainability filters [55] and the scale of fulfillment of managerial criteria (filters) provided by Technology Readiness Levels (TRL) scale of development of technological solutions [57]

Then, in this state-space model of the advancement of eco-innovative solutions, the most efficient path–from initial economic interest motivating the start of development of a solution (case *a1*) to the demonstration that a potential (prototype) solution works in an environment relevant for sustainable development (cases *f6; f7*) –corresponds to the Manhattan distance:

$$d_{ij} = \left|x_i - x_j\right| + \left|y_i - y_j\right|$$

where (x_i, y_i) and (x_j, y_j) are the lattice graph coordinates of vertices i (= a1) and j (= *f7*), with the additional constraint (prior information coming from the field of innovation management) that problem definition should not go higher than TRL4 level specifications (to avoid premature specialization to economic variables, and also regarding TRL(2–3) as an optimal compromise between the need to obtain in-depth understanding of a problem and the need to avoid premature specialization).

Fig. 3 Identification of a list of concepts of interest on the TRLs–SFs map in Fig. 2 used as adjacency matrix (of a semantic network). "Home" is a target (stable) location of a concept's meaning. The range is the space of possible locations leading to a home

Reality (and its representation)	Home	Range
Industrial Revolutions	a9	a5 - a9
Industry 4.0 (as of now)	a7	a1 - a7
Industry 5.0 (as declared)	f9	f1 - f9
Society 5.0 (as envisioned)	f9	f1 - f9
Sustainable Development	f9	f1 - f9
Sustainability Transitions	f7	f1 - f7
Energy Transitions	f7	f1 - f7
Eco-innovation	f7	f1 - f7
Climate Changes	c9	c5 - c9
Urban Resilience	f6	f1 - f6
Eco-Cities	f8	f1 - f8
Knowledge-Action Models	f9	f1 - f9
Complex Dynamic Systems	f9	f1 - f9
Coupled Human and Natural Systems	f9	f1 - f9
Technobiosphere	f9	f1 - f9
Anthropocene	f9	f1 - f9

Used as an adjacency matrix:

$$A_{ij} = \begin{pmatrix} 0\,0\,0 & 0\,0\,1 \\ 0\,0\,0 & 0\,0\,1 \\ 0\,0\,0 & 0\,0\,1 \\ 0\,0\,0 & 0\,1\,2 \\ 0\,0\,0 & 1\,2\,2 \\ 1\,1\,1 & 2\,2\,1 \\ 2\,2\,2 & 2\,1\,1 \\ 2\,2\,2 & 1\,1\,1 \\ 1\,1\,1 & 1\,1\,1 \end{pmatrix}$$

where the columns i designate TRL1–9 and rows j designate the succession of six steps along the process of problem definition and resolution across sustainability filters, the model is compact-equivalent to a semantic network of the kind used in semantic technologies and knowledge graphs [e.g., 39, 62–64], thus allowing a more straightforward mapping of concepts across different literature parcels and practical interests, e.g., to see how far on the TRL scale can a project or concept be efficient, i.e., when do opportunity costs begin to outweigh benefits defined in terms of sustainability transition in the space state (Fig. 3).

This is the background for discussing the place of Industry 4.0 in current developments toward smart and sustainable cities and societies (in the next sub-chapter). But before that discussion, it is worth linking with other methods. Most notably, this model is equivalent to a reverse Kalman (statistical) filter [65–67], in that you already know the states you want to reach and you use available information to determine which states in the state space are thermodynamically efficient. In the described model, green states above the front represent transitions to the high opportunity cost: not the most efficient but still rather acceptable (because they are not a large diversion from the shortest path and represent potentially epistemically useful situations that bring supplementary information and useful questions). More broadly, the model is also reciprocally compatible with other explicitly entropy-minded models and approaches, e.g., with strategic/targeted data acquisition [39, 68, 69] and data-driven business analytics aiming at compatibility with sustainable development [70, 71].

These being said, placing the concept of Industry 4.0 in a general context of research can reveal intrinsic solutions for recuperating many of its constitutive elements into future-oriented eco-innovation. One good place to start is the modern framework of complexity sciences, notably "complex dynamic systems" and "fractal manufacturing systems," which "allows the introduction of resilience requirements (capacity to react to changes in a turbulent environment) and to reduce the complexity of its structure, operation and management" via modularity [72]. In perspective, this is a most promising aspect of Industry 4.0, because it relates straightforwardly to network properties (and other effects of complex dynamic systems) as already applied in engineering through cluster-detection methods, e.g., different versions of the Louvain algorithm [73–75], (hyper)graphs-based approaches, ABM and MAS [e.g., 75–78].

Modularity also links to core network dynamics as related to different phases of projects aiming at generating new solutions for resilience and sustainability [39, 79] and is a basis for addressing other open issues related to interoperability within CDS [80] and inside environmental-social-economic systems. In that sense, the proposed model allows a mathematical/computational regard on the management of RDI for sustainable development, by representing the process of generating eco-innovation as an optimization problem that can be broken up in subproblems (e.g., the lists of yes/no questions constituting the SFs and the TRLs) that can be decided by expert decisions, i.e., by defining each project as a problem with optimal substructure and then using the Bellman equation and related techniques to facilitate understanding of, and resource allocation within, complex projects. In this sense, the thermodynamic efficiency front in the model above represents the minimal cost function associated with the maximum utility in the final outcome.

3 Discussions

3.1 Where Does Industry 4.0 Fit into This Picture?

Based on a literature-based critique of the concept itself in the broader context of sustainability, the short answer is: as of today, the concept is outside the path toward sustainability.

In the introduction of the concept [50], it was noted that, when we talk about the Internet of Services, "The interoperability of all functions/services that are based on the new cyber-physical systems, including those in open control loops, necessarily goes through semantic technologies" (original text in German: *"Erst durch semantische Technologien wird die Interoperabilität aller Dienste, die auf den neuartigen Cyber-Physischen Systemen aufsetzen, auch in offenen Regelkreisen sichergestellt"*). Furthermore, "The products themselves thus have direct access to all higher-level process data and can 'decide' in detail—while avoiding the loss of information that often occurs in centrally organized systems due to the (necessary) compression of information. This makes it possible, for example, to better meet not only the economic but also the special ecological requirements of 'green production' for a CO_2-neutral, energy-efficient city" (original text in German: *"Die Produkte selbst erhalten so unmittelbaren Zugang zu allen übergeordneten Prozessdaten und können detailgenau ‚entscheiden* "*– und dies unter Vermeidung des Informationsverlusts, der häufig bei zentral organisierten Systemen aufgrund der (notwendigen) Verdichtung von Information erfolgt. Damit ist es beispielsweise möglich, nicht nur den ökonomischen, sondern auch den besonderen ökologischen Anforderungen einer ‚grünen Produktion "für eine CO_2-neutrale, energieeffiziente Stadt besser gerecht zu werden"*). However, one needs to consider and define the systemic problem itself *before* optimizing for efficiency. The presumption that one first becomes "cyber" and then "eco" is unfounded. Sure enough, one can use "cyber" insights up to a point on the TRL scale, but then one needs to go to the right in the series of sustainability filters before going up on TRLs.

The analysis hereby converges with other explicit cross-examinations of Industry 4.0 and sustainability [81–84], which observed that a relation between the two is quasi-nonexistent. In spite of general promises and speculations based on efficiency assumptions, Industry 4.0 gives only a marginal consideration to environmental and social aspects (by hypothetical derivation from the economic gains obtained through automation) and simply ignores the complex dynamic relations between nature, society, and economy. Consequently, the current notion of Industry 4.0 per se is irrelevant for concrete generation of solutions toward sustainability, but each of its component ideas and technologies can independently input the transition to sustainability, e.g., via smart solutions integrated in new eco-innovation/eco-city projects, programs, and scenarios.

In a broader discussion, the concept was indeed a promoter of projects (and hence a useful generator of data, information, knowledge, results, and experience) and was fit for its time, but better concepts are now needed to achieve the transition to sustainability. The alternative implies high opportunity costs, as do all options that fall outside the effective path toward sustainable solutions. Two issues are key. First, Industry 4.0 relies on the idea of highly integrated production systems, but we know from general network analysis that, in any system, optimization for efficiency also means a loss of overall versatility/resilience: this makes it unfit for survival in the transition to sustainability. Second, its business models are grounded in neoclassic economics, which considers inputs such as raw materials (and natural resources in general) as externalities. This is obviously incompatible with sustainable development. Because the impacts of human activity on the environment overstretches the limits of our planet's natural systems' carrying capacity, the tight connection between our species and our planet must be properly recognized, understood, and "internalized," i.e., factored in the economic models sitting behind technology and innovation.

By using the correspondence between TRLs and the six stages described above as an adjacency (co-occurrence) matrix, we can pinpoint the location of Industry 4.0 and other related concepts of interest discussed in the literature and in this chapter. This helps us visualize both the distance between different concepts (and the situations they describe) and the ultimate goal of sustainable development from a combined, technological, and systemic perspective. Thus, concepts that describe the direct or implicit achievement of sustainable development belong to case *f9*. Industry 4.0 may have aimed initially at helping in the transition to sustainability but, in reality, remained inconsequential for social and ecologic aspects, thus being more akin to the technological revolutions from pre-sustainability times. Even though Industry 4.0 is already demonstrated in principle in some sectors, available information only allows us to located it in the case *a7*.

The conflict of real-life priorities between people and their planet is the crux of the current unsustainability crisis of Humanity. This is best illustrated by climate changes and numerous globally relevant sectoral crises starting from conflicts over resources, typically known in economics and sustainability studies under the name "tragedy of the commons." When people do not have a common previous understanding (representation) of their problem and, for that matter, do not coordinate enough, their common resource (of any sort, from a body of water to the entire planet) will inevitably become depleted by individual overuses (as everyone will hurry to use it before somebody else does: a typical situation of prisoner's dilemma and related social dilemmas). There is a silver lining, since we know from practice that people are capable to overcome this type of social dilemmas in local settings. But the grand challenge is (1) finding viable solutions in (almost) all cases around the world and (2) finding solutions at higher-than-local scales, where understanding and action are much more difficult [7, 8, 85].

3.2 How Do Cities Fit In?

In the literature on Industry 4.0, the concept of smart city is usually cited as a prime example of application but the discussion on cities remains confined to technological topics, which highlights the intrinsic limitations of Industry 4.0. This means two things: (1) the notion of Industry 4.0 is very far from competently describing what cities are and can be, (2) expanding the discussion to understanding cities as whole biophysical-social-economic systems can actually help understand better how Industry 4.0 could contribute to successful transitions to sustainability in cities and in human societies.

When we talk about entire human communities, it is important to acknowledge that cities (but also towns and villages, either directly or via their nearest city) have a double character: local and global [86], with identity features like wide international scope and high capacity to attract greenfield foreign investments (FDI) contributing to a city's "smartness" [87]. On the one hand, cities serve as real "growth machines" for their hinterlands [88, 89] and are themselves the product of their local context, notably by their strong reliance on local natural resources, i.e., minerals (water, salt, etc.) and ecosystem goods and services making up the carrying capacity of the local ecosystems [89, 90]. On the other hand, in the twenty-first century's globalized world (and the technobiosphere mentioned in the introduction), planetary fluxes of goods and services (matter-energy and information) and people are best understood as exchanges within a global network of interconnected cities. Some so-called world cities like New York, London, and Tokyo are more influential than others, but all cities (even the smallest) have some contributions and benefits [87, 89, 91–93].

The closeness of a city to sustainability goals is therefore a matter of how advanced that city is in the transition from a purely local identity to a strong local and global identity [86]. Indeed, this is the core challenge for city planners and managers for the next years and decades. In the transition to sustainability, any city that is demonstrably engaged in a process of exploration of potential futures and pursues a transition to sustainability can be considered an eco-city [94, 95]. In this regard, communities are rather unequally advanced: from total ignorance and disinterest to occasional commitments (e.g., sectorial programs) and through to whole-city commitments to sustainable development [96–98]. At the same time, as I discuss in the other chapter I wrote in this book, precisely because of their double local and global character, cities represent a good unit for system-level experimentation and embody the best tradeoff between scales: they are large enough to be representative for the human systems (society) but small enough to keep project management possible. This makes cities ideal for the much-needed systemic experimentation for sustainability [89, 94, 95, 99], on the condition that the beneficial "fluid" network dynamics between cities (as well as between experts in different areas and between them and other knowledge-holder actors) are not destroyed by rigid "one size fits all" kinds of public administration prioritizing control [100].

In such conversations, one pattern is particularly insightful: the use of a "city port" (land-/sea-/air-port) as a basis and hub of development and renewal (or "urban regeneration") of metropolitan areas [101, 102]. This reminds us of the historic role that railways and train stations had in urban and economic development in the nineteenth century [25, 103]. Because they generated noise and pollution, but also because of their peculiar character (i.e., issues related to public health and social acceptance), train stations were initially located outside the town itself but then have gradually been assimilated into local urban shapes and functions—not least because their sheer presence and function stimulated urban development [104]. In addition, train stations had important (and now forgotten) contributions to life styles and social development. For instance, the era of trains was also the era of clocks, and personal (pocket) watches were uncoordinated until professionals and private individuals started to adjust their individual and collective times (and behavior) according to commonly available times like "the clock of the train station." In time, train stations also became physical and mental references: meeting points and, respectively, cultural symbols [105, 106]. In quite a concrete sense, such pre-digital transformations heralded the subsequent urban evolution toward "smart cities".

In today's European context of good public transportation, land areas with very high population densities can be easily connected economically with electricity-powered high-speed trains. This represents a strong competition for the (GHG-emitting) air travels across medium-long distances (300–500 km), which has important impacts on cities and their inhabitants [e.g., 107], notably in terms of local and broader agendas related to mitigation of (and adaptation to) climate changes, especially the systemic transition to renewable sources of energy. Together with advanced communication technologies, such changes in modern life and work have already generated a plethora of concepts, like inter alia, "multi-modal transportation," and "smart grids." These concepts started out in the same conversations that inspired Industry 4.0 but now connect more easily to sustainability goals and thus have a clearer potential to participate in viable new techno-social-economic configurations toward smart cities and societies.

3.3 We Need a Science-Based Regard on Industry 4.0 to Re-make It or Break It

The idea of Industry 4.0 (or fourth industrial revolution; in German, *Industrie 4.0*) follows its own division of history, where the first three cycles of the five series described above (Sect. 1.1) are collapsed into a single "first industrial revolution" in which handcraft was largely replaced by machines. Then, from a German viewpoint, there was a "second industrial revolution" that started with the turn into the twentieth century and was characterized by mass production (roughly equivalent to the 4th industrial revolution from Sect. 1.1), followed by the third one (5th in Sect. 1.1) dominated by automation of production "via electronics and IT" [50]. These being said, Industry 4.0 actually corresponds more to a deep phase of their third industrial revolution (era of computers) only "enriched" with robotics, artificial intelligence, nanotechnology, and biotechnology. Then, this way of dividing history may hold from a local German perspective, notably because the first three industrial revolutions generated in Western Europe by technology–market interplay actually spread into Germany later (and mostly as one big wave), in the form of state-driven development of rails and heavy industry in the final quarter of the nineteenth century [15]. But it has no broad basis in the literature on world development, and its authors didn't actually claim one: their proposition was published (in German) in a news outlet of a technology and business association, advertising an upcoming talk scheduled in 2011 at the Hannover Messe, an industrial fair held yearly in the city of Hanover. Afterward, the term reverberated abroad and quickly became popular, (a) presumably because of the strong international influence of the German industry, but also, as it has been argued in the field of management, (b) because the particular wording in this construction has the typical properties of a fashionable meme [108]. In other words, many concepts have some intrinsic virtues, but this particular term may have taken off because of some strong rhetorical attributes and in spite of its lack of a clear intellectual structure [75]. Last but not least, it seems that the hype around it has peaked and now is on a downswing [109].

Meanwhile, certain policy-driven teams working on behalf of (or in collaboration with) the European Commission (EC) show a certain confusion around technological-social-economic terminology. The EC talks about the so-called industrial "greening" intended by the EC-proposed "Green Deal" as being a "Third Industrial Revolution" [110]. In some other conversations and public documents, the term "Industry 5.0" has been proposed as a new vision that "actually nests the Industry 4.0 approach in a broader context, providing regenerative purpose and directionality to the technological transformation of industrial production for people-planet-prosperity rather than simply value extraction to benefit shareholders," i.e., a "human-centered" and more "value-driven" approach, unlike Industry 4.0, which is "technology-driven." In principle, Industry 5.0 appears better, as it comes closer to sustainable development goals. However, the documents making these propositions lack scientific justification (indeed, even broader academic references are quasi-totally marginal in those documents). This simply leaves EU-proposed concepts in uncertainty, as a mere product of some group with an interest in the topic but whose (type and level of) expertise is unknown or unproven [111–114]. On the one hand, such terminological inconsistencies are understandable: they just bring out some legitimate questions and searches. Policy makers contradict themselves but scientists also contradict themselves; this is how science works at the frontier, and this is also how policy-making proceeds before practical consensus is reached through active critique and improvement. "Chaotic" vocabulary reflects the normal hesitations that are caused by the fast development of science and technology and the complexity of the problem of interest, all in a context of chronic persistence of simultaneously occurring unresolved societal problems which different actors perceive as falling within their purview. Indeed, semantic pluralism is necessary and to be expected in healthy debates at the frontier of progress. Basically, the European Commission and the EU states are in a process of searching ways forward. On the other hand, searches and debates are only effective when they enable real-life operation, which underscores again the key role of science and the need for "a new social contract for science and scientists" as explicitly anticipated 25 years ago [115].

All in all, since the term Industry 4.0 has gained a certain traction and embodies the current tensions between science and society, it does warrant purposeful clarification [116]. By contrast, the current definition of "Industry 5.0" ignores science and appears more like a political manifesto. At best, it comes as just another rhetorical opportunity for brandishing a new fashionable term, as the limitations of the "already-old meme" Industry 4.0 are becoming more obvious [75, 108, 109]. At worst, it betrays some intents or propensities that may exist in some professional or/and political circles to substitute science with ideology in the process of policy-making. For the practical purpose of this chapter, the notion "Industry 5.0" has no real content to analyze.

Industry 4.0 was proposed as a policy concept driven by national industrial and business goals [50]. As such, it leaves aside key historical details and debates concerning innovation patterns in socio-economic systems and simply attempts to conceptualize the promise of computing power-driven highly integrated automated manufacturing (in short, cyber-physical production systems) in a way that would allow German industry to assert itself globally. Although the term was initially more generous, notably aiming at stimulating the broader transition to sustainable development, it quickly evolved to narrowly highlight the capacity of big companies to optimize manufacturing lines. This (1) contradicts societal sustainability goals and also (2) puts the more innovative but less resourced small and medium enterprises (SMEs) in a position where they have to either ignore the entire Industry 4.0 movement or become critically dependent on large international companies. This was probably not the original intent of its authors, which were explicitly aware of the great importance of SMEs for the German economy [50].

Versions of Industry 4.0 are known from different Western economies, e.g., "Industria 4.0" in Italy, "Industrie du future" in France, "Manufacturing USA" and "smart manufacturing" in the United States, and "Made smarter UK" in the United Kingdom [117], alongside terminological counterparts in East Asia. In 2015, China launched the program "Made in China 2025," which complements the Belt and Road Initiative (BRI) [118] and appears to strongly emulate Industry 4.0 as a political strategy (i.e., more than a policy) to move from low-end manufacturing to a high-tech profile that would compete with the West [80, 119, 120]. This approach has already triggered a strong backlash from Western countries displaying their own technological nationalism [120] and wasn't particularly successful in practice [118, 122], but remained in place and might be upgraded in the next 5-year plans of China. Another interesting notion is "Society 5.0" proposed in Japan [123], which echoes Industry 4.0 (in its search for a society where people's life is enhanced by artificial intelligence and cyberphysical systems) and is being echoed back by Industry 5.0 with the idea of a "human-centered" society. Therewith, Japan seeks to carve for itself a role of global pioneer in man–machine interactions and futuristic technologies that also recuperate tradition into politically driven visions, a process that has been called "imagineerism" [124].

This global "game of memes" can be properly understood if it is placed in the broader context of the world's economy and communication technologies: national institutions try to gain pre-eminence in public arenas so as to influence the international "ecosystem" of economic actors and nudge advantageous economic dynamics, e.g., to attract foreign domestic investments (FDI) into their own country and to facilitate access of national firms to foreign markets. Such strategies do not exclude sustainability —quite on the contrary, they can fuel creativity and stimulate eco-innovation. While the United States is by far the world's RDI and business leader and the pace-maker of the world economy, the EU tries to position itself as the world's leader in "green growth" (a "green dealer"), and China tries to consolidate up its production capacity so as to become an all-times necessary manufacturer. But global supply chains are undergoing profound changes.

In this sense, very relevant is also the recent emergence of another fashionable term: circular economy. Originating with environmental engineers, it broadly refers to the proven or potential benefits of recycling, in the logic of cradle-to-cradle monitoring of a product's life time so that the making of a physical product avoids unnecessarily excessive use (therefore extraction) of natural resources, and thus helps diminish the environmental footprint of that product. If used in its original context, the term "circular economy" is appropriate [125]. Outside of it, however, the term has no scientific basis and does not apply (which does not mean that certain of its underlying ideas cannot find further useful application, but that this becomes a different level of a highly technical discussion). This basic observation, however, is not an obstacle for those that are interested more in the symbolic and rhetorical possibilities of the words composing the construction "circular economy." In spite of its epistemic and operational shortcomings [126, 127], this term is being uncritically used in non-scientific conversations and non-evidence-based policy-making. It has become a terminological abuse turned into political credos loaded with personal preferences and a starting point for scientifically unfounded claims and flawed arguments. The original term was pulled out of its technical basis and drawn into an ideologically motivated "battle of buzzwords" [128]. An extensive critique of the term "circular economy" would fall outside the scope of this chapter. Suffice it to say, within the broader discussion on Industry 4.0 and sustainability that unreserved promotion of unstudied constructions like "economic circularity" is naive: it shows a lack of basic understanding of natural biogeochemical cycles and of the fundamental properties of natural (and man-made) complex dynamic systems. It comes as an illusionary promise of quick fixes through "silver bullet" policies or technologies, and it obscures the fact that real solutions are themselves systemic and require sustained effort to develop: in-depth study, creativity, experimentation, test, and optimization. Inasmuch as it disregards such efforts and the lifetimes of those who have been doing the hard-but-right work, this hardens already difficult problems and creates new ones. All this "activism" imposes on all of us a giant waste of valuable resources, and it squanders the already short time that humanity may still have to become sustainable.

In brief, in any effort to understand Industry 4.0 and related notions, we are talking about national policy attempts to position local industrial capacity in the international competition for techno-economic preeminence, and while this or that country (or actor in general) dreams about "playing the first fiddle" in at least some sectors, inadvertent advocacy of scientifically illiterate views leads to disaster.

Finally, this highlight leads me to another issue that requires attention. Yes, it should go without saying that rhetoric is no substitute for science, and replacing evidence with ideology creates more harm than good. Still, debates over techno-economic paradigms should stay open: conceptual explorations should be understood as a natural part of our social interactions. The becoming of knowledge is part of our modern ethos; ultimately, it is about what it means to be human [129]. For what this chapter is concerned, by using the holistic-systemic regard upon sustainability, the proposed model facilitates practical integration of ideas from different angles that may appear hard to connect. For example, all works related to *ju-RAMI*—the "legal reference architecture model 4.0" (in German: *juristisches Referenzarchitekturmodell Industrie 4.0*), which accompanies some of the German funding schemes for Industry 4.0 and is directly relevant for smart grid architectures integrating different energy sources in the transition to a low-carbon economy [130] —belong to the social subsystem (in the nested inclusion relationship evoked here) and thus provide practical descriptors for the SoSF sustainability filter of the model.

4 Conclusion and Outlook

Policies and management must be grounded in a good mastership of different concepts that come and go in academic and public agoras. Politics may be the "art of the possible" but ancient and recent history proves that ignoring or dismissing scientific evidence through ideology and voluntarist policies results in catastrophic social experiments. As with the Michurinism and Lysenkoism in soviet-dominated regimes ("We cannot wait for Nature's good graces – to take them from her is our goal" [47]), such approaches have failed and would fail again. Similarly, restricting our attention to the "1% inspiration" and away from the "99% transpiration" behind progress (as in the popular saying attributed to Thomas Edison), or giving preference to actions that are naively or deceptively motivated by clichés like "we must show that we are doing something (even when the objectively best course of action is doing less or nothing)," is self-destructive because this obliviates the reality that we live in (and depend on) complex dynamic systems. Attaining sustainability requires us to work with nature (not against it); legitimate politics protects dialogue and resists dictatorial or/and populist rush temptations. We need to fully acknowledge the fact that sustainability is not some mythical game to be hunted with a silver arrow by some demigod hero but a hard issue and a serious societal goal that requires cogent action and co-operation between actors and stakeholders.

To that aim, this chapter has reviewed the grounds for modern industrialization ideals as incapsulated by the notion of Industry 4.0 and has proposed a way forward by combining the basic sets of necessary but insufficient conditions (expressed as managerial filters) for systemic sustainability and technology development, to generate a state-space model. This was then used as a backdrop for a critical analysis of the notion Industry 4.0 and as a start basis for discussing other approaches and public ideas toward smart (and sustainable) cities and societies.

As summed up in Fig. 4, the central finding is that Industry 4.0 is not (as such) on a path to sustainability but many of its components can independently inform the making of solutions toward sustainability. To that aim, one logic place to start could be within the original limits of "circular economy" principles, i.e., recycling [84, 131], but on the condition that such actions do not self propel to toxic extremes. On the one hand, policies and projects must avoid undue generalizations, i.e., not to exacerbate politically or commercially driven exaggerations and overpromises

GENERAL CONCEPTS	Sustainability Filters: EnSF	SoSF	EcSF	Sustainable Development
Paleolithic / stone age	yes/no	yes/no	yes/no	yes/no
Neolithic revolution (12-8th centuries BCE)	yes/no	yes/no	yes/no	yes/no
Industrial revolutions (18-20th centuries)	yes	yes/no	no	no
Neoclassical economics	yes	yes/no	no	no
Industry 4.0 (as such)	yes	yes/no	no	no
Industry 4.0 (components)	yes	yes/no	yes/no	yes/no
Ecological economics / 'green growth'	yes	yes/no	yes	yes/no
Progress of Economy (GDP per capita)	yes	yes/no	yes/no	yes/no
Progress of Science	yes/no	yes/no	yes/no	yes/no
Progress of Education	yes/no	yes/no	yes/no	yes/no
Progress of Social Life & Institutions	yes/no	yes	yes/no	yes/no
Industry 5.0 (as declared)	yes	yes	yes/no	yes/no
Society 5.0 (as envisioned)	yes	yes	yes/no	yes/no
Circular economy	yes/no	yes/no	yes/no	yes/no
New technologies (ML-based included)	yes/no	yes/no	yes/no	yes/no
Open innovation (favoring IP-sharing)	yes/no	yes/no	yes/no	yes/no
Eco-innovation	yes	yes	yes	yes
Eco-cities	yes	yes	yes	yes
Smart cities	yes/no	yes/no	yes/no	yes/no
Technobiosphere / CHANS	yes/no	yes/no	yes/no	yes/no
Non-renewable energy sources	yes/no	yes/no	yes/no	yes/no
Renewable energy sources	yes/no	yes/no	yes/no	yes/no
Reduction & elimination of toxic pollutants	yes/no	yes/no	yes	yes/no
Environmental protection in general	yes/no	yes/no	yes	yes/no
Climate Change (mitigation of)	yes/no	yes/no	yes	yes/no
Climate Change (adaptation to)	yes/no	yes	yes/no	yes/no

Fig. 4 The general status of Industry 4.0 and related notions vis-a-vis the main sets of requirements for compatibility with sustainable sevelopment (i.e., necessary but not sufficient conditions) as summarized by sustainability filters (economic – EnSF, social – SoSF, ecologic – EcSF; see Fig. 2) and the logic outcome to be expected

that violate the basic laws of physics and are akin to ideas known in the history of science as "perpetuum mobile" and other myths. On the other hand, only covering a narrow set of requirements (as per usual) as a way to avoid big mistakes does not equal progress either. In the complex dynamic systems in which we live, box-checking individual requirements means that (a) sustainability may still be missed, i.e., the transition to it "isn't over until it's over" and (b) sustainability per se represents a dynamic equilibrium that can be lost again if misunderstood or disrespected (with devastating negative consequences in terms of opportunity costs and societal demotivation). Instead, if the biophysical, social, and economic details of sustainability are placed in a systemic perspective, projects can gain internal structural coherence and, consequently, can rely on a knowledge–action matrix of resource allocation that follows a thermodynamically optimum path which protects value, avoids waste, and allows intelligent use of existing ideas, methods, and tools.

The same caution of equilibrium applies across the board, useful insights coming out from experiences in all sectors. For instance, approaches based on "open innovation" are not focused on technological innovation alone but seek broader value creation [132] and thus can profoundly contribute to eco-innovation. In the same vein, one observes that the systemic transition to renewable energy sources is still incipient. Most technologies aiming at mitigating climate changes by reducing CO_2 emissions are currently in their early TRL stages [133] and therefore the planning horizons of intended policies depend on the learning curves of technologies that may (or may not) become mature on medium and long terms [134–136]. A similar reasoning applies to many environmental management and policy issues, from complex pollution in densely populated land areas to coupled bio-physicochemical dynamics in the hydrosphere [e.g., 7–9, 55, 137–139].

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Part IV
Innovative, Connected and Monitored

Smart Roofs System: Moisture and Temperature Monitoring on Smart Roofs

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1 Introduction

Sustainable development is a wide-ranging concept that brings challenges with theories adjusted by worldviews of different organizations, such as big companies, governments, social reformers, and environmental campaigners. All of them give their own meaning on what sustainable development means, which in turn affects how issues are expressed and actions proposed. Sustainable development is often presented as the intersection of three main sectors: economy, environment, and society, aiming to give the three together in a sensible way, settling conflicts [1].

One of the ways to improve sustainability in society is by increasing product durability, and the need for lower building energy consumption has led to research and development of new adaptive materials for the built environment [2]. Increasing durability increases competitiveness, because the longer the service life, lower will be the cost of the service that a product provides per unit of time. Furthermore,

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maintenance costs will be reduced with the decrease in the replacement of structures and recovery of degraded parts [3].

It is important to point out that, about issues related to sustainability and environmental responsibility, the construction industry has had a significant impact on resources, environment, society, economy, and human health. CO_2 emitted by the production of construction materials is more than those emitted by the transport industry [4]. Furthermore, buildings are responsible for more than 40% of the global energy consumed and approximately one-third of the gases emitted. Data such as these increase the need to reduce the production of construction materials. Increasing the durability of buildings and their components means reducing the need to produce and build new buildings and components/materials, which represents a direct reduction in environmental impact caused by the construction industry.

Fast urban development in cities tends to ignore the environmental and social aspects of urban life. A substantial amount of natural landscape is changed into building mass and hard surfaces, creating environmental risks for existing and future cities [5]. Urban regions tend to be warmer than the rural areas that surround them; this phenomenon is called an "Urban Heat Island" (UHI). Those cities and towns have been studied for decades and have been demonstrated that UHI is caused by many elements including the large use of man-made materials such as asphalt and concrete in urban areas, which results in the loss of evapotranspiration and in larger heat storage capacity [6].

Over more, latest research includes an emphasis on both improving building performance and on mitigating excess urban heat with the research of reflective rooftops capacity to save energy and to cool urban heat islands. The use of reflective exterior surface materials and urban vegetation (i.e., street trees and green roofs) are the most promising and common methods of mitigating urban heat and enhancing building performance [7].

As part of a construction, a roof is the top of a building which serves as protection against weather conditions such as rain, snow, heat/sun, and wind. Because of increasing demands for comfort and durability, recent years witnessed a surge in advanced roof developments in terms of design, material composition, and space utilization. For example, a flat roof with a slope of less than 10° allows its use as a habitable area, which is more common in hot climates, in commercial spaces. Furthermore, its use has also increased for architectural reasons [8].

Watertightness is immediately thought of as one of the functions that depend upon the performance of waterproofing materials, either traditional solutions, such as some bituminous membranes, or non-traditional, such as liquid products or systems [9]. Another important feature in growing demand is the ability of the roof surface to reflect the incoming sunrays, so as to prevent/dissipate heat and keep the roof fresher than a conventional one, even when subjected to high values of solar radiation [10].

Research, development, and innovation in the field of building materials have led to the emergence of a wide range of certifiable, beneficial products, and systems [11]. The industry of waterproofing materials has already generated many new solutions that can be applied in mono- or multi-layer systems where each layer has a specific function [12].

