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Digital transformation: perspectives from the industrial and cultural heritage studies sectors

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Abstract

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Digital transformation: perspectives from the industrial and cultural heritage studies sectors

by Diego Carmine Sinitò

This thesis provides an overview of the topic of digitization by analyzing the industrial and Cultural Heritage studies sectors. For each of the two sectors, the technologies that represent the state of the art and case studies to achieve the objectives arising from the analysis of the two different sectors were presented. In particular, for the industrial sector, issues related to Industry 4.0 were addressed: analyzing how companies can benefit from the ongoing fourth industrial revolution. The proposed solutions help companies to develop more efficient production processes and to fulfill the requirements imposed by Italian regulations. Regarding the Cultural Heritage studies sector, several case studies were proposed with the aim of developing new tools to make communication from museums to visitors more efficient. Through digitization, museums can become phygital entities: where the physical and digital worlds work closely together with the goal of eliminating physical barriers.

Contents

Chapter 1

Introduction

1.1 Introduction

Over the past decade, thanks to continuous developments in technology, information technology has become increasingly central in our daily lives. Every day, we interact with multiple technological tools and software that support us by making information available to us or helping us perform certain activities. This technological development has affected almost all aspects of our lives, such as work, leisure, and interpersonal relationships, revolutionizing the way we live.

The great acceleration of this revolution has been caused by different factors during the last 10-15 years. These factors can certainly be identified in the decreasing cost of technology, the wide diffusion of mobile devices with great computational capabilities, such as IoT devices or smartphones, and the possibility of having constantly available a faster and faster internet connection. The combination of increasingly feature-rich devices and a continuous improvement of the network has contributed to the birth of services and further revolutionary technologies. We are referring here to the cloud, which allows us to have software and data available anytime and anywhere. Consequently, the constant use of software has led to the generation of huge amounts of new data. Therefore, the concept of big data is born, along with the development of powerful analytical tools. Finally, another main factor is the development of evolved artificial intelligences capable of performing some tasks even better than humans. This profound cultural transformation is called digitization. By using this term we mean not just the introduction of digital technologies, but the desire to optimize, simplify, accelerate and make more agile all our activities in all the areas of our life. Considering this premise, it is easy to see that the topic of digitization is a very broad field that covers virtually every sector and includes a large number of technologies. In my research, I have focused my attention on two areas: the world of industry, with special attention to the Small and medium-sized enterprises (SMEs) and their problems, and the culture industry with a particular focus on museums.

In order to get an idea of the complexity of the topic, first of all we have to acknowledge the use of another term, which is digitalization, and consider the distinction between digitization and digitalization. In recent years, the discussion and research about the use of data has been organized under these two headings. For some authors, digitalization has been defined as the way many domains of social life are restructured around digital communication and media infrastructures (Brennen and Kreiss, 2016). On the other hand, digitization has been defined as the increasing use of digital technologies for connecting people, systems, companies, products and services (Coreynen, Matthyssens, and Bockhaven, 2017). It involves standardizing business processes and is associated with cost cutting and operational excellence (Ross, 2019). It also refers to the act of making analog information digital. This is not the place for an in-depth examination of this issue, and reference is here made to other studies on the subject (Frenzel-Piasentin et al., 2021). However, following these definitions, the term digitization will be used here in relation to studies conducted during my research.

Another complex issue is that, when we talk about digital we must consider a vastness of tools and technologies. We must add to this a high speed of development, which appears to be almost out of control. With this in mind, we can deduce that it becomes very difficult to keep up with the continuously evolving digital scenario. Given the complexity of the sector, a very import role has been played by states that cyclically draw up development programs on large time scales with guidelines to follow. We can cite for example "The Digital Agenda for Europe", which is one of the seven key pillars of the "Europe 2020 Strategy", a development program for the 2010-2020 decade. The near future regarding digital development will be led by the "NextGenerationEu" development plan, which includes measures for research and innovation, via "Horizon Europe" program. Keeping these documents as guidelines, we can extract the goals to be achieved through digitization for the sectors of our interest.

The main goal for the first sector can be identified with the general improvement in terms of business, which means digitizing production processes, integrating collaborative software where different types of users can carry out their work activities according to their tasks, integrating data streams proceeds from heterogeneous sources (management, production, machinery), providing tools for performance monitoring, and fostering smart working. As far as the cultural industry is concerned, the main goals can be identified in the preservation and better understanding of our cultural heritage, as well as the improvement and expansion of knowledge communication methods. To achieve these goals it is necessary to address digitization related to preservation and study, i.e., the creation of digital copies of artifacts, the development of platforms for sharing with the purpose of fostering research. Following the production of digital content, a path of digital communication must be addressed, that is, leveraging the obtained resources to develop innovative fruition tools, using platforms and apps that give the possibility of enhancing the onsite experience and the opportunity of remote access, taking advantage of new techniques to facilitate the goals of education and instruction, such as gamification, plus the support of new technologies for immersive fruition, such as virtual reality and augmented reality.

The achievement of these goals has proven to be quite challenging, but it must be pursued in order to accomplish a growth from the perspective of digitization and to be competitive not only at the European level but also globally. As mentioned earlier, it is not possible to reach a digital transformation exclusively through the introduction of new hardware or software, but it is necessary to go to a deeper level that involves the entire workflow. This must be rethought from a digital perspective by aiming at the dematerialization of document flows, the automation of parts of it by reducing manual steps that can be a source of error, and at the same time ensuring greater control and transparency over the execution of each activity. The problems to be addressed are related both to basic technological problems, such as the choice of hardware/software architectures, data storage solutions, heterogeneity of devices and data flows leading to poor integration, and to problems of an integration nature, because new tools can be difficult to use due to unnecessary features or ineffective user interfaces, compromising the success of the digitization process due to a poor user experience.

The aim of my research path, after a careful analysis of the application scenario, was then to define an action plan for the digitization of business processes aimed at the integration of information flows obtained from the interconnection with 4.0 machinery. In the first phase, the technologies to be used and hardware/software architectures were identified, then an infrastructure was designed and implemented such that all information flows could be integrated with what was identified in the first point. Finally, the proposed solution was implemented in two real case studies conducted in collaboration with two companies. After the analysis of their workflows, two software were designed and implemented with the aim of integrating two new 4.0 machines into the existing workflow. This would ensure an improvement in the production process in terms of quality of the same and compliance with the regulations required by the case.

In the museum field, on the other hand, the research was focused on identifying new technologies and techniques for the improvement and enhancement of the fruition tools that museums can provide for visitors in order to transform it in a digital place that can be explored even outside of the physical building. The research was conducted in collaboration with the University Museums Network (Sistema Museale d'Ateneo - SiMuA) of the University of Catania. A further step was achieved through the DREAMIN (Digital REmote Access to Museums and research INfrastructures) project, which had among its goals to make museums and research centers accessible remotely. Three technologies were explored to meet this need: web applications, serious games and digital twins. The result of these activities was finally concretized in three products: first, a web application that allows visitors to build a personalized visit inside the Museum of Mineralogy, Petrography and Volcanology; second, a serious game that allows to impersonate a researcher in the mineral-petrographic field, diluting in a simplified way the processes of investigation carried out on minerals and the tools used; third, a device capable of creating a digital copy of the Focault Pendulum experiment installed at Città della Scienza, another museum part of the group.

1.2 Outlines

This thesis consists of five chapters and it is structured as follow:

- Chapter 1 investigates the developments in technology today and the new opportunities deriving from them for the industrial and cultural sector;
- Chapter 2 introduces the concept of Industry 4.0 and the role of digitization in the industrial sector with a quick view on the technologies that are in the state of the art. Moreover, an overview on European and Italian regulations is provided;
- Chapter 3 explains the requirements to satisfy to be in compliance with industry 4.0 Italian regulation, then a solution hardware/software is proposed. Finally two case studies where the proposed solution is implemented are showed;
- Chapter 4 discus about the need for Cultural Heritage and which techniques can be adopted to meet these needs. We discus about three different products developed with the aim of make a Museum not only a physical building but a phygital[1] place;
- Chapter 5 summarizes the final considerations on this work by analyzing the proposed solutions and the results obtained.

[1]The term phygital is used to describe any experience involving the meeting and contamination of the physical and digital

Chapter 2

Industry 4.0

2.1 Digitization in the industrial sector

Three industrial revolutions have taken place over time to date. Each of them was initiated by the entry of a new technology into the industrial sector. Starting with the one in the late 1700s, with the advent of steam engines, to the most recent one that saw the introduction of the first computers into factories around 1960-1970. These revolutions brought a radical change not only in industrial production, but also in society. Since then, technology has never stopped innovating itself. This continuous evolution has been and still is fuelled by man seeking more advanced tools to improve his existence.