The waterproofing solutions available on the market are mainly of two types: prefabricated (roller membranes), such as asphalt, PVC or Poliurhea fabrics and liquid membrane solutions (mortar) [14–16]. The solutions that Saint-Gobain Weber Portugal [12] currently commercializes are liquid polymer membranes—acrylic or polyurethane resins—solvent-based. The solvent base solution incorporating polyurethane (PU) [17] has satisfactory technical performance but is an imported product requiring a specific production process. Furthermore, during the application, it requires additional safety conditions mainly due to emissions of VOC (Volatile Organic Compounds) and potential presence of isocyanates that are very harmful to the health of the applicator [18]. According to Healthy and Environment Alliance [19], the scientific evidence on the many links between buildings and health has increased substantially in recent decades, proving that, sometimes, the characteristics of a building carry a wide range of health risks. Many of the resulting problems are caused by toxic substances emitted by some building materials (e.g., VOC and isocyanates) [20]. Even in extremely low quantities, these can be carcinogenic or have an impact on the respiratory tract, allergic, or immunological effects, among others. Thereby, they present risks to users (construction professionals) and the inhabitants and who end up being in constant contact with these substances. The importance of choosing toxicity-free materials for buildings is also highlighted in a report, named "The Role of Safe Chemistry and Healthy Materials in Unlocking The Circular Economy," by Ellen Macarthur Foundation [21], which also points out that, besides being less polluting and ensuring the construction of a healthy home and work environment, it promotes recycling of materials according to the principles of the circular economy. Moreover, it can also boost the looping of materials at the end of its use. The development of liquid membrane solutions in aqueous dispersion is crucial to present more sustainable and less polluting solutions. This type of membrane is easier to formulate and has a high elasticity [22]. However, this type of solution still has performance and durability limitations when compared to other liquid-based waterproofing solutions. Its use is therefore limited when it requires resistance to the action of atmospheric agents and superior mechanical resistance, mainly when applied on roofs, and where it becomes extremely necessary to its watertightness and consequently high cracking resistance [23]. In addition, the existing solutions have different colors [17, 24], ensuring greater reflectance, lower thermal amplitudes in materials and, consequently, lower risk of cracking [25]. On the other hand, in most cases, mechanical performance (resistance to cracking and punching) is improved by combining these membranes with a nonwoven sandwich-shaped incorporated [26]. The success of this combination, however, depends on a set of factors such as chemical compatibility between the textile nonwoven structure and the solvent used in the waterproofing membrane. In case of incompatibility, the result is the dissolution/degradation of the non-tissue and consequent loss of mechanical performance of the system and physical compatibility between the same materials [27]. This issue is truly relevant, especially in ensuring that the drying process of the applied membrane takes place without delay by the action of the non-woven textile structure. This process is natural when the waterproofing membrane is solvent-based but can be difficult if its base is aqueous, considering the natural tendency of water absorption and retention of textile fabrics. Considering the above, it is admitted that the current cracking resistance methodology required by the applicable normalization is hardly representative of what may occur on site. In fact, it is common for technicians to indicate the difficulty of performing the test under reproducible conditions, and ultimately, it is unconvincing to ensure that the results remain in use.

Given the presented, and considering these potential limitations, the Smart Roof System project intends to develop a liquid membrane of polyurethane in aqueous base that presents equivalent technical performance to the best solutions of liquid membrane solvent-based, with the environmental and health advantages referred above. The system will use an innovative textile reinforcement structure as a complement to the process of drying the aqueous-based membrane where appropriate (for example, in colder and wetter weather). This structure will comprise the integration of an active heating system with temperature and moisture sensors working as indicators of the degree of drying/humidity and temperature in the system for application of new layer of the waterproofing membrane. Furthermore, the continuous monitorization of the signals coming from sensors will be indicators of a potential or existent rupture of the system with water infiltrations.

Specifically, this contribution presents the first steps for this advanced roof waterproofing system composed of a water-based polymeric membrane with infrared (IR) reflective additives, reinforced with a smart textile substrate used to optimize the advantages of this innovative waterproofing, thermal reflective, and fast drying water-based polymeric membrane. Based on the study of different types of yarns and pattern drafts, a textile reinforcement structure was developed in accordance with predefined technical requirements as grammage, thickness, mechanical and chemical resistance, and low hydrophilicity. Furthermore, in this work, yarns were used, made with low hydrophilicity materials in balance with specific pattern drafts to enhance the fast-drying process of the membrane, which happens through the evaporation of water. The integration of printed sensors on the waterproofing membrane structure is proposed to monitor both the moisture content and temperature. The measuring of the moisture is intended to aid in the comprehension of the membranes' drying process, meaning the period at which the membrane can be considered completely cured. Furthermore, a continuous monitorization of moisture after curing of the membrane is important to detect early roof infiltrations. The temperature monitoring can provide valuable insights regarding the occurrence of thermal events that can impair the integrity of the membrane structure. In the future, temperature sensors will also be crucial for the active heating system control on the waterproof structure.

Results show that the waterproof membrane presents a TSR capable of reducing the risk of cracking. The developed textile reinforcement structure presented higher robustness when integrated with the water-based polymeric membrane and was created following all the technical requirements defined in Smart Roof Systems Project. Regarding the monitorization of moisture and temperature, the innovative printed sensors developed for this project were successfully integrated with the waterproof structure and could sense the moisture and temperature successfully.

2 State of the Art

This section presents the literature review of the most important works related with the evaluation of surfaces, the existent reinforcement textile on the market, and the development of printed sensors.

Flat roof systems top surface consists of a coating impermeable to fluids, like rain. Nonetheless, finish coatings present defects, such as cracking that lead to water penetration. Degradation agents, include solar radiation, temperature and relative humidity fluctuations, and action of rain. To reduce this defects, EAD 030350-00-0402-Liquid Applied Roof Waterproofing Kits, refers the use of solar reflective coatings, for the purpose of protection against solar radiation. It is considered thar 99% of solar radiation comprises wavelengths (λ) ranging from 300 to 2500 nm [28, 29]. The solar spectrum consists in solar radiation that reaches the solar surface and includes ultraviolet (UV), visible light (Vis), and infrared (IR) radiation [30]. The solar radiation falling on a surface can be absorbed, transmitted, and/or reflected. In addition to these processes, surface roughness and emissivity, which quantifies the emitted energy of a surface, and has impacts on surface temperature [31]. Thus, it is important to measure the surface reflectance capacity along the solar spectrum, as a function of the wavelength. In specific IR radiation, which has a high impact in surface temperature without contributing to the color observed in the material [32]. That color results from the incidence of visible radiation on human eye, without certain wavelength, which were absorbed by the observed/colored surface, giving it color. Thus, the color perception, which must correspond to human eye interpretation, is a subject to personal interpretation. To patronize this evaluation, the international commission on illumination (CIE) developed the CIE lab system, based on primary colors, that specifies colors and color differences in a clear and systematic way, based in three color coordinates, L*, a*, and b*. Coordinate L* measures the surface luminosity and varies from 0 (back) to 100 (white), coordinate a* correlates tones red (+a*) and green (−a*), and coordinate b* tones yellow (+b*) and blue (−b*). The color difference—ΔE^*—reflects the human eye perception of color difference and it is calculated based on the geometric coordinates L*, a*, and b* [30]. To achieve the goal of reducing the membrane defects, avoiding cracking, it is essential to develop innovative impermeable membranes with improved thermal management properties. This development requires implementation of thermal performance characterization techniques in the developed solutions that may include functional solutions, such as IR reflective agents.

Based on existing reinforcement textile for waterproofing structures available on the market, it is possible to highlight that the pattern draft woven structures can be critical to the drying process and final mechanical performance. In case of non-woven fabrics widely used in this segment, as solvent-based membrane reinforcement, i.e., geo textile non-woven fabric in PP and PES form Jaeger [33], the closed structure hinders the membrane drying process, as it absorbs the material and delays the water evaporation and does not allow a combined composite between the materials resulting in a layered system. In addition, these non-woven fabrics present low tear resistance. At the same time, woven fabric structures with a very open mesh draft pattern and density also do not respond to the balance between mechanical reinforcement, quick dry, and the membrane ease of transfer through the fabric. The glass fiber mesh coated with acrylic resin [34], also applied as waterproofing membranes reinforcement, is an example that an open structure can allow membrane transfer, resulting in a more homogeneous composite than in the case of non-woven fabrics, but it does not presents sufficient mechanical strength to reinforce and improve the membrane mechanical properties. Moreover, both non-woven fabrics and glass fiber mesh show considerable loss of tear strength when exposed to the highly alkaline environment promoted by the membrane. Such observations demonstrate the lack of qualified products on the market and guided the definition of technical requirements needed for the development of a differentiated and qualified reinforcement textile structure.

Over the last years, printed electronics have been widely explored for the development of functional and smart devices. This growing interest is mostly related to the compatibility of printing techniques with flexible and stretchable materials, allowing the production of conformal devices with added value [35]. Other advantages are related to the low-cost of production and the reduced complexity of these processes, specifically when compared to conventional technologies [36, 37].

Printing techniques can be classified as indirect or direct processes, whether a mask is employed or not to print the desired patterns [38]. Particularly, screen printing is the most known indirect technique due to its simple process and wide exploitation in several industrial sectors. This technique resorts to a porous screen mesh with designed patterns (known as open areas) that define the printing mask. During the printing process, force is applied on the screen mesh with a moving rubber blade, allowing the passage of the respective ink through the open mesh and depositing it onto the substrate, therefore replicating the desired pattern [35]. Given the nature of this process, it can be easily scalable for mass production, achieving high production throughputs [39].

The compatibility of printed technologies with several substrates broadens the range of possible applications [37]. One of the most interesting examples is the textile substrates, which are washable, stretchable, and conformal smart solutions can be easily produced with a seamless integration [40]. By acknowledging these characteristics, several reports can be found in the scope of printed textiles. Kuzubasoglu et al. [41] developed a temperature sensor for wearable systems directly printed on a textile structure by resorting to an ink-jet process. A polyamide-based taffeta fabric was the selected substrate, being its surface compliant with the sensor's direct printing without any previous treatment. Three types of inks compatible with the ink-jet rheological properties were produced to evaluate their performance as a resistive temperature sensor. The most promising response was obtained with a CNT/PEDOT:PSS sensor, which exhibited a sensitivity of $-0.31 \pm 0.03\%/°C$

and also a good mechanical stability. Komazaki and Uemura [42] reported the development of a humidity sensor on a polyester textile based on a PDMS/$CaCl_2$ micro-composite. The sensor was fabricated by screen printing, being composed of conductive electrodes, a passivation layer, and the composite as sensing layer. The capacitive response of the sensor followed a non-linear behavior, which was not significantly affected when under a bending state. In an alternative approach, Mattana et al. [43] integrated printed temperature and humidity sensors in a fabric by using a conventional weaving process. Initially, sensors were produced on polyimide substrates by adopting an ink-jet technique. Afterward, stripes containing the sensors were inserted into the textile as a weft yarn (by replacing a standard yarn). From the experimental results, the temperature sensors exhibited an extremely linear and fast response, whereas the humidity sensors demonstrated the required ability to detect variations in the humidity, even though with a long response time.

Nevertheless, research works explored in literature are predominantly oriented for wearable applications and do not refer to printed sensors directly integrated on reinforcement structures for waterproofing systems. Moreover, other sort of proposed solutions for this specific application are seldom reported. Sophocleous et al. [44] developed a sensor based on screen printing techniques for *in situ* and real-time monitoring of moisture on concrete. To assess it, the modification of the concrete's electrical resistivity is measured between conductive electrodes by resorting to a four-point probe method. The sensor is produced as a 3D structure and exhibits a high wear resistance to the corrosive environment, being directly implanted in the concrete during construction.

3 The New Smart Roof System

This section presents a detailed explanation of the developed moisture and temperature monitorization system. The Smart Roof System depicted in Fig. 1 represents a conventional flat roof composed of four layers. The first one is concrete, followed by an insulation board. On top of that, it is possible to find two layers of cement mortar reinforced with a fiberglass mesh. Since insulation materials are porous and without significant mechanical resistance, this component is relevant to ensure compatibility with the different insulation materials and guarantee mechanical resistance of the waterproofing system. The last component, which is the subject of investigation in this contribution, is constituted by two layers of a waterproofing membrane reinforced with a smart textile.

Specifically, in Fig. 2, it is possible to understand the waterproofing membrane with more detail. This system is composed of two layers of a waterproof and thermal reflective water-based membrane reinforced by a smart textile which includes temperature and humidity printed sensors. This innovative reinforcement textile was created to improve the mechanical properties of membrane, to maintain sufficient strength after loss of resistance caused by the alkaline environment and to enhance the fast-drying process of the membrane, which happens through the evaporation of

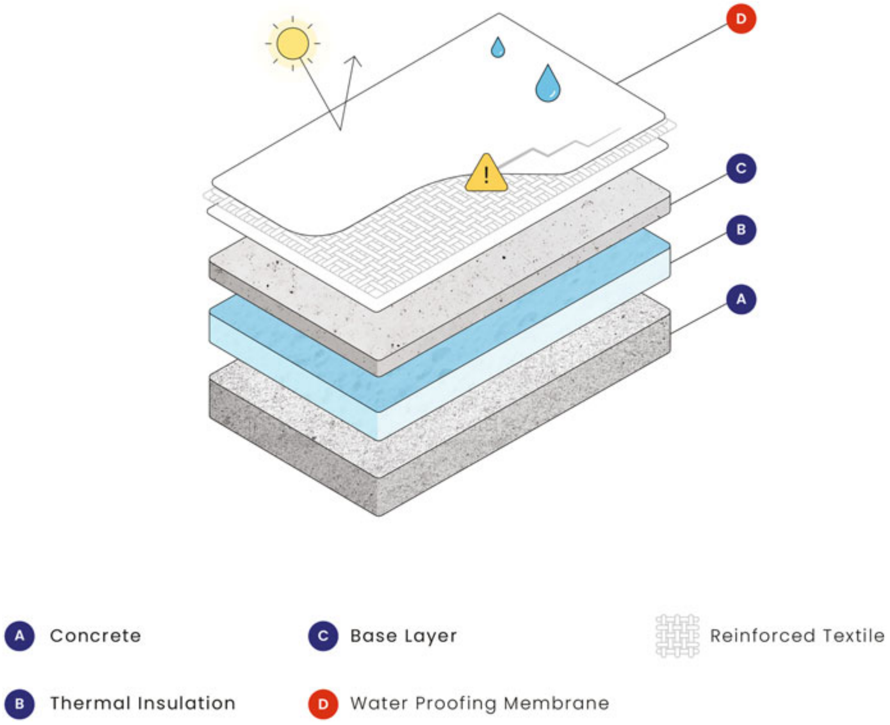

Fig. 1 Smart roof system

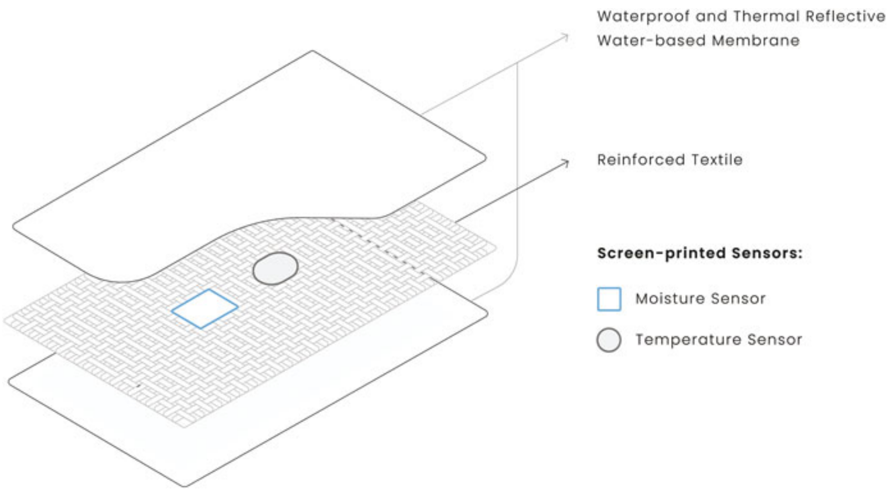

Fig. 2 Advanced roof waterproofing system

water. The printed sensors are used with the purpose of monitoring the structure's internal state, allowing an analysis of the drying process state during the curing process and to evaluate the internal state of the structure during its life cycle.

Following, the different components of the advanced roof waterproofing system, depicted in Fig. 2, are explained in detail, highlighting all the innovative aspects of this intelligent structure.

3.1 The Waterproof Membrane

To evaluate the thermal performance of the surfaces, it is important to assess the surface total solar reflectance (TSR), color, and surface temperature. The implementation of these methodologies was verified in a sample produced with PUD aqueous membrane from Saint-Gobain Weber Portugal (Fig. 3). This membrane is a water-based dispersion of polyester-polyurethane resin, in a concentration ranging from 40% to 70% w/w, one or more radiation reflection enhancer additive in a concentration ranging from 3% to 10% w/w, a polyurethane rheological agent in a concentration ranging from 0.01% to 0.10% w/w, an alkaline pH regulator between 0.01% and 0.1% w/w, usually amine based, to stabilize the dispersion, wherein the membrane forms a film at a temperature above 5 °C inclusive, elongation at break of 500%, tensile strength of 8 MPa, tear strength of 27N/mm (both measured by ASTM D412-06 and AST D412-00), and a viscosity ranging from 50,000 to 100,000 mPa.s.

Following, each methodology used to obtain the TSR, color coordinates, and thermography are explained in detail.

Fig. 3 Sample of PUD aqueous membrane from Saint-Gobain Weber Portugal

3.1.1 Total Solar Reflectance

The TSR quantifies defuse and specular reflection of the surface, based on ASTM E903: Standard Test method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres ranging from 300 to 2500 nm [45], TSR results are based on the reflection spectrum obtained from the sample and results from the integration of reflected percentage per solar irradiance (Eq. 1) for the ranging wavelength.

$$\%\mathrm{TSR} = \frac{\int p(\lambda_i) \times E_{\lambda i} \times \Delta_{\lambda i}}{\int E_{\lambda i} \times \Delta_{\lambda i}} \tag{1}$$

$$\Delta_{\lambda i} = \frac{\lambda_{i+1} - \lambda_{i-1}}{2} \tag{2}$$

Where %TSR is the total solar reflectance percentage over a given range of λ, $p(\lambda)$ is the percentage of reflectance for a given λ, $\Delta_{\lambda i}$ is the range of the wavelength integration, and $E_{\lambda i}$ is the standard spectral irradiance defined in ASTM G173 [46]. The implementation of these methodologies was verified in a sample produced from PUD aqueous membrane from Saint-Gobain Weber Portugal, Fig. 3. The determination of TSR was performed through an UV-Vis-NIR spectrophotometer CARY 5000 with a 150 mm external DRA-2500 integrating sphere, calibrated accordingly to procedures detailed in the ASTM E903-96 standard. All specimens were conditioned at a controlled room temperature of 23 °C and 50% relative humidity for a minimum period of 24 h.

3.1.2 Color Coordinates

The determination of color coordinates was performed accordingly to ASTM D 2244-Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates and ASTM E 308-01 Standard Practice for Computing the Colors of Objects by Using the CIE System [45, 47]. An UV-Vis-NIR spectrophotometer CARY 5000 with a 150 mm external DRA-2500 integrating sphere, calibrated accordingly to procedures detailed in the ASTM E903-96 standard was used for the analysis. All specimens were conditioned at a controlled room temperature of 23 °C and 50% relative humidity for a minimum period of 24 h. Reflectance spectrums were obtained for the wavelength range between 400 and 700 nm, with a wavelength interval of 10 nm at six different zones per specimen of each sample. The CIE 1964 supplementary standard observer was 10° with a D65 illuminant.

3.1.3 Thermography

IR thermography is a non-destructive technique that allows the mapping of the surface temperature, based on the inherent capacity of all objects above absolute zero emitting infrared radiation. The analysis system is composed of an IR source, an IR camera, *Flir A320*, and a data acquisition system. The IR camera quantifies the IR radiation emitted by the object, through Stefan–Boltzmann equation (Eq. 3) that allows the formation of thermography [48, 49].

$$E = \epsilon \sigma T^4 \tag{3}$$

where E is the radiative heat flux ($W \cdot m^{-2}$), T is sample's surface temperature (K), σ is Stefan–Boltzmann's constant ($5.67 \times 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}$), and ϵ surface emissivity (ϵ).

The test method for determination of total hemispherical emittance of materials was performed according to ASTM C 1371—Standard test method for determination of emittance of materials near room temperature using portable emissometers [50]. An emissometer (D&S) model AE1 RD1, calibrated before each measurement, was used for the analysis. All specimens were conditioned at a controlled room temperature of 23 °C and 50% relative humidity for a minimum period of 24 h. The emittance of opaque and conductive materials is obtained through direct measurement with the emissometer, performing six measurements per sample. An emittance value of (0.85 ± 0.02) was obtained for the analyzed specimen.

3.2 *The Reinforcement Textile*

The technical requirements defined for the development of the textile reinforcement structure are related with the grammage, thickness, mechanical and chemical resistance, and low hydrophilicity of it. Following such technical requirements is justified by the need for a lightweight and flexible reinforcement textile structure that is thick enough to comply with the standard minimum thickness for reinforced waterproofing membranes (2 mm), with bidirectional resistance to improve the mechanical properties of membrane and maintain sufficient strength after loss of resistance caused by the alkaline environment (pH 12–14) promoted by the membrane after application and during the life cycle. Also, using yarns made with low hydrophilicity materials in balance with specifics pattern drafts to enhance the fast-drying process of the membrane, which happens through the evaporation of water.

To achieve these goals, continuous 100% recycled PES (polyester) composition filament yarns with a linear mass of 167 × 2 dtex and a twist of 300 turns/meter

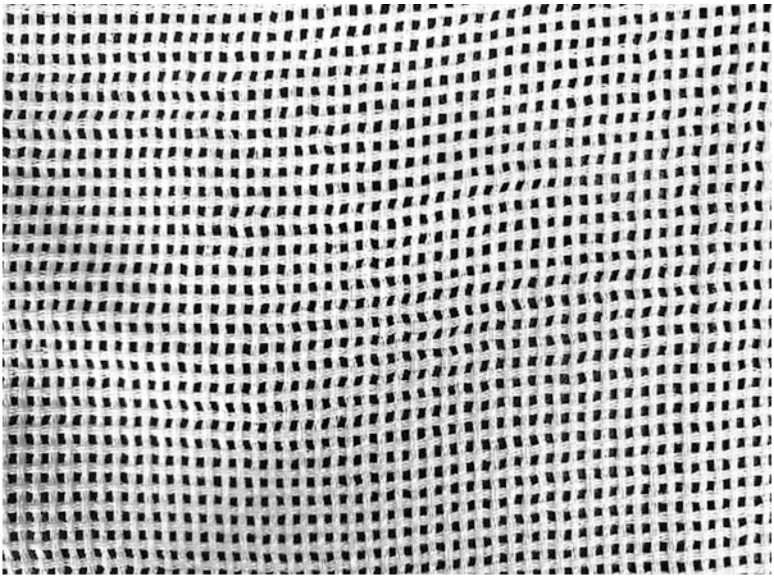

Fig. 4 Woven fabric structure R22

were used in the direction of the warp (19 yarns/cm) and weft (23 yarns/cm) of a woven fabric structure denominated R22, depicted in Fig. 4.

In terms of the texture, the pattern draft and density of the R22 warp and weft yarns were defined, to develop the woven fabric structure with a small mesh pattern (1.5 mm). This allows the optimal membrane transfer through the structure, promoting its adhesion with the textile structure and fulfilling the requirements of low grammage (155 g/m^2) and thickness (0.8 mm) with high bidirectional tear strength on the overage of 300N and breaking strength on the overage of 1200N. Specifically, the twist of 300 turns/meter conferred the best relation between the increase mechanical strength desired without damaging the filaments and the yarns' characteristics. It was also possible to observe that this yarn twist reduces the loss of resistance caused by the alkaline pH of the membrane as the twist difficult the chemical attack on the yarn core. After the application of the membrane, the R22 tear strength showed to be higher than the usual market systems (waterproofing solvent-based membrane reinforced non-woven fabric/glass fiber mesh). The pattern draft of the R22 woven fabric structure was also designed and developed to enable the integration of printed humidity and temperature sensors. In addition to all the technical parameters achieved in the development of this textile reinforcement structure, the physical properties of lightweight, malleability, and flexibility allow an easy handling and application on construction site, according to the professional workers. Regarding application workers and, as an advantage, the water-based membrane does not affect the health of the applicator, due to the low level of COV emission, not being necessary the use of protective individual equipment during the application process.

3.3 The Printed Sensors

Printed humidity and temperature sensors were designed to comply with the parameters of grammage, thickness, and mechanical and chemical resistance (e.g., exposure to highly alkaline environment (pH 12–14)) specified for the reinforcement textile structure. Following, each type of the developed sensors is explained in detail.

3.3.1 Moisture Sensor

Printed moisture sensors can be defined as resistive or capacitive, whether the sensing material has a dependency of its electrical resistivity or relative permittivity on the surrounding moisture [51]. In the scope of this study, a capacitive principle was considered, with the membrane itself acting as the sensing material of the sensor. One of the main advantages of this type of principle is related to the fact that the sensor does not require a direct contact with the environment that is being monitored, preventing its early damage and improving its lifetime [52].

Due to the selected transduction principle, the sensor can be designed in a simple way. The device proposed in this work is based on two coplanar conductive electrodes parallel to each other. When integrated on the membrane structure, the electrical capacitance measured between these electrodes changes according to the drying of the membrane. Since this phenomenon is translated by a loss of water, the dielectric properties of the material change as a function of time [42].

Furthermore, it should be noted that, for printed sensors, the capacitive response is influenced by the distance between the electrodes. Nonetheless, an important aspect to consider is related to the performance of the reinforcement textile structure after the sensor's integration. The textile structure has periodic openings that are fundamental for the correct cohesion between the base and top membrane layers. When a printed sensor is integrated on the textile, it inevitably obstructs the openings coinciding with its area, hindering the binding of the layers, and therefore minimizing the performance of the reinforcement. As a result, the sensors must be designed in a way that their impact can be disregarded, which can be attained by developing devices with reduced dimensions.

After selecting a configuration for the sensor according to the abovementioned aspects, several devices were screen printed by resorting to a commercial silver ink. These sensors were printed on polymeric substrates and then laminated onto the textile structure with a polyurethane membrane, also working as a protection membrane to the printed film. The produced sensing textile was further integrated in the membrane structure as represented in Fig. 5, with the sensor being oriented downward.

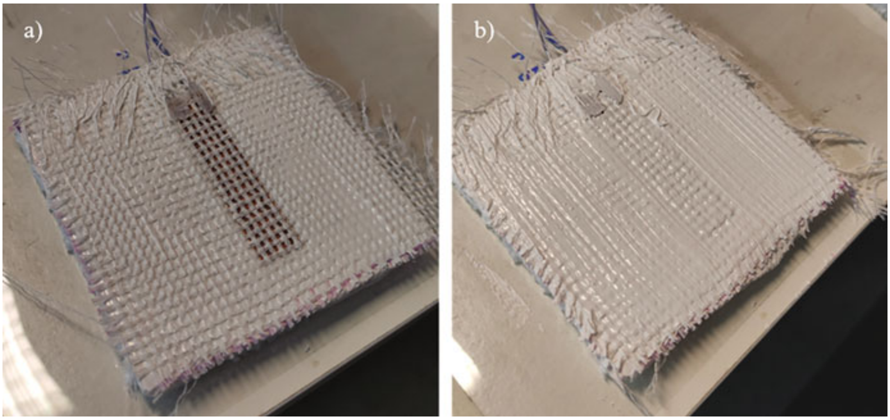

Fig. 5 Integration of a printed moisture sensor in the waterproof membrane: sensing textile inserted on top of the base layer (**a**) and first top layer deposited onto the textile (**b**)

3.3.2 Temperature Sensor

Regarding the operation principle of printed temperature sensors, they can be simply divided in three groups: resistive devices, thermistors, or thermocouples [36]. Both resistive devices and thermistors rely on the temperature dependency of the electrical resistivity of their respective sensing material, respectively, a metal and a semiconductor [53, 54]. In contrast, thermocouples reckon to the thermoelectric effect, being based on a junction of two materials with distinct Seebeck coefficients [55].

By acknowledging the final application of this work, a resistive operation was selected due to its simple transduction principle and typical linear behavior within the temperature ranges that must be monitored. Additionally, several metallic materials are compatible with the properties required by screen printing inks, with these exhibiting an outstanding performance and stability. For the purposes here described, a commercial silver ink was selected to produce a reliable sensor for further integration in the waterproof structure.

Furthermore, an important aspect considered in the development of the printed sensor was related to its geometry. Since the textile structure must be capable to absorb the membrane and allow the binding between the base and top layers, the integration of the sensor on the textile is expected to have a negative impact on that behavior. Therefore, to minimize this impact, the sensor's geometry was designed to have a circular shape with a diameter of 2 cm, without compromising the reading sensitivity.

After these initial definitions, temperature sensors were screen printed onto polymeric substrates and then laminated on the textile structure with the aid of a polyurethane membrane that also works as a protective layer of the printed film. Figure 6 demonstrates the integration of the sensing textile in the membrane

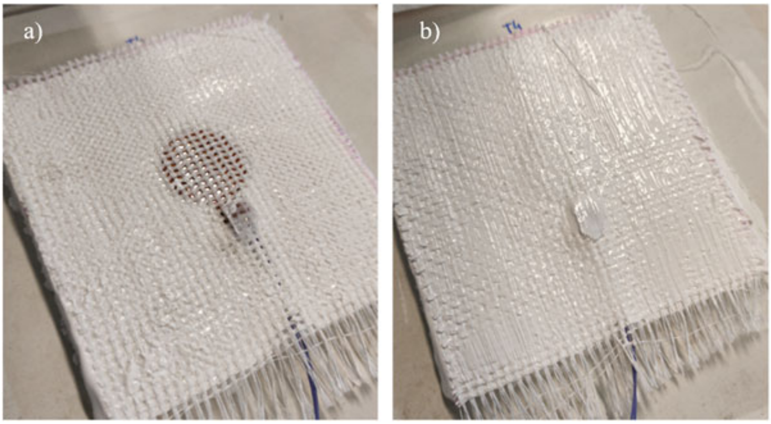

Fig. 6 Integration of a printed temperature sensor in the waterproof membrane: sensing textile inserted on top of the base layer (**a**) and first top layer deposited onto the textile (**b**)

structure for further evaluation of sensor's performance. As for the integration methodology, the base membrane layer is firstly deposited and then the textile is embedded on top of that layer, with the sensor being oriented downward. Subsequently, the top layers are further applied, bonding with the base layer on the areas that are not obstructed. From Fig. 6 it is also possible to observe the obstruction imposed by the sensor when the textile is inserted on the membrane.

4 Results and Discussion

This section starts by presenting the dedicated electronic system used to characterize the developed printed sensors. Next, the results obtained in the thermal performance evaluation of the waterproof membrane are introduced. Following, the results regarding the tear resistance of the developed reinforcement textile are presented. Finally, at the end of section, the printed sensors response, when laminated on the reinforcement textile and integrated with the waterproof membrane, are presented.

4.1 Electronic System for Sensors Characterization

To adequately characterize the developed printed sensors, a dedicated electronic system was developed. The architecture of the developed hardware is depicted in Fig. 7. The board can simultaneously read data from eight digital, eight capacitive, and eight resistive sensors. To correctly characterize the printed sensors, the ground

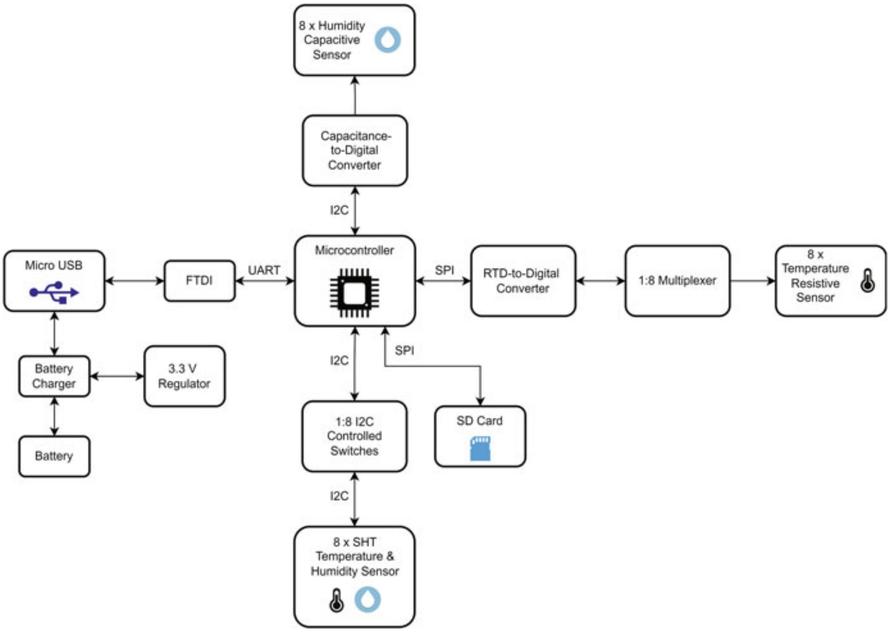

Fig. 7 Architecture of developed hardware

Table 1 Electronic components

Module	Electronic module
Battery charger	BQ24078
Regulator	TPS63051
Microcontroller	PIC18F27K42
Capacitance-to-digital converter	FDC2114
I2C controlled switches	TCA9548A
RTD-to-digital converter	MAX31865A
Multiplexer	ADG708

truth was obtained by reading digital commercial humidity/temperature sensors (SHT31 [56]) during experiments.

Electronic components used to implement the different modules described are presented in Table 1.

4.2 *Membrane Thermal Performance*

The evaluation of the membrane thermal performance is demonstrated below by analyzing its total solar reflectance (TSR), color, and temperature.

4.2.1 Total Solar Reflectance

TSR is the percentage of irradiated solar energy reflected by the sample. For its determination, reflectance spectrums were obtained for a wavelength range comprised between 300 and 2500 nm at six different zones per specimen. According to standard E903 and using the reference solar spectrum from the standard ASTM G173-03, the TSR and TSA were calculated for the entire range of wavelengths associated with the solar spectrum (300–2500 nm), as well as the division by the different spectral regions (UV, Vis, and IR). In addition, considering that the sample is opaque, total solar absorption (TSA) which is the percentage of irradiated solar energy absorbed by the sample was determined. Average values of solar reflectance and solar absorptance obtained for the analyzed specimens are shown in Tables 2 and 3.

From Tables 2 and 3, we can observe that the PUD aqueous membrane from Saint-Gobain Weber Portugal reflection capabilities decrease from Vis, IR, and UV radiation, being 91.5 ± 0.4, 86.1 ± 0.3, and 12.1 ± 0.1, respectively. Due to its opacity, the absorption values, for the radiations evaluated follow an inverse behavior to the reflection. This resulted on an average TSR and TSA of 85.2 ± 0.3 and 14.8 ± 0.3, respectively.

4.2.2 Color Coordinates

Color coordinates, based on the average values of reflectance obtained for the analyzed specimen, are shown in Table 4.

Table 2 TSR of PUD aqueous membrane from Saint-Gobain Weber Portugal

Total solar reflectance (%)	85.2 ± 0.3
Solar reflectance for UV region (%)	12.1 ± 0.1
Solar reflectance for Vis region (%)	91.5 ± 0.4
Solar reflectance for IR region (%)	86.1 ± 0.3

Table 3 TSA of PUD aqueous membrane from Saint-Gobain Weber Portugal

Total solar absorptance (%)	14.8 ± 0.3
Solar absorptance for UV region (%)	87.9 ± 0.1
Solar absorptance for Vis region (%)	8.5 ± 0.4
Solar Absorptance for IR region (%)	13.9 ± 0.3

Table 4 Color coordinates of PUD aqueous membrane from Saint-Gobain Weber Portugal

Coordinate	Value
$L*$	97.00 ± 0.04
$a*$	−0.08 ± 0.02
$b*$	3.61 ± 0.02

4.2.3 Thermography

The sample's surface thermal profile when exposed to approximately 500 W per m^{-2} of IR radiation is shown in Fig. 8. It is possible to observe (Fig. 9) an increase in sample surface time along with IR exposure time. Nonetheless, due to the limitation of radiation source power, ambient temperature, and sample thermal properties, a temperature stabilization at approximately 67 °C is achieved after 20 min of exposure to IR radiation.

These performance tests explored different characterization techniques and proved its applicability to the development of innovative impermeable membranes with improved thermal management properties.

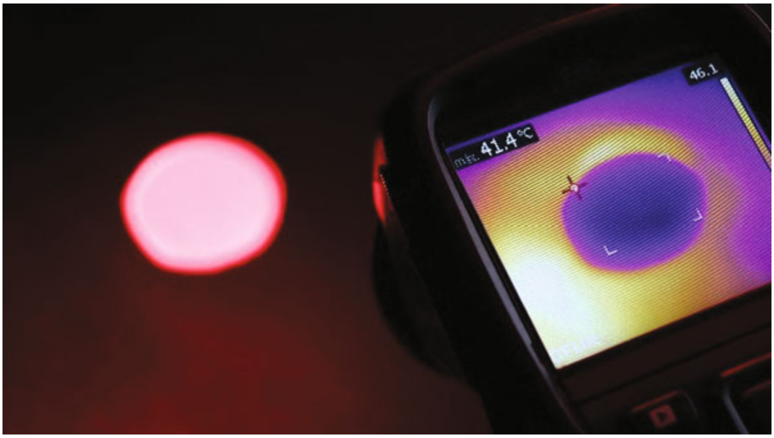

Fig. 8 Sample exposed to IR radiation

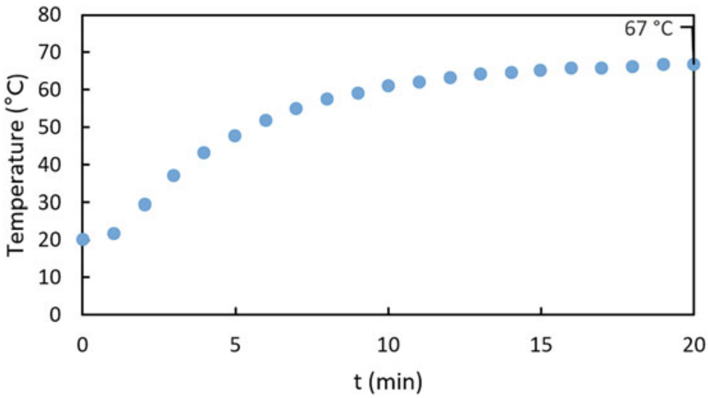

Fig. 9 Sample's surface thermal profile, while exposed to IR radiation

Table 5 Tear resistance of waterproofing structure

Property	Standard	Waterproofing system	Other (prior art)
Tear resistance (N)	EN ISO 13937-4:2000	Length–110N Width–120 N	Length–42N Width–34 N

4.3 Reinforcement Textile

Table 5 presents a comparison between the tear resistance obtained for the innovative waterproofing system (water-based waterproofing membrane and reinforcement textile) developed in this work and a typical solution presented in market. The solution of prior art comprises a similar water-based membrane integrated with a PES non-woven fabric.

As seen in Table 5, the tear resistance imposed by the reinforcement textile structure, presented in this contribution, is considerably higher than the solution of prior art. The reinforcement textile, developed in this work, thus presents a bidirectional resistance to improve the mechanical properties of membrane and maintain sufficient strength after loss of resistance caused by the alkaline environment (pH 12–14) promoted by the membrane after application and during the life cycle.

4.4 Printed Sensors Response

The results regarding the printed sensors response are presented below. First, the moisture sensors response after the deposition of the waterproof membrane is shown. After that, the temperature sensors response after the integration on the advanced waterproofing system is presented.

4.4.1 Moisture Sensor

The evaluation of the capacitive response of each sensor was initiated immediately after the deposition of the top layers, as presented in Fig. 5. With this characterization, it was intended to understand the behavior of the capacitance as a function of time to ascertain about the variations that result from the drying process of the membrane. Figure 10 presents the behavior of one sample during this assay, being representative of the remaining samples under test.

As seen in the presented graph (Fig. 10), the behavior is given by an initial increase of the capacitance (increase of dielectric constant) which can be related to the cohesion of the base and top membrane layers, affecting the material distribution. Following the peak in the capacitance, the values start to decrease (decrease of dielectric constant) with the loss of water present in the membrane, resulting in a reduction of the moisture content. To define the threshold at which

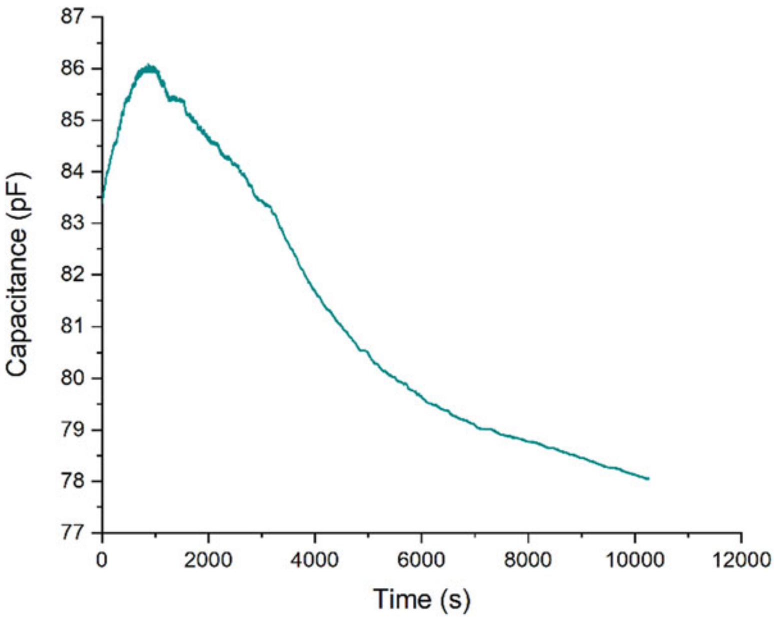

Fig. 10 Capacitance behavior of a printed moisture sensor integrated in the membrane structure, after the deposition of the top layers

the sample can be considered dried according to the required specifications, the capacitance must be further correlated with the moisture values.

At this stage of work, the obtained results suggest that the integrated sensors resisted to the alkaline environment of the membrane without damages that could compromise their integrity and hinder their correct operation. Therefore, the selected materials and processes exhibit an excellent compatibility with the reinforcement textile structure and membrane proposed.

An additional test was performed with samples that presented cracks on the dried structure to understand how that occurrence could be further detected by the sensors. A volume of 2 mL of water was deposited on top of the samples, while the capacitance of the embedded sensor was registered as a function of time. Figure 11 comprises the results for one of the cracked samples subjected to this test, as well as of a non-cracked sample for comparison.

From the analysis of the capacitive response, it can be observed that the sensor detects the presence of water on its surroundings by increasing the capacitance value, which can be easily identified to define a threshold value. This response is then followed by a decrease to the base capacitance with the drying of the sample. In contrast, by analyzing the results obtained with samples without cracks, no relevant changes on the capacitance were detected. Therefore, this analysis seems to be suitable to identify the presence of cracks in the membrane, which are not desirable in a real application, or even the occurrence of other damages on the structure. It

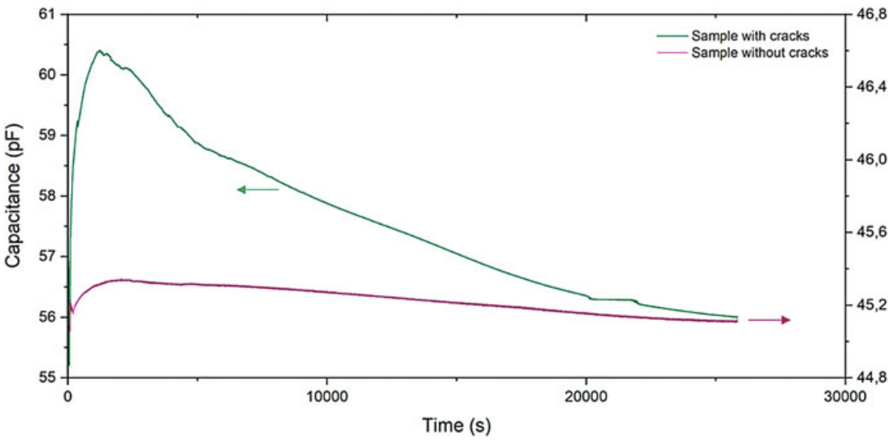

Fig. 11 Capacitive behavior of a cracked sample due to the deposition of water on the top surface of the structure

is important to notice that this information requires the presence of water, as for example, in an event of rain.

The discussed results validate the solution proposed in this work, with the integration of moisture sensors in the reinforcement textile structure to monitor the membrane's drying process and to measure its moisture content for an extended period, as well as to detect other events. Since this type of solution is not currently available on the market, these results can be of high value in the scope of the intended application.

4.4.2 Temperature Sensor

After the integration of the sensors on the waterproof structure, the respective electrical resistances were initially evaluated to ascertain if the membrane alkaline environment compromised the devices' integrity. From this analysis, no significant changes were observed when comparing the resistance values measured before and after the integration, suggesting that the sensors' materials exhibit a good chemical resistance.

Once guaranteed the integrity of the sensors, the characterization proceeded with the determination of the resistance behavior as a function of temperature, establishing the respective calibration curves. The prepared samples were analyzed on a climatic chamber, with fixed relative humidity, for temperatures ranging from −10 to 80 °C, simulating thermal conditions at which the structure can be subjected in a real application. Figure 12 exhibits the behavior of one sensor, being representative of all the evaluated samples.

Analyzing the results, it can be concluded that the response of the printed temperature sensors follows a linear behavior according to the premises. A sensitivity of

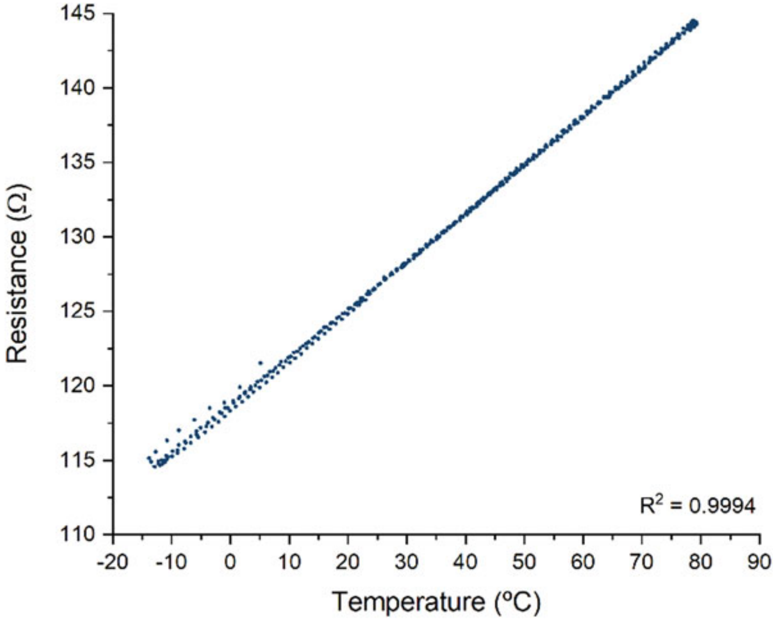

Fig. 12 Calibration curve of a printed temperature sensor measured after its integration into the membrane

0.33 Ω/°C can be determined from the slope of the curve. A higher sensitivity could be obtained by modifying the dimensions of the sensor. However, it would probably imply an increase of the impact on the textile performance. Nevertheless, the results here discussed demonstrate the suitability of this solution and the capability of integrating a printed temperature sensor in the proposed waterproof structure for improved functionality.

5 Conclusions

This contribution presented an advanced waterproofing system composed by a waterproof and thermal reflective water-based membrane reinforced with an innovative smart textile containing printed moisture and temperature sensors. The reinforcement textile was capable of being flexible but at the same time ensuring minimum thickness for reinforced waterproofing membranes improving the mechanical properties of membrane and presenting higher strength after loss of resistance caused by the alkaline environment, when compared with usual market systems. Results showed that the tests made on PUD aqueous membrane are applicable in the development of innovative impermeable membranes with thermal properties. Furthermore, it was proved that the developed printed sensors can be integrated successfully in the reinforcement textile without losing performance, when in contact with the alkaline waterproofing membrane.

The innovative contributions of this work are related with the development of the R22 woven fabric made for the reinforcement textile structure that are different from the market available products and with physical properties that fulfill the technical requirements defined in the Smart Roof Systems project. Since the literature review does not refer to printed sensors directly integrated on reinforcement structures for waterproofing systems, the presented results, related with printed sensors, are of high value in the scope of the project.

Regarding the future developments, the goal is to use thermal insulating materials, i.e., glass bubbles, in the membrane thermal performance as color of the surface. In parallel, the incorporation of IR reflective pigments, commercially available and/or synthesize, to maximize IR reflection capability as well as obtaining the desired membrane colors, i.e., white, gray, and orange. The printed sensors will be evaluated in terms of the number of sensors needed by square meter. Efforts will be made to increase the sensitivity of the temperature sensors. Furthermore, an active heating system composed of coated copper yarns inserted on the reinforcement textile structure by weaving process will be developed.

Acknowledgments This work was\addtocontents{toc}{\protect\enlargethispage*{-12pt}} developed in the framework of SMART ROOF SYSTEMS project (n.46957), which was co-financed by Portugal 2020, under the Operational Program for Competitiveness and Internationalization (COMPETE 2020) through the European Regional Development Fund (ERDF).

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Next-Generation Fashion Ecosystem: A STVgoDigital Approach

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1 Introduction

Over the last century, with the increase in the population's purchasing power, there has also been an unbridled increase in consumerism, which led to an increase in the consumption of natural resources as never before. Currently, however, the population is increasingly becoming aware of its environmental footprint and is gradually adopting more sustainable consumption habits. On the other hand, changes in society also led to major changes in users' interests; fashion and clothing industries are clear examples of that. If previously the population tried to wear the latest trends in clothes, nowadays the individual identity of each person gains more prominence.

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"STVgoDIGITAL: Digitalization of Textile and Clothing value chain" Project is a structural project of the Portuguese Textile Cluster that promotes the use of digital transformation of textile and clothing sectors to promote those industries' potential. STVgoDigital project comprises a set of research initiatives with a strong collective impact and high inductor and demonstrator effect.

Aligned with the Portuguese Textile Cluster strategy, namely with the strategic pillar Industry 4.0, which attempts to promote the digitalization and the adoption of new technologies by the textile and clothing sector. The project brings together the textile and clothing sectors and other complementary sectors enhancing the transition to the paradigm of Industry 4.0 by building new and complementary value chains.

This work presents the developments performed in STVgoDigital's subproject Next Generation Fashion Ecosystem 4.0 (PPS3) which aims to create a system that enables enterprises to successfully answer to orders of small series, and even unit production, driven by greater demand for customized products and taking advantage of local or regional identity, both in terms of creativity and production capacity.

Fashion Ecosystem 4.0. Project results from the recognition that textile and clothing sectors must transform themselves to successfully respond to the increasing reduction in the size of orders and even reach unitary production, because of greater demand for personalized and unique products, both in terms of creativity and production capacity. This trend toward increasingly customized products requires a distinct industrial response, which must focus on flexibility and creating new business opportunities. To this end, the Next-Generation Fashion Ecosystem is based on three integrated pillars:

1. Open fashion platform aiming to explore a new relationship model between the several actors that integrate the value chain;
2. Microfactories are being referred to in the fashion industry by their contribution to the challenges of customization, production close to the place of consumption, and more sustainable solutions aligned with customers' demands. A microfactory consists of a complete production line, capable of producing a garment in a reduced implantation area when compared to a traditional industrial unit. Today's textile microfactories gravitate toward two technologies: digital stamping and automatic cutting. Digital printing has proven to be a strong innovation and impact on the sector [1]. It consists of direct printing, through inkjet technology, on textile substrates, without resorting to any intermediate, flat, rotary, or paper frame. It is a technology that offers high flexibility and reduced setup time, among other advantages, despite its still costly, it's perfectly harmonized with the customization and mass customization;
3. Customization. Currently, most of the biggest fashion brands have around eight or more collections per season and fast fashion approaches, such as those of the Inditex group, presuppose the continuous production of small series, in greater harmony with the search for each product [2]. Currently, consumers are interested in customizing their products, by their design, shape, and size. This is a big challenge as it requires a significant industrial transformation to allow

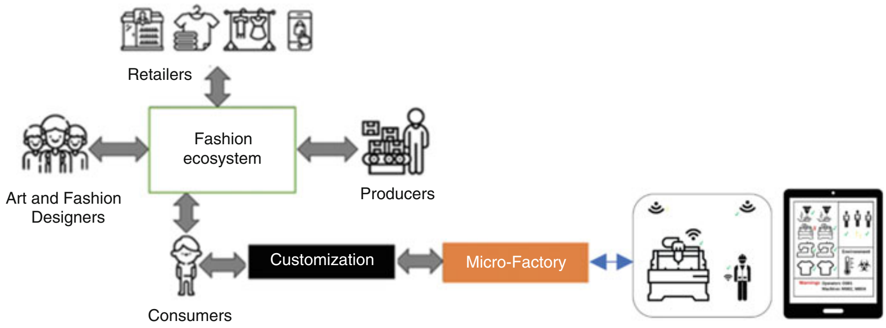

Fig. 1 Fashion ecosystem. (*Source*: STVgoDigital Project)

the production of unique products. The trending search for customized products leads to an increase of small orders forcing a major transformation in industrial capacity to supply its customers, as it must respond to a greater number of requests, associated with lower production volumes. This requires the creation of platforms that establish the connection between the downstream and upstream actors of the value chain, as a way of assuring a real-time response and with a very fast tuning capacity, to accommodate natural fluctuations in demand.

The main goal of the Next-Generation Fashion Ecosystem project is to develop a digital ecosystem that brings together the main actors of the textile and clothing sectors, promoting an environment that offers greater interaction and openness between them and enhancing new business and production models. This ecosystem seeks to support models of more local, granular fashion businesses while being able to provide an industrial response, namely to the production of small series, or even unitary ones, when exploring the concept of microfactory as presented in

The proposed ecosystem, presented in Fig. 1, is divided into two core activities, one focused on the development of a platform to support the fashion ecosystem and the other one, devoted to the development of a textile micro-factory microfactory, which efforts are presented in this work. This microfactory microfactory considers the development of (a) A microfactory microfactory model for the textile industry i4.0; (b) Enabling machines for Industry 4.0; (c) Development of a microfactory digital platform; (d) Advanced customized production control and management systems; and (e) Size-fitting systems. To complement the development and validate them, a textile micro-factory microfactory was created where the solutions developed are being implemented and will be tested and validated.

This chapter is organized into six sections, namely: (1) Introduction; (2) Fashion Ecosystem; (3) Industry 4.0 in Textile Industry; (4) The impact of Digitization of the Sustainability of Textile and Clothing Value Chain; (5) Industry 4.0 micro-factory for textile and clothing industries; (6) Conclusions.

In Sect. 1, Introduction, the problem was briefly presented. The project Next-Generation Fashion Ecosystem 4.0, its goals, and its technical organization were also presented. Section 2, Fashion Ecosystem, presents the state of the art regarding the fashion ecosystem and the problems that support the development of this project. Section 3, Industry 4.0 in Textile Industry, presents a brief overview of Industry 4.0, the technological revolutions, and their impact. Section 4 presents the impact of Digitization on the Sustainability of the Textile and Clothing Value Chain. Section 5, Industry 4.0 micro-factory micro-factory for textile and clothing industries, presents the work developed along the project and is divided into three subsections: Sensing Systems,; Smart Hub, and Plug & Produce Protocol. Section 6, Conclusions, presents the major conclusion on the work performed, future work, and constraints.

2 Fashion Ecosystem

Each year textile industry consumes 98 million tons of non-renewable resources [3]. Fashion industry itself is estimated to consume 93 billion cubic meters of water a year being responsible for the emission of up to 10% of worldwide CO_2 emissions [4–8]. Only 0.625% of worldwide water is suitable for use, although an enterprise that produces 20 kg/day of textile products consumes around 36.000 liters of water. The amount of water will vary accordingly to the type of textile structure, the materials, and the processes required for its production. Different textile processes led to different environmental footprints. Studies reveal that the cutting process originates up to 25% of the textile products' waste while textile dying is currently the most pollutant of textile processes being responsible for 20% of industrial water pollution [9–12].

Of the 3500 substances commonly used in textile processes, 750 were classified as dangerous for humans and 450 for the environment, leading to damage to the environment but also the health of textile operators and the communities close to textile facilities. Due to which, every year 3,575,000 people die from diseases transmitted through water [13–15].

Fast fashion led to major changes in garment purchase habits also in the number of times a garment is worn. Nowadays the number of times a garment is worn has decreased by 36% in the past 20 years because of changes in the mindset promoted by a 30% decrease in its price. Currently, European Textile Industry has 171,000 enterprises responsible for 1.7 million employees and emission of 1535 tons of CO_2/year. Each European citizen purchases an average of 14 new products or 26 kg of textile products per year from which just 7.4 are produced in Europe. New dyeing technologies such as "Air dyeing" are being used trying to reduce water consumption in the textile industry, allowing a reduction of 95% in water and 87% in energy consumption compared with traditional dyeing processes [15–19].

The growing awareness of the consumption of resources led people to adopt more sustainable habits. On the other side, people want their garments to be a reflection of their individuality and seek products that reflect their own individuality. As a result, current trends in fashion require changes to the conventional fashion ecosystem. The need for customized products together with the greater awareness of sustainable consumption imposes major changes in fashion industry that can only be implemented with several changes in the fashion ecosystem itself.

Currently, fashion ecosystem is optimized for mass production, the production of big batches allowing enterprises to reduce production costs and time but are not ready to produce small batches or even unitary ones. Most enterprises have a sampling line, but that line is usually used to develop a prototype of a product aiming for it to be approved to produce big batches. They are not suitable to produce unitary or small batches as the processes are usually very manual and costly. STVgoDigital aims to support the change to a more sustainable fashion ecosystem, which allows the production of unitary or small batches at a reduced price.

STVgoDigital proposes a digitally supported fashion ecosystem, which integrates several actors of the fashion value chain, digitally mediated. STVgoDigital aims to present customers and producers with a neutral mediated purchase platform that allows users to customize their products and produce them. STVGoDigital Fashion Ecosystem Platform aims to aggregate different profiles of the value chain, representative of the different roles related to the demand, offer, and production of fashion products. Currently, in the existing solutions, the role of the mediator is very much present and is not neutral in the exercise of mediation, either because it adds its stamp to the product (support to the designer in the conception of its product) or is restrictive on factors of production.

STVgoDigital aims to be a neutral platform that just supports the interaction between customers and producers. The proposed ecosystem supports the communication and interaction between different actors, to ease the creation of a supply chain capable of operationalizing a part of the product's life cycle, from the design to the final product. In this way, this project also supports the development of a new business model based on the production of on-demand small series. STVgoDigital solution presents characteristics of open innovation while opening and promoting a sustainable community and aggregating production supply and bringing production closer to the remaining actors of the fashion value chain.

3 Industry 4.0 in Textile Industry

Over the last decades, an incredibly fast technological demand led to interesting results at academic and industrial levels. Since the introduction of new equipment and technologies to process innovation, several things changed at the industrial level. Although the biggest fourth industrial revolution only in the last decade started to arise with the introduction of concepts of the so-called Industry 4.0. The concept of Industry 4.0 was introduced in 2011 at the Hanover Fair in Germany as a strategy to mitigate the increasing competition from overseas and to differentiate German and European Union industries from other international markets [20, 21]. Industry 4.0 aims to create "smart factories" where digital systems, physical resources, and human workers are connected and able to communicate promoting industrial agility, flexibility, adaptability, and efficiency, allowing flexible and adaptable industrial

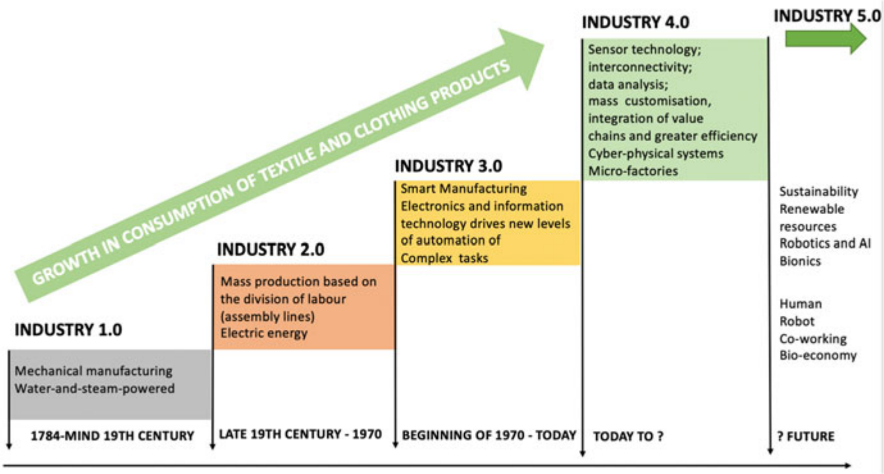

Fig. 2 Industrial revolutions phases. (*Source*: Adapted from Refs. [26–31])

environments with the usage of innovative solutions that promote the legalization of production processes [20–25]. STVgoDigital solution implements Industry 4.0 concepts to digitize production resources.

Led by technological, business, environmental and social changes, industry requirements changed over time and are increasingly more rigorous and accurate [24]. The industrial paradigm changed and improved the ability of enterprises to answer to customers and market demand. At the same time, on the other hand, the increased investment in research has boosted fast technological development. As time goes by, the complexity of the developments increases, and the physical effort of the operators is being replaced by intellectual effort. Fig. 2. presents the major challenges promoted by the industrial revolution, while at the beginning of the twentieth century, the recent introduction of electricity revolutionized industry allowing the development of machinery and the introduction of mass production, Later the developments in electronics allowed the optimization of those solutions, and more recently the development of CPS solutions and the Industry 4.0.

The adoption of mass production and modularization of production led to the increase in production capacity and to the reduction of risks for production and business. In the 1970s, the introduction of computers and the application of deep knowledge promoted the automation of industry [29].

Industry 4.0 is a transdisciplinary concept that promises to take the industry to its next generation, providing enterprises with more agility, flexibility, adaptability, and efficiency through the integration of a diversity of technologies. Technologies such as Cloud Computing, Big Data, the Internet of Things (IoT), or Artificial Intelligence. A key factor for this revolution transversal to all those technologies is data, already considered by many to be more valuable than gold itself [30–32].

An effort was made to identify concrete actions to transform Industry 4.0 challenges into opportunities for integrating these technologies into equipment and systems.

Industry 4.0 is being implemented in textile Industry to support the optimization of different processes mostly aiming to improve resource management, increase production capacity, and reduce costs. Most of those solutions focus on the reduction of energy and water consumption [33]. The rise of the so-called Smart Factories allowed enterprises to become more competitive in a mass production environment [34].

Data plays more than ever a key role in industrial management. The information obtained from it has a high value. But that data only has value, when it can provide useful information, and knowledge that contributes to the improvement of products, or processes allowing somehow to increase the revenues with its usage. New innovative approaches to data models are emerging and intend to revolutionize the world as it is known, promoting both internal changes to an entity, and extending throughout its entire value chain.

At a global level, industrial collaboration has a huge potential to reduce production and logistic costs. The use of innovative ICT tools will help enterprises to have better management of their resources and to optimize their use. It will be translated into the reduction of waste, but also of the enterprise green footage.

The production capacity will increase, and new business models are created as a result of changes to the previous ones. Innovation and industrial transformation will increase revenues [35]. Individually, the optimization of the production plan will optimize the use of resources, which will allow the waste of resources, from raw materials to water and even energy. The early detection of non-conformities will allow the reduction of non-conformities and wastes [33, 34].

The awareness of circularity and sustainability is changing the way textile enterprises manage their resources. To support that, ICT technologies have been implemented on the shopfloor to reduce the production cost and improve product quality and production capacity at the same time while allowing the reduction of waste produced.

The digitization of textile processes allowed the optimization of products and processes. The transformation of industrial production using technologies such as simulation, cloud computing, additive manufacturing, augmented and virtual reality, cyber security, industrial internet of things, autonomous robots, vertical and horizontal collaboration, system integration, IoT, big data and analytics allowed textile industry to be one of the most pollutant industries in the world, to become a sustainable industry [36–38].

The approach followed in this work proposes the sensing of the industrial environment using IoT sensors that are connected to the platform ThingsBoard, which integrates different software and virtual resources. The data collected is stored in a cloud server to be analyzed.

Digitization allows the optimization of resource usage and promotes vertical and horizontal collaboration allowing better planning and collaboration inside each enterprise and across the entire value chain.

STVgoDigital PPS3 aims to develop an interoperable platform based on the technologies previously mentioned and supported by an IoT architecture approach to computationally support the agilization of textile processes. The adoption of an appropriate data model that can support the specific needs of an enterprise could be the factor that will determine the future of an enterprise. The data model developed considers all the resources and processes that matter for the daily enterprise operation whether it's a productive or a non-productive resource, to provide complete and accurate agile management.

This work proposes a better awareness of enterprise resources, promoting the combination of software and hardware combined with a robust platform that assures the agilization of production processes and resources consumption integrated with machinery equipped with intelligent sensing or other devices connected in such a way that the computational platform assures access and monitor to several parameters involved in the manufacture of textile products. STVgoDigital platform is based on several basic rules and methods. Based on two different points of view: provide better resource management and improve customer relationships supporting the production of customized products. The project presents a modular cloud architecture scalable to support the overall processes of the textile industry and supports the interoperability between processes, systems, machines, and devices. STVgoDigital proposes an innovative data model that supports sustainable textile production allowing the creation of a homogeneous sensor network, autonomous and independent, both in terms of technology and in terms of information transmission, it was designed to allow an efficient operation of all enterprise resources.

Real-time monitoring allows early detection of non-conformities or breakdowns on machinery allowing an early intervention that will on one side avoid the waste of resources and on the other side avoid the increase of the problem that occurring and its damage to machinery and textile parts and the consequent security issues that might arise putting in risk workers safety.

The impact of the project can be grouped into three main areas: competitiveness, growth, and sustainability. The benefits of STVgoDigital are derived from the proposed contributions in terms of efficient tools to improve the processes of collaboration and optimization of communication, maintenance, and resource management. Allowing enterprises to diversify and innovate the products offered according to the current market demand increases the capacity of the enterprises to penetrate new market niches to be able internally to overcome the evolutionary challenge. This solution has a strong impact on enterprises' sustainability. At an economical level because it allows them to have better management of its stocks of products and raw-materials consumption. At the environmental level, proper resource management allows for the reduction of waste, it is achieved by better production planning, better usage of resources, and improvement of product quality. At social level, the project ensures workers' safety and well-being. Allowing a better usage of resources, STVgoDigital allows enterprises to increase their production capacity, increasing enterprises competitiveness and promoting their growth.