Although not many years have passed since what we can define as the last industrial revolution, right now the whole sector is experiencing a new period of expansion thanks to the implementation of the latest technologies in the productive process. If the revolution of the early 1970s is known for the entry of electronics and information technology, which brought increased levels of automation to the industrial sector, quantitatively increasing production, the current digital revolution, defined as Industry 4.0, focuses on all those digital technologies that are able to increase the interconnection and cooperation of resources (people or information systems) without being limited to one sector rather than another (Tiraboschi and Seghezzi, 2016). The digital transformation is based on some fundamental technical principles, which outline the profile of a company that work with an Industry 4.0 methodology and they are to be conceived as the base of the new workflows. A company which effectively employed them in business practices will have a major impact on the success of the organisation itself, the company will be more profitable than more traditional organisations and working conditions will be improved. They are:

- **Interconnection**: ability of the assets and resources of the production chain (machines, men, processes) to interact and exchange information with internal and external systems through the use of a data exchange network. These constant collaborations and connections overcome the limit of individualism and non-collaboration by improving the operability of a system and problem solving that can be shared in real time to all areas involved;
- **Virtualisation**: which means a virtual reproduction of the company, realised through sensors applied to the components of the physical processes. These allow the configuration of the company's digital twin, whose combination with the physical assets generates the cyber-physical system that underpins the concept of Industry 4.0. Advances in technology have enabled the connection between physical and virtual worlds, making it possible to go beyond the limits imposed by reality and offer more satisfying solutions. The virtual world is used to create an new reality, in order to understand from this how the product or process can be improved, giving us the possibility to test changes without altering the physical product or the process, but through a realised simulation that represents reality. Virtualisation makes it possible to run simulations that can handle rapidly changing market conditions;
- **Decentralisation**: this refers to the ability of intelligent systems, rendered as such by technology, to take decisions autonomously and act without human intervention, being able to recognise any anomalies in processes and to modify their behaviour autonomously. This is the case with all mechanisms endowed with artificial intelligence, such as robots, which, precisely through decentralisation, can understand what is happening around them and act accordingly without external intervention;
- **Remote interaction**: with this function it is possible to remotely interact with complex systems, monitor its processes or intervene on it, without being at the

physical location where systems are installed;

- **Real-time processing**: in order to be more productive and effective, and to solve any problem in the shortest possible time, functions are required to quickly gather information, extract useful value from it and exercise immediate action. In this way, every aspect of the production process responds to requests in a timely manner. This makes it possible to achieve complete integration between production and maintenance, involving fully autonomous operators capable of carrying out maintenance activities to prevent breakdowns or downtime;

- **Modularity**: it allows to modify production mechanisms in response to market demand, through the integration of the value chain with the information system;

- **Service orientation**: the role of technology has been and still is to contribute not only to the creation of a new product or process but to offer services that can be exploited for the company's own benefit. Hence the concept of the Internet of Services, which can be of various types, such as warehouse control, logistics services, monitoring of product transportation, which contributes positively to efficiency and productivity;

- **Sustainability**: it consists in optimising the consumption of energy resources to enhance environmental and social aspects, while also improving working conditions;

- **Interoperability**: the ability of two or more systems belonging to different companies to exchange data in order to create networks of companies that can extend beyond national borders so that even small and medium-sized companies can increase their competitiveness.

Those aspects are fundamental for correctly interpreting the concept of Industry 4.0. It should not be forgotten that the essence of 4.0 innovation presupposes that, through the increased interconnection between actors, machines and devices, there will be a unification of all technological innovations in order to integrate the entire production chain. Underestimating this important aspect would run the risk of equating digital transformation with the sole and exclusive adoption of new technologies. This transformation at the production level must be combined with an evolution of the company's strategic vision seen as a whole, understood as a retraining not only of the workforce, which must be trained in the skills necessary for this purpose, but also of readiness in the face of an increasingly changing market demand, all aimed at a medium- to long-term vision. This revolution involves all company functions without excluding any of them.

2.2 Enabling technologies

The fourth industrial revolution has thus been driven by a series of new technologies that blur the boundaries between the human being, the internet and the physical world. There are at least nine technologies that can be counted on for this transformation of industrial production (Rüßmann et al., 2015): big data and analytics, autonomous robots, simulation, horizontal and vertical system integration, industrial internet of things, cybersecurity, cloud computing, additive manufacturing and augmented reality.

Big data represents a process of collecting and processing a large amount of data that is produced on our planet on a daily basis. These data come mainly from online activities, communications, photos and videos, sensor data and the Internet of Things. In fact, almost all of the actions that we perform on the web every day always leave a digital trace (data) that companies and institutions can use to their advantage. It is precisely through the analysis of these data entered into the network by users or created from digital business processes that companies can optimise their production procedures, understand the behaviour of potential customers and foresee market changes. They can also obtain new information about their own production processes, thus transforming a set of simple data into added value. For instance, IoT devices, such as Radio frequency identification (RFID) has been widely used in supporting the logistics management on manufacturing shopfloors (Zhong et al., 2015). Within such environment, enormous data could be collected and used for supporting further decision-makings such as logistics planning and scheduling.

Thanks to this big data approach an expert system was developed, which is able to guide end-users to carry out associated decisions.

Autonomous Robots are machines that perform even very complex tasks (behaviours or assignments) with a high degree of autonomy, a feature that is particularly desirable in sectors such as space flight, home maintenance, waste water treatment or the provision of goods and services. For several years now, robots have been introduced to increase flexibility and efficiency in various production plants, such as car manufacturing. The robots are able to cover the entire car production process, including moulding, body-in-white welding, painting, engine machining and are able to produce even different models on the same line with little time to change from one model to another.

Even in agricultural autonomous robots are widely used (Bergerman et al., 2015). Thanks to new navigation systems that include obstacle detection subsystem, preventing the vehicle from colliding with people, trees, and bins, it is possible to use robot without a constant human supervision. Many trials showed that the autonomous orchard vehicles enable efficiency gains of up to 58% for fruit production tasks conducted on the top part of trees when compared with the same task performed on ladders. Anecdotal evidence collected from growers and workers indicates that replacing ladders with autonomous vehicles will make orchard work safer and more comfortable.

The term Simulation refers to that process which, through simulation by means of models, makes it possible to visualise updated workflows before adjusting the production line, thus enabling the parameters of the production process to be predicted and established a priori. In this way, it is possible to set up machinery correctly, reducing machine set-up times. Other examples of simulation are augmented reality (AR) or virtual reality (VR) scenarios. In these cases, simulations can be used for educational purposes, such as staff training, increasing the safety of workers in the company. In this way, in addition to accelerating the learning process, it is also possible to have objective tools for evaluating the skills developed. (Webel et al., 2013).

System Integration is defined in engineering as the process of coordinating all the subsystems that are components of one large system, so that they work together and the system is able to provide overall functionality. An example of this is the process of linking computer and software systems, which are physically and functionally different, but which can nevertheless act as a coordinated whole. Integration can be of two types, vertical and horizontal. Vertical System Integration is the process of integrating subsystems according to their functionality. This type of integration is performed rapidly and involves only the necessary suppliers. Horizontal System Integration or Enterprise Service Bus (ESB) is an integration method in which a specialised subsystem is dedicated to communication between other subsystems. This reduces the number of connections (interfaces) to just one per subsystem that will connect directly to the ESB. The ESB is able to translate the interface into another interface. This reduces integration costs and offers extreme flexibility. With Industry 4.0, horizontal and vertical system integration means that companies, suppliers and customers are as closely connected as departments and business functions.

The Internet of Things has been defined in (Ashton et al., 2009) as the extension of the Internet to the world of concrete objects and places. Each "thing" belonging to the Internet of Things is uniquely identified by an Internet address that can be accessed over the network and is able to interact with connected information systems. In general, a distinction is made between the Internet of Things for consumers (IoT) and the Internet of Things for companies (Industrial Internet of Things - IIoT). In the consumer-oriented concept (IoT), the focal points are people, home applications, electronic devices, cars, computers and many other everyday objects. The IIoT, on the other hand, creates opportunities for enterprises, production plants or entire sensor networks. Thanks to the application of sensors and the Internet, physical objects are able to communicate and interact with each other so that they can make decisions autonomously and in real time, thus decentralising decision-making. The amount of objects connected to the Internet is increasing exponentially, confirming that the world is moving towards an increasingly connected future. With the advent of the IIoT and the increase in networked information, it becomes necessary to implement a solution to the problem of cyber security in industrial control systems that guarantees the safeguarding of sensitive data. The complexity of the IIoT requires that cyber security must be provided from the design phase of the components that make up the automation system. The digital transformation of production processes and the use by companies of cloud systems have significantly increased the attack surface by hackers against companies and institutions, effectively increasing exposure to cyber crime. Cybercrime (criminal activities carried out through computer tools) has money as its main motive; the typical tool that enables the perpetration of such crime is Ransomware malware, a software that restricts the user's access to the infected device, demanding a ransom to remove this restriction. One of the most recent ransomware attacks, launched on a global scale affecting more than 100,000 systems in 105 countries, particularly in Russia, Ukraine, India and Taiwan under the codename Wannacry, had the ability to completely lock the infected machine and automatically demand, via a message, a sum of money in bitcoin currency in order to unlock it. Ransomware Wannacry attacked many hospitals, companies, universities and government organisations across at least 150 universities, having more than 200,000 victims. It locked all computers and data (Mohurle and Patil, 2017).