4 The Impact of Digitization on the Sustainability of the Textile and Clothing Value Chain

Textile and clothing industries are implementing ICT technologies, mainly in the last decade since the rise of the Industry 4.0 concept. The digitization of those industries allowed enterprises to have a better awareness of their resources.

Optimization of production planning and scheduling is one of the main solutions that contributed to improving efficiency and increasing production capacity. Those solutions used to be focused on the optimization of resource usage in mass production environments, allowing to improve production capacity, increase product quality, and reduce production cost.

Some solutions also aim to support enterprise collaboration mostly vertical collaboration which refers to promoting collaboration between the different stakeholders of an enterprise. Horizontal collaboration refers to the collaboration between partners of the same value chain and still has some challenges to overcome.

STVgoDigital Project supports vertical and horizontal collaboration along the hierarchical structure of enterprises. The project contributes to improving communication and resource management strategies. It supports the optimization of resources management through the monitoring and control of production in real time. This monitoring allows early detection of non-conformities or breakdowns on machinery and tools allowing an early intervention that will on one side avoid the waste of resources and on the other side avoid an increase of the problem that is occurring and the damage to machinery, tools, and parts and the consequent security issues that might arise from that putting in risk workers safety.

At the horizontal level, allowing customers to directly communicate with their suppliers to customize their own products or enterprises to manage their production planning in accordance with the planning of a partner that is responsible for a previous process of the product's production process.

STVgoDigital allows monitoring resources, namely machines, environments, and operators. Machines are a crucial part, and they are responsible for transforming the raw material and parts into added-value products, so their monitoring can help enterprises at several levels. The project allows machinery monitoring promoting early detection of non-conformities, and if needed to stop production and adjusting setup configuration or perform maintenance operations to correct or minimize the production of non-conformities and prevent damages to the equipment. The impact of the project can be grouped into three main areas: competitiveness, growth, and sustainability.

The benefits of STVgoDigital are derived from the proposed contributions in terms of the development of flexible and efficient tools to improve textile processes and optimize communication, maintenance, and resource management which contributes to answering customers' demand for customized and sustainable products. This solution allows enterprises to diversify and innovate the products offered to the current market, increasing their capacity to penetrate new market niches and internally overcome the evolutionary challenge.

This solution has a strong impact on enterprises' sustainability. At an economical level, STVgoDigital allows better management of stocks of products and raw materials while allowing it to fulfill the specific needs of each one of its customers. At the environmental level, proper resource management allows the reduction of waste and resource consumption, which is achieved by better production planning, better usage of resources, and the improvement of product quality and customization. Any enterprise's main goal is to be able to assure its sustainability. Assuming to meet its customers' demand and being able to compete in a concurrent market.

The world is currently facing an enormous environmental crisis, predicted for several decades that is nowadays presenting increasingly more proof of the impact of the bad management of resources worldwide. Sustainability can be analyzed at the same time at four levels: environmental, economic, social, and cultural as presented in Fig. 3 [28, 37]. Environmental sustainability is achieved through the reduction of the enterprise's green footage, it can be achieved through the adoption of more effective resource management strategies and can be combined with residues valorization techniques. Those changes if properly implemented will automatically have an impact on the enterprise's economy. As economical sustainability is the one that in the end determines business success, ensuring a positive balance between income and expenses. At the social level, it assures that each task is performed by qualified people and managed to assure that the proper amount of human work is suitable for each specific task that assures safety for the workers and also assures that

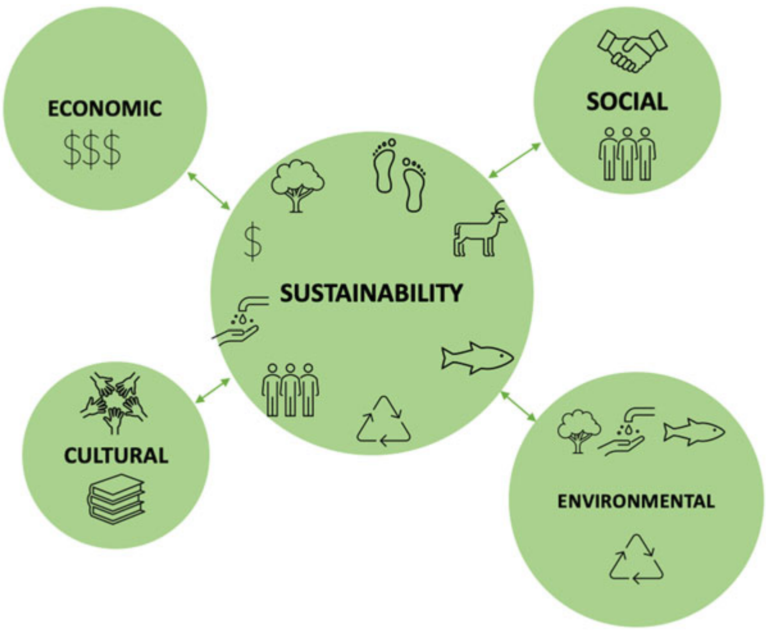

Fig. 3 The four levels of sustainability and product lifecycle. (*Source*: Refs. [28, 37])

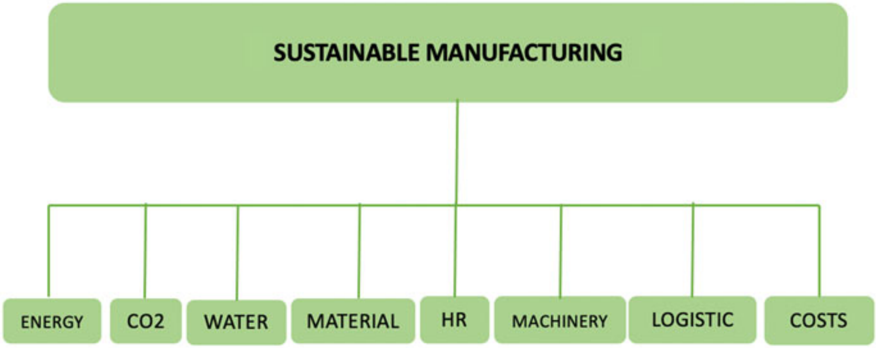

Fig. 4 Criteria for analyzing sustainability in manufacturing enterprises (*Source*: Cunha et al. [44])

ergonomic issues are taken care of as much as possible. Workers will constantly be monitored to prevent potential health issues. For Hawkes, "The cultural dimension focuses on its use as a concept to describe the community creation of values, meaning and propose in life; and cultural vitality is essential to a healthy and sustainable society as social equity, environmental responsibility, and economic viability" [37].

The concept of sustainability was defined in 1987 in the Bruntland report and was then adopted by the United Nations' World Commission on Environment and Development (WCED): "sustainability means being able to satisfy current needs without compromising the possibility for future generations to satisfy their own needs" [38].

The four visions of sustainability are combined in all product lifecycle phases (design, manufacturing, delivery, use, and end of life) and can be assured through the usage of new innovative ICT systems that optimize the management of resources and allow users to have a clear awareness of effective resource usage. Fig. 4 presents the criteria for analyzing Manufacturing Enterprise's sustainability which STVgoDigital considers to supporting an agile manufacturing environment assuring its sustainability. The Sustainable Manufacturing criteria used in the present work were the result of the combination and alignment of several authors' criteria aligned with textile industry specificities [38–43].

A sustainable manufacturing environment should assure proper management of its resources, namely, CO_2 emissions, water and energy consumption, materials and resources usage, machinery usage, operation, and maintenance, and logistic and cost-efficiency. The manufacturing industry consumes 33.33% of the worldwide energy [43]. Although in 2018, the overall energy consumption increased by 2.9% compared with the previous year. The consumption of electricity and coal increased by 5.9% and 26%, respectively, while the consumption of crude, oil, and gas decreased by 3.7%, 1.5%, and 1.4%. It was also verified that a 3.9% increase in CO_2 emissions was caused mainly by India . In Portugal, the biggest change was the decrease in the production of renewable energies, 16%. These results show a step back in the way to a sustainable world, hopefully, it is just a time to change, and better results will be presented in the coming years [37].

Proper usage of those resources is needed to assure a sustainable manufacturing solution. The diversity of resources involved in the entire value chain presents a huge potential for improvement. Through real-time monitoring of resource usage engaging IoT devices installed in machinery and industrial environments, it is possible to analyze production processes and environment detecting early-stage potential problems that might lead to major problems allowing the detection and correction of any breakdown or defect in an early stage. This early intervention allows enterprises to avoid waste of resources that would result from a later detection of those issues.

Allowing a better usage of resources, STVgoDigital allows enterprises to decrease their environmental footprint, increase their production capacity while producing unitary or small batch series and supports the production of highly customized products aligned with current market trends while contributing to environmental sustainability, it also increases enterprises' competitiveness promoting its growth.

The usage of innovative data models to improve the management of enterprise resources nowadays can be the reason why an enterprise succeeds or fails in the current concurrency environment that lived worldwide. This approach eases industrial management allowing agile resource management at several levels. Providing enterprises with the tools they need to support agility to provide customers' demand, decrease production costs, improving flexibility and sustainability through better usage of resources, which is also represented in the costs of usage of those resources. STVgoDigital allows enterprises to have agile industrial management through the reinforcement of maintenance processes, the maximization of the usage of machinery, and minimizing the production of non-conform products.

STVgoDigital allows enterprises to offer its customers sustainable and customized products through a robust platform that supports the digitization of microfactories providing them with the ability to assure efficient production through the monitoring and control of production, improved planning, better maintenance, better efficiency, and optimization of overall enterprise resources management. The improvements achieved by the usage of such technologies can lead to improvements that can decrease up to 30% of production costs and up to 20% in quality management and non-conformities production [39].

Although these results are very relevant, this work can be incremented by other enterprises and industries. The results of these solutions can be improved through the implementation of interoperable solutions within the value chain. Besides that, this kind of solution can be implemented in other industries or business areas, with similar results. The expansion capacity for other industries and processes maximizes its applicability. The solution presented allows enterprises to have an interoperable computing platform, as a human–machine interface (HMI) between a wide range of equipment and processes for the integral processing of textile products. Allowing to overcome the evolutionary challenge of the overall monitoring of all enterprise resources, from data collected from ERP, MRP, and even data collected directly from industrial equipment allowing us to have a complete awareness of what's happening in an industrial environment.

5 Industry 4.0 Micro-factory for Textile and Clothing Industries

STVgoDigital Fashion Ecosystem 4.0. aims to develop a microfactory for the textile and clothing industries to support its transition to Industry 4.0. A fully automated microfactory concept is expected to be a reality in the future, although currently, it is still a long way to go before micro-factories spread all over the world. STVgoDigital project aims to contribute to the creation of those kinds of solutions, namely, providing a micro-factory to be implemented in enterprises to support human operators. This micro-factory ensures manufacturing operations, namely, confection, handling of raw materials and other materials, the configuration of the equipment, and the monitoring of the operations, all in addition to the digital solutions being implemented.

Along with the project is expected the development of an autonomous microfactory framework, but also as a complement to the existing equipment and systems currently available in enterprises. The goal of this project is to validate the concept of an autonomous unit as a first step toward accessing topics such as urban manufacturing or made-by-measure.

This project aims to develop an integrated, operable, and digital unit of a textile micro-factory, integrating IoT and digital twin approaches. Plug & Protocol is being developed to be applied to industrial equipment for IoT environments. With the progressive advance of digital transformation, the industrial environment is characterized by the growing collection of data from its equipment and by an operational integration that allows operating equipment remotely.

However, the integration of a heterogeneous park of machines, whether in terms of manufacturer, age, or existing firmware, requires an additional effort from IT teams, mainly in contexts characterized by the absence of IoT platforms, which turns the potential of the IoT into an endless data collection project and in the construction and storage of data sets. This project seeks to contribute to minimizing this problem, by seeking to develop a Plug & Produce solution for industrial equipment in IoT environments. Size-fitting algorithms are being developed to support a size recommendation system based on a consumer's body measurements. It's intended to develop a system that, starting from a basic model of a garment, and the consumer's body measurements, it's able to carry out the tailor-made, adapting the base model to its body measurements.

Nowadays the industry faces new challenges every day, motivated by highly complex demands and the agility required. Enterprises need to adapt to provide their customers with products following their expectations. However, delivering high-quality products in short timelines can be a tough challenge. First, assure that each resource needed will be available on time and that any delays that could happen will not impact the deadlines agreed upon with the customer. With all the resources available it is better to assure the production on time and quality.

Cyber-Physical Systems (CPS) are being used to support these processes although not all of them are ready to properly support this management for several reasons, from the lack of the requirements definition, lack of knowledge about processes, a partial analysis of the problem, communication and knowledge transfer failures, lack of resources, or inefficient use of them, or even architectural problems in the definition of the solution are problems faced in several solutions in any time of its lifetime. The combination of technologies such as Cyber-Physical Systems, Artificial Intelligence, Integration, and Interoperability, Cloud Computing, IoT, and Virtual and Augmented Reality with the deep evolution achieved in the different business/industrial fields allowed enterprises to answer their customer's demands [43].

This project concerns the production of added-value products that result from the management of information from the entire value chain to take the most of the usage of enterprise resources. The developed model addresses the needs of enterprises and final customers who will benefit from the products aiming to boost innovation and technological development by digitizing different processes, from designing, different production processes, and storage. STVgoDigital Data Model aims to support the overall management of textile processes supporting collaboration along the hierarchical structure of the enterprises and improving communication and resource management strategies.

5.1 Data Model for an Industry 4.0 Microfactory

In the textile and clothing sector, enterprises use a wide range of equipment and systems although most of them can't communicate with each other. The complexity of managing different systems and the complementary information generated by each one of them needs to be analyzed separately which is a major challenge. The integration and interoperability of the solution being developed aims to assure that the independent solutions being used by each enterprise can all be integrated and can communicate with each other using STVgoDigital platform.

To support the development of the platform, all the components were planned, as stated in its data model. This project aims to develop a micro-factory to support the transition of Textile Cluster to Industry 4.0. It aims to become a reference for Industry 4.0 in the textile and clothing sectors. To support the implementation of the proposed solution, a Data Model was developed for the Industry 4.0 Microfactory that promotes the digital transformation and integration of industrial equipment in IoT environments. The work developed focuses on the capacitation of digital printing machines but does not ignore all the other resources, namely, the human agents involved in the manufacturing process.

The increasingly fast demand for new technologies, generated by constant market changes, requires extreme solutions to keep answering industry needs. A new business paradigm, where each enterprise is aware of the need to think globally and not individually so far, has emerged.

To fulfill industrial needs in Industry 4.0 era, it is necessary to focus on the global value chain, giving companies the tools they need to manage all their processes. However, the development of new systems is much more complex than ever before, as multiple systems require multidisciplinary knowledge to be successfully connected, and communication a key to success. First, it is needed to analyze each industrial process separately and then establish relations between all the processes and the data exchanged. Data models are defined to allow each enterprise to get the specific data it needs, and at the same time, they are so generic that they can fit any enterprise's requirements.

The diversity of realities in different enterprises allows the data models to be as specific as they fit exactly each enterprise's needs, and they are so generic that they can fit all the companies' needs at the same time, even with the differences between them.

Collaboration can bring lots of advantages to the partners mainly considering micro-factories. The use of ICT systems to improve and encourage collaboration and better management of resources will be able to provide a collaborative solution to enterprises, even the smaller ones that have limited access to resources, allowing them to be closer to each other, but mainly closer to their customers. The definition of a data model to support the development of textile micro-factories contributes to improving the sustainability of businesses through better management of industrial resources.

Over the time, several approaches arose aiming to organize the management of data and systems architecture. RAMI4.0 (Reference Architecture Model) and IIRA are two of the most accepted reference architectures that leverage existing standards to standardize the development of Industry 4.0 applications. Reference Data Models exist to align the development of solutions in specific areas. In this specific case, and in the case of any project that is oriented on the precepts of Industry 4.0, this is extremely important due to the need to ensure integration and interoperability for the correct operation of the system, as well as for the maximization of its functionalities. The reference data model reflects the semantics and standards applied by stakeholders and should be as complex as the system that it is intended to be developed since it should represent the source of knowledge needed to solve the problem or need that led to the creation of the project.

RAMI4.0 is a reference architecture for industrial modeling first proposed by BITCOM, VDMA, and ZWEI. RAMI 4.0 has improved the model previously proposed by SGAM (Smart grid Architecture Model), proposing a tri-dimensional model to allow the combination of interconnected features from technological to economical levels [37]. RAMI 4.0's architectural model proposes to split data into several data layers, namely: business, functional information, communication, integration, and assets. Within each of those layers, data is categorized by hierarchical levels, namely, Product, Field Device, Control Device, Station, Work Centers, Enterprise, and Connected World [44].

Acting in three levels: Hierarchy, Architecture, and Product Lifecycle. At an architectural level, it intends to ensure the connectivity between all the resources from people, systems, and equipment, ensuring flexibility, communication, integration, and interoperability for all products and processes. At the architecture level, it intends to support the storage and processing of data and knowledge generation, allowing the collection of data from different systems and devices, providing the transformation of information from the physical layer to the logical layer, for example, using IoT devices. Concerning the product life-cycle level, it is intended to support all stages of the product throughout its life cycle, in terms of research and development, production, marketing, operation, and maintenance.

To ensure that the needs of all stakeholders are ensured, IIRA-Industrial Internet Reference Architecture (IIRA) model focused on four “points of view”: business, use, functionality, and implementation. RAMI 4.0 and IIRA are examples of the available models, which can be replaced or combined with other existing models, depending on the complexity and goals of each project [45].

Technology innovation and new research on business models and processes allow enterprises to innovate their business models, or even create new ones. The same happens with processes, enterprises can adapt to change, to learn how to do their best with the available resources. The present approach takes advantage of the knowledge achieved from real-time data collection and sharing of information between different systems. Information flow begins its route along well-defined and delineated routes, with data being sent by organizational hierarchy to databases that allow active tools to process, aggregate, and process information for different purposes considered relevant. Some scientific studies have developed conceptual models for structuring sensor networks allowing access to a subset of information (data) collected by the sensing systems, responsible for providing data in real time. Other authors identify different applications of IoT, covering car parking in cities; vibration monitoring or mechanical and structural conditions of materials in buildings or bridges; cargo handling and stock management; logistics, and industrial control among others. Finally, as several authors argue an open internet of things inevitably raises security and privacy issues. The research, therefore, seeks to develop security technologies that help prevent unauthorized access and use of stored data and the identification of access by tracking its sensors.

The analysis of the different textile processes provided an overview of the market, covering key factors and risk factors that lead to the identification of opportunities and needs. Centralized management of resources provides agility and flexibility and increases enterprise production capacity and quality [39, 46].

To implement the concepts of a digital micro-factory that supports vertical and horizontal collaboration, connectivity becomes a crucial factor in supporting and enabling this collaboration. On a vertical level, it is intended to aggregate all internal information, both at the management and factory levels. So, it is important to implement an efficient system that allows the connectivity of people, systems, and devices. At the horizontal level, it is intended to guarantee the connectivity of products and processes, and it must be supported by cloud-based solutions. The effectiveness of this collaboration is supported by existing standards to ensure the adequacy and speed of communication. For STVgoDigital project, it is important to identify the appropriate standards for equipment, raw-material, and products. This work helped to understand the link between technology development in research and business. The results can validate the solution and help identify the alignment between needs and opportunities for both research and industry partners.

5.2 Enabling Machines for Industry 4.0

Aiming to promote digital transformation and the integration of industrial equipment in IoT environments, the solution being developed focuses on the digital printing process and equipment but does not ignore all the other processes and equipment, namely, the human agents involved in the manufacturing process. It also aims to develop a plug and produce a protocol that will enable productive systems to become flexible to make them quickly operational. To enable machines for Industry 4.0, the solution developed is composed of a sensing system, a Smart Hub, and a Plug & Produce Protocol.

5.2.1 Sensing Systems

The sensing system developed can be divided into three different monitoring goals: equipment, environment, and operators. The integration of sensing systems aims to monitor the micro-factory (work environment, temperature, CO_2, dust), to ensure the optimal conditions of operation for the equipments and environment quality for the operators. This sensing solution provides the system the ability to monitor and send the information collected from the shop floor to the microfactory's management and control platform, to optimize and enhance its quality. In an industrial environment, to assure the quality of processes and products is essential that the environmental conditions are within the recommended patterns. Monitoring parameters such as temperature, humidity, and gases that may be released by the inks during the digital printing process into the micro-factory are essential to assure process and product quality.

STVgoDigital sensing system is responsible for acquiring data from the digital printing machine allowing it to compare the values with standardized and recommended ones assuring that production parameters are compliant with its ideal conditions. The sensing system developed includes a communication system, a voltage regulation system, and a data processing and acquisition system for the several sensors integrated, namely, temperature, humidity, accelerometer, and dust detection. Dust detection sensors need to be located close to the equipment's ink nozzles. The sensor data will be acquired by the Smart Hub which will send the data to the IoT layer, where it will be processed. The sensing system uses a 24 V power supply, having a voltage regulation system for 5 and 3.3 V to supply the remaining electronic components.

Operators are essential elements in the production process and integrating them in the context of the digital micro-factory is essential. Monitoring the biometric data of the industrial operator allows for preventing possible situations of risk or illness. In this sense, its steps and heart beating rates are monitored to be processed allowing the early identification of potential risk situations.

In this sense, there are currently thousands of increasingly reliable wearable solutions on the market that allow the monitoring of biometric data in real time. Both SmartBands and SmartWatches are digital watches that provide their users with different features according to each specific model. SmartBands have dedicated features, aiming to monitor health parameters or fitness parameters. While SmartWatches, in addition to the features provided by SmartBands, also can have all kinds of features depending on each model and the features available, as a result, their cost is higher depending on their brand and features. SmartBands, are simpler, have more limited functionalities, and aren't usually as accurate as SmartWatches, although it is a more affordable solution, however, it is very limited and even if in some cases it is possible to consult a history of the data collected, it was not possible to identify any solution that allows exporting that information to be processed. To increase the potential of the application for this project, it was decided to use a SmartWatch, since it provides a more versatile solution.

A decisive factor in the process of choosing the wearable to use was also its operating system, Wear OS operating system was selected as the most suitable one. Wear OS, initially known as Android Wear, is the operating system for Google wearable solutions, compatible with the Android operating system also owned by Google. The option for selecting this as the crucial factor for choosing the operating system to use lies in its reliability and flexibility, which allows it to easily be integrated and implement different functionalities.

The biometric parameters of the operators will be monitored using a SmartWatch to identify and predict potential risk situations for the operator and prevent the risk and provide the operator with the care it might need. The monitoring of the equipment includes sensors to monitor the temperature, humidity, accelerometers, and dust that are integrated into the Digital Printing Machine.

5.2.2 Smart Hub

Some facilities were identified as textile and clothing micro-factories; however, those were only demonstration facilities and have not yet reached the operational status capable of constituting a viable option in industrial and business terms. With the progressive advance of digital transformation, the industrial environment is characterized by the growing collection of data from its equipment and by an operational integration that allows operating equipment remotely.

To ease the integration of several sensors that will be used to measure several physical quantities inside and outside the micro-factories, digital printing machine was developed as a Smart Hub. The data is sent to the central server of the micro-factory, to be analyzed and processed to improve the performance of the production process. The Smart Hub was designed to have a wide variety of communication peripherals to increase the range of sensors and actuators that can be integrated into it, whether it exists on the market if it is developed within the scope of this project or it would be developed even after the completion of the project.

Communications are performed through cables or wireless to increase the ability to communicate with a wide range of protocols existing in the automation industry. The Smart Hub is a minicomputer, which runs a very stable Linux-based operating system allowing the installation of a wide variety of open-source software and databases.

The Smart Hub uses a SOM (System On Module) from the Raspberry Pi Foundation chosen due to the large community of people who develop open-source software for these popular microcomputers. This aspect is fundamental for research and development projects in which the unknown is sought. Over time, new software has emerged because there is a large active community developing new technologies, which can be useful along this project and which can add value to it.

Raspberry Pi Compute Module 4 (CM4) is a SOM that contains a processor, memory, an eMMC Flash, and power circuitry. These modules allow a designer to leverage the Raspberry Pi hardware and software stack in its custom systems and formats. Additionally, these modules have extra IO interfaces beyond what is available on Raspberry Pi boards, providing more options for the designer. Raspberry Pi CM4 design is loosely based on the Raspberry Pi 4, Model B, and for cost-sensitive applications, it can be provided without eMMC installed. While previous generations of Compute Module shared the same form factor mechanically compatible with DDR2-SODIMM, the new CM4 and CM4Lite are different. CM4's electrical interface is performed via two 100-pin high-density connectors and a new physical format that occupies less space when connectors are considered. This change is due to the addition of new interfaces; a second additional HDMI, PCIe, and Ethernet. The addition of these new interfaces, especially PCIe, would not have been possible to preserve the previous form factor.

RCM4 was created for the development of new products supporting the robustness of the industrial environment, while Raspberry Pi itself was created for educational purposes; the main difference is the CM4 that has the option of having flash memory to run the operating system. In traditional Raspberry PI, the operating system is installed on an SD card, which over time suffers corruption problems. CM4 offers a variety of options, allowing the user to choose the module according to the specific goals of each final product to be developed.

Based on the characteristics of CM4 and its several options, the Smart Hub was developed to take advantage of all the potential of this computing module. One of the Smart Hub's goals was to have a wide variety of physical interfaces, allowing it to be able to communicate with the widest range of devices on the market or to be developed within the scope of the project. It supports several communication protocols wired or wireless. Figure 5 presents the architecture of the Smart Hub.

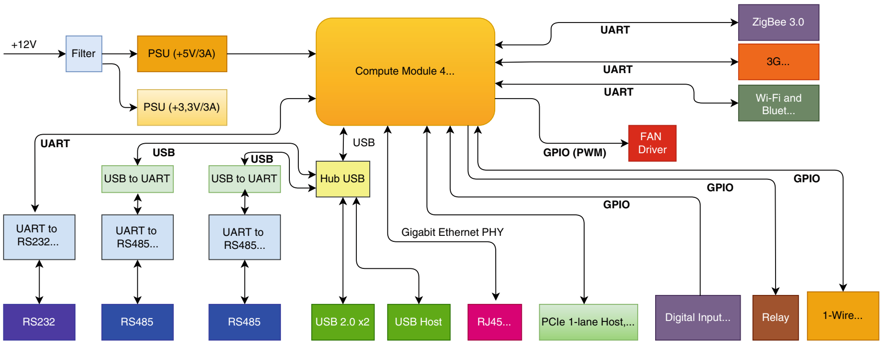

Fig. 5 Smart Hub's architecture. (*Source*: STVgoDigital Project)

STVgoDigital's Smart Hub was developed to provide the largest number of interfaces with the robustness required to be used in an industrial environment. The Smart Hub is powered at 12 V DC and consumes a maximum power of 25 W operating in a temperature range from −20 °C to +85 °C. To ensure that the temperature does not exceed the SOM, it has a heatsink with a fan to lower it. The fan can be controlled via a PWM signal from the SOM itself according to temperature to help control the temperature. The Smart Hub is ready to be installed in industrial environments and to work 24 h a day. RS485 and RS232 communications are electrically isolated (2500 V DC) to ensure no damage is done to the computing unit. The digital inputs of the Dry Contact type and the 1-Wire bus are electrically isolated (1500 V DC).

The USB HOST connection is made on the micro-USB connector, which is used to install and configure the operating system. The Smart Hub has two USB TypeA ports for general use and one RJ45 communication port for Ethernet communication (1 GB). CM4 has an input for sensors that communicate using the 1-Wire communication protocol, which can be connected to the (+, D, −) terminals. It has three dry contact digital inputs that are connected to the terminals (COM, DI 0, DI 1, DI 2). The Smart Hub has a relay that allows the activation of small loads where the contacts are available on the terminals furthest to the right. The Smart Hub has two RS485 communication ports allowing access through terminals A, B, and the ground. It also has an RS232 serial communication port through the RX, TX, and ground terminals.

This module has a wide variety of wired and wireless interfaces to integrate the largest number of sensors and actuators currently available on the market and others that could be developed. The Smart Hub runs a Linux-based operating system, specifically the *Raspbian,* which is a Debian variant based on the ARM hard float, being a part of the Wheezy architecture, optimized for the ARMv6 instruction set of the Raspberry Pi hardware. This Linux distribution offers over 35,000 .deb packages, which are pre-compiled to be easily installed on Raspberry Pi computers. Its packages are specifically configured for optimal performance on Raspberry

Pi's ARM11 hardware. Raspbian contains the LXDE desktop environment, the OpenBox window manager, the Midori browser, tools for software development, and sample source code for multimedia functions.

Raspbian is the project of a small, dedicated group of developers, and is not affiliated with the Raspberry Pi Foundation or the Debian project. Currently, for Raspbian, drivers are required for a wide variety of hardware, which allows the operating system to control devices. Also are included wired and wireless communication systems, and in this equipment are included technologies such as LAN (1 Gb), RS232, RS485, Wi-fi, Bluetooth, 3G, and ZigBee.

The operating system that runs on the Smart Hub provides a wide variety of software that allows conveying of data in a wide range of existing communication protocols, such as Modbus, MQTT, etc. The greatest advantage of this operating system is the fact that there is a large community developing software for him, and the available packages can be easily installed to take advantage of the most current technologies on the market. Raspbian allows the installation of several database models such as TinyDB, SBLite, MariaDB, MongoDB, PostgreSQL, Firebird, etc. Raspbian operating system allows the development of software in a wide variety of programming languages, allowing developers to take advantage of many free tools for software development.

Two sensor modules were developed to perform the reading of several physical quantities to monitor the air quality of the environment in which the digital printing machine operates. Digital printing machines must operate in industrial environments, however, for the correct operation of the machine, the environments, where it is inserted, need to respect parameters such as temperature, humidity, oxygen, CO_2 concentration, dust particles, and noise. The data can be sent to a central server of the micro-factory to be analyzed and consequently improve the performance of the production process.

The sensor module developed, called IndoorSensor module 1, has a processing unit of the ESP32 series from Espressif Systems. ESP32 is a low-cost, low-power microcontroller series. It is also a system-on-a-chip with a built-in microcontroller, Wi-Fi module, and Bluetooth chip. ESP32 series uses a Tensilica Xtensa LX6 microprocessor with dual-core and single-core variants and includes an integrated balun-style RF antenna, power amplifier, amplified low-noise receiver, filters, and power management modules. ESP32 was created and developed by Espressif Systems, a Chinese company based in Shanghai, and is manufactured by TSMC using its 40 nm manufacturing processes.

ESP32 is a surface mount-based printed circuit board (PCB) module where the ESP32 SoC is inserted directly into the PCB as these are designed to be easily integrated into any printed circuit board. The module has an inverted F-type antenna projected onto the PCB in a serpentine line. Below is a list of the different types of antennas used in the modules. In addition to flash memory, some modules include pseudo-static RAM (pSRAM).

Based on the ESP32's features and its various options, the IndoorSensor module 1 was developed to take full advantage of this processing module's potential. The purpose of this sensor module is to monitor the physical environment of the operation of the industrial digital printing machine. IndoorSensor module 1 can monitor particles, gases, pressure, humidity, and temperature. Module 1 has a sensor that allows the detection of pollutant particles that are present in the air. The sensor used is the SPS30 model from Sensirion, an advanced PM (Particulate Matter) optical sensor. The measurement principle is based on laser scattering and makes use of Sensirion's innovative contamination resistance technology. This technology, together with high-quality and durable components, allows accurate measurements from the first operation and throughout its lifetime of more than 10 years. In addition, Sensirion has advanced algorithms that provide superior accuracy for different types of PM and high-resolution particle size classification, opening up new possibilities for detecting different types of environmental dust and other particles. With dimensions of just 41 × 41 × 12 mm, it is also a perfect solution for applications where size is important, such as air quality devices. The range sizes of mass concentration that this sensor measures have different ranges (PM1.0, PM2.5, PM4, and PM10). The sensor communicates with the processing unit via an I^2C bus.

IndoorSensor module 1 has a gas sensor that measures several physical quantities; this model of the brand BOSCH (BME680) is the first gas sensor that integrates gas, pressure, humidity, and temperature sensors of high linearity and high precision. It was specially developed for mobile and wearable applications where size and low power consumption are critical requirements. BME680 assures, depending on the specific operating mode, optimized consumption, long-term stability, and high EMC robustness. To measure air quality for personal well-being, the BME680 gas sensor can detect a wide range of gases such as volatile organic compounds (VOC).

The IndoorSensor module 1 has an input for connecting a temperature sensor, which has the advantage that its cable can be extended to a few meters in length. The sensor is the MAXIM brand DS18B20, which communicates through a 1WIRE communication bus. This sensor allows to measure the temperature of a specific point close to the sensor module and has an advantage of being waterproof.

There is the possibility of wired communication via RS845 (Modbus RTU) and wireless via Wi-Fi via MQTT. Figure 6 presents the architecture of the Indoor Sensor module 1.

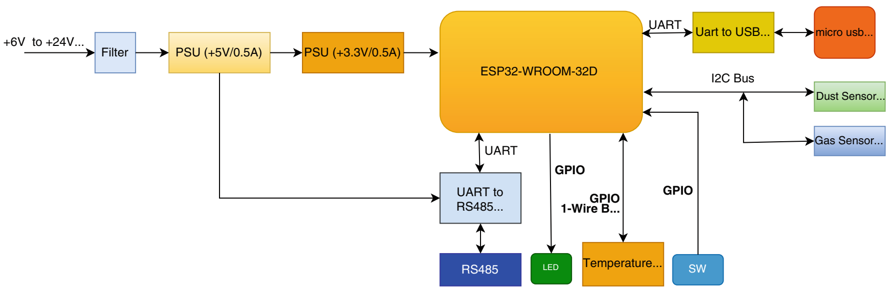

Fig. 6 Indoor sensor module 1's architecture. (*Source*: STVgoDigital Project)

The integration and configuration of this IndoorSensor module 1 are carried out through a web page, where the server runs inside the processing unit.

Another sensor module was developed, the IndoorSensor module 2. A unit-based printed circuit board (PCB) uses a PIC18F27K42 Microcontroller Unit (MCU), allowing the measurement of oxygen concentration, CO_2 concentration, and noise level. This MCU integrates a rich set of core independent peripherals, intelligent analog peripherals, and large Flash/RAM/EEPROM memories. These MCU offer 28, 40, and 48-pin devices and also offer a host of low power features, performance improvements, and design flexibility options that easily and quickly enable the complex set of functions required by many of today's embedded control applications. In this context, the MCU is responsible for monitoring and controlling the information collected by different peripheral sensors. That will then be processed and communicated via RS845 (Modbus RTU) wired communication to the Smart Hub interface [48].

IndoorSensor module 2 has oxygen and CO_2 concentration sensors for indoor application. The oxygen sensor used was a MIX8410, an electrochemical oxygen sensor developed by Mixsen. Under the catalysis of the electrode, a redox reaction occurs on the working electrode and the counter electrode, thereby generating an electrical current. Measuring the current generated allows to get the concentration of oxygen. The range of values supported by this sensor device varies from 0 to 25%ppm, operating in a humidity range from 15 to 90%RH, with a 10 s response time. The output response of this sensor was connected to a signal conditioning circuit and after that to the MCU for processing the signal information regarding oxygen concentration.

For CO_2 concentration monitoring, the sensor used was SCD30 from Sensirion which offers an accurate and stable CO_2 concentration level measurement. It uses an NDIR measurement technology for CO_2 detection, a best-in-class from Sensirion, the humidity and temperature sensors are also integrated into the same sensor module. This CO_2 sensor employs a dual-channel principle for the measurement of CO_2concentration, the sensor compensates for long-term drifts automatically by its design. The lowest module height eases its integration into different applications and enables customers to develop new solutions that increase energy efficiency and simultaneously support users' well-being [48]. The range of values of this sensor device is from 400 to 10000 ppm, with an accuracy of around 30 ppm and 20 s at response time. The embodied humidity and temperature sensors have an accuracy of 3% RH and 0.5 °C, respectively. This sensor response was reported by I^2C communication for MCU, present in IndoorSensor module 2.

A noise monitoring sensor was also integrated into IndoorSensor module 2, to monitor the noise produced by the different machines inside the micro-factory that might be heartful to human hearing being uncomfortable and unhealthy. The sensor used was created using a simple electret condenser microphone (an example CMEJ-0627-42-P, from CUI devices), coupled to a conditioning system, which provides an audio output, but also a binary indication of the noise located, and an analog representation of its amplitude. Those three outputs are simultaneous and

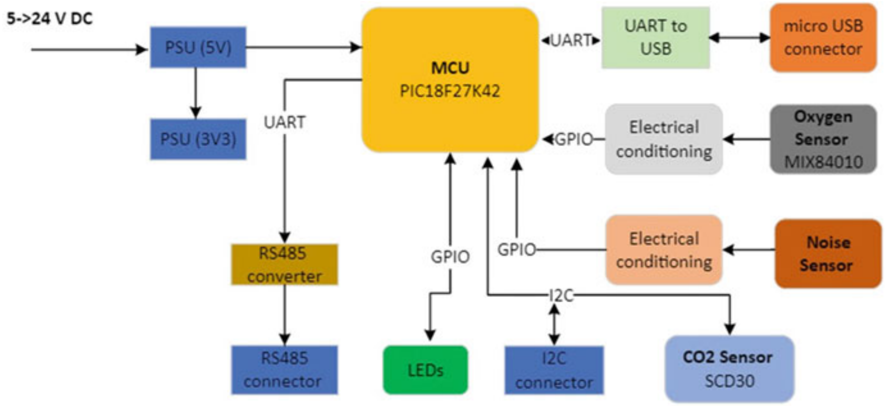

Fig. 7 Indoor sensor module 2 architecture. (*Source*: STVgoDigital Project)

independent; these signals are processed by MCU, where the levels of noise were defined.

The IndoorSensor module 2 is incorporated by wired communication systems, such as RS232, RS485, and I^2C, ensuring the connection with the SmartHub or attached as a slave module within IndoorSensor module 1. Figure 7 presents the architecture of the Indoor Sensor module 2.

Regarding the equipment's monitoring, another sensor module was developed, named EQmonitoring module board, which integrates a modular Printed Circuit Board able to monitor particles, internal vibrations, humidity, and temperature, inside the industrial digital printing machine, in the use case, or other industrial machine in specific/critic locations. The purpose of this sensor module is to monitor the physical environment that might affect the machine's operation, collecting data from the inside of the machine and sending it to a central server supporting the microfactory, to be processed and analyzed allowing to optimize machine's performance and quality of production processes.

EQmonitoring Module has humidity and temperature sensors with digital output, it used a SHT31 from Sensirion which offers high reliability and long-term stability with low power consumption, fast response of 8 s for relative humidity, and 2 s for temperature, with a typical accuracy of ±2% RH and ±0.3 °C. EQmonitoring Module includes enhanced signal processing, two I^2C addresses user-selectable and communication speeds up to 1 MHz. The supply voltage can range from 2.15 to 5.5 V and the operating temperature ranges from 40 to 125 °C.

For monitoring matter particles, the sensor SPS30 from Sensirion was selected, in which the measurement principle is based on laser scattering and uses Sensirion's innovative contamination resistance technology. SP30 allows the identification of PM2.5 to PM10 particles, which refer to matter particles with a diameter of up to 2.5 microns and 10 microns, respectively, and are among the most dangerous air pollutants. Due to its small size, PM2.5 particles can travel deep into the human lungs and cause a variety of health problems, for example, triggering asthma attacks or contributing to cardiovascular diseases. SPS30 allows the implementation of innovative air- quality monitoring devices that prevent damage from air pollution. It presents the best performance when operated within its normal recommended temperature and humidity range from 10 to 40 °C and 20–80% RH, respectively, with fully calibrated digital output for PM number and mass concentration values. UART and I2C interfaces and supply voltage from 4.5 to 5.5 V [46–48]. In the context of application inside the digital printing machine, this sensor has the capacity of monitoring the particles puffed during the digital printing process, at the same time monitoring particles in the air can damage the quality of the digital printing.

Another sensor applied to this module was the LIS3DH from STMicroelectronics, an ultra-low-power high-performance three-axis linear accelerometer, with digital I2C/SPI serial interface standard output. This sensor has dynamically user selectable full scales of ±2g/±4g/±8g/±16g and is capable of measuring accelerations with output data rates from 1 Hz to 5.3 kHz. LIS3DH has an integrated 32 level first-in, first-out (FIFO) buffer allowing the user to store data to limit intervention by the host processor, with a high-performance acceleration sensor, available in a small thin plastic land grid array package (LGA) 16 3 × 3 × 1.0 mm, with a power supply from 1.71 to 3.6 V, and a temperature range from −40 °C to +85 °C [40]. The implementation of this sensor aims to detect anomalies during the movements or actions of the head nozzles array during the printing process inside the digital printing machine. Vibration results in irregularities on the images printed resulting in a non-conformity. Another feature associated with it is its capacity to detect the need for preventive maintenance of the nozzle arrays.

EQmonitoring Module is like other developments, it uses wired communication systems, such as RS232, RS485, and I2C, for connecting with the SmartHub or being attached as a slave module within IndoorSensor module 1. Figure 8 presents the architecture of the EQmonitoring module board.

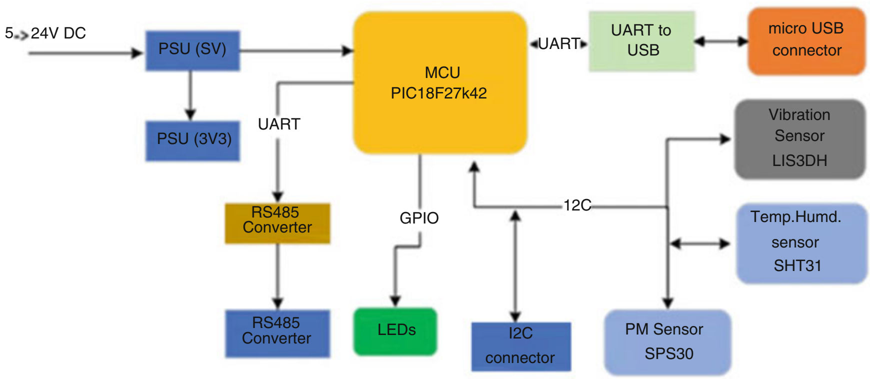

Fig. 8 EQmonitoring module board architecture. (*Source*: STVgoDigital Project)

To complete integration of equipment in the IoT layer, a Plug&play protocol is being implemented and takes advantage of the Smart Hub developed. With the progressive advance of digital transformation, the industrial space is characterized by a growing collection of data from equipment and by an operational integration that allows to operate equipment remotely. However, the integration of heterogeneous machines, whether by their manufacturer, age, or existing firmware, requires an additional effort from IT teams, mainly in a context characterized by the absence of IoT platforms, which transforms the internet of things in an endless number of potential data collection projects. This project seeks to contribute to minimizing this problem, seeking to develop a plug&play or Plug&Produce protocol suitable for the integration of industrial equipment in IoT environments.

The plug&play concept was popularized in the 1990s, related to the connection of external devices to a computer and the latter's ability to recognize the device and immediately be able to communicate and operate that device. Until then, configuring a device was a job that required human intervention. With advances in the internet of things, the opportunity to extend the concept to industrial equipment appears as an opportunity 50 51, leading to the designation of Plug & Produce. The scenario becomes more complex when considering the heterogeneity of equipment and industrial interfaces, as well as the expected longevity of industrial equipment. Plug&play industrial equipment is often approached from the sensor side, shifting the focus to the plug&play sensor approach52. If such an approach can be correct, a sensor is immediately ready to send data to a given destination, including industrial equipment implies another level of connection, where the semantics and syntax of the data have a higher level of abstraction, as well as the connection established between the equipment and its digital twin, namely, in carrying out remotely triggered actions.

5.3 Micro-factory Digital Platform

A digital platform customized to the reality of the Portuguese Textile Cluster and able to support the concept of the micro-factory is being developed. Even thought it is an IoT platform, this one is customized in providing services that support interoperability, data management, and incorporates the plug&produce concept.

STVgoDigital project implements a digital platform customized to the reality of the Portuguese Textile and Clothing Cluster and the concept of micro-factory. The implementation of a digital platform, in addition to being an IoT platform, is customized and provides services that support interoperability and data management and incorporate the plug & produce concept previously presented.

The digital platform was implemented and is customized to the reality of the ecosystem proposed and to the concept of the micro-factory. The platform supports the management and operation of a textile microfactory and the definition of an architecture to support the management and control of production.

The platform allows systems and devices management, device interconnection, data management (accessibility and processing), and generation of automated control. Besides, the system's architecture may also differ, with one being allocated in the cloud (either in the form of Platform-as-a-Service (PaaS) or Software-as-aService (SaaS)) or in a local server. Several platforms such as AWS IoT, Azure IoT, Kaa IoT, Thingspeak, and Particle were considered. However, Thingsboard was the chosen platform, as it is an open-source platform for data collection, processing, and visualization, as well as device management and connectivity, using IoT protocols such as MQTT, CoAP, and HTTP. It also supports both cloud and local versions. This platform allows for the creation of rule chains, which help in the processing of the collected data. Thingsboard is compatible with two types of databases: relational and non-relational. It uses PostgreSQL to store all its entities, with the option of using Cassandra or TimescaleDB to store time-series data. Additionally, it uses Remote Procedure Calls (RPC) to control devices, i.e., to ensure bidirectionality. It integrates a REST API and supports Websockets subscriptions, which makes it possible to forward data to other services. Furthermore, it also has the Thingsboard IoT Gateway software, which is useful to connect external systems such as MQTT, OPC-UA, Modbus, BLE, CAN, BACnet or SNMP, to the platform [40].

As for the connection of the devices with Thingsboard, it may not be as straightforward as expected since this platform specifies topics and message structure. Most of the devices, however, present its own information model and data structure, which may present some incompatibilities.

The architecture in which an MQTT broker assumes the central role of the platform, with all other system components connecting to it, publishing, or subscribing to data is presented in Fig. 9.

5.4 Advanced Customized Production Management and Control Systems

An advanced customized production management and control systems enabling the information collected and stored in the digital platform allows the construction of a virtual view of the factory floor. A digital model of the production system was developed with the creation of a digital twin.

As for the operational stage, orders are important in the planning and management of microfactory resources, however, from an operational point of view, the production unit must be agnostic of orders. From an operational point of view, the relevant contents are the parts included in the order. Thus, an order should be broken into several parts, independently processed.

Production orders should be the main input of the microfactory. It must specify the information needed to produce a particular part. A standardized way of describing a part should be defined. The distribution of a product file to several producers will ensure it to be understood the same way by all stakeholders.

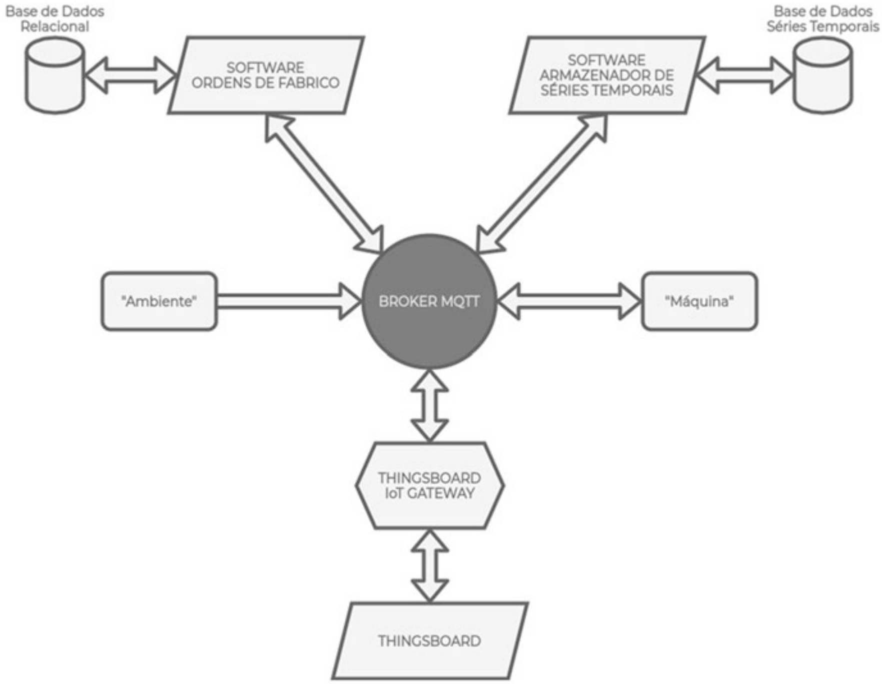

Fig. 9 Digital platform architecture. (*Source*: STVgoDigital)

Given the nature of this project, this part production order is a single file with a defined information model, since the information contained in this file is intended to be processed and interpreted automatically. Therefore, it is not possible to use product sheets in PDF format, since an automatic system will not be able to interpret this file to retrieve the required information. Thus, a standard format must be used to represent structured information, such as the JSON format, for example. It should be noted that it is possible to encode files of other types (JPG, PNG, DXF) within a JSON file.

A production order is generated when it is understood that one or more articles must be produced. However, to generate a production order, there is an intermediate nesting step, where the items to be grouped in a single production order are selected.

A production plan is a specification that defines what needs to be produced and how. Production plans are created from production orders, and there are specific production plans for each process/machine. These must contain the information needed to produce the specific process and information regarding the configuration of the machines needed for it.

Additionally, a production plan allows the production of a sequence of production orders, so it is assumed that there is a relationship between them. Specifically, although each one is independent, it is connected to others in terms of status. For example, the reduction plan of a cutting machine will only be available for execution when the digital stamping production plan is finished; as in the production order, the first step is the digital printing and the second is cutting.

It can then be assumed that a production order will have different status: Creating, On Hold, In Production, and Finished. Creating is the initial status that is assigned at the time of creation. On Hold is the status when it is ready to be produced, that is, the Production Plan that precedes it has been finished. In Production is the status when production has started and finished is the status when the production has ended.

Once an order arrives at the microfactory, it is broken down into the parts that integrate it. These parts are described in a production order. Additionally, the operational specifications for each part should be attached. While a product production order describes the characteristics needed to produce the product, the operational specifications define the needed configuration of each process and/or machine for its production.

The definition of the proper interfaces to support advanced management and control production systems enables the virtual management of the factory. To make this vision possible, a model was developed to support a digital production system: digital twin. Currently, there are several perspectives capable of translating this digital modeling of the factory, such as MES, APM, or simulation systems.

5.5 Size-Fitting Systems

Size-fitting consists of adapting a garment's measurements to the customer's body. It is based on the so-called measurement points, the points that form a bridge between the piece's measurements and the consumer's body parts. The relationship between these two entities is not linear as there is a difference between clothing size and body measurements. Otherwise, it would be a case of producing pieces that fit the body like a second skin. In addition to a product's design and shape, to better support and satisfy the need for customized products, product sizing has gained attention as different body shapes are increasingly considered due to societal changes.

Currently, there are two basic approaches to addressing the issue of size-fitting: the usage of a size chart, a strategy known in the fashion sector and admittedly lacking and the usage of predefined formulas that extrapolate the measurements of the base model [41, 42]. The application of size charts is the most common approach as it allows mass production of clothing. Each piece is produced according to a finite set of sizes defined at the design stage, which gives rise to known alphanumeric sizes "S," "M," "L," "XL," for shirts or sweaters, or numerical "50," "52," "54" for pants, among others. This approach had its origins in the United States, during the civil war when faced with the need to mass produce uniforms, and later, in the 1940s and 1950s, when the first attempts were made to define standards or benchmarks as a contribution to discipline the market [43, 37]. Having a defined set or a range of sizes does not naturally solve the problem for all consumers as a set of points is not enough to accurately represent bodies and their differences.

Additionally, as the differences between bodies are not linear, one can not assume proportionality between the various parts of the human body. Population sizes differ depending on the region of the globe, for genetic reasons and habits. Furthermore, the morphological dimensions of a population vary over time, because of new health and social habits, with the addition of practices such as veganism or sport, for example. Thus, the found solution is far from perfect, making it difficult for a consumer to buy a garment and get the adequate size without trying the garment, for example.

Having identified the limitations of the current sizing approach, the increase in e-commerce platforms and their growth in business volume in the last year led to the emergence of different digital solutions to address the current issues, such as SIZOLUTION, GetWear, and 3DLOOK, among others. Additionally, virtual fitting rooms were developed to enhance the shopping experience, although most of the available solutions differ in their technologies and accuracy. Additionally, this kind of technology isn't widely used due to its cost and size [44–46].

Research and market reality are not always in harmony. If, on the one hand, anthropometric studies of populations can help brands and designers to adjust their patterns, on the other hand, market globalization does not allow e-commerce to adjust the charts and sizes for all the markets.

The usage of computational technologies transformed the textile industry, from the garment's design to its production. Technologies such as Computer-Aided Design (CAD) introduced three-dimensional design, aiding the creation of customized patterns. Although such systems do not learn from experience, they facilitate the quick creation of patterns by using several measurements as input [47]. Additionally, the development of patterns using individual measurements, without a previously existing pattern, has been explored. In that regard, an algorithm that generates the pattern through mathematical calculations or artificial intelligence is required. Thus, in such a personalized approach, the required measurements and sketches are obtained digitally and subsequently sent to cut [48].

There are two main methods to generate patterns in the conventional garment's design: flat pattern, which includes 2D design, and 3D draping, where the fabric is turned into a garment directly on the mannequin. Even though it is more complex, automatic pattern generation mainly focuses on the latter method. It is also important to note that when a new product is designed, there are usually two different aspects to consider: comfort and how well the product fits the person [49].

To find a strategy to develop a size-fitting system, it is important to figure out which features might affect a product's fit. In addition to the body measurements, which directly affect the garment's fit on a person, other features may also play a role. For instance, it is common to assume that the required measurements for an upper-body pattern in men depend on their chest girth, height and that all other measurements can be inferred from such values. However, the analysis of significant samples of anthropometric data demonstrates that this is not the case and that the correlation between body measurements is more complex.

Regarding market solutions, some arise as size-fitting solutions, without clear information about technologies and algorithms that sustain their strategy, with special focus on ZyseMe and SON OF A TAILOR [50, 51].

To solve the aforementioned problems, the STVgoDigital approach aims at using artificial intelligence approaches, such as machine-learning algorithms, to generate a made-to-measure male shirt. Using features as input, in addition to body measurements, the shirt's critical points can be predicted, creating a custom-made pattern, automatically. To validate the obtained solution's results, two methods will be used: a digital validation using simulation software, CLO3D, and a real-context validation with the physical production of made-to-measure shirts.

6 Conclusions

Next-Generation Fashion Ecosystem Project proposes a solution that is compliant with the current needs of textile and clothing market, namely, regarding the need of customers for customized products, regarding the need and opportunity for the consumers to customize its products and for enterprises to be able to produce small batches.

STVgoDigital proposes the creation of the Next-Generation fashion Ecosystem supported by the cloud platform developed. STVgoDigital proposes a conscious textile production allowing an eco-friendly product manufacturing. To support the growing need for customized products, an Industry 4.0 micro-factory for textile and clothing industries was developed. The presented solution differentiates from the solutions currently available in the market, namely, providing a digitally supported ecosystem, which integrates several actors of the fashion cycle, which are digitally mediated, an integrated and digital textile micro-factory, a Plug&Play system applied to industrial equipment supporting IoT environments and size-fitting algorithms.

STVgoDigital microfactory solution has proven to provide a better resource management strategy supported by an appropriate and innovative data model allowing enterprises to go to the next level of business sustainability, improving its environmental, economic, and social impact. The usage of innovative data models to improve the management of enterprise resources nowadays can be the reason why an enterprise succeeds or fails in the current concurrency environment lived worldwide. This approach eases industrial management allowing agile resources management at several levels. Providing enterprises the tools they need to support agility to answer customers' demand, decrease production costs, and improve its flexibility and sustainability through better and conscious usage of resources, which also reflects in the costs of usage of those resources. STVgoDigital allowed enterprises to have agile industrial management.

The improvements achieved by the usage of such technologies can lead to improvements that can decrease up to 30% of production costs and up to 20% in quality management and non-conformities production [44]. Although these results are very relevant, this work can be applied in other enterprises and industries. The results of this solution can be improved through the implementation of interoperable solution within the value chain. Besides that, this kind of solution can be implemented to other industries or business areas, with similar results. The expansion capacity for other industries and processes maximizes its applicability. The solution presented allows enterprises to have an interoperable computing platform, as a human-machine interface (HMI) between a range of equipment and processes for the integral processing of textile parts. Allowing to overcome the evolutionary challenge of the overall monitoring of all enterprise resources, from data collected from ERP, MRP, and even data collected directly from industrial equipment allowing to have a complete awareness of what is happening in industrial environment.

The work presented is still ongoing although it is being validated by the industrial partners that integrate the project consortium. The solution being developed integrates all the conventional processes of textile and clothing industries and is suitable for a quick and easy implementation in the shopfloor any enterprise. The project will allow enterprises from those sectors to be able to have a better planning and management of their own resources, at the same time it will provide them the flexibility to adapt for the production if small or unit batches allowing them to be more competitive in a fast-changing ecosystem.

To validate the solution being developed, a laboratory scenario is being created simulating a textile microfactory that includes a broader production chain, which includes operations such as digital printing, spinning, or weaving. The purpose of this approach is to develop an integrated textile microfactory, comprising the physical, operational, and digital assets, thus defining the three aspects that characterize it. It also aims to contribute to the validation of the concept as a solution to produce small batches and unit batches.

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Public Transportation Occupancy Rate

Pedro Silva, Joana Campos, José Matos, José Salgado, Carla Salazar, Hugo Costa, Filipe Portela, and Daniel Carneiro

1 Introduction

The preferential mobility of using public transportation over private vehicles is a well-known and beneficial measure in terms of the environment, finances, time, and even safety [1, 2]. Transport optimization is a subject that can be dealt by modern-day urban planning. Jha et al. in their study refer that urban planning can answer questions about transport optimization and others which can help people to live their daily lives efficiently and easily [3].

There are several urban centers with public transport networks suitable for their operational flow, with well-defined routes and schedules relevant to their daily use by commuters, due to the growing demand for better mobility systems [4, 5]. But little attention has been paid to real-time predictions of passenger occupancy rates in public transport. Users do not have access to information that could be fundamental for their final decision, especially on long journeys, such as the occupancy rate of seats or space for boarding and other critical aspects of public transport service quality [6]. Occupancy is limited by the vehicle's maximum capacity, as it refers to the number of people that can be inside a vehicle at a particular time. It indicates the number of vacancies, which is the sum of the available number of seats and standing places [7]. The number of available places on a bus determines whether passengers can get on and continue their journey, and the availability of seats determines

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the comfort of the journey. These two factors are considered by passengers when planning their trip, namely, in terms of routes and forms of travel [8].

Overcrowded public transport can result in long traffic jams, denied boarding, and consequently reduced reliability in provided service [9]. Reducing overcrowding is an important factor to consider regarding improving the quality of public transport [10]. Some studies show that public transport passengers are willing to pay a higher price if the transport occupancy is lower [11].

Daily commutes in main metropolitan cities in Portugal continue to be excessively dependent on individual transport. Unfortunately, public transport is underused, and its demand is far from what is expected. Anyway, public transportation continues to be mostly used by those who have no alternative [12, 13]. About Lisbon, which is one of the European cities that uses Moovit, the facts and statistics on the use of public transport are not very encouraging. On average, commuters wait for 14 min for transportation, but over 41% wait longer than 20 min. 49% of the users spend more than 2 h on public transportation every day [14]. People waste plenty of time commuting, and there is an excessive dependency on individual transportation. Therefore, public transport usage optimization plays a very important role to increase the demand for this kind of mobility [15].

Optimization of transport services to better inform possible commuters can benefit from vehicle occupancy real-time information [16]. In this context, and from the user's point of view, obtaining reliable and timely information regarding the occupancy rate of public transport can lead passengers to make better-informed decisions about how, when, where, and/or whether to travel. From the service provider's understanding, it can bring short-term benefits, such as a quick response to unexpected events, and in long term, it can adapt its services accordingly to users' demands [17]. But an automatic collection of data regarding the occupancy of passengers in public transport is not seen as a priority for most service providers, which leads to service planning based only on historical data and not on real-time data.

Scheduling public transport routes based on passenger flow allows service providers to avoid empty routes and consequently reduce environmental pollution [18]. By making urban transport convenient and efficient, it can significantly contribute to the increase in the demand for public transportation, reducing the number of private vehicles circulating in urban areas [19]. Cities need more than one mobility option, not only the usage of private vehicles. It must be provided alternatives for more fluid traffic flow, promoting a better balance of public space privileging the use of public transportation [20].

This project intends to contribute to the mitigation of one of the biggest problems of modern society, the intolerable traffic jams by contributing to resource optimization, urban mobility improvement, and pollution reduction. With all this in mind, this work presents an approach for a low-cost proof of concept system capable to detect passenger flow inside a bus aiming to achieve a minimum accuracy rate of 70%. Adopting bulk detection devices able to detect people combined with the use of wireless communication for data exchanging, this solution aims to conceive a system capable of accomplishing ioCity's main goal, passenger flow monitoring [21].

In this work, a state of the art regarding the occupancy rate of public transport is presented, highlighting different approaches already implemented to assess data from public transportation usage. In addition, a comparison between the bulk solutions available was performed to analyze its main characteristics. An overview of the system proposed is presented to demonstrate its conceptual idea. It also presented a atate-of-the-art analysis of Time of Flight (*ToF*) and *BLE* technologies, the main approaches proposed. Along this work, those technologies will be accurately described to understand all their characteristics.

Master and slave devices and hardware development were highlighted as part of the system architecture of the proof of concept solution. Subsequently, the tests and validation performed regarding *ToF* and *BLE* technologies are presented. Finally, it presented a discussion and the conclusions regarding the work developed and future work were discussed.

2 State of the Art

Many advances have been made in the public transport industry to determine bus occupancy rates. Throughout the years, technologies have progressed from basic manual counting methods to costly automated methods which sometimes require invasive vehicle modifications, still verifying a lack of reliable and effective data collection.

To optimize public transportation services for its target audience, a study was performed regarding its prices, frequencies, bus sizes, and distance between bus stops. The conclusions of this study allowed to adapt and evolve the technology used for passenger counting. Many studies analyzed the occupancy rate using mathematical algorithms to predict the number of bus users, although the solutions identified are not 100% accurate and do not share real-time information with their users.

One of the methods used to monitor bus occupancy rate is based on Weight-In-Motion (WIM) systems which rely on the weighing of the vehicle, to estimate its average number of passengers. WIM stations classify vehicles using weight sensors and determining the distance between axles through the automatic number plate recognition cameras (ANPR), storing that information in a database. The main problems related to the measurement of the gross weight of the vehicle are related to its fuel level, passengers' baggage, and its motion which can directly interfere with the measurements and forge the results [22].

In a study performed by Agard B et al., the approach used to quantify the occupancy rate, in public transportation, is using smart card data. The process starts in the emission locations where users can buy smart cards, following the validation of the card inside the bus. All buses possess a predefined route, and every time the GPS reader identifies the stop where it is boarding, the system validates the location and internally stores the card number, date, time, validate status, and stop number. Data exchange with a remote server happens at the end of each day, to protect the confidentiality of each user. The information can be processed to understand patterns like the hours with passenger flow along the day, weekdays with higher affluence, and the locations preferred by users [23].

Inspired by the measurement of seat occupancy capacitive sensors, widely used in car seats to detect the presence and position of people in cars to improve airbag systems [24], a study in Africa followed the same approach, by detecting the number of people in a bus using capacitive sensors on its seats. This study announces a low-cost setup using the measurement between an electrode and its surroundings, connected to a microcontroller that in addition to collecting the data, also transmits the information via ZigBee. The complexity of the system increases as the number of seats to be measured goes up, despite the maintenance and solution's installation costs within the vehicle, this ensures greater flexibility. Besides the good results of detecting objects in the seat, it doesn't exactly mean the presence of a person. It can also be a simple bag or other appliance with detectable weight [25]. To mitigate this situation, in a work presented by Nguyen, H et al., a different type of sensor was added, an infrared (IR), that allows a more precise and effective distinction between objects on seats [26].

With the evolution of technology and image quality, there are several projects based on computer vision being developed using this type of approach to determine the number of people on a bus. One example is a work carried out by Chao-Ho Chen et al., where an automatic people counting system based on bidirectional passenger flow is presented. The camera captures the entire surrounding environment and splits it into different blocks. These smaller blocks will feed an integrated algorithm capable to identify movement and distinguish between passengers and inanimate objects. After identifying people, it counts people entering or leaving the bus allowing the system to know the exact number of people on the bus with an accuracy of 92% [27].

In another work carried out by Liciotti D et al., instead of using a camera, they used a Red Green Blue-Depth (RGB-D) sensor located in each bus door that obtains similar results when compared to the previously described method. Despite this similarity, the advantage of this specific project is its reduced cost, inexpensive computational power, and flexibility to obtain real-time information with the use of an Analytical Processing System which allows access to information regarding bus occupation, as well as some statistics. Anyway, one of the major issues identified by this kind of approach is its incompatibility to handle a large flux of people which normally happens in urban areas [28].

Using a single camera, the system described by Yang T et al. was able to run at 25fps in two simultaneous 320×240 image sequences with a 96.5% accuracy rate without any code optimization and on a single computer. Besides the good accuracy of camera-based systems, questions regarding the user's privacy can easily represent a step back in using these systems, since they can know the exact time and location of an individual [29]. Adding to these disadvantages, camera-based systems need strong algorithms and computational power. To simplify the algorithms used, Mukherjee, S et al. divide their algorithm into three components: people's detection, tracking, and validation. People's detection is accomplished using the Hough circle technique. Once a person enters the circle, it is tracked using an optical flow until it is no longer seen in its range. The tracker is generated through a spatio-temporal background subtraction technique. The number of valid trajectories represents the number of people who passed through the detection area of the camera. With promising results, the proposed algorithm had a 30% accuracy increase and increased 20% its precision when compared to similar algorithms [30].

In the work presented by Stec M. and Herrmann et al., the followed methodology used *ToF* sensors combined with 3D data processing allowing a robust people's counting system. Comparatively to 2D color or monochrome image sensors, 3D depth sensors are not significantly affected by shading, illumination variation in the observed scene, or object color modification. For this reason, the extraction of background can be accomplished with simple algorithms [31].