It seems clear that, with the introduction of the Internet of Things, cyber crime today more than ever before can cause a significant damage to companies, institutions and individuals, not only from an economic point of view but also from a social point of view, as it can also put the very lives of citizens at risk. With Industry 4.0, indeed, it is possible to interact with physical objects directly remotely and thus issue orders or gather information using even just a smartphone. Concealed behind this convenience, however, is the possibility that unwanted persons can enter into communication with these objects and thereby cause harm to us. A striking example of such a problem emerged in the automotive sector: Fiat-Chrysler was forced to immediately withdraw 1.4 million cars from the market after the technology magazine Wired reported that hackers could have taken control of the car in question, the Jeep Cherokee, through its Internet-connected entertainment system (Ring, 2015). It is therefore clear that, small and large companies can no longer underestimate these dangers, but rather should invest in security to be able to contain the risk of losses that such attacks can bring.

In computer science, the term Cloud Computing refers to a paradigm for the provision of computing resources, such as data storage, processing or transmission, characterised by on-demand availability through the Internet from a set of pre-existing, configurable resources (Mell and Grance, 2011). According to the NIST

(National Institute of Standards and Technology), Cloud Computing is a model that allows on-demand access on a network, from anywhere, to a set of shared and configurable computing resources (e.g. networks, servers, storage, applications and services) that are rapidly provided and released with minimal management effort or interaction by the service provider. Cloud computing, therefore, provides data and resources to computers or other devices, thus offering numerous benefits to enhance the capabilities of robots by increasing the efficiency of the services offered.

Additive Manufacturing is the identifying name for a whole series of manufacturing techniques and technologies in which the finished product is formed without the need to cast the material in moulds or remove it from a rough shape. The best known industrial version is 3D printing, the technique of building three-dimensional material objects by adding ultra-thin layers of material on top of each other. Klaus Schwab, founder of the World Economic Forum, on the occasion of the release of his latest book entitled "The Fourth Industrial Revolution", reports how additive manufacturing in general is the technology he would bet most on in the coming years. 3D printing, in fact, can be used in practically all sectors. In the field of construction engineering, the first 3D printed houses have already been built. In the medical field it will be possible in the next few years to print organs for transplantation. In the aerospace and defence sectors it is still being used for the production of complex components (Liaw and Guvendiren, 2017; Souza et al., 2020; Kalender et al., 2019). These are just a few examples of how new 3D printers can make production more efficient and qualitatively better. The cost of these machines has also drastically decreased from € 20,000 per unit to less than € 1,000 since 2010, making them affordable for everyone. Even managers of smaller companies, therefore, should consider the impact this manufacturing innovation could have on their operations.

Most of these technologies are already in use, even if only in very large companies, so it can be said that the real innovation introduced by the fourth industrial revolution is nothing other than the union of all production activities, traditionally isolated, into a single integrated production flow, made possible by the combined use of these nine technologies. This new production system will also change companies' relationships with their suppliers, customers and will also change the existing relationship between man and machine. Thanks to lower technology costs, ultra-fast internet connections, efficient cloud systems, connected machines and sensor networks, and the production of big data, it will be possible to achieve a high degree of flexibility in production, a high degree of product customisation that will make it possible to no longer consider the consumer as a mass but as an individual with his or her own specific needs, and optimised production through automatic calibration. All this will have an impact on the reduction of production costs, mainly due to the reduction of waiting times between the design, production and marketing of products. The special feature of the fourth industrial revolution can be summarized as: the increasing integration of services, software and machines through Internet in industrial production.

2.3 The role of regulatory authorities in the digitization of industry

The fourth industrial revolution is having a profound impact on companies, progressively giving rise to new business models and forcing them to implement effective strategies to ensure their ability to govern in a rapidly changing operating environment. Companies, however, are not the only actors called upon to implement the appropriate changes to their organisation. Political representation is also required to acknowledge how the world is changing and learn from this revolution in order to implement adequate measures capable of exploiting, in their entirety, the benefits that digitization entails from both a social and economic point of view. The purpose of this paragraph is to set out what has been done at the legislative level in Europe, and then in the European countries, with a particular focus on Italy, in order to highlight how they have reacted and what they have done to get all the possible benefits of the Industry 4.0 revolution.

2.3.1 EU policies

In 2017 the European Commission stated that more than 41% of EU companies have not yet adopted new advanced technologies, even if encouraging data ensure that 75% of the respondents see new digital technologies as an opportunity, while 64% of

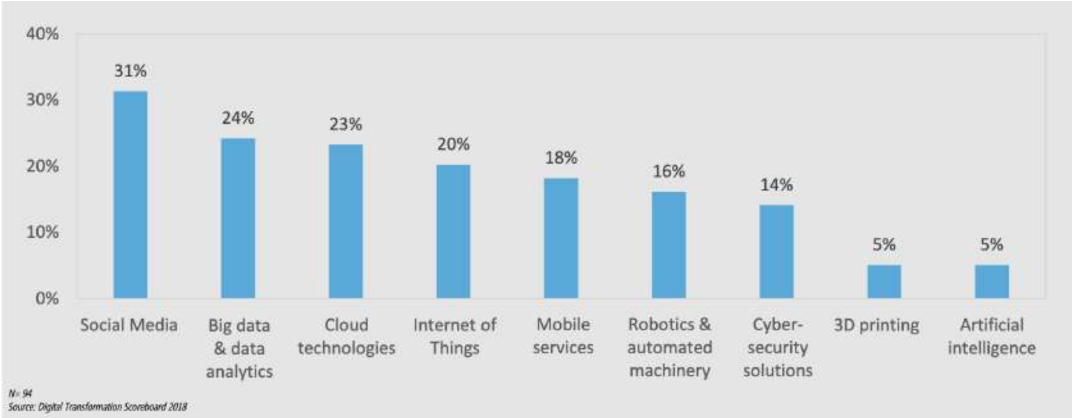


FIGURE 2.1: Level of new technologies adoption among participants of Digital transformation scoreboard 2018 survey.

those who have invested in them have achieved positive results (Vidas-Bubanja and Bubanja, 2017).

Despite this, companies still prefer traditional solutions belonging to what is referred to as the "first digital wave", such as e-commerce, social media, management, while the adoption index of high-level technologies still remains quite low (Fig. 2.1). This reluctance towards new technologies is mainly found in the fact that it is considered necessary to upgrade the skills of the workforce before new digital process can take place efficiently and functionally. On the other hand, such requirements are not necessary using traditional system.

To this must be added the inability of entrepreneurs to use these technologies, wrongly accustomed to short-term thinking and implementation. These are negative aspects compared to the real and concrete benefits that digitization would bring within their companies. To address the new challenges posed by Industry 4.0, most European governments have implemented dedicated Industry 4.0 policies. Indeed, it has become a common thought to have clear measures and measurable targets in order to incite companies to embark on a path of digitization of production processes. The European Union has helped set guidelines on how to manage the technological transition to Industry 4.0, which can be found in programmes formulated at national level. The action plans of the EU Member States have several common elements, especially with regard to objectives. First of all, it is necessary to strive for constant sustainable development, i.e. a form of national economic development that is compatible with environmental protection and social objectives in order to strengthen and renew business competitiveness. The various member states adopt policies geared towards the pursuit of these goals, although they differ in the means and methods used, such as Germany, which focuses on manufacturing, being a country with high manufacturing ties, to keep up with low-cost foreign competition. Other widespread objectives are the creation of next-generation technologies, innovative production accompanied by the perfecting of industrial processes, supporting SMEs (Small and Medium-sized Enterprises) in this respect to boost competitiveness and change (Small and Enterprises., 2018).

Of course there are countries that distinguish themselves in the adoption of certain policies, such as Spain and France, which finance those companies that join the programme by adopting the market-based model. In the case of Spain, the size of the loan varies depending on the type of technological interventions planned and the characteristics of the company, with a range of coverage from 25% to 70%. France, on the other hand, combines a large number of financing instruments, e.g. loans and tax incentives with private R&S investments. Sweden, on the other hand, is driven and financed primarily by industry. The UK's unique feature is that it has established seven technology centres, whose presence serves to provide companies with state-of-the-art industrial technologies and experts, thus reducing the risk involved in innovating projects and thus stimulating such initiatives. In this panorama of a constant search for technological innovations, where their propagation and application is in any case a priority, Italy is an exception as it also focuses on research and development. In order to make these policies as feasible as possible, nations benefit from predominantly public funding, but there is certainly no lack of subsidies from the private sector. These subsidies must be accompanied by concrete implementation measures, which most EU member states have concretized in the so-called top-down approach, i.e. identifying the main goal without analysing it in detail in its parts, which are reviewed by the various stakeholders in order to define them by adding specificities to the design.