Not indifferent to this problem, Google adapted the Google Maps mobile application to include live information regarding traffic delays for buses and its crowdedness predictions. Anonymously, each passenger can notify Google of the current occupancy rate of a specific public transport and Google will then inform other users about the reliability of using that specific transportation [32].

While developing new technology, in the initial phase, several different approaches are adopted to understand its pros and cons. The decision to rather commercialize the solution or not needs to be based on a careful analysis of the achieved conclusions.

It was possible to identify a company that uses technology and methodology very similar to what is intended to be developed along the project described in this document. DILAX company, mainly focused on people counting and tracking, announces a 99% measure accuracy for its most robust detection product, DILAX SLS-1000 [33]. Using patented structured Light Technology, it has the capacity not only to accurately detect people but also to detect wheelchairs, bicycles, and baggage being certified to be used in both buses and trains. It can work in extremely dark or bright environments because it creates a 3D profile of the object without using video technology. It is equipped with Artificial Intelligence (AI), capable to learn additional objects classes and works completely anonymously, not storing real images of the passengers [34].

Mentioning some other DILAX passenger counters, DILAX PRT-400 uses 3D stereo vision technology with a wide visual angle of 120° capable to differentiate between adults, children, and inanimate objects. While DILAX IRS-320R counts users according to the triangulation method using infrared technology. It is maintenance-free, has Ingress Protection IP65 and Impact Protection IKO8, and is also vandalism proof [34].

Another important device to be mentioned is the DILAX PCU for automatic passenger counting. This component has the responsibility to store, collect, and process counting data collected by previously described sensors in combination with GPS information and time tracking. It also can automatically transfer the counting data via GSM, GPRS, or Wi-Fi. Its maintenance and configuration can be

Table 1 Comparison between DILAX's devices and their main characteristics

	DILAX SLS-1000	DILAX IRS-320R	DILAX PRT-400
Technology	Patented structured light	Infrared	3D stereo vision
Methodology	Create a 3D profile of the object	Triangulation method	Wide visual angle of 120°
Differentiates between adult and children	✓	X	✓
Stores real images	X	X	✓

made locally or remotely [34]. Table 1 presents a summary and a small comparison between the devices and their main characteristics.

3 System Overview

Considering that the Use Case working environment for the solution being developed is a bus, it is important to understand how the system will be installed. All possible installation variations should be considered as different buses can have different requirements. Considering that most buses used for public transportation have two different doors usually, the main to enter and the secondary to exit, it is crucial to have a system capable to detect the passengers' flow through both. Therefore, the main idea was to adopt a master/slave approach where the master and slave devices are located inside the vehicle, above the main and secondary doors, respectively. Figure 1 presents a diagram that represents the conceptual idea of the final solution for this project.

With the master device represented in Fig. 1 (1) and the slave device represented in Fig. 1 (2), both should have the capacity to analyze passengers' flow in their corresponding door. Another characteristic that both devices must have is the ability to communicate with each other. As the master device's responsibility is to share with the user the total amount of passengers inside the bus, data exchanging between both the master and slave is crucial. Otherwise, master would just have information about passengers' flow at the main door and the information about the secondary door would be lost.

4 Technologies

After understanding the studies presented in the state of the art, the approach decided to be followed by ioCity was to use Time of Flight (*ToF*) sensors for passengers' flow detection and Bluetooth Low Energy (*BLE*) for communication between master

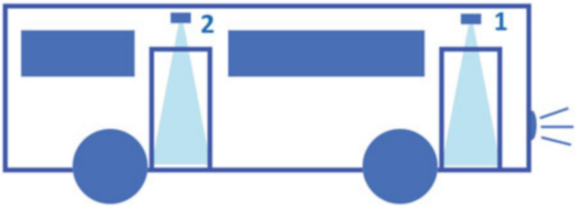

Fig. 1 ioCity's project conceptual proposal

and slave. The next topics details each one of them with a special focus on all the main components as well as their corresponding inclusion in the final system.

4.1 Time of Flight (ToF)

In recent years, several solutions regarding video cameras are being developed, but a geometry purely image-based in a 3D reconstruction scene is still a challenging problem. *ToF* sensors can capture full frame depth images and, suitable for capturing 3D information in real-time, they can contribute to photo-realistic 3D image rendering dynamic scenes [35]. Capturing depth information can allow applications to be more feasible and robust.

There are usually two types of zone-level counting systems: sparse, which means the detection of motion is performed in a narrow cone angle below a small number of sensors; or dense, when a large number of sensors is trying to sense an environment, or even the use of wide field-of-view sensors [36]. Most common motion sensors use Passive Infrared (PIR), but it only detects heat motion, which limits stationary people recognition resulting in false negatives [37].

ToF systems are being used for more than 30 years, in Radar and Lidar applications, and its main principle consists of sending a signal and measuring its return signal. The distance is measured by the multiplying time of flight signals with its corresponding speed [35].

Some preprocessing steps are required when processing the *ToF* data, being crucial for detecting bus occupancy [38]. Besides the dense depth maps provided by *ToF* sensors, the main challenge is its resolution, which is below the one registered in stereo depth maps from color images. Another challenge is the measurements' corruption by random noise and non-trivial systematic measurement bias [31].

Besides these limitations, as already mentioned in the s*tate of the art*, one of the most common approaches used for passenger counting systems is *ToF* infrared light-based sensors. Even though there are some different possibilities inside infrared light-based sensors, such as structured light technology developed by DILAX [33] or the simple usage of a *ToF* sensor, as presented by STMicroelectronics [39], all of them offer quite good reliability perspectives.

The use of *ToF* sensors to detect bus occupancy can provide a balance between its installation cost, privacy issues, and measurement accuracy. Even though it is low-resolution, these sensors can provide occupancy information and protect occupants' privacy while reducing computational complexity [36].

4.2 BLE

Created in 1998 by five major companies (Ericsson, IBM, Intel, Nokia, and Toshiba) intending to create a license-free technology for universal wireless connectivity, Bluetooth was born. Its link speed, communication range, and transmission power level were chosen to be low-cost, power-efficient, and single-chip [40].

Since then, a lot has changed and evolved for Bluetooth, such as enhanced data rate, high speed, low energy (allowing a step forward toward energy efficiency), and, more recently, Mesh technology, fully optimized for the Internet of Things (IoT). *BLE* fifth generation is achieving two times the transmission speed, four times the transmission range, and eight times the broad capacity comparing to Bluetooth 4.2 [41]. Figure 2 presents the protocol stack for *BLE*.

Starting with its physical layer, *BLE* can control over 40 frequency channels in the 2.4 *GHz* band and, together with its link layer, the controller is complete. The link layer works with a master and slave protocol, where the master can have multiple slaves, while one slave can only have one master, forming a piconet. In this topology, the slaves are in sleep mode and are awake by their master for access coordination using a Time Division Multiple Access (TDMA). All the data is transmitted using the same frequency channel and, when the package is received by the slave, it will send a packet in reply to its master until all the packages were sent. The link layer uses a stop-and-wait flow control mechanism which is a good recovery capability for errors.

The host includes the Logical Link Control and Adaptation Protocol (L2CAP), the Attribute Protocol (ATT), and the Generic Attribute Profile (GATT). L2CAP is

Fig. 2 Bluetooth low-energy protocol stack

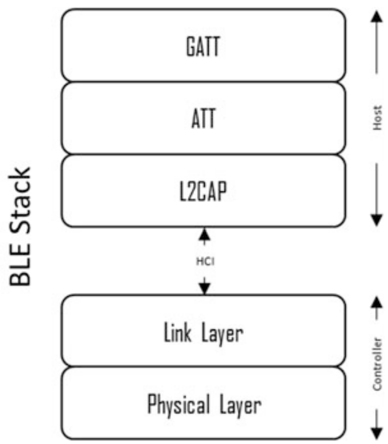

Table 2 BLE main characteristics

Characteristic	*BLE*
Core	ARM Cortex M4
Frequency	2.4 GHz
Maximum data rate	2 Mbps
Power output	4 dBm
Sensitivity	−96 dBm
Memory size	512kB Flash; 64 kB RAM
Serial interfaces	I2C; SPI; UART
Current receiving	5.5 mA–10.4 mA
Current transmitting	5.5 mA–15.2 mA

the layer responsible to support upper layer data unit fragmentation, reassembly, and flow control, in processes called *recombination* and *fragmentation*. ATT and GATT are new layers present in the *BLE*, replacing the serial port protocols in classic bluetooth. In ATT, communication between two devices is accomplished by a client–server protocol. Rules are defined in GATT and are independent of the slave and master protocol. The server is responsible to send two types of non-requested messages: first, are notifications not confirmed by the client and the second is a request for the client to confirm. The client can send commands to the server to attribute values. GATT is responsible to define the framework that uses ATT to find services and exchanges of characteristics between the devices.

The communication between the controller and the host is a standard protocol called Host Controller Interface (HCI). This protocol is also responsible to manage the communication between the user application and the hardware, defining commands, and events to transform raw data into data packets and send them via serial port between two layers [42–44].

With this said, to accomplish information sharing between both master and slave devices wirelessly, *BLE* has the right potential to be used in this system since it presents quite good reliability, low-cost, and low-power consumption [45]. Regarding throughput, even though tests reported by Dian F. et al. present a maximum data rate of 221.7 kbps, for this application, it is enough since the amount of data and its refresh rate are not very demanding (passengers flow rate in public transportation) [46]. Having as reference the nRF52832 microcontroller from *Nordic*, it was possible to identify some of its main characteristics which are present in Table 2 [48].

5 System Architecture

As previously mentioned, ioCity's final solution consists of two different devices: master and slave. Those devices should be capable to cover passengers' flow between both doors and report that information to each other through *BLE* technology as presented in Fig. 3.

Fig. 3 Architecture of ioCity's proof of concept solution

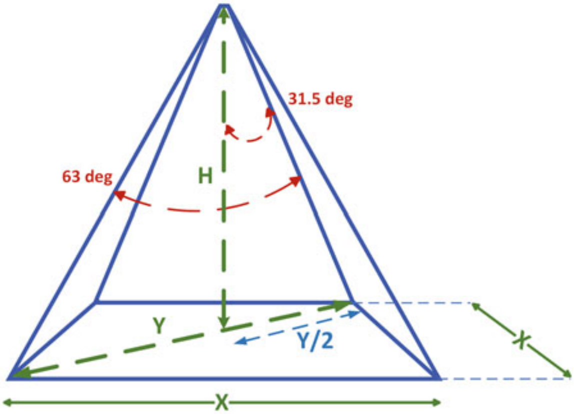

Fig. 4 *FoV* representation for *ST* sensor *VL53L5CX*

Since their functionalities are very similar, all main electronic components that integrate those devices are the same. The main difference will be the firmware running inside each one of the main controllers. The next chapter details the main electronic components used on these devices.

5.1 Master and Slave Devices

As master and slave must analyze passenger flow, *ToF* technology needs to be included in both devices. Thus, a *ToF* sensor needs to be used in this project to feed the passenger counting system. Anyway, a proper investigation needs to be performed to validate the usage of any kind of sensor.

Therefore, a *ToF* sensor from *ST* [47] was chosen as a strong possibility to be included in this study and feed the passenger's counting system. With a maximum of 64 detection zones, up to 400 cm of detection capacity, 63° of diagonal detection volume (45° horizontal and 45° vertical), and a low-cost solution when compared to other alternatives, this sensor has interesting characteristics to be used in such a system.

Taking a closer look at Field of View (*FoV*), as reported by the datasheet, this sensor presents a detection volume with 63° diagonal and 45° for both vertical and horizontal planes. Figure 4 presents in detail *FoV*'s area covered by this sensor.

With the diagram presented in Fig. 4, now it is possible to analyze some values and verify if this is a reasonable *FoV* for people detection in a bus environment. Since both vertical and horizontal detection volumes are 45°, the projection result of the *FoV* in a perfectly horizontal plane that is a square, with side length X as represented in the base of Fig. 4. Now, analyzing the average people's dimensions, a square with a side length of approximately 40 cm should be enough to embrace the upper body part, mainly head and shoulders. With these numbers, using some basic trigonometry and the Pythagorean theorem, it is possible to find the distance between the sensor and *FoV*'s plane (*H*) represented in Fig. 4.

$$Y^2 = X^2 + X^2 <=> Y = \sqrt{X^2 + X^2} = \sqrt{2} * X \tag{1}$$

where *X* is the square side length of sensor's projected *FoV* and *Y* is the hypotenuse of the same square in Eq. (1).

$$\tan(31, 5) = \frac{Y/2}{H} <=> H = Y * \frac{1}{2 * \tan(31, 5)} \tag{2}$$

where *Y* is the hypotenuse of sensor's projected *FoV* square and H is the distance between sensor and *FoV*'s plane in Eq. (2).

Replacing variable *Y* in Eq. (2) by its value presented in Eq. (1), the final equation which correlates variable distance between sensor and *FoV*'s plane (*H*) and sensor's projected *FoV* square side length (*X*) is the one represented in Eq. (3).

$$H = X * \frac{\sqrt{2}}{2 * \tan(31, 5)} = X * 1, 1539 \tag{3}$$

where *X* is the square side length of sensor's projected *FoV* and H is the distance between sensor and *FoV*'s plane in Eq. (3).

Using a 40 cm reference for the sensor's projected *FoV* square side length (*X*) as already mentioned, the final distance the between sensor and *FoV*'s plane (*H*) is approximately 46.16 cm. This means that the sensor needs to be 46.16 cm away from the obstacle to be capable to have a square sensing area with a 40 cm side length surrounding it.

Now, taking into consideration that the mean height of the Portuguese population is somewhere about 170 cm, to have a considerable sensing area the bus sealing needs to be at least 46.16 cm higher. Doing some simple math, the bus sealing height reached with these numbers is somewhere about 220 cm. This value is quite acceptable and considering the normal buses used for public transportation, the usage of the analyzed sensor seems to be feasible.

Regarding wireless communication using *BLE*, among the several options currently available in the market, the *Bluetooth* controller chosen was *nRF52832* [48] from *Nordic*. In terms of communication characteristics, this controller has +4 dBm of maximum transmission power together with −96 dBm of reception sensitivity.

Regarding development itself, *Nordic* also presents an *SDK* with several example codes for many *BLE* topologies that can be included in this system. Regarding its financial costs, this controller has also a low price which helps the final system cost to be kept as low as possible.

Another component that has crucial importance in this system is its antenna. To keep the system's size as small as possible as well as its price, the chosen antenna was [49] High Frequency Ceramic Solutions −2.4 GHz Mini Antenna, from SMT, with an average gain of −0.5 dBi [49]. Gathering all this information and using a range calculator available on Bluetooth® Technology Website, it's expected that this solution reaches a 16 m range for the most challenging environment when path loss comes into the picture [50].

Analyzing a normal bus does not present any kind of difficult obstacle for signal propagation. Therefore, if in a very challenging environment the range is around 16 m, inside the bus the maximum range should be considerably higher. As previously mentioned, the master and slave will be located on top of each bus's doors, which means that the distance between both devices will certainly be less than 16 m. For this reason, in terms of wireless communication, all electronic devices are verified and validated for usage in this system.

5.2 Hardware Development

After the selection of *ToF* sensor and *Bluetooth* controller, the main components for this project, the next step is the selection of the remaining components to develop functional integrated hardware. Considering the project's main goals, the hardware was constructed having in mind three main requirements:

- Low power
- Low cost
- Small dimensions

Considering these three essential topics, the hardware conception can be separated into three different blocks:

- Sensorization
- Battery ICs
- Processing and Communication

All these described topics can be observed through the block diagram presented in Fig. 5.

Starting with the *ToF* sensor, mentioned above, it is the device that has the responsibility to detect and collect all the information regarding moving objects. Later, together with an algorithm specially designed for the effect, all this information is processed to understand if there was any entry or exit on the sensing door. For this functionality, the sensor *VL53L5CX* was selected, for its small dimensions,

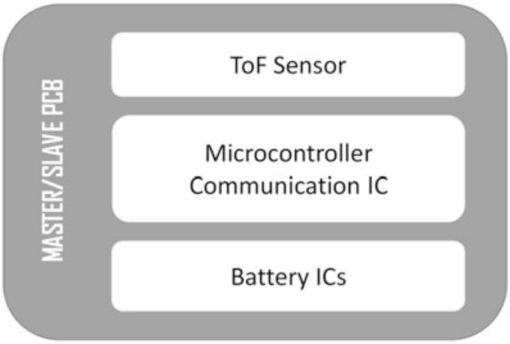

Fig. 5 Block diagram for final hardware concept

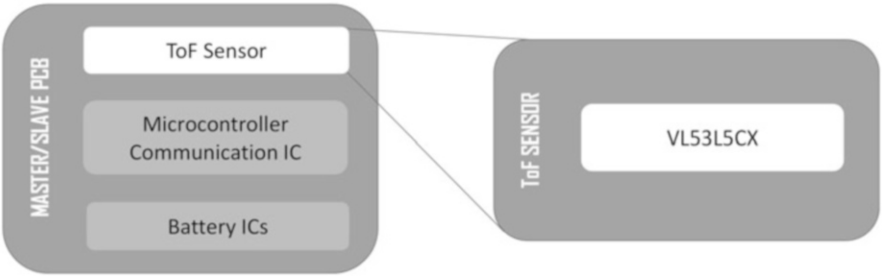

Fig. 6 Block diagram discriminating the *ToF* sensor in use

and large possibilities in applications. The diagram in the Fig. 6 discriminates the sensor's reference.

Regarding data processing, the information collected by the sensor needs to be handled by a dedicated microcontroller with quite robust processing power and memory space. Several microcontrollers with this kind of characteristics can be easily found in the market but, for this case, the aimed one is *STM32L431CC6*. It belongs to *STM32L431xx* family from *ST* company [40]. Although microcontroller is robust, it is not capable to communicate wirelessly by itself. That is where the previously mentioned *Bluetooth* controller comes into the picture. *nRF52832* from *Nordic Semiconductor* is a *Bluetooth* 5.3 *System on Chip* (SoC) supporting *Bluetooth Low-Energy*, *Bluetooth mesh,* and *NFC*. Regarding the processing component, this *SoC* presents an *ARM Cortex-M4 MCU* with a floating-point unit and 32 MHz clock frequency [52]. Although the presence of a microcontroller with such interesting characteristics as the one presented by this *SoC*, its usage to embarrass the previously mentioned algorithm responsible for people detection would be a little problematic. Since *nRF52832 SoC* is a single core device, the division of both processing power and memory space by *BLE* stack and detection algorithm on the same core could be catastrophic. As *Bluetooth* technology has timing restrictions, the inclusion of another major task such as running a detection

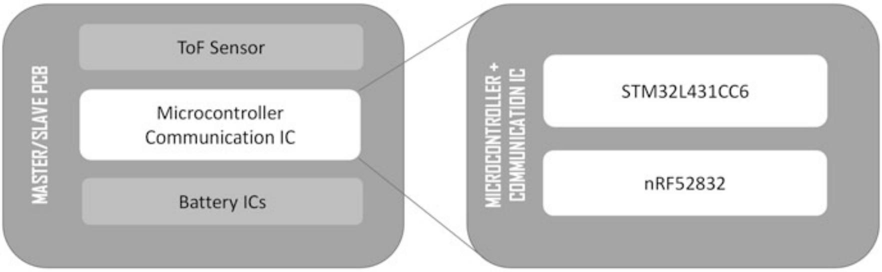

Fig. 7 Block diagram discriminating microcontroller and communication IC

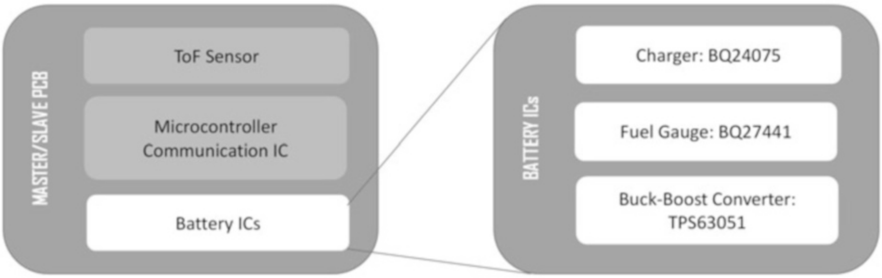

Fig. 8 Block diagram discriminating battery ICs

algorithm could cause any delay in *Bluetooth* data processing and, consequently, deal with *Bluetooth* communication failures. Another important device is the antenna. With the announced gain of −0.5 dBi, this antenna will keep enough communication range to assure that messages will effectively be sent between both devices. The block diagram in Fig. 7 discriminates the microcontrollers used for processing information and communication.

Ultimately, to power up the system, a battery will be included. As any other system powered by a battery, this one needs the necessary components to assure its right operation. The components are described in Fig. 8.

The voltage of any battery varies according to its charging level, and for this case, the voltage of the tested battery changes between 3.7 V, when fully charged, and 2.8 V, when fully discharged. The system is powered at 3.3 V and, for this reason, a converter capable to support positive and negative voltage amplitudes on the input when compared to its output voltage needs to be included in the final hardware design. This type of converter is called a buck-boost. Regardless of the input voltage, the output voltage level is always expected for powering the system. For the development of the hardware, the selected buck-boost was the *TPS63051* from *Texas Instruments*. This device has a fixed output voltage of 3.3 V and the input voltage can vary between 2.5 and 5.5 V [53].

As much as the buck-boost converter, the presence of a device capable of detecting the battery state of charge is very important. Such a device is called a fuel gauge. The one selected to this effect was *BQ27441* from *Texas Instruments*, capable of proving system-side fuel gauging for single-cell Li-on batteries. It communicates via *I2C* and provides information like remaining battery capacity, state of charge, and voltage. The size of the component is 2.5 mm × 4.00 mm, and it is ideal for space-constrained applications [54]. When the battery state of charge is low, the need for charging is imminent to avoid power failure and consequent system failure. For this reason, the hardware was designed to be capable to accomplish this task.

The connection with the outside is made with an *USB-C* connector, which promotes a power source variation. After the *USB-C* cable connection, the system is powered by the external power source (*USB-C*), and the battery is charged by the *BQ24075* from *Texas Instruments*. This component allows charge currents up to 1.5 A, powering the system while simultaneously and independently charging the battery. It has power stage and charge current sense functions integrated that controls the three phases of battery charging: conditioning, constant current, and constant voltage in addition to the IC junction temperature [55].

Gathering all the *ICs* described above, a Printed Circuit Board (*PCB*) was designed. The design of the proposed *PCB* is presented in Fig. 8. Its dimensions are 24.9 × 36.1 mm, fulfilling the small dimension requirement.

Regardless of its design, it is important to highlight some important aspects about the *PCB*. It was designed with the *ToF* sensor integrated but, due to eventual installation constraints, its final design may require an adjustment of the sensor positioning to have a better perception of its surrounding area. Considering that, the headers located on the right side of the *PCB* were conceived. This way, it is possible to connect to the *PCB* an external sensor positioned in the most convenient location to improve final system performance. Regarding sensor data processing, as already mentioned, it will be accomplished by an external microcontroller. Although it is not represented in Fig. 9, its connection with the proposed *PCB* can be done through headers designed on top of the *PCB*. Connected to *UART* pins on the *Bluetooth* controller, this header can be used by the external microcontroller to notify *Bluetooth SoC* about the result of the *ToF* sensor data processing via *UART* protocol.

6 Tests and Validation

For a quicker hardware validation of the previously achieved theoretical results, development boards from both ST and Nordic were tested to perform the needed validations.

Regarding the *ToF* sensor, the expansion board *X-NUCLEO-53L5A1* from *ST* [57] and interface software provided by *ST* were used to promote the collection of some real values from *ToF* sensor *VL53L5CX* [47]. Regarding this sensor's validation, three different test scenarios were considered:

- Object on top of the sensing area

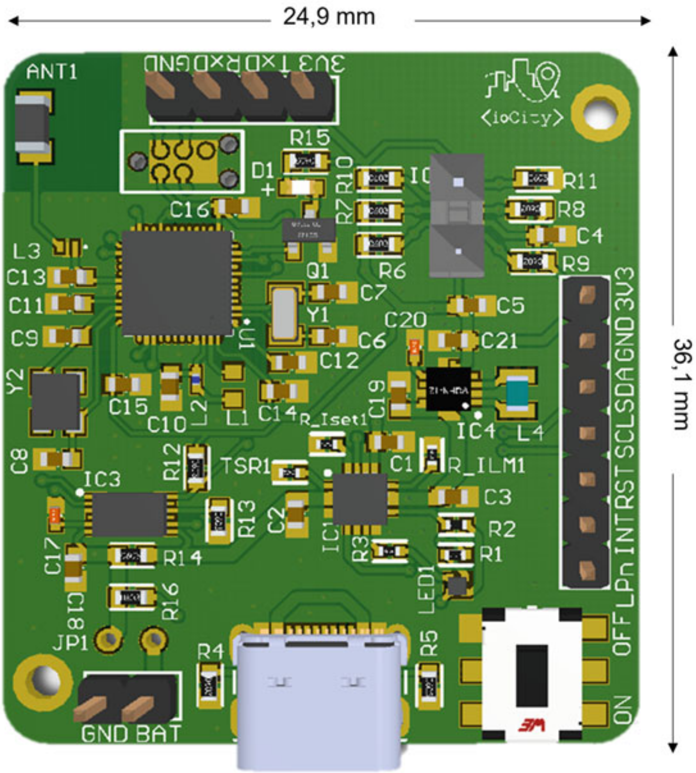

Fig. 9 PCB developed under the project

- Object in middle of the sensing area
- Object on the bottom of the sensing area

To properly validate this sensor, it should detect the object in all three test scenarios previously described. Using *ST* interface software, all three different test scenarios were executed with a small ball as the object to detect.

First, the mounted scenario was the one with the object in the middle of the sensing area and, as visible in Fig. 10, the sensor was capable to detect it. This can be easily noticed by taking a closer analysis on matrix color code since the colors somewhere in the middle of the matrix are different from the ones presented in its surrounding areas.

Second, the couple of remaining test scenarios was accomplished. As illustrated in Fig. 11a, b, the color code is very similar for all three matrix samples independently from the object position. Thus, sensor behavior is very stable in its full sensing area and can provide quite reliable information for any detection algorithm.

Regarding *BLE* communication, a couple of *nRF52DK* development boards from *Nordic* [58] were used to simulate two different devices communicating with each

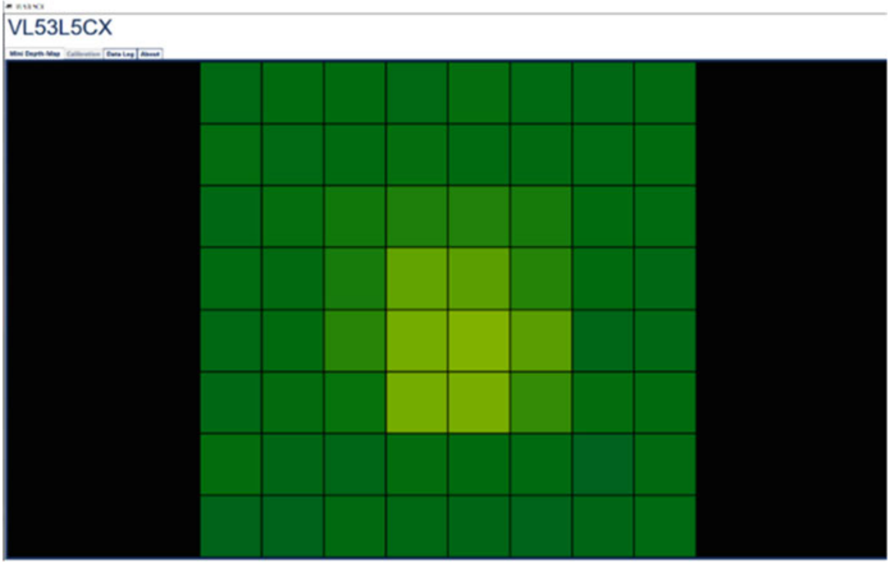

Fig. 10 *ToF* sensor output with an object at the middle of sensing area

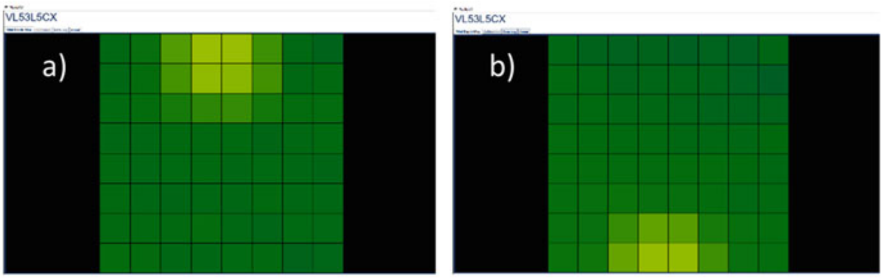

Fig. 11 *ToF* sensor output: (**a**) with an object at the top of sensing area; (**b**) with an object at the bottom of sensing area

other. To ease the validation process, a couple of examples from *Nordic SDK* were uploaded into both controllers. Figure 12 presents the default state of both controllers after their firmware upload.

Analyzing the code description provided by *Nordic*, the default state of both devices is expected since connected *LED*s are turned on (bottom right-side *LED*s).

Now, as the connection is established, it is necessary to understand if both devices can communicate with each other.

As demonstrated in Fig. 13a, b when the configured button of the respective controller is pressed, the corresponding paired device receives the button pressed notification from its pair and turns on one of its *LED*s. With this behavior, both devices can communicate with each other and actuate accordingly. For the system

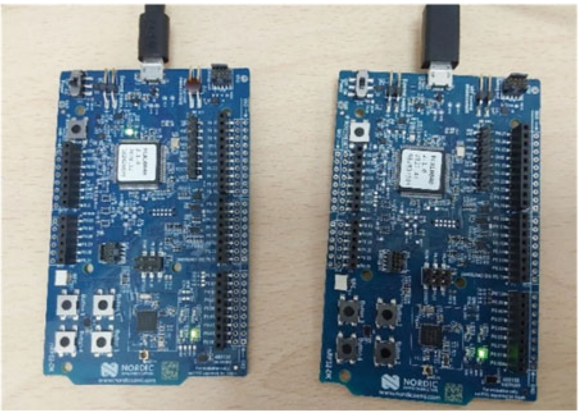

Fig. 12 Default state of both devices after firmware upload

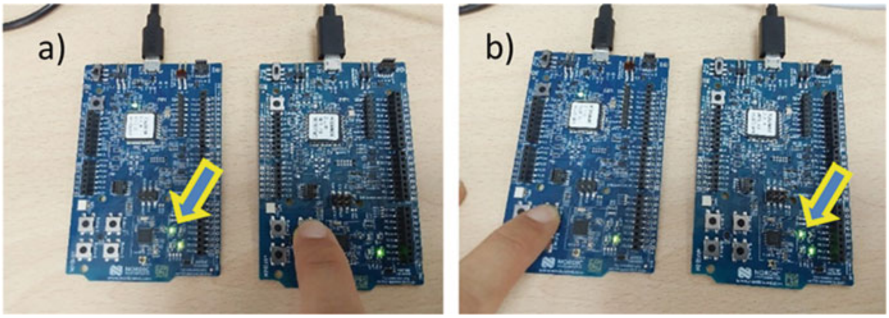

Fig. 13 (**a**) Primary device response to secondary device actuation. (**b**) Secondary device response to primary device actuation

described throughout this document, this is the exact expected behavior and, therefore, the usage of *nRF52832 SoC* [48, 52] is valid.

7 Discussion and Conclusions

As expressed through this document, the implementation of a system capable to monitor and notify its users about the bus occupancy rate can follow several approaches. Independently from the chosen approach, rather if it is computer vision systems, seat presence detectors or infrared light-based sensors such as ToF, all allows to offer quite reliable performance.

When compared to other implementations, the approach adopted by this project always considered the fact that it should be as less intrusive as possible. In other words, it is expected that the development of an independent Plug&Play system with the capacity to be installed in any bus configuration. This represents a huge advantage to other system alternatives since the installation process would be very simple and without any major modifications.

Regarding its financial costs, the design and conception of the system with low financial costs was also set as a requirement despite it would represent a lack of performance when compared to other systems. However, the anticipated balance between performance and financial cost has very good perspectives.

About the detection technology, the chosen ToF sensor VL53L5CX from ST [47] presents very promising results. Although its resolution is somehow limited with an 8×8 matrix of data, its reliability in different light conditions together with its low-cost are aspects that overlap any reduced resolution. As results reveal, throughout its entire matrix, the detection is quite uniform. Independently from the object's position, it is similarly detected all over the entire sensor's FoV. This is a very important characteristic because people will cross entire sensor's FoV once they enter or exit the vehicle.

Considering wireless communication, a first analysis to bluetooth's main characteristics anticipated a perfect fit to the system in development. Mainly used for short-range and peer-to-peer (P2P) communications, the obtained results reveal that this technology has the potential to be successfully included in this project. As one of the most used wireless communication technologies, Bluetooth is a constant from smart wearables like smartwatches to a simple cellphone from any brand, which represents several positive aspects. From the beginning, the fact that this technology is so widely used in most gadgets people use means that this is a reliable technology. Another important aspect is its price. With a huge demand for this type of technology, silicon manufacturers produce large quantities of this kind of devices and, therefore, its prices tend to be much more competitive.

Regarding Bluetooth's main disadvantages, this project is shortly affected. When compared to Wi-Fi, for example, Bluetooth presents a lower bandwidth and, consequently, lower data rates. Anyway, since the amount of data exchanging in this system is not very demanding, this topic may not be an issue. Another point that can arise when Bluetooth is referred to is security. In some cases, system's hacking by bad actors can be very problematic if data being exchanged is sensitive. In this case, any type of hacking would not represent a special benefit to its executant since data being exchanged is just the number of passengers entering or exiting a vehicle. However, an external intrusion on data exchanging promoted by a hack would lead to bad data sharing with the final user.

In conclusion, such a system with the announced capabilities may represent a welcome move to public transportation management. Although there exists similar products on the market, rather the financial or installation costs associated to those products sometimes are not tolerable by responsible entities and, consequently, it is not used. With the approach proposed, these topics can somehow be mitigated to contribute in a positive way for the traffic reduction inside city centers.

8 Future Work and Known Issues

ioCity system itself has space to incorporate valuable additions. Since this system aims to monitor passengers' flow in a specific vehicle, this kind of information can be very useful considering the scalability of the solution. The possibility to collect this information from several vehicles could represent an excellent asset to any public transportation manager. When analyzed in a long or even medium term, this type of data can be revealed as very important to fleet management. From old routes mitigation due to lack of passengers, to the creation of new ones to maximize bus usage by citizens, this information helps to improve rentability and minimize resources consumption. To accomplish this task, the system would need to be able to send bus's occupancy rate to the outside. Therefore, the integration of LTE device seems to be a wise decision.

Concerning the detection sensor itself, despite all the advantages announced in conclusions chapter, the previously mentioned reduced ToF sensor's resolution promotes a negative impact on final solution. During most busy parts of the day, like rush hour for example, the tendency is to have entrances and exits with closer space gaps between passengers. Due to sensor's limited resolution, this closer gap can be imperceptible to the sensor and, consequently, feed the detection system with information which will deal to counting errors. Anyway, this suspicious use case lacks a proper validation, and, for that reason, additional tests need to be performed in future developments.

Moving now to an upper system abstraction layer, one of the most, if not the most, important topic that should be explored in future developments is the detection algorithm. Fed with matrixes of 8×8 data measurements provided by previously mentioned ToF sensor, the best detection approach should be explored to maximize sensor's potential and minimize passengers count mismatches.

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Remote Traffic Light System to Support Traffic Light Maintenance

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1 Introduction

Currently, transportation became essential in every aspect of life which increases traffic jams [1]. Traffic jams cause a lot of social and economic loss all over the world [2]. This increases commute time, delays deliveries, workers to get delayed for work, and the emission of gases increases and affects the quality of life [3, 4]. Socially traffic jams are a major cause of stress for society as it reduces people's and goods' mobility [5]. Traffic flow is a major contributor to urban pollution due to the high concentration of gases emitted by motor vehicles [6, 7]. Traffic Light systems are the better solution to ease traffic flow or in opposition contribute to the worsening of traffic jams [8].

World's population is growing from 746 million in 1950 to 7.6 billion in 2019, and the tendency is to increase quickly [9, 10]. Associated with these growth trends, there is a growing need for people to move to city centers (to work, access public services, shop, or walk) and urban areas that have been growing in terms of population and area, aggravated by the increase in the use of private cars for its convenience. Currently, in Europe, almost 70% of the population lives in large cities or closer to cities, and it's expected that in 2050, that value increases to 80%. Currently, there are 1.446 billion vehicles on Earth, and Portugal is one of the top 10 countries with the highest number of vehicles per capita, 0.75 [11, 12]. On the other hand, the massive construction of new roads and unorganized buildings resulted

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in an incoherent road system both in its layout and its signage, which originates problems in managing traffic and people.

Traffic light systems are used to manage traffic flow, but also to control vehicles' speed and density, providing a safer environment for pedestrians at crossroads and supporting the mobility of emergency vehicles [13]. Traffic lights are widely used mainly in city centers to assure efficient ease of traffic flow. Although due to accidents, weather conditions, energy failures, or technical problems, they can become inoperable and lead to serious congestion in city traffic flows.

Smart traffic light solutions contribute to one of the main pillars of Smart Cities, the Smart and Green Transportation Systems, through the creation and improvement of smart cities solutions, namely, reducing road traffic congestions, commuting times, and gas emissions allowing safer and cleaner environments for its citizens [14].

Smart Cities contribute to the sustainable development of cities. Information and Communication Technologies (ICT) are at the base of smart cities as it eases the management and control of the different resources and allows an automatized and smart answer to changes in real time. Currently, most traffic light systems are still controlled by static algorithms that manage traffic flow according to the defined strategy for each intersection [15]. Although new solutions are being implemented to autonomously adapt traffic flow according to with different criteria such as the presence of emergency vehicles, the number of cars in each way, or the presence of pedestrians.

Smart cities are becoming a reality as the search for more sustainable and efficient solutions increases. Cohen defends the transition into Digital Cities is happening in three phases: (1) technology-driven, (2) technology-enabled, led by cities, and (3) citizen co-creation. In the first phase, the integration of technology at different levels in the cities allows its digitization. In the second phase, the engagement of municipalities is essential to assure that the developments are aligned with the specific goals and needs of the city. The third and last phase is to ensure the engagement of the citizens in this ecosystem [16].

The efficiency of traffic light systems is the result of their proper planning. This means each system, that will support traffic management in a specific intersection, must be studied and analyzed individually, but also analyzed together with the other systems around since it will only be able to ensure adequate management of the traffic flow if it is coordinated with the others traffic light systems that are in its surroundings to guarantee the best traffic flow within a city and especially in the points where the occurrence of traffic jams is frequent [17].

Most smart city projects are still supported by municipalities or local governments as their effect is somehow limited to the specific reality of the place where it's being implemented. IoTrafficLight aims to contribute to the "smartization" of cities worldwide through the development of smart traffic light management systems that improve the management of traffic flow, reducing systems downtime.

In Portugal, in the last decade, there has been a great effort to digitize all the sectors of society, from communication with municipal and/or governmental entities to systems that promote resource sharing, digital systems for processing urban permits, systems for monitoring, managing consumption and quality of natural resources such as water, systems to support the sharing of resources and goods, systems to support the maintenance of public spaces in which any citizen can signal a need to maintain spaces or to signal the need to support animals or even to identify situations of non-compliance with the law [18–21]. The investment in smart cities has taken place in large cities, but also medium-sized cities engaged themselves in this field with innovative projects and solutions that allow their citizens to be involved and take advantage of these solutions.

Traffic flow management is guided by the definition of the phases of the traffic light system. A phase indicates at each time which should be the status of each one of the traffic lights that integrate the traffic light system. The definiton of the phases of a traffic light system must be done considering, not only the intersection in which it is located, but also all of its surroundings, since the coordination of the phases of different traffic lights allows a more efficient optimization of traffic flow than each intersection individually. When this coordination is not verified, there may be a blockage of traffic in cases where the roads that should have their phases synchronized end up being opposite in lagged phases, thus harming the adequate agility of the traffic.

Currently, the search for a more sustainable society means that all aspects and habits of society are adjusting to this new reality, from changes in consumption habits to the adoption of more sustainable lifestyles, and also in terms of institutional and governmental procedures. More sustainable habits have been adopted by changing processes, products, and more sustainable components. Thus, traffic light systems have also become more sustainable, either through the implementation of more sustainable energy systems or through the implementation of intelligent systems that automatically turn off when the presence of vehicles is not detected, allowing savings of around 40% in energy costs and 50% in maintenance costs [22, 23]. This work presents the developments performed along IoTrafficLight project. The solution developed is currently available for SINALARTE's customers at https://iotl.ss-centi.com/. IoTrafficLight project developed a traffic light controller with an integrated sensing/actuation system for fault detection, prevention, and correction supported by an online platform, complying with the legislation applied in the European Union and SINALARTE's standards. This work allowed to solve problems that weaken road traffic in urban areas such as the ones caused by the usage of passive (roundabouts) signaling which is deficient mainly when there are traffic congestions, on the contrary activate solutions have higher installation and maintenance costs, however, it allows active monitoring, control, and prioritization of traffic lanes compared to conventional and even smart traffic light systems IoTrafficLight reduces systems downtime increasing its efficiency in road traffic management, but it also substantially decreases maintenance costs.

IoTrafficLight project created tools to improve the urban environment, through innovation in active signaling systems, as it developed energy-efficient solutions to support remote maintenance management and sensing solutions that improve traffic flow through traffic light regulation with the introduction of autonomous and self-managed systems.

The development of this concept started with the development of a real-time traffic management platform. A preventive and corrective maintenance system analysis in real-time maintenance scheduling, reducing breakdowns and automatically correcting them and activating immediately the operation of redundant systems. Allied with maintenance management, a sensing system was developed allowing counties to be aware of the environmental quality in their city and to provide the changes to improve its environmental quality by changing traffic flows or reducing it in specific places.

As the system previously implemented was not collecting data relevant to maintenance processes, it was not possible in the project's time to implement a machine-learning solution to predict the maintenance of traffic light systems.

However, the solution was studied and compared with the different machine-learning solutions that are most suitable for SINALARTE. Tests were carried out with representative data and the algorithms that can be implemented with the most success were identified. The initial data collection process is ongoing and will allow the training of the algorithms. After the completion of this process, SINALARTE will later implement those algorithms in the developed system to allow interaction with the traffic flow control system.

This chapter is organized into five sections, namely: (1) Introduction; (2) Traffic Flow Management; (3) Remote Traffic Light System; (4) Conclusions; (5) Issues.

In Sect. 1, Introduction, the problem was briefly presented. Also was presented the IoTrafficLight project, its goals, and its technical organization. Section 2, Traffic Flow Management, presents the problem of traffic flow management and the problems that support the development of this project. Section 3, Remote TrafficLight System, presents the work developed along the project and is divided into five subsections: Sensing Systems; Gateway, Cloud Server, Web Interface, and, Validation. Section 4, Conclusions, presents the major conclusion on the work performed and future work. Section 5 presents the major constraints and issues that happened during the project.

2 Traffic Flow Management: An Overview

Over the last decades, traffic light systems became increasingly common, as it allows to ease traffic flow, pedestrians to cross a street without putting their lives at risk, and also allow general safety in traffic. There are several types of traffic light systems, some more evolved than others. The simplest systems are fixed-time traffic light systems that are only configured to show a certain color (green, red, yellow) after a few minutes or seconds, depending on its location. There are also dynamically controlled traffic light systems that adapt themselves according to traffic conditions.

Over time, more technological traffic light systems were developed. Table 1 presents a comparison between the IoTrafficLight solution and other traffic flow management solutions identified in the literature. Kisung Lee designed the Mobious

Table 1 Comparison between IoTrafficLight solution and other traffic Flow management solutions

	IoTrafficLight	Ekene	Vackflores	UniSignal	Citelum Group EDF
TrafficLight monitoring to identify non conformities	X	X			
Automatically adapt traffic management	X				
Notify the user to proceed to maintenance action	X	X			
Powered by solar energy			X		
Speed control	X		X		
Road conditions			X		
Weather conditions			X		
Customized shaper for colorblind people				X	
Real-time monitoring of equipment and services	X				X
Real-time diagnosis	X				X
Eases traffic flow according to emergency					X
Adaptive traffic flow management	X				X
Manages and coordinates multiple traffic light systems	X				
Traffic flow management	X				X
Environment monitoring	X				
Monitor traffic-lights operation	X	X			
Manages traffic-lights maintenance	X	X			

Strip Lamp aiming to reduce visual clutter from lights [24, 25]. On the other hand, Roberto Vackflores designed a system powered by solar energy that performs the normal functions of a traditional traffic light, allowing drivers to know its maximum speed limits, road conditions, and weather information [26]. UniSignal is a system designed to help colorblind people, its traffic light systems use shapes along with colors to help avoid any confusion [27]. EkoLight, designed by Damjan Stan Kovic, is a traffic light system that reduces air pollution with a countdown indicator around the red light that lets drivers know how long they have to wait at traffic lights allowing them, in theory, to turn off their engines [28, 29].

Citelum Groupe EDF is a French company specializing in public and private lighting management that provides a traffic light system supervised by MUSE, which remotely monitors devices that provide real-time control and diagnosis of all equipment and services, communicating with the city's command center for emergency management [30]. It provides some data analysis features [31].

Different AI techniques have been explored to optimize the traffic management process. Table 2 presents a comparison of IoTrafficLight with AI solutions for traffic light systems management. In 1994, Hoyer proposed a fuzzy logic-based model to develop an intelligent system for monitoring and controlling traffic light systems, capable of simulating and comparing different traffic flow situations, thus ensuring the adaptability of the system to each situation [32]. Wen proposed a dynamic and automatic control system for traffic lights that use RFID technology and PDAs with the support of a wireless internet connection [33]. Ghazal tries to go even further by proposing a solution for monitoring and controlling adjacent intersections [34]. Huawei currently sells three types of smart traffic management solutions, acting in terms of prevention, security, and traffic flow optimization. Huawei provides solutions for vehicle speed control using Artificial Intelligence and Big Data, allowing the identification of suspicious or already flagged vehicles [35].

Verizon offers a complete traffic flow management system integrating magnetometers in the asphalt to detect the amount, speed, and distance between vehicles; it also provides a system that allows adjusting of the brightness of the LEDs of the traffic lights according to the traffic density, which allows reducing around 80% of energy consumption [36].

In 2012, Carnegie Mellon University, Pittsburgh, launched a traffic management system, supported by AI, capable of counting the number of vehicles (using cameras) and managing the traffic flow accordingly [37]. The same type of approach to data collection, combined with AI for traffic management systems was also proposed by Milton Keynes – England 2018 [38]; Manchester – England 2017 [39]; Las Vegas – E.U.A. 2019 [40]; Bengaluru – India 2019 [41]; and Hangzhou – China 2018 [42].

Currently, there are patented solutions for the management of traffic light systems. Elsheemy proposes a transversal solution capable of communicating with existing infrastructures (such as traffic management systems, radars, etc.), and receiving signals from mobile networks and/or GPS to assist the action of emergency teams and security forces [43].

With the evolution of vehicles, some projects are focused on the communication and exchange of information between themselves and their surrounding infrastructures, such as traffic lights, to optimize traffic flow. World Sensing developed a system that allows the global connection between traffic control systems, infrastructure, agents, etc. In this way, it is possible to centralize several existing systems, such as traffic control systems, vehicle counting systems, surveillance cameras, incidents, etc. Audi V2E (Vehicles to Everything – Vehicles for everything) developed a solution focused on sharing information from traffic lights with vehicles and vice versa, to reduce vehicle stops, reducing driving times, waiting time and, consequently, vehicle's fuel consumption [44]. The Port of Hamburg has a solution that allows heavy vehicles to communicate with traffic lights and vice versa to reduce their stops. Within a certain radius, vehicles can communicate with each other, through WLAN technology, in real-time to optimize traffic at intersections [45]. In Phoenix, USA, a project is being implemented to include a traffic man-

Table 2 Comparison of IoTrafficLight with artificial intelligence solutions for traffic light systems management

	IoTraffic-Light	Hoye r	Ghazal	Huawei	Verizon	Carnegie Mellon University	Elsheemy	Phoenix
TrafficLight monitoring to identify nonconformities	X							
Automatically adapt traffic management	X							
Notify the user to proceed to maintenance action	X							
Speed control	X				X			
Real-time monitoring of equipment and services	X							
Real-time diagnosis	X							
Eases traffic flow according to emergencies				X				
Adaptive traffic flow management	X	X				X		
Manages and coordinates multiple traffic light systems	X		X					
Traffic flow management	X	X	X	X	X	X		
Identification of vehicles			X					
Automatic light adjustment				X				
Connected to vehicles							X	
Environment monitoring	X							X
Monitor TrafficLights operation	X							
Manage TrafficLights maintenance	X							
Integrate sensing system	X				X			

agement platform supported by AI to optimize flow, safety, and emissions. The system takes advantage of the technology present in vehicles, namely, its connection with infrastructures, and can identify the type of vehicle (light passenger, light goods, heavy goods, heavy passengers, bicycles, pedestrians, etc.) [46]. Alan Turing Institute and Toyota Mobility Foundation are carrying out studies to understand how artificial intelligence can make traffic management systems more dynamic and responsive [47]. In addition to ensuring adequate traffic flow management, traffic light systems are also responsible for ensuring adequate management of pedestrian flow, ensuring that they can move safely. In this sense, some work has also been carried out to ensure a balance between the flow of traffic and pedestrians' flow ensuring everyone's safety.

Some solutions focus on ensuring the safety and comfort for pedestrian when crossing the streets and when waiting for them. Casini proposed a solution that allows pedestrians to visualize the time remaining for a traffic light to change, a solution that turned out to be widely adopted particularly in urban areas with more pedestrian traffic [48]. In Vienna, Austria, in 2020, a traffic light supported by AI was developed which can identify the user's intention to cross the streets without pressing any button. Thus, situations such as long waits, pedestrians crossing during red lights, or pedestrians pressing the button forcing vehicles to stop, and then no one crosses, can be avoided or even eliminated [49].

With the evolution of technology and autonomous vehicles, there is an emergence of different solutions focused on obtaining traffic information, the status of traffic light systems, and a fusion of this information to provide a better driving experience to drivers. Regarding the maintenance process of traffic lights and traffic light systems, it was possible to identify a series of approaches currently followed, from less-organized maintenance to well-defined procedures defined by competent authorities. However, it is possible to verify that there is a great margin of optimization for those processes. Existing solutions are not efficient, and the automation of these processes guarantees an improvement in service, a reduction in costs, and traffic light systems downtime.

Regarding the solutions that focus on managing the maintenance of traffic light systems, there are only a few references to them in the literature; it was not possible to identify any solutions currently available in the market besides Citelum Groupe EDF solution. Table 3 presents a comparison of IoTrafficLight with Traffic Light System maintenance solutions. Ekene proposes a predictive maintenance model that allows monitoring the quality of the light emitted by the traffic light, thus allowing to identify problems with the light emitter in advance, notifying maintenance teams of its repair, even before the light fails [49]. On the other hand, Belarfaoui proposes a solution based on PetriNets and rule-based algorithms (RBAAs) to optimize the efficiency of the management of traffic light maintenance processes [50].

The solution developed differs from the state-of-the-art solutions as most of them only focus on traffic management and don't consider maintenance. Usually, if there is any anomaly in a traffic light system, the company will not have access to that anomaly, it will only know what happened when someone goes to the place to find out what happened and then needs to come back to solve it.

Table 3 Comparison of IoTrafficLight with traffic light system maintenance solutions

	IoTrafficLight	Ekene	Citelum Group EDF	Belarfaoui
TrafficLight monitoring to identify nonconformities	X	X		
Automatically adapt traffic management	X			
Notify the user to proceed to maintenance action	X	X		
Powered by solar energy				
Speed control	X			
Real-time monitoring of equipment and services	X		X	
Real-time diagnosis	X		X	
Ease traffic flow according to emergencies			X	
Adaptive traffic flow management	X		X	
Manage and coordinate multiple traffic light systems	X			
Traffic flow management	X		X	
Environmental monitoring	X			
Monitor traffic lights operation	X	X		X
Manage traffic lights maintenance	X	X		X
Integrate sensing system	X			

The only solution that considers traffic light systems management are the ones proposed by Ekene, Belarfaoui, and Citelum Groupe EDF. The only solution that is currently being commercialized is the one proposed by Citelum Groupe EDF, although the need for external sensors will increase its price. The solution proposed by Citelum Groupe EDF already has a better maintenance process for traffic lights and is also able to control traffic in general [51]. Compared to IoTrafficLight, there are a lot of similarities. The disadvantage of the Citelum company is that it needs monitoring equipment, and this makes the price of traffic light systems much higher. IoTrafficLight does not need any additional monitoring system and can monitor everything in real-time, the cost of traffic light systems is more reasonable, while the status of all the networks and the system can provide a more complete solution.

Usually, in predictive maintenance scenarios, data is collected over time to monitor equipment's conditions aiming to find patterns that can help to predict and prevent failures. Predictive maintenance avoids exceeding resource usage detecting anomalies and failure patterns through early warnings [52].

Machine learning is a field of computer science that aims to "teach" computers to learn and act without being explicitly programmed to do it. More specifically, machine learning is an approach to data analysis that involves building and adapting models, allowing programs to "learn" through their experience. Machine learning considers building algorithms capable to adapt its models to improve their ability to make predictions [53].

Preventive maintenance brings numerous benefits to production environments. The case of traffic signal systems is no exception since the failures in traffic signal systems might be a result of the lack of maintenance actions and the lack of failure prediction in the system, thus causing an increase in its downtime and demanding repair. In addition, these failures can cause a significant increase in traffic, particularly in intersections, thus making this analysis relevant.

Continuous monitoring of the current in each LED light allows not only to verify if it is possible for the system to be operational but also the degradation of each light in a traffic light module, thus minimizing its downtime, since a repair can be performed without stopping the system along the repair time. The most common problems that occur in traffic light systems are the lack of operation of a LED, this happens when a LED light didn't turn on, decreased its brightness, or starts flashing.

IoTrafficLight continuously monitors each LED light, allowing it to evaluate and compare the performance of all traffic light systems, improving the generation of alerts for more efficient ones, and allowing earlier warnings. This process is important because late warnings might lead to the occurrence of damage that otherwise could have been avoided.

First, to perform this procedure, extensive data collection was required to obtain a true history of the traffic light signal systems. For this case, the most relevant metric for creating a dataset is the current measurements in each light of traffic light. However, other metrics can be calculated to help in the prediction process, such as the time since the last maintenance (considering the several types of maintenance that exist), time that each LED has been ON (considering the possible levels of brightness that the light can be on), estimated life of the lamp based on the manufacturer and calculate the difference in current between the last few days.

An interesting metric for analysis would be the LED light efficiency which is calculated by the luminance of a LED light divided by its power. However, to measure the luminance of a LED light continuously, it would be necessary not to have interference from other light sources, namely sunlight, since on a clear day the luminance would be higher and therefore the LED light would supposedly indicate greater efficiency than on a cloudy day, and therefore this calculation would be ineffective.

Data analysis allows to discover of patterns in data that lead to the choice of different configurations, thus optimizing the algorithms, such as the definition of thresholds for sending different types of alerts, or even the detection of outliers, thus avoiding to sending a serious alert due to a sensor reading error.

Since ambient sensor data is being captured, it allows visualizing whether the LED light has a higher degradation when it is exposed to different atmospheric conditions. For this, different statistical techniques are being used to analyze the correlation between system variables/parameters.

Initially, an unsupervised model, K-means was applied to check if the data distribution is evident, that is, the algorithm without knowing the target class can predict the class to which a given input belongs. As for supervised algorithms, it can start by applying those that are typically used to predict the lifetime of a certain product, namely, K-Nearest Neighbors, Naive Bayes, Random Forest, and Logistic Regression.

There is currently a great diversity of traffic light system solutions focused on the optimization of traffic flow. However, these solutions end up leaving aside the issue of optimizing maintenance processes which will end up having a significant impact on traffic management solutions.

3 Remote Traffic Light System

This work presents the development of a Remote TrafficLight System that allows monitoring of traffic light systems, to agilize traffic flows, and to manage maintenance processes. IoTrafficLight proposes a system for monitoring and management of traffic light systems that allows solving the limitations in existing traffic light systems, such as monitoring the status of traffic light systems and their corresponding traffic lights in real-time, traffic flows, environmental conditions surrounding each traffic light system, empower each traffic light system with an alert system and a customized maintenance system, remotely to control some features of traffic light systems to provide temporary resolution for certain problems. To achieve this purpose, the system architecture was developed that supported the development of the solution presented in Fig. 1.

IoTrafficLight solution is composed of a Cloud Server, a Gateway, input and output boards, and an Administrator Page. There are three different types of users in this system: ADMIN, the administrator of SINALARTE; MANAGER, the administrator of the company that owns a traffic light system; and USER, the maintenance technician. The administrator of SINALARTE has access to all traffic light systems installed and is responsible for creating new systems, and new users controlling the companies associated with each traffic light.

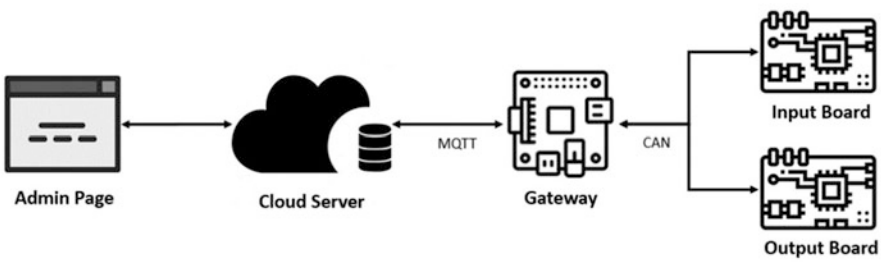

Fig. 1 IoTrafficLight's system architecture

3.1 Sensing Systems

The sensing system relies on the input and output boards developed to communicate with the system. The input and output boards are connected to the controller via a CAN Bus. The input boards are responsible for acquiring the status of buttons, radars, and presence sensors.

The output boards are responsible for the activation of the outputs and the acquisition and conversion of the outputs' electrical current consumption. Since the system must be scalable and modular, the Output Boards are configured via CAN messages at the start-up of the system. To achieve this, CAN Massage IDs to the controller, Input Boards, and Output Boards was allocated. These groups are presented in Table 4.

IDs allocated to the boards have an offset of 0x0000 0100, this means that the protocol theoretically supports up to 256 output boards and 256 input boards. The board ID is determined by a selector present on the respective boards.

There are two types of message groups: the broadcast group and the addressed group. The broadcast group is sent by the controller and received by all boards connected to the CAN bus. The addressed group is sent by the controller or the board and it is only addressed to one another. The messages sent by the master are presented in Table 5.

Messages sent by the output board are presented in Table 6.

The controller at the initialization phase performs the scan command, where all boards connected to the CAN Bus respond with their respective scan message. If two or more boards possess the same ID, it will issue an error message to the corresponding bus.

Considering the goals previously presented, a Printed Circuit Board (PCB) was developed with the ability to control the traffic lights and at the same time monitor the current consumed by each one of the LED lights connected to a single channel. The developed PCB has eight individual channels and was designed to operate traffic light systems of Alternating Current (AC) or Direct Current (DC). To make it possible the most important blocks of the system, the sensor block, and the actuation block, had to be thought with extra care to maintain the modularity capabilities and, at the same time, the robustness for the eventuality of being used with the power grid. For the sensing part, which is intended to measure the current, the ACS723LLCTR-05AB from *ALLEGRO microsystems* was selected which allows the measurement of current between −5 and +5 A in both alternating current and direct current. In addition, this element guarantees galvanic isolation

Table 4 Input boards and output boards

Description	Base value (hexadecimal)	Board offset (hexadecimal)
Controller	0x0000 0000	–
Output boards	0x0001 0000	0x0000 0100
Input boards	0x0002 0000	0x0000 0100

Table 5 Messages from the input board

CAN message ID	Description	Data size (bytes)
0x0000 0000	Error	0
0x0000 0001	Scan	0
0x0000 0002	Configuration mode	1
0x0000 0003	Total number of stages	2
0x0000 0004	Current stage	2
0x0000 0005	Dimming value	1
Board ID +0	Stage configuration	6
Board ID +1	Read request from output 1	0
Board ID +2	Read request from output 2	0
Board ID +3	Read request from output 3	0
Board ID +4	Read request from output 4	0
Board ID +5	Read request from output 5	0
Board ID +6	Read request from output 6	0
Board ID +7	Read request from output 7	0
Board ID +8	Read request from output 8	0

Table 6 Messages from the output board

CAN message ID	Description	Data size (bytes)
Board ID	Scan response	0
Board ID +1	Output 1 read	4
Board ID +2	Output 2 read	4
Board ID +3	Output 3 read	4
Board ID +4	Output 4 read	4
Board ID +5	Output 5 read	4
Board ID +6	Output 6 read	4
Board ID +7	Output 7 read	4
Board ID +8	Output 8 read	4

between the power circuit and the signal acquisition circuit, has great accuracy, is cheap, and has a small footprint. The sensor has an analog output that varies between 0 and 5 V, the supply voltage, with an offset of 2.5 V to be able to convert the AC current to a positive signal that can be read by the microcontroller. Since the selected microcontroller has a maximum supply voltage of 3.6 V, it was necessary to use an external ADC with eight or more analog inputs. The ADS7128IRTER was selected from *Texas Instruments*, with 12 bits of resolution and an I2C interface, which has different pins to supply the analog and digital parts, ideal for the intended application. Regarding the selected microcontroller, the STM32L476R from ST Microelectronics is a high-performance Arm Cortex M4 that integrates a single precision floating point unit containing a full set of digital signal process instructions. This characteristic allows complex calculations to be performed quickly compared to the traditional set of instructions present in the processor of the microcontroller making it suitable to process and calculate the inbound data of the external ADC [54–56].

For the actuation part, the Integrated Circuit (IC) Si8751 was selected, from Skyworks, which allows the creation of a Solid-State Relay (SSR) with the specific requirements of the application. This IC controls two external MOSFETs that when connected correctly allow the load control in both alternating current and direct current. The selected IC has a digital interface that allows a direct connection with the microcontroller, like the current sensors, this one has galvanic isolation between the power part and the control part, which guarantees the safety of the system. In addition to these characteristics, the choice of this solution allows for mitigating all the problems associated with relays normally used in several applications of this type [57].

A zero-crossing detection (ZCD) circuit was also integrated to allow current control of AC loads and an AND gate at the solid-state relay controller inputs. The integration of these elements is due to the need to control the brightness of the traffic lights.

As a power supply, the system uses the 12 V available on the CAN bus connector and on the PCB, where two power supply units are integrated to convert the 12 V to 3.3 V and 5 V necessary to correctly supply the various elements that make up the system.

Figure 2 presents the 3D model of the developed PCB with all the elements mentioned above, and also their interactions. It measures 100 mm $\times$ 142 mm. The components more relevant to this development are signaled in Fig. 3. The component for the interaction with the other elements of the global system, such as the connector to the CAN bus, which receives a 12 V power supply, and the output connector, where the lights of the traffic signals, will be connected. In the same way, it is possible to identify the pairs of MOSFETs that interconnect with the SSR controller composing the actuation component. On the lower side of the PCB are presented the components related to the sensing part.

To control the developed hardware, it was needed to program the microcontroller contained in the output boards. The firmware (developed for ST Microelectronics STM32L476RG) is responsible for activating the desired outputs and acquiring the output's electrical current values.

The output boards were designed to be modular and scalable; therefore, its firmware contemplates the mechanisms to achieve these requirements through the ID selector capable of achieving 16 Output Boards in the same bus, communication via CAN Bus, and on-the-fly configuration of outputs. The Output Boards have a base ID of 0x10000, and its offset is calculated through the value of the ID Selector multiplied by the hexadecimal value of 0x100. The ID is then used to configure the output board's CAN Filter which is configured to receive all broadcast messages and addressed messages to its ID, ignoring addressed messages to other boards.

The output board is configured through the stage configuration message; this message indicates the state of all outputs at a determined stage. The format of this message is illustrated in Fig. 3. The first two data bytes of the massage are reserved to identify the stage number, giving a reach of 65,535 states. The next two bytes are allocated to the outputs' state, where a division of two bits was performed to allocate the three possible output states for all eight outputs. An output state with a

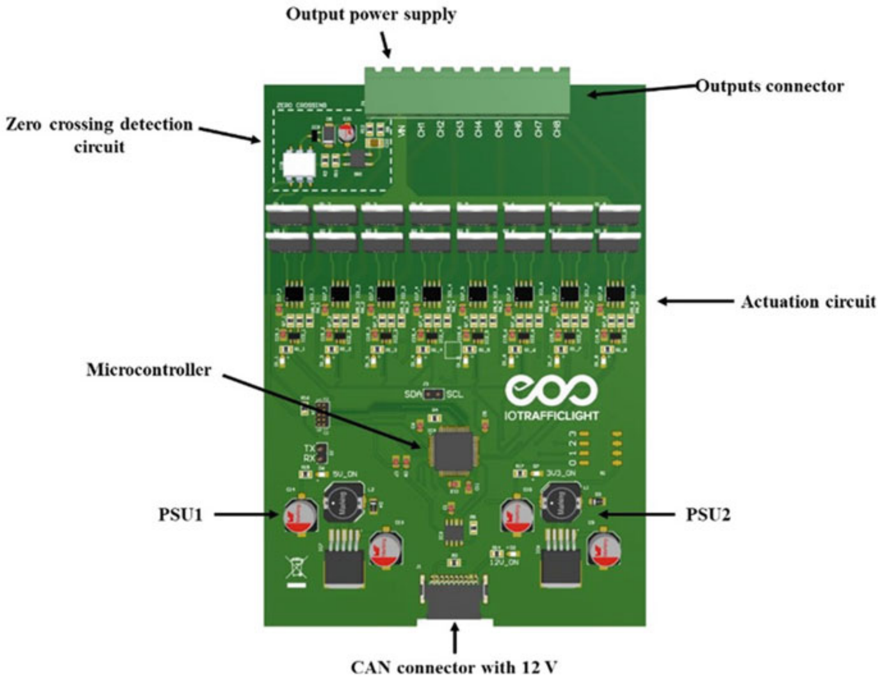

Fig. 2 Outputs PCB architecture

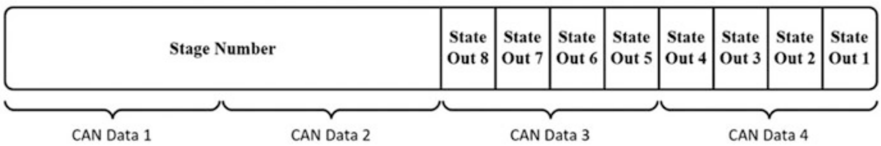

Fig. 3 Stage configuration message's data format

value of 0 indicates a disabled output. An output state with a value of 1 indicates an enabled output and an output state with a value of 2 indicates an intermittent output that toggles with a periodicity of half a second. When the output board receives this type of message, its contents are stored in the internal table allocated in the RAM memory, which will be accessed later in the run sate and therefore is not modifiable in the run state.