2.3.2 The Italian case: the "National Plan Industry 4.0"

After a general analysis of the European context, we will now look at how Italy has implemented the objectives to be pursued and what measures have been taken by the institutions, in particular by the government, to foster digitization. It is necessary to emphasise how, following the 2008 financial crisis, the Italian economy has severely been affected by the negative consequences of the crisis, especially in the manufacturing sector, where Italy was one of the major powers on a European level. For these reasons, digital transformation represents a real and concrete advantage to be grasped and implemented in order to restore the economy of companies hit by the crisis. However, there are difficulties in implementing the digitization of enterprises. In particular, within the Italian industrial sector, there is a lack of large companies and especially ICT companies that can drive technological development and change, since Italy's great economic strength lies with small and medium-sized enterprises. This implies that there is a lack of financial resources and, at times, even problems in obtaining the necessary financing for this purpose. For this reason, the "National Plan Industry 4.0" was presented by former Prime Minister Matteo Renzi and the then Minister of Economic Development Carlo Calenda in September 2016. The main objectives pursued by this plan are to innovate and fortify the opportunities deriving from Industry 4.0, encouraging and supporting funding. These objectives make productivity more adaptable, allow for qualitatively better products, as well as increase production and enable the process of getting the final product to market faster, increasing competition within the Italian industrial landscape. In order to achieve these goals, it was necessary to set key and accompanying guidelines, which inspired the drafting of the Industry 4.0 plan. The first key guideline, i.e. that concerning innovative investments, has as its main objective to encourage the following aspects:

- investments with greater transformative content using digital technologies and new machinery in a 4.0 perspective (through the super depreciation measure, hyper depreciation measure and tax credit);
- investments on industrial research and development.

2.4 Capital goods

A great opportunity of growth for Italian companies is also provided by the possibility to exploit incentives for the modernisation of industries and production processes. In this case the Italian government has been farsighted and the Parliament, in 2016, had already passed measures for the modernisation of Industry 4.0 to encourage the purchase of new capital goods. The Parliament has precisely defined which categories of investment and which assets could be considered recipients of the incentives. In addition, the has been defined a precise list of the characteristics that each new tangible equipment should have in order to be considered 4.0 capital goods.

According to Annex A to Law No 232/2016, in order to be considered capital goods for the purposes of the legislation, a machinery must belong to one of the categories specified in the document:

- machine tools for removal;
- machine tools operating with lasers and other flow processes of energy (e.g., plasma, waterjet, electron beam), EDM, electrochemical processes;
- machine tools and equipment for making products by processing materials and raw materials;
- machine tools for plastic deformation of metals and other materials;
- machine tools for assembly, joining and welding;
- wrapping and packaging machines;
- de-manufacturing and repackaging machine tools for recover materials from industrial waste and end-of-life return products (e.g., machines for disassembly, separation, shredding, chemical recovery);
- robots, collaborative robots and multi-robot systems;
- machine tools and systems for conferring or modifying the surface characteristics of products or functionalization of surfaces;

- additive manufacturing machines used in industry;
- machines, including traction and operating machines, instruments and devices for loading and unloading, handling, weighing and automatic sorting of parts, automated lifting and handling devices, AGVs and flexible conveying and handling systems, and/or equipped with part recognition (e.g. RFID, viewers, vision systems);
- automated warehouses interconnected to factory management systems.

All of the above machines must be equipped with the following features:

1. control by CNC (Computer Numerical Control) and/or PLC (Programmable Logic Controller);
2. interconnection with the factory computer systems with remote loading of instructions and/or part programs;
3. automated integration with the factory logistics system or with the supply network and/or with other machines in the production cycle;
4. simple and intuitive human-machine interface;
5. conformity to the most recent parameters of safety, health and hygiene at work;

The requirements just described are mandatory (MR) and all five must be present. In addition, a machine must have at least two of the optional requirements (OR):

- remote maintenance and/or remote diagnostics and/or remote control systems;
- continuous monitoring of working conditions and process parameters by an appropriate sets of sensors and adaptability to drifts of process;
- feature of integration between physical machine and/or model of the plant and/or system of simulation of the machine itself (cyberphysical system);

- devices, instrumentation and intelligent components for integration, sensing and/or interconnection and automatic process control also used in the modernization or revamping of existing production systems;
- filters and systems for treatment and recovery of water, air, oil, chemical and organic substances, and dust with systems for reporting filter efficiency and the presence of anomalies or substances that are unrelated to the process or hazardous, integrated with the factory system and capable of alerting operators and/or stopping machine and plant operations.

Therefore, it is often and willingly easy for a machinery manufacturer to comply with points OR1, OR4 and OR5 of the mandatory requirements. On the other hand, it is particularly difficult to concretely satisfy those of the bidirectional interconnection (sending instructions or part programs in both directions) or the satisfaction of automated integration without knowing the place where the machinery will be installed and without knowing the systems in use. The responsibility of fulfilling requirements OR3 and OR4 is usually left to the company that purchase the machinery. In this case we can refer to this machinery like ready for Industry 4.0 but not already usable for the purpose of collecting the benefits provided for Industry 4.0 in term of financial aid provided by the Italian government.

At this point, it is necessary to make an appropriate distinction between 4.0 systems and 4.0 mobile vehicles (e.g., tractor machines). In this case, the requirements of interconnection and automated integration are deemed to be satisfied by automatic and semi-automatic driving, which however must not be limited to its remote switching on or off. Precisely in the case of mobile machines, it is not possible to consider only the GPS location with related remote map as a sufficient implementation of the interconnection and automated integration.

We will not discuss optional requirements (OR) at this time because they strictly relate to the manufacture of the machinery and therefore their fulfillment is deferred to the machinery manufacturer, who will decide which ones to implement.

Considering the OR2 of Annex A, that requires the bidirectional interconnection with the factory informative system, it is essential to consider the use of the international standard communication protocol such as the Modbus TCP/IP or OPC-UA that are used by a large part of machinery PLCs or the REST API for machinery that provide a cloud.

To satisfy the OR3 of Annex A, that requires the automated integration, we have several options. The case of M2M is the simplest to imagine for production processes that require multiple processing steps carried out by different 4.0 machinery which are able to communicate and work in a synchronized manner with respect of the various production phases, using an international recognized protocol for communication. Instead, if we want to integrate the machinery to the company workflow it is necessary to analyze the processes in order to develop a integration solution based on the needs of the company. The new process should introduce a benefit for the company and/or the customers. Considering the integration with the logistic processes, an example is represented by referring to identifiable incoming lots with a barcode that allows to trace the entry of the single lot and the various processing phases carried out by 4.0 machinery, and use it to track the positioning of the output semi-finished product or of the finished product in a specific position in the warehouse. This tracking therefore allows you to make a correct use of 4.0 in an automated integration key of the logistics process. In the absence of this flow, for istance it is possible to carry out an evaluation of integration of the machinery within the supply chain: this means that both the customer and the supplier who use a 4.0 automaton as an intermediary for their workflow, are automatically informed of the start of the specific activity phase until the end of the activity.

Therefore, automated integration with the logistics factory system takes place through the access to the machinery interconnected to the factory computerised system. In this case we can use the term Manufacturing Execution System (MES) to refer to a computerised system whose main purpose is to manage and control the productive function of a company. Thanks to the connection with the machines and by using the information they transfer, it is possible to further improve the communication of orders, the advancement of quantities and time, the storage in the warehouse, as well as it is possible to collect process data to be analysed from a Big Data perspective.

Chapter 3

A framework for integration 4.0

Having taken note of the Italian regulatory requirements regarding capital goods, it is easy to see the need for a structured approach to the integration of 4.0 machinery within company workflows in order to be in compliance with regulations and allow companies to obtain the resulting tax incentives.

The path leading to the formulation of a complete solution in terms of both hardware and software is based on a number of initial assumptions about the technology used. It allows interfacing with as many machines as possible, it is able to communicate via the Internet, it offers the possibility of integrating with different external services, it is oriented towards open source solutions, and it uses a low-cost structure. Based on these premises, a solution was developed that could be readily used and as flexible as possible. Subsequently, the chosen solution is implemented in two companies, offering the possibility of testing the entire architecture with two case studies.

In the following paragraphs, we will analyse 4.0 machinery and industrial data exchange protocols, the hardware/software architecture developed to enable information exchange between machinery and external services on the cloud, and finally, we will analyse two case studies of automated integration within company production processes.

FIGURE 3.1: The electrical panel of a 4.0 machinery where is possible to see a Siemens S7 1500 PLC installed.

3.1 Technical characteristics of 4.0 machines

In manufacturing, the core of Industry 4.0 is the connection between physical systems (in particular machines) and information systems. Machines used in production processes are connected to computer systems for collecting and analysing production data. In this case, we speak of IoT machines. From an analysis of the Italian Industry 4.0 law, it is possible to define the technical and scientific characteristics that tangible goods, in this case machines, must possess in order to be part of the Italian Industry 4.0 plan. In particular, we will focus on Annex A1: Capital goods whose operation is controlled by computerised systems or managed through appropriate sensors.

The two key characteristics to be considered 4.0 machines are as follows:

- control by means of CNC (Computer Numerical Control) and/or PLC (Programmable Logic Controller)
- interconnection to factory computer systems with remote loading of instructions and/or part programs

A Programmable Logic Controller, or PLC (fig. 3.1), as request in the first point is intended like a is a ruggedized computer used for industrial automation. These controllers can automate a specific process, machine function, or even an entire production line. The PLC receives information from connected sensors or input devices, processes the data, and triggers outputs based on pre-programmed parameters. Depending on the inputs and outputs, a PLC can monitor and record run-time data such as machine productivity or operating temperature, automatically start and stop processes, generate alarms if a machine malfunctions, and more.

A further clarification on the second point is given to us by a circular of the Revenue Agency (Circular No. 4/E of 30/03/2017), where it is explained that: "the characteristic of interconnection to factory computer systems with remote uploading of instructions and/or part programs is met if the asset exchanges information with internal systems (e.g.: management system, planning systems, product design and development systems, monitoring, even remotely, and control, other factory machines, etc.) by means of a connection based on documented, publicly available and internationally recognised specifications (examples: TCP/IP, HTTP, MQTT, etc.). Furthermore, the asset must be uniquely identified, in order to recognise the origin of the information, through the use of internationally recognised addressing standards (e.g. IP address)".

Starting from these technical indications and taking into account our initial intentions, i.e. to support as many machines as possible using open technologies, it will be possible to analyse the solutions proposed in the state of the art in order to make the choice of the most suitable communication protocols for our purpose.

3.2 Communication protocols

With the main objectives in mind, the choice of a universal communication protocol falls mainly on the OPC-UA protocol. However, as the latter is not always available, being a higher-level protocol, Modbus TCP/IP is chosen to integrate communication with the remaining devices as well.

The main features of each of the two protocols will be described below, focusing on addressing modes, data types, functionality.

3.2.1 OPC and OPC-UA

Up to very few years ago, the communication systems for industrial automation applications were oriented only to real-time performance suitable for industry and maintainability based on international standards. Among others, the most diffused industrial protocols today are, for instance; the wired based EtherNET/IP, PROFINET, Powerlink and EtherCAT; and the wireless based IEEE802.11, ISA100.11a and Wireless HART. However, it is known that interoperability between systems of different vendors with different protocols is always difficult because of the incompatible information models for data and services. Industry 4.0 manufacturing systems cannot rely only on such legacy approaches in order to reach the required flexibility level.

The most promising solution for this challenge is OPC, the interoperability standard for the secure and reliable exchange of data in the industrial automation space. It is platform independent and ensures the seamless flow of information among devices from multiple vendors. The OPC Foundation is responsible for the development and maintenance of this standard (Iwanitz and Lange, 2010).

The OPC standard is a series of specifications developed by industry vendors, end-users and software developers. These specifications define the interface between Clients and Servers, as well as Servers and Servers, including access to real-time data, monitoring of alarms and events, access to historical data and other applications.

When the standard was first released in 1996, its purpose was to abstract PLC specific protocols (such as Modbus, Profibus, etc.) into a standardized interface allowing HMI/SCADA systems to interface with a "middle-man" who would convert generic-OPC read/write requests into device-specific requests and vice-versa. As a result, an entire cottage industry of products emerged allowing end-users to implement systems using best-of-breed products all seamlessly interacting via OPC.

Initially, the OPC standard was restricted to the Windows operating system. As such, the acronym OPC was borne from OLE (object linking and embedding) for Process Control. These specifications, which are now known as OPC Classic, have enjoyed widespread adoption across multiple industries, including manufacturing, building automation, oil and gas, renewable energy and utilities, among others.

With the introduction of service-oriented architectures in manufacturing systems came new challenges in security and data modeling. The OPC Foundation developed the OPC UA specifications to address these needs and at the same time provided a feature-rich technology open-platform architecture that was future-proof, scalable and extensible.

OPC Unified Architecture (UA), released in 2008, was designed to enhance and surpass the capabilities of the OPC Classic specifications. OPC UA is functionally equivalent to OPC Classic, yet capable of much more:

- **Discovery**: find the availability of OPC Servers on local PCs and/or networks
- **Address space**: all data is represented hierarchically (e.g. files and folders) allowing for simple and complex structures to be discovered and utilized by OPC Clients
- **On-demand**: read and write data/information based on access-permissions
- **Subscriptions**: monitor data/information and report-by-exception when values change based on a client's criteria
- **Events**: notify important information based on client's criteria
- **Methods**: clients can execute programs, etc. based on methods defined on the server

OPC UA has been designed to facilitate the exchange of information across the hierarchy of systems that commonly coexist in industry: Enterprise Resource Planning (ERP); manufacturing execution systems (MES); control systems; and, last but not least, field devices. OPC UA has a message based communication and a Service Oriented Architecture (SOA) with clients and servers connected to any types of networks.

A client application may use the OPC UA client API (application program interface) in order to send/receive OPC UA service requests/responses to/from the OPC UA server. From the programmer point of view, the OPC UA client API is like an interface that decouples the client application code from the client OPC UA communication stack. In the OPC UA API, there is a discovery service that can be used to find available OPC UA servers and to explore their address space. Clearly, the OPC UA communication stack converts the calls to the OPC UA API to proper messages for the underlying network layers. In the servers, the OPC UA server API and the OPC UA communication stack are very like the client ones. As additional feature, the server has the so called "address space" in which it can expose the object to be exchanged. In OPC UA, a multiplicity of data structures (called "nodes") can exist, representing, for instance: variables, complex objects, methods (i.e., remotely called functions) and definitions of new types for creating new OPC UA metadata. A hierarchical structure of arbitrary complexity can be created with OPC UA since an object node may contain other variables, objects, methods and so on. In other words, the OPC UA address space is the information model for the communication: real hardware devices or real software "objects" (sensors, actuators, software applications, etc.) are available for OPC UA communication only if they are modelled, added to the address space and finally discovered by the OPC UA clients (Ferrari et al., 2018).

This protocol offers great advantages, since it standardises access to information in the classic scenario of a company where machines from different manufacturers and with different hardware all work together. At the same time, a high-level protocol also allows us to abstract the representation in memory of the type of data we wish to access. For example, if we want to read a value of type double that usually occupies 32 bits, using a low-level protocol such as Modbus we would have to take care of reading two consecutive 16-bit registers and put the result together according to the coding used (big endian or little endian) and finally apply a conversion. The same operation carried out using OPC UA, on the other hand, is achieved by means of a single high-level request, which will then be split into several operations but in a completely transparent manner to the user.

Unfortunately, this technology is not always compatible with the PLC CPUs installed on machines, in which case the only available option is to use simpler protocols operating at a lower level.

Attribute	DataType	Description
NodeId	NodeId	Unique identifier of the node inside OPC UA server space
NodeClass	NodeClass	It describes the class of the node (eg. Object, Variable, Method)
BrowseName	QualifiedName	Allows clients to identify the node during the browsing of OPC UA server
DisplayName	LocalizedText	It contains the name to be used when showing the node in an interface with the translation based on locale
Description	LocalizedText	Optional attribute for node description
WriteMask	UInt32	Optional attribute that specifies which node attributes can be modified by clients
UserWriteMask	UInt32	Optional attribute that specifies which node attributes can be modified by the user currently connected to the server. The set must be a subset of the set specified in WriteMask

TABLE 3.1: A set of attributes common to all NodeClass.

Data representation

OPC UA introduces two basic concepts for information modelling: Node and Reference. A Node has a NodeClass that defines its purpose (e.g. instance, type, etc.). Attributes are used to describe a node. The set of attributes of a node is entirely determined by its NodeClass and cannot be extended. To model additional information about a node, it is necessary to use Properties. A list of attributes common to all NodeClasses is given in the table 3.1.

A Reference is a connection between two nodes. In practice, it is nothing more than a pointer to a node. A Reference cannot be accessed directly, it must be accessed indirectly by accessing the node that contains it. A Reference has no attributes or properties that distinguish it; instead, in order to establish the semantics of a Reference (i.e. how two nodes are connected) an OPC server can define ReferenceTypes, which are exposed in the address space as actual nodes, so that clients can access the relevant information. Custom ReferenceTypes support single inheritance and must have exactly one parent ReferenceType. In addition to the attributes common to all node types, a ReferenceType also has those listed in the table 3.2. In the event that

Attribute	DataType	Description
IsAbstract	Boolean	Determines whether the ReferenceType can be used to create references or whether it exists for the sole purpose of organizing the ReferenceType hierarchy
Symmetric	Boolean	Indicates whether the reference is symmetrical or not. A example of a symmetrical reference is sibling-of, while an asymmetric one is parent-of
InverseName	LocalizedText	Specifies the semantics of the reference in the reverse direction. For example, the InverseName of the parent-of reference could be son-of. It can only be valorized if the reference is asymmetric and must be valorized if it is not abstract

TABLE 3.2: A set of attributes for a node of ReferenceType.

additional characteristics are to be defined for an association between two nodes, the Reference is replaced by a Proxy, i.e. an object that references both nodes and contains the necessary properties.

Objects

Object class nodes are used to structure the address space. An object contains no attributes other than those common to all nodes, but the data it encloses is presented through the use of variables. An object can also be an EventNotifier, which a client can subscribe to in order to receive notifications regarding the occurrence of events. Objects are used to group variables, methods and other objects. Methods and variables are always part of at least one object and can only be called in the context of the object they belong to. Figure 3.2 shows an example of an object that contains objects, variables, methods and generates events.

Variables

A node of class Variable represents a variable of a certain type. A client can read and write the Value field of a variable, and can also request to be notified when its value changes. The table 3.3 shows the main attributes of nodes of type Variable.

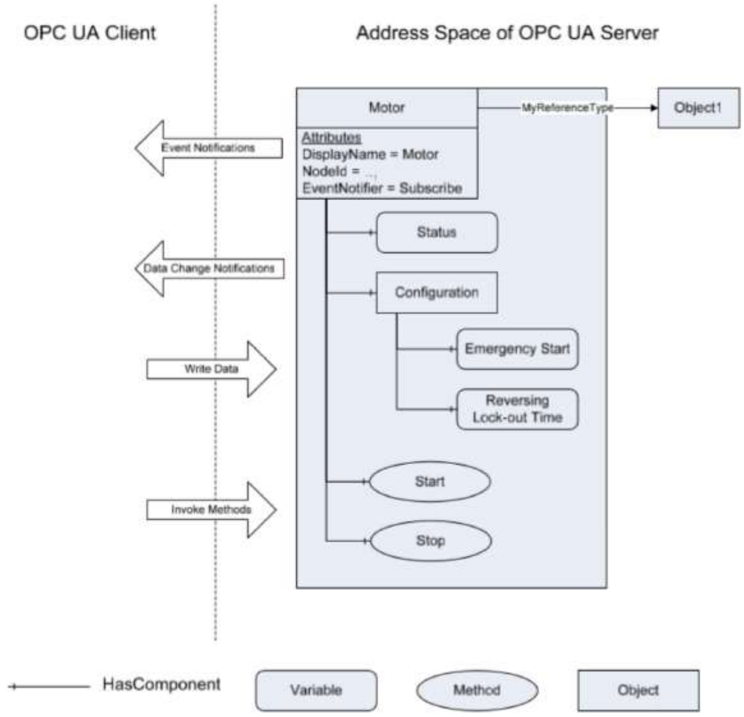


FIGURE 3.2: An example of the structure of an OPC UA object (Mahnke, Leitner, and Damm, 2009).

Attribute	**DataType**	**Description**
Value		The value of the variable
DataType	NodeId	The DataType is calculated from the combination of the DataType, ValueRank and ArrayDimensions attributes. Since DataTypes are represented as nodes, this field contains the NodeId of the DataType of the attribute
ValueRank	Int32	Determines whether the value is an array and, if so, allows you to specify its size (one-dimensional, two-dimensional, etc.)
ArrayDimensions	UInt32[]	Optional attribute that can be valued only if the value is an array. Indicates, for each dimension of the array, the number of elements contained

TABLE 3.3: A set of attributes for a node of class ReferenceType.

Property	DataType	Description
InputArguments	Argument[]	Optional property that defines the parameters of the method. If it is not valued, the method does not has input parameters
OutputArguments	Argument[]	As InputArguments but for the output of a method

TABLE 3.4: A set of properties for a node of class Method.

As can be deduced from the table, OPC UA natively supports multidimensional arrays. A client can read, write or subscribe to changes in an array or part of an array.

Methods

A node of class Method represents a method, i.e. an operation that must be executed relatively quickly. For procedures of long duration, initiated and controlled by the client, OPC UA uses the concept of a programme instead. Declaring a method in OPC UA means specifying its name and its InputArguments and OutputArguments properties, i.e. defining its signature, but not its implementation. The table 3.4 shows the main attributes of nodes of type Method.

3.2.2 Modbus TCP/IP

Data communication protocol was created for digital monitoring of industrial machinery with Programmable Logic Controllers (PLCs) from the same manufacturer, Modicon - today Schneider Electric, in 1979. Positioned at the application level of the OSI model, in its serial version it switched from EIA/TIA RS-232 to RS-485 communication to take advantage of the increased communication distance and reliability in electrically noisy environments, thus extending its adoption to manufacturing industries. In 2004 it was released to the Modbus Organisation, a non-profit association of device manufacturers and users implementing the protocol, which is charged with publishing the specifications free of charge, promoting adoption of the protocol and maintaining active development (*Modbus organization* n.d.).

Communication is of the request/reply type and is oriented towards the remote control and programming of compatible equipment. Specifically it is based on reading and writing registers that are named according to the function offered and are addressed with a 16bit number (65,535 positions):

- **Coils**: boolean memory locations (1bit) that can be written and read;
- **Discrete Inputs**: boolean memory locations (1bit) that can only be written by I/O peripherals and read by a master;
- **Holding Registers**: 16-bit memory locations that can be written and read;
- **Input Registers**: 16-bit memory locations that can only be written by I/O peripherals and read by a master;

Operations are expressed by a number in the range 1-127 and in addition to reading and writing describe special registers for diagnosis and references, leaving some free intervals for manufacturer-defined functions.

Several registers can be read in a single read request, in particular it is possible to set up a device to use a pair of contiguous 16bit addresses in order to use them together and have 32bit precision numbering. The transmission speed and reliability of modern networks, even over long distances (the specification for RS-485 recommends distances of less than 12m), led to the conception of a variant allowing encapsulation over TCP, replicating in full the behaviour described so far. This allows routing in modern Ethernet networks (IEEE 802.3) and addressing the various devices with IP. A packet (ADU) is then defined and implemented, which includes a specific header (MBAP), the functions, the payload itself, as well as an element for error checking. Two interlocutors are thus created, defined as client and server, and following those in the classic protocol, operational requests are expected to be made by the former, and then processed by the latter.

The exchange is carried out in four stages, as shown in fig. 3.3:

1. **Request**: the request is first made by the client who then initiates the transaction (identified by a number on 2 bytes);
2. **Indication**: it is the status of the server when interpreting the request just received;

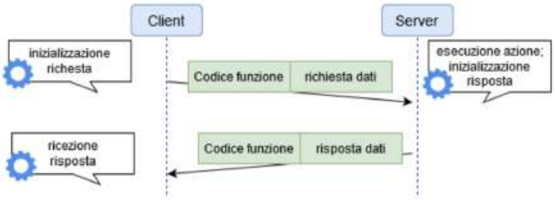


FIGURE 3.3: An example of the stack for a Modbus TCP request.

3. **Response**: you then send the message itself which takes this name;
4. **Confirmation**: the client then responds with a confirmation of receipt and closes the transaction.

Request and Response are accompanied by a specific code for the requested function, which may change in the return depending on the outcome. These codes include register access (read or write) and diagnostic functions. Some codes are shown in the table 3.5.

3.3 Implementation of a web API for industrial communication

The basis of our framework is the intention to be able to connect the industrial machinery with the software in use in the company. Therefore, we chose to implement a web API that can be queried both from the company network and from the outside, offering an interface for any application that needs to access the information offered by the 4.0 machines. What has been realised is a REST API that exposes methods for reading and writing data on the 4.0 machines installed in the company

Code	Operation	Register
01 (01h)	Read	Discrete Output Coil
02 (02h)	Read	Discrete Input Contacts
03 (03h)	Read	Analog Output Holding Registers
04 (04h)	Read	Analog Input Registers
05 (05h)	Write single	Discrete Output Coils
15 (0Fh)	Write multiple	Discrete Output Coils
06 (06h)	Write single	Analog Output Holding Registers
16 (10h)	Write multiple	Analog Output Holding Registers

TABLE 3.5: Main public function codes of a Modbus command

network. APIs, Application Programming Interface, are mechanisms that allow two software components to communicate with each other using a set of definitions and protocols. API architecture is generally explained in terms of client and server. The application that sends the request is called the client and the application that sends the response is called the server. The client sends requests to the server as data. The server uses this client input to initiate internal functions and returns the output data to the client. Nowadays, it is possible to implement a web API in many ways: SOAP, web socket, REST. In our case the choice falls on REST for its simplicity of implementation and immediacy. REST stands for "Representational State Transfer" and defines a series of functions such as GET, PUT, DELETE etc., which clients can use to access data from the server. Client and server exchange data via HTTP. The main feature of the REST API is statelessness. Statelessness means that servers do not save client data between requests. Each request is processed individually and the communication channel is interrupted with the response. Unlike a web socket, no further data can be sent to the client after the response. Requests from the client are made to the server by means of URLs similar to those entered into a browser to visit a website, the response from the server is simple data encoded using the JSON format.

After the definition of the communication protocols with the machines and the type of service to be implemented to access this data, it was decided to use Python to implement the server software that has the task of exposing two end-points, one for reading and one for writing, of data and variables on the industrial machines.

Three libraries were used for the implementation of this service, which fulfil the main tasks: the connection to the machines by means of the OPC UA protocol, the connection to the Modbus TCP/IP protocol and the realisation of the REST API.

- **opcua-asyncio**[1]: is an asyncio-based asynchronous OPC UA client and server based on python-opcua;
- **pyModbusTCP**[2]: this library give access to modbus/TCP server through the ModbusClient object;

[1] opcua-asyncio project website: `https://github.com/FreeOpcUa/opcua-asyncio`
[2] pyModbusTCP project website: `https://github.com/sourceperl/pyModbusTCP`

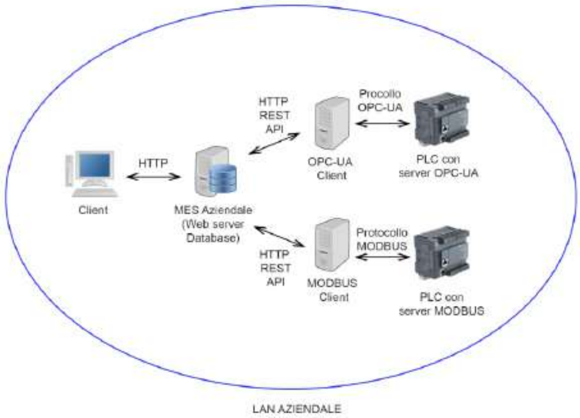


FIGURE 3.4: An example of the network configuration for the framework.

- **Flask**[3]: is a popular Python framework for web application development. It comes with built-in functionality and minimum requirements, making it easy to get started and flexible to use.

The network configuration diagram shown in fig. 3.4 is an example of possible configuration of our framework for interconnection. A client who wants to use an MES-type application from his workstation makes a request to a server where the application resides. The MES to obtain the information of the machines necessary to process the request will make calls to two services also exposed on the company network. Each service takes care of the connection with the machines using one of the two protocols seen above. Having obtained the necessary data, the MES will be able to process the content and respond to the client that made the request.

To make the architecture more flexible, the two services, OPC UA and Modbus, are started up separately. In case one of the two is not needed, it may also not be started.

We will now analyse in detail the type of requests and the parameters that are sent to each of the two services.

3.3.1 OPC UA service

The service is built using Flask as the basis for implementing a minimalist web application. This service exposes two end-points that take care of reading and writing

[3]Flask website: https://flask.palletsprojects.com/en/2.2.x/

variables to machines where an OPC UA server is available. The connection to the machines is made using the opcua-asyncio client library.

Reading

The end-point for reading data is exposed using GET requests at the following address:

GET */api/resource/node/get*

To make a request, the following parameters must be specified:

Name	Data type	Description
ip	string	IP address of the OPC UA server
port	integer	Port of the OPC UA server
user	string	Username for an OPC UA server that require login (Optional)
pwd	string	Password of the user (Optional)
address	string	Address of the variable to read
type	string	This can be *word* in order to obtain a conversion from an integer value to a binary representation

If the request is carried out correctly, we will obtain a reply in JSON format with status code 200 and the value of the variable we wanted to read. In the case an error is generated during the request, which could be caused by the wrong input of the parameters, we will get a JSON response with the error code and description. Some error codes are shown in the table 3.6. Other server errors are handled using a return status code with the value 500, the HTTP status code for a generic error response. This means that the server encountered an unexpected condition that prevented it from fulfilling the request.

Error code	Description	Motivation
1	Bad request	Some mandatory parameter is missing or format is wrong
11	Server not found	IP address or port is wrong or OPC UA server is offline
12	Authentication failed	Wrong username or password
13	Node not found	Wrong address for the variable
14	Access failed	The variable is not readable (or writable, in the case of setting a value)
21	General error	General error during the acquisition of the data from the machine

TABLE 3.6: Error codes returned from OPC UA service.

Writing

The end-point for writing data is exposed using POST-type requests to the following address:

POST */api/resource/node/set*

To make a request, the following parameters must be specified as the body of the request, using JSON encoding:

Name	Data type	Description
ip	string	IP address of the OPC UA server
port	integer	Port of the OPC UA server
user	string	Username for an OPC UA server that require login (Optional)
pwd	string	Password of the user (Optional)
address	string	Address of the variable to write
type	string	Data type of value of variable to write. Allowed type are: boolean, integer16 (16 bit), integer (32 bit), float, string
value	mixed	Value to write

If the request is carried out correctly, we will obtain a reply in JSON format with status code 200 with the value of the variable read immediately after the write, to verify that the value has been updated correctly. In the case where an error was generated during the request, which could be caused by incorrect parameter insertion, we will get a JSON response with the error code and description as in the case of reading (see error table 3.6). Again, other server errors are handled using a return status code with the value 500.

3.3.2 Modbus service

The Modbus service will be used to communicate with all those machines that do not have an OPC UA server for data exchange. Again, Flask was used to implement a web service that will resolve the various requests sent by the clients. The service exposes two end-points, for reading and writing data to machines exposing a Modbus TCP server. The connection to the machines is made using the pyModbusTCP client library.

Reading

The end-point for reading data is exposed using GET requests at the following address:

GET */api/resource/node/get*

To make a request, the following parameters must be specified:

Name	**Data type**	**Description**
ip	string	IP address of the Modbus TCP server
port	integer	Port of the Modbus TCP server
register	string	Name of the register to read. Accepted values are: *coil*, *input register*, *holding register*
address	integer	Address of the memory location to read
type	string	Type of the data to read. This is used in order to know how many memory location read and which data conversion apply. Accepted values are: *word*, *integer*, *integer32*, *float*. The parameter is mandatory if register is *input register* or *holding register*
endian	string	Type of encoding, options are: *little endian*, *big endian*. The parameter is mandatory for 32bit data types such as *integer32* and *float*

If the request is carried out correctly we will obtain a reply in JSON format with status code 200 with the value of the variable we want to read. In the case where an error was generated during the request, which could be caused by the incorrect insertion of the parameters, we will obtain a JSON reply with the error code and description, some error codes are shown in the table 3.7. Other server errors are handled using a return status code with the value 500.

Writing

The end-point for writing data is exposed using POST-type requests to the following address:

POST */api/resource/node/set*

To make a request, the following parameters must be specified as the body of the request, using JSON encoding:

Name	**Data type**	**Description**
ip	string	IP address of the OPC UA server
port	integer	Port of the OPC UA server
register	string	Name of the register to write. Accepted values are: *coil*, *holding register*
address	integer	Address of the memory location to write
type	string	Type of the data to write. This is used in order to know how many memory location write and which data conversion apply. Accepted values are: *word*, *integer*, *integer32*, *float*. The parameter is mandatory if register is *holding register*
endian	string	Type of encoding, options are: *little endian*, *big endian*. The parameter is mandatory for 32bit data types such as *integer32* and *float*
value	mixed	This can be *word* Value to write

In the case in which the request is carried out correctly we will obtain a reply in JSON format with status code 200 with the value of the variable read immediately after the write, to verify that the value has been updated correctly. In the event that an error was generated during the request, which could be caused by incorrect parameter input, we will obtain a JSON response with the error code and description as in the case of reading (see error table 3.7). Other server errors are handled using a return status code with the value 500.

Error code	Description	Motivation
1	Bad request	Some mandatory parameter is missing or format is wrong
11	Server not found	IP address or port is wrong or Modbus TCP server is offline
14	Access failed	The variable is not readable (or writable, in the case of setting a value)
21	General error	General error during the acquisition of the data from the machine

TABLE 3.7: Error codes returned from Modbus service.

3.4 Case studies

In this section we will illustrate two case studies where the proposed framework for bidirectional interconnection with machinery 4.0 has been used. In addition, we will describe how smart machinery was used inside the production process and integrated with software already in use in companies or specially developed.

3.4.1 L'Antincendio

The first case study concerns the benefits of industry 4.0 applied to process compliance in the sector of safety and fire prevention conducted with the company L'Antincendio S.r.l., based in Matera (Italy). The company is specialized in the fire prevention sector, thanks to the installation and subsequent maintenance of systems and devices for fire prevention. The maintenance of fire prevention products is one of the most important activity of the company, and if this activity is not optimized and managed correctly, it can become very onerous with risks on the related regulatory compliance.

The company put a lot of effort and resources to innovation of its products. To continuously monitor devices, the company has conceived, designed and patented an IoT system using QR code technology and cloud application to monitor all the installed devices in a simple and intuitive way and to carry out routine verification operations. By logging in with his credentials, each customer is able to access all the devices installed in his facilities very quickly. He can also check their status and

FIGURE 3.5: Device home page of the cloud application for customer (In Italian language).

obtain information on the history of the maintenance carried out (Santarcangelo et al., 2018) as shown in fig. 3.5.

The web application obtains the updated data on safety devices and maintenance carried out on them from the software EuGenio[4], a stand-alone software for Microsoft Windows developed by CEA Estintori, that is widely used in this sector. The EuGenio's data are stored in a Microsoft SQL server, so a routine every day export the new data from EuGenio database to the cloud application MySQL database.

Using the cloud applications, customers can access many important information about the security device owned such as: technical sheet, ledger of maintenances, upcoming deadlines. Moreover, customers can have a direct line with the company to report anomalies of the device or evaluate the services. This data are available for CRM (Customer Relationship Management) software.

With the aim of offering a superior quality service to its customers, the company has equipped itself with a new machinery (fig. 3.6) compatible with the requirements of industry 4.0 that give them the possibility to certify the maintenance process in an anti-elusive way.

[4]EuGenio web page: https://www.ceaestintori.it/it/eugenio-il-software-le-manutenzioni-periodiche

FIGURE 3.6: A picture of the new machinery for the maintenances of the powder extinguishers.

Description of the machinery and proposed solution

The MAS 4.0 system[5] allows the filling of portable and wheeled powder extinguishers from 1 to 100 kg capacity with filling speed of 1Kg/sec. equipped with dual filling programs, fast and slow for maximum filling accuracy on any type of tank. It comes with a set of sensors that make it capable of accurately measuring the amount of powder released. For this reason, a tailor-made module has been developed and modelled according to the company workflow and the data available at the machine.

The scope of this new module allows a maintenance technician, after logging in with their credentials, to start the maintenance process of a particular kind of fire extinguishers after a dialog with the 4.0 refill station. There are two moment during when we want to exchange information with the machinery. At the beginning we want to setup the correct recipe, based on the model and weight of the fire extinguisher. At the end of the process we want to check the real amount of powder was released.

The MAS 4.0 system is connected to the company network and is able to communicate using an OPC UA server available on the Siemens S7-1500 PLC that is the heart of the system. It communicates all the results of the operations carried out by means of a PLC, providing a set of very important parameters, such as the number of

[5] AESSE Impianti MAS 4.0: https://www.aesseimpianti.com/mas-4-0/

FIGURE 3.7: A screen took for MAS 4.0 HMI where is possible to see the recipes, configuration and alerts.

kg of powder dispensed during the last reloading operation (fig. 3.7). These parameters are acquired and stored in a database, together with the timestamps associated with each single operation performed by the machine in order to certify the refilling process and give to the customer an high quality services.

The new module is available as web application and it is developed using Symfony PHP framework and MySQL database as back-end, the interface of the web application is developed using HTML5, CSS and Javascript. The Apache web server and MySQL database are running on a virtual machine with Windows 7 Server edition. In the same machine the OPC UA service is running to at port 5000 and it acts as bridge between the MAS 4.0 OPC UA server and the web application. Operator can connect to the web application using a common smartphone and WiFi connection to the local network where the server is running.

The workflow of refill operation is summarized below:

1. Operator login in the web application;
2. Scan QR code of fire extinguisher and start a maintenance;
3. The system check if the refiling station is available and set the recipe based on the model of the fire extinguisher;
4. Operator refill the fire extinguisher at the station;

5. Using the web application operator end the maintenance, system get the last operation on the refilling station and it checks if the operation has been correctly executed. If yes the maintenance mode ends and result is store on the database.

First of all, the operator will frame the QR code placed on the device that will allow him to connect to the object of the IoT network. Once connected, it will be possible to obtain some basic information about the device, such as: unique identifier, description, serial number, year of production, type of device; and it will be possible to start the refilling process using the 4.0 filling station (fig. 3.8).

After correctly selecting the product by means of the QR code and verifying the connection with the 4.0 machine, the operator can press the "Start maintenance" button to start the charging process. In the event that the 4.0 machinery is offline, the operator will not be shown the start maintenance button and consequently it is not possible to carry out maintenance operations.

After reloading the fire extinguisher using the machine, the operator can return to the application and send the result using one of the two buttons. In the event that the operator selects the "Complete maintenance" button, the software connects

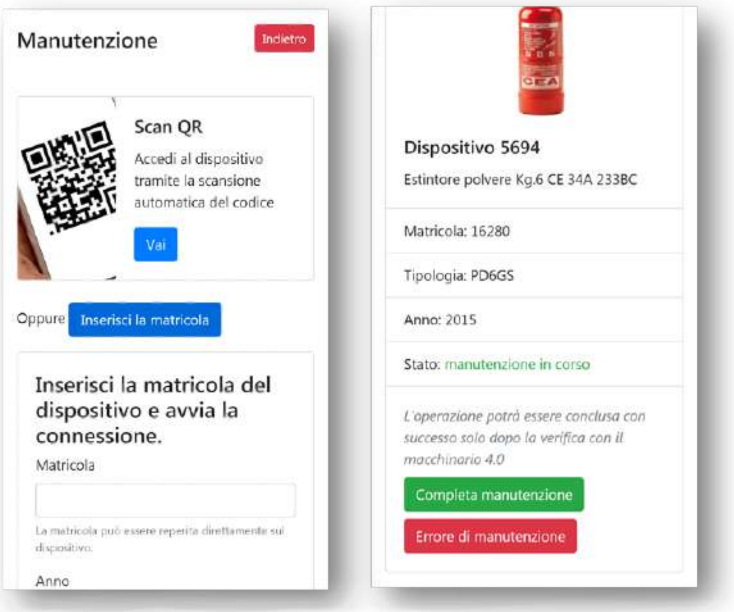


FIGURE 3.8: On the left the main screen of the maintenance workers web application where is possible to connect a security device; on the right the section dedicated to device main screen is showed, from this section on possible to start and the maintance process.

to the 4.0 machine and queries the register of operations carried out by crossing the data relating to the timestamps, the type of operation selected on the machine and the amount of powder actually dispensed. Only if all these parameters are compatible with the device on which we started the maintenance, the operation will be completed and saved in the company database. If the parameters are not verified, for example a fire extinguisher with a capacity of 9kg has been reloaded using only 6kg of powder, an error message is shown to the maintenance technician and it will be impossible to complete the operation and therefore the subsequent registration in the company systems.

The use of the 4.0 machinery has been integrated into the maintenance processes of company safety devices thanks to the use of a QR code that allows you to identify the exact product with its initial state, carry out maintenance operations through the machine, record the activity carried out verified in compliance and prepare the delivery plan of the device ready for return to the customer. The activity information is recorded in the system and is accessible in a simple and transparent way to the customers through the cloud application accessible from the same QR code of the device.

Thanks to the interconnection of the machinery and the app it will therefore be possible to certify automatically and in an anti-elusive way that the recharging operation actually took place in that declared time range and that the right quantity of kg of powder has been dispensed based on the type of fire extinguisher on which maintenance is being carried out.

3.4.2 Derado

In this section we will analyse the case study of Derado S.r.l., a company that operates in the distribution of frozen food in Matera (Italy). The treatment of food products forces the company to respect high standards of safety and certification of the process phases. Frozen products are subjected to a freezing process to bring the temperature down to -18 °C or, in some cases to even lower temperatures. Once it is frozen, the product must be transported using appropriate means and techniques to preserve its quality. This is where the “Cold Chain” comes in. The purpose of the cold chain is to preserve the product in the best possible way, to guarantee its integrity, hygiene standards and food safety. It is in the interest of all operators, i.e. producers, transporters and distributors, to guarantee the quality of the product and thus respect the cold chain. For this reason, each of them is called upon to follow the current regulations and to use the tools at their disposal to check that the procedures are carried out correctly.

One of the most important steps in maintaining the cold chain is certainly the moving of products from the distributor's cold storage to the end seller's cold storage. During this phase, the products leave the distributor's cold store and are loaded onto appropriately refrigerated vehicles. Product loading operations are therefore the ones exposed to the greatest risk with regard to the integrity of the cold chain. In our research we consider three main areas of the factory, that are different for functionality and temperature. The cold rooms, where the products are stored at temperature of -28°C. Shipment room, the area where pallets full of frozen product wait until can be loaded on the refrigerate vehicles at a temperature between 0 and 4 °C. Both cold and shipment rooms are contiguous and located on the ground floor. Outside of the factory, at -1 floor