To properly configure the boards, they must be in configuration state; otherwise, the boards will ignore the received message, since the device is in the run state. The output boards switch to run state after receiving a configuration mode message containing the value representing the run mode.

Another feature of the actuation system is its capability of controlling the brightness of the lights connected to the outputs, since the maximum brightness is only used during the daytime; a company can save costs by reducing the brightness of the traffic lights at night-time thus reducing the electricity bill. The brightness control feature considers the type of supply present to implement the suitable dimming mechanism.

The DC dimming mechanism implemented is a Pulse Width Modulation (PWM) with a frequency of 100 Hz, the brightness is adjusted by controlling the pulse width of the generated signal. AC dimming differs from DC dimming, the last one is simpler to implement and doesn't need extra hardware, whereas AC dimming requires the Zero Cross Detect (ZCD) to detect when the signal crosses the zero value, this is required because the actuation needs to be executed precisely, otherwise a flickering may be noticeable due to bad implementation. To ensure this, the firmware implements the features provided by the microcontroller's Timer 2 to perform this actuation purely by hardware by configuring the peripheral in the Combined Reset Trigger Mode with PWM Generation. The timer trigger and reset are performed by the ZCD circuitry that is connected directly to the Timer 2 Trigger Source pin, enabling the timer when the ZCD goes to a logic level low and resetting when it goes to logic level high, this way it can be guaranteed that the actuation will only function when the wave is not crossing the zero value.

Figure 4 presents AC dimming's sequence diagram. Dimming is then applied via a PWM, where the frequency of the generated signal is double the AC supply since the dimming must be performed in the positive and negative parts of the AC wave. The modification of the dimming value is performed through the timer's shadow register which refreshes the dimming value's register in the next dimming cycle. In both implementations, the dimming is performed by the timer's hardware, eliminating the system overhead of this functionality that could interfere with the acquisition feature. The output's electrical current values' acquisition is performed independently of the actuation of outputs; this ensures that these two functionalities don't interfere with each other despite using the CAN Bus as a shared resource.

The output boards are designed to support different supply systems due to different client requirements, from AC supply to DC supply, the acquisition of these values is identical, but the calculations are different since in AC supply the standard electrical current values are the True RMS value and in the DC supply is the mean value [58]. Another aspect that can differ in AC supply is the frequency that varies between 50 and 60 Hz from country to country [59].

To determine the supply system, the firmware implements in the initialization a detection method that counts the ZCD's number of pulses generated in 1 s; if none is detected, it identifies as a DC supply; if less than 102 pulses are detected, it identifies as a 50 Hz AC supply; if more than 101 are detected, it identifies as a 60 Hz AC supply. The supply system detection is also used to initialize the proper dimming mechanism.

The external ADC connected via I2C Bus is configured to constantly perform sequential acquisitions in all eight channels, despite the low speed of the I2C communication bus of the microcontroller, it is possible to acquire periodically 10 samples per power cycle per channel, being oversampled by a factor of five [60]. The oversample is needed to perform an accurate calculation of True RMS values. The I2C data transfer is performed via Direct Memory Access (DMA), freeing

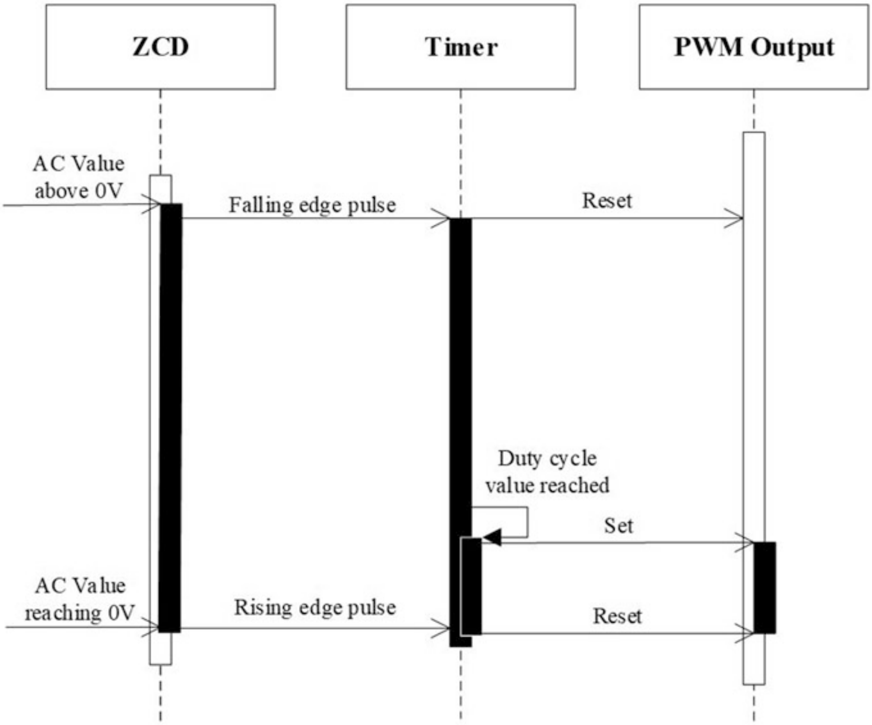

Fig. 4 AC dimming's sequence diagram

the microcontroller from waiting for the transfer to be completed; this process is illustrated in Fig. 5.

The calculations of the True RMS or mean values of all channels are performed by the Digital Signal Processor present in the chosen microcontroller; these calculations are performed after the DMA transfer has been completed, making the calculated values immediately available to be sent if the controller requests it.

At the start-up, the firmware initializes the internal and external static peripherals, granting its proper initialization, it is also in this stage that the firmware checks the type of supply connected to the outputs, configuring the peripherals accordingly to its functionalities. After that, the firmware configures the CAN Filter considering the ID present in the ID Selector, defining the Board ID at the startup. The state machine of an Output Board is illustrated in Fig. 6.

After that the output board enters in configuration state, in this state, as previously mentioned, the firmware of the output board waits for the controller to send Stage Configuration messages to configure the outputs' state for each stage and to receive the total number of stages. The outputs in this state are always disabled and so are the brightness control and the output's sensor data acquisition.

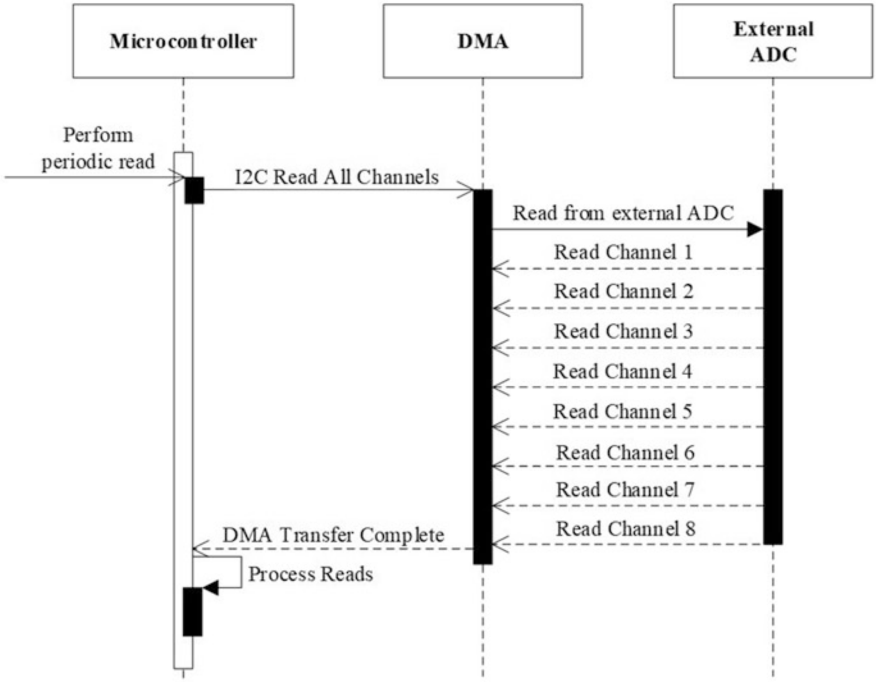

Fig. 5 Acquisition sequence diagram

The Output Board's firmware exits this state when a Configuration Mode message is received with the corresponding Run Mode value, changing the state to Run State. In the Run State, the firmware performs the actuation of outputs—based on the previously received configurations—upon reception of the Current Stage message, which defines the Current Stage of the whole Traffic Light.

The output's sensor data acquisition is performed simultaneously and independently of the actuation in the Run State. The firmware acquires continuously the eight channels of the ADC, converting and performing the calculations upon reception of new values. This grants that the value of a determined output sensor is ready to be sent immediately after the Read Request message is received, instead of waiting for a full power cycle.

The brightness control's value can be modified in the Run State and the Configuration state, but the control is only active during the Run State, being disabled in Configuration Mode.

The Output Board's firmware exits the Run State when a Configuration Mode message is received with the corresponding Configuration Mode value or when an Error message is received, changing the state to Configuration State.

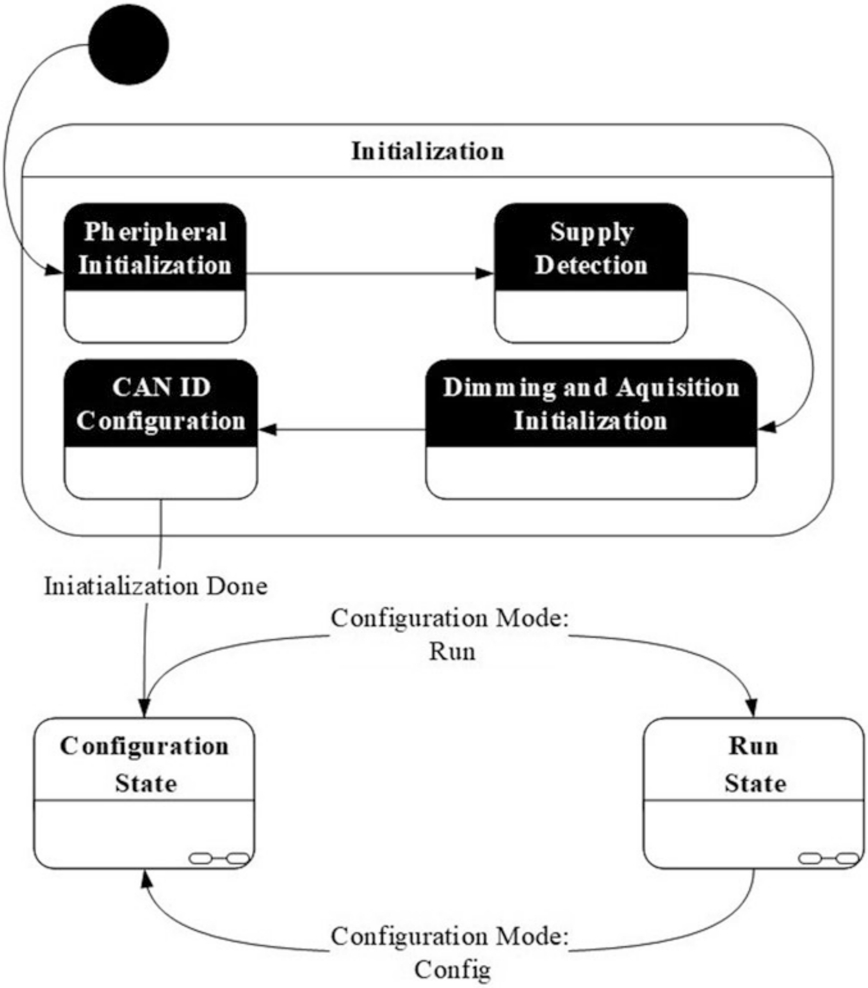

Fig. 6 Output board's state machine

3.2 Gateway

Globally, traffic light systems are ruled by EN 12675 standard currently being applied in European Union. The standard is clear as to its goal "to specify the functional safety requirements of the equipment used to control light signals. This standard aims to control light signals and all associated traffic streams. Its main concern is the safeguarding of people and property from the dangers caused by the occurrence of conflicting light signals." The standard lists each type of conflicting

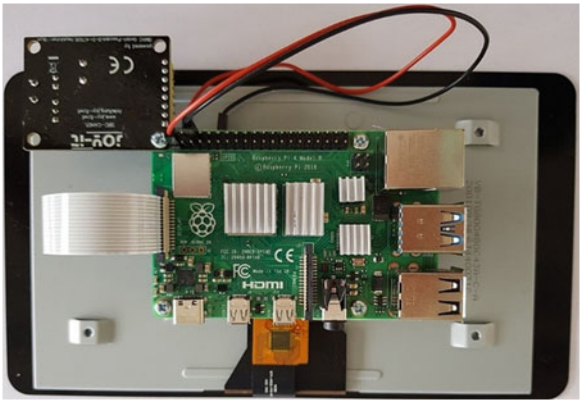

Fig. 7 Traffic light control unit

situation in light signals, classifying it so that faults could be identified in the same way throughout Europe.

Traffic light systems are not limited to informing road users about the correct timing to cross an intersection safely, but it also aims to monitor light signals themselves and verify their correct working, avoiding situations of conflict as classified in the EN 12675 standard.

Potential conflict situations should always be identified in the initial phase of construction of each traffic light system for a given intersection through the analysis of diagrams of all the possible traffic phases. A traffic phase is a set of states of all the light signals that constitute the traffic light system at each moment and is defined in such a way that there are never conflicting traffic flows.

Each traffic light system is programmed according to the phases and timings identified to it, according to the identified traffic typology and density. In addition to programming, preventive maintenance is essential through the real-time monitoring of the different phases to verify that the system complies with them scrupulously so that failure situations or conflicting currents do not arise. If this happens, the system must be prepared to act according to the situation, based on the specifications of EN 12675 standards.

Figure 7 presents IoTrafficLight Gateway that measures 86 mm $\times$ 57 mm. This gateway is the digital representation of a system, which aggregates all the information, it is composed of a Raspberry Pi with a Linux operating system, a CAN HAT, and software specifically designed for this project. This control unit will be connected to a motherboard that will monitor the behavior of the remaining electronic boards throughout the system operation.

This control unit has a local interface composed of a TFT LCD 7 monitor with a touchscreen, which allows users to act and monitor the behavior of the traffic light system on site. The use of a Raspberry Pi with Linux allows greater flexibility and portability of the system, ensuring the possibility of growth and adaptation to the different road needs that may arise in the future.

The configuration of parameters of traffic light behavior, when the system operates in the desired location, is the responsibility of the gateway. The gateway during system start-up communicates to electronic boards what will be their behavior and configures all the state changes necessary for the correct functioning of the system.

Regarding its application, the first step is to create the parameters in a standardized version of several possible scenarios (treadmill, crossing, junction, etc.) in such a way that these scenarios are generic situations and that, at the time of use, it is only necessary for the implementation site.

The gateway can have internet connectivity, allowing its connection to the cloud server using the MQTT communication protocol, where part of the management and monitoring can be done using the system administration website. However, it should be noticed that the system does not need internet connectivity to ensure its operation. With fault detection and environmental monitoring, the system can react on-site in the most appropriate way to the situations that may arise during its operation.

3.3 Cloud Server

The cloud server is the central component of the entire system and, therefore, is responsible for controlling, storing, and distributing information throughout the system. The server was built using a container architecture, which allows each service or component to be independent of the other.

The software developed implements all the server logic related to the basic functions of the system, that is, CRUD operations (Create, Remove, Update and Remove) on the different structured documents in the data model. The general architecture of the system, presented in Fig. 8, considers a cloud server divided into the different services/components that integrate it. A server with a container structure was also implemented to develop a modular and safer system.

In this way, IoTrafficLight provides a modular and secure system since no container is accessible from the outside world unless it is explicitly configured to be. Thus, the cloud server has a proxy that is the only access point to the system, and being responsible for authorizing which ports are open, managing all the traffic received by the server, and enforcing and renewing all TLS certificates. The frontend server is responsible for serving all the static content of the webpage, while the backend server contains all the logic hidden from the user, including ways to access information, and access management, among other things. The database contains all the information stored on a previously defined data structure. MQTT broker is responsible for managing several connections of the traffic light systems and transmitting this data to the cloud server. Other services might be implemented as the need for them is identified. The cloud server was developed in Javascript, using the NodeJS platform, using external libraries or frameworks (e.g., Express).

Since the software system collects confidential information about the status of traffic light systems spread across different locations, information security and

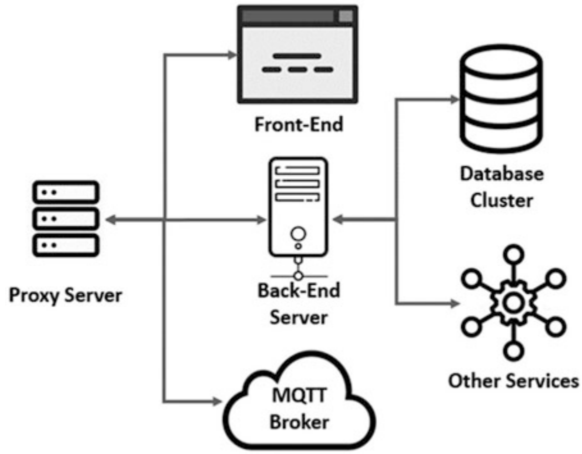

Fig. 8 Cloud server architecture

control over data access need to be assured. Thus, to control such access, an authentication service was developed. Authentication can be performed using the normal procedure (email and password) or using external entities, such as Microsoft Outlook. The last one is also known as authentication delegation and enforces the OAuth2.0 authentication standard. OAuth2.0 is a software industry standard that explains how an authentication flow must be carried out to guarantee the maximum security of user data.

The cloud server is also responsible for validating, processing, and storing the different values received in the database or, when requested, returning the requested information.

Communications are carried out through MQTT, HTTPS, and Websocket communication protocols. MQTT is responsible for managing the several connections of the traffic light systems and transmitting its data to the cloud server, allowing the system to have bidirectional communication, in real-time which is assured by Websocket. Websocket is a protocol that guarantees bidirectional, real-time communication between the web application and the cloud server. The platform communicates with the server via HTTPS and Websocket protocols. HTTPS (Hyper Text Transfer Secure) protocol is the standard protocol for the web, working exactly as HTTP. The difference from the letter "S" in the acronym is an extra layer of protection, indicating that sites and domains that have this protocol are safe for the user to access. This protocol also has protection, and this is done by digital certification, that is, encryption is created to prevent threats and attacks on the internet from having undue access to user information [61, 62]. The digital certificate is the SSL certificate, which creates a protected channel between the client and server [63, 64].

The Data Model is responsible for defining how all the system information will be stored accordingly to the defined data structure. This database is only accessible by the cloud server for security reasons. A MongoDB database is used as it offers advantages in IoT projects mainly due to its availability and scalability [65, 66]. The data stored is the basis for applying Machine Learning.

IoTrafficLight platform created a data model to store all system information. In all the tables of the database, there is information on a unique identifier that is an id and the creation date for the entity in question.

The enterprise is the main entity in this data model, since it is the one that will aggregate the traffic light systems and all the information associated with it and aggregates its users. An enterprise can have several users associated and each user can have several companies associated with it. An enterprise may have none or several traffic light systems associated with it. Each traffic signal system is associated with a specific company and a specific county. A traffic light system may have none or multiple traffic lights. The traffic signal system has associated with it the identification of its company, its location, which in this case includes its longitude and latitude coordinates, and the type of location. There are three possible types of locations: intersections, pedestrian crossings, and straight lines. A traffic light is associated with a particular traffic light system. A traffic light is associated with its identification, location (longitude and latitude coordinates), and the reference of its manufacturer. A traffic light system may have one or more modules, both for cars and pedestrians. A module is a set of sensors and is associated with a traffic light, it can have one or more sensors associated with it and zero or no active alerts. Each module is associated with the id of its associated traffic light = and sensors. The type of sensor includes parameters such as lighting (red, green, yellow, information, and green and red pedestrian signals), environment (PM1.0, PM 2.5, temperature, humidity, and noise), power, and button. Measurement is associated with the measurement values of a sensor at a specific moment in time. An Alert is associated with a given module and can have several maintenance actions associated with it. Because an alert can have multiple maintenance actions associated with it, an intermediate entity was created to associate each alert. Each maintenance action can have several services associated with it. A maintenance action also has its creation date, a status associated, and the date of the last update.

Each user is associated with a particular enterprise.

A service is represented by an intermediary table between a maintenance action and a user. A service has associated the id of the user who performed the maintenance action, the id of the maintenance action, its description, and creation and update dates.

To allow adequate access to information, three different types of users associated with the system were defined based on the needs of each one of them. This allows adjusting the information to which each user type can access the system. There are three types of user roles: admin, manager, and user. An admin is a SINALARTE employee. This is the user with the highest access privilege in the entire system and the only one with access to the system administration page. A manager is a customer of SINALARTE. It has permissions and full access to the data of its traffic lights and traffic light systems. An user is responsible for carrying out maintenance actions on the traffic lights.

Admin is the user who has information about all companies, traffic lights, and traffic lights systems in IoTrafficLight's platform. It has access to this information, and an overview of all the alerts that originated and those already solved. It has permission to create new users and enterprises as well as associate users with enterprises. Admin is also responsible for the creation of traffic light systems, traffic lights, and modules and their association with the corresponding enterprise.

An user associated with an enterprise, an manager, can manage the information of its enterprise. Unlike the admin, a manager only has access to the information of the enterprise it is associated with, as so, it can only access information regarding the traffic lights and traffic lights systems of its enterprise. A manager has permission to create more users associated with its enterprise. Those users can have the same privileges as managers or users. A manager can request the schedule of a maintenance action for an alert generated by a traffic light. A scheduling request will be sent to the user.

An user is responsible for keeping the traffic lights functional and without any type of anomaly that might affect their proper operation. It can consult pending maintenance actions of its enterprise and schedule a date to carry out that maintenance action on a traffic light. It carries out the maintenance action and then updates its status, which indicates if it was solved or not.

IoTrafficLight Platform allows SINALARTE to manage the information about all the systems it develops, namely, the general information on the total number of companies, traffic light systems, and traffic lights.

3.4 Web Interface

The web interface developed assures user interaction with IoTrafficLight solution. IoTrafficLight interface was developed on Typescript (a strongly typed programming language that is based on Javascript) using an angular framework and OpenLayers library.

Angular's platform includes a component-based framework that allows to build scalable web applications and also includes a collection of built-in libraries that allow the use of a wide variety of features such as routing, form management, and communication between clients and servers.

To identify the location of companies, traffic light systems, and traffic lights, the use of maps was implemented using the Open Layers library, an open-source Javascript library that promotes the use of all types of geographic information and allows the insertion of a dynamic map in web pages. This library provides an API for building web-based geographic applications.

Figure 9 is presented the main page for the administrator of SINALARTE, where the user with that role can globally monitor the systems, monitoring everything that is added to it. In green color is presented the total amount of companies, traffic light systems, and traffic lights, while in red is presented the numbers of the ones with problems. This information is updated in real-time accordingly to the data collected.

Fig. 9 Dashboard SINALARTE administrator

Fig. 10 Traffic light system page

SINALARTE can visualize in an easy way customers, this information also includes a map with its corresponding locations each customer is represented with a marker on the map, if it is green, the company does not have any problem with its traffic light systems, although, if the marker is red, it means that the company has any problem on its traffic light systems.

Figure 10 presents an example of a traffic light system, composed of two traffic lights that represent a narrowing of the road, it presents the system page, presenting on the left the list of its traffic lights and the problems in the modules associated with it. On the right side is presented a map with the traffic light system's location, with the exact positioning of each traffic light.

Figure 11 presents an example of a graph of the monitoring of a lighting module, belonging to a previously added traffic light. It allows users to be aware of the

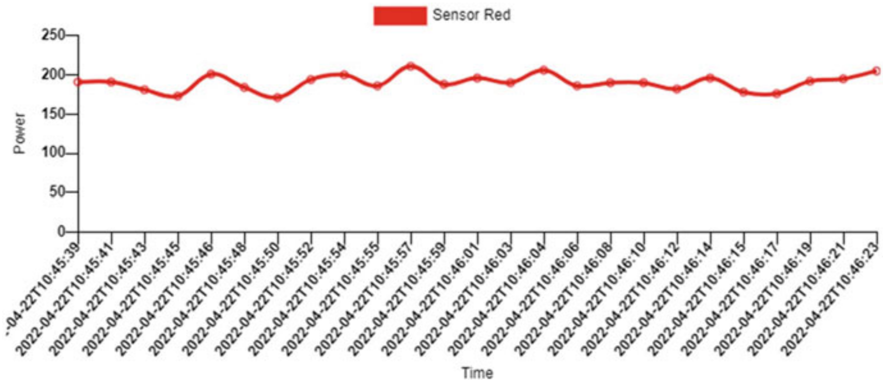

Fig. 11 Red light module power reading

behavior of the module in a more interactive way, while the system is learning from this data and informing about the proper functioning of the light module.

With this type of interface, the IoTrafficLight system can inform the responsible for each system when a non-conformity is detected.

3.5 Validation

To validate the solution developed, a test scenario was created simulating the real operating environment of the system. The scenario installed simulates a traffic light system corresponding to a junction. This junction consists of three traffic lights as shown in Fig. 12, the road B intersects with road AB. Traffic light A controls the traffic for vehicles heading from A to B or C. Traffic light B controls traffic heading from B to A or C. And traffic light C controls the traffic for vehicles heading from C to A or B.

Traffic light A includes two lighting modules that replicate its operation. Traffic light B also contains two lighting modules that replicate its operation, a traffic light for pedestrians, and a flashing light for vehicles wishing to turn left toward C. Traffic light C also contains two lighting modules that replicate its operation and a pedestrian traffic light.

Data referring to the operation is being collected from this traffic light system simulating a real environment. Monitoring the consumption of each lighting module is the main factor when evaluating the traffic lights' status in the developed system. In this scenario, there are 15 different outputs in the system, three at traffic light A, six at traffic light B, and five at traffic light C. Each output board supports the collection of data from up to eight sensors, so for this scenario, two boards were used.

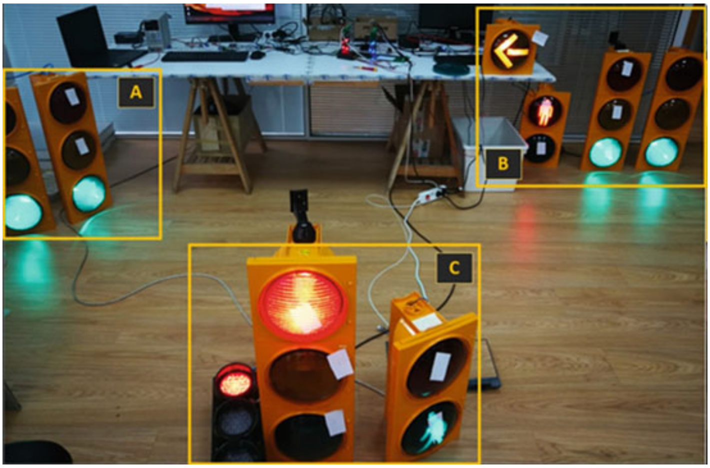

Fig. 12 Junction scenario

No standard requires that the lighting modules are all the same, which will bring greater complexity to the monitoring of the energy consumption of your lighting systems. In a real environment, there are repeater modules, that is, modules that act in the same way but are in different locations of the traffic light, they are used so that the drivers do not have difficulty visualizing the state of the traffic light and they are represented in the test scenario in all vehicle control lighting modules. To obtain different results from the measurements of the other semaphores, the semaphore C includes traffic lights A and B.

The values collected and stored by the system are available to users through the cloud platform. One of the objectives of this system is that over time, since all modules have their record in the database, it would be possible to evaluate the behavior of each traffic light system, crossing information from all other traffic light systems. With the implementation of machine-learning algorithms, it will be possible to predict the occurrence of any anomaly in the operation of any module, thus making it possible to carry out preventive maintenance and optimization of the assembly of traffic light systems, making the systems increasingly efficient.

The prototype also includes an environment-sensing system. In this validation scenario, this system is also installed, and, although it is in a controlled environment, the values collected were validated and are reliable, so the system is prepared to be installed in a real environment.

The data collected by these sensors will allow whoever is managing the places where the traffic light systems are installed, to improve the environmental conditions of the environment that surrounds them, for example, by adjusting the traffic flow in the place. Another objective of these sensors is to understand if the environment that surrounds the traffic light systems can contribute to worsening the state of degradation of the traffic light lighting system.

Real-time monitoring of traffic light systems is extremely important, as it allows managers to ensure the correct functioning of their systems, keeping them always operational. To simulate the occurrence of anomalies, a light was purposely turned off and an alert was automatically generated on the administration page regarding the traffic light system.

To test the alerts service of the IoTrafficLight system, many alerts were generated and the system presented good results when dealing with large amounts of data, which was one of the main requirements of this system because, with the configuration of more traffic lights in the system, the amount of data generated will increase exponentially.

After the alerts are generated, it is intended to treat the modules that are malfunctioning in this traffic light system. For this, the maintenance system was developed, where all the alerts that are intended to be resolved in a maintenance trip will be selected.

4 Conclusions

IoTrafficLight project aimed to develop a traffic light controller composed of a sensing/actuation system for fault detection/prevention/correction and data generation and alerts for an online platform, complying with the norms and standards of SINALARTE. It aimed to assure communication between traffic light systems and enterprises. This communication allows enterprises to receive alerts whenever there's something different with their traffic light systems. These alerts are very useful, as it allows us to identify the problem related to each traffic light system without having to travel to its site. Traffic light systems are able to adapt to flow conditions. Allowing advantages over competitors that do not have it, as it allows more efficient and cost-effective management. The project also contributes to reducing traffic congestion and reducing the inoperability time of traffic light systems.

IoTrafficLight's solution presents more efficient management of the road network and the users that circulate on it. It also contributes to guaranteeing the quality of life of the city's inhabitants and visitors through the improvement of its environment and a better ordering of traffic and pedestrian flows, as well as developing urban mobility by easing the accessibility of citizens to places and services, in addition to the safety of people and goods reducing the risk of accidents.

IoTrafficLight allowed the development of cloud-based software for monitoring and management of traffic light systems, allowing for streamlining of the management and maintenance processes of traffic light systems, namely, changing its operating modes, and carrying out repairs through redundancy circuits (maintenance). It allows real-time communication with the traffic light systems and, depending on the information received, it generates alerts, for example, preventive maintenance alerts. It also allows remote changes to the traffic light operation mode for temporary resolution of possible problems or malfunctions of the corresponding traffic lights or traffic light systems allowing to schedule corrective maintenance actions.

A sensing system supports the cloud-based software allowing to monitor several physical and electrical parameters. At the electrical level, sensors will be placed at various stages of the circuit. In the first instance, the voltage and current at the energy input will be monitored using hall effect sensors due to their robustness, linearity, and reduced impact on the system. The collection of this data will allow the monitoring and control of the energy consumption of the system, enabling the detection of faults and the evaluation of the quality of the electrical energy supplied by the distribution network. IoTrafficLight project contributes to easing road traffic safety and efficiency and reduces traffic jams.

Compared with the traffic light maintenance solutions, from the solutions identified, the one currently being commercialized is the one produced by Citelum Group EDF. The difference is that the solution requires the installation of external commercial sensing systems to monitor different parameters which increase the costs of installing that solution. As IoTrafficLight implements a solution composed of low-cost bulk sensors which allow it to be extremely efficient at a low budget.

5 Issues

The project was affected by internal and external factors that led to the need to adapt the developments to the realities being faced. The main constraint faced was related to the lack of historical data available to implement Artificial Intelligence solutions during the project. It was not yet possible to implement in the real environment machine learning solution to support the early detection of non-conformities in traffic lights. At the time, data is collected from the sensors installed in the traffic light to create a knowledge base for the application of the algorithms. In the future, the algorithms identified as the most promising ones will be implemented to allow the prediction of failures.

On the other side as the project was held during the worst phase of the COVID19 pandemic, it suffered from the closure of enterprises around the world and mainly the lack of electronical components that were being adapted along the project to develop a solution capable to be replicated the solution developed to the traffic light commercialized by SINALARTE. As most of the electronical components still suffer from the lack of components, it was decided that the most promising components would be selected even if currently there are no stocks in the market that will allow its industrialization or even prevision to have. As soon as stock becomes available, SINALARTE will purchase and start to integrate into the commercialized solutions. The limitation of stocks also limited the number of prototypes produced along the project for validation and data collection to train the algorithms.

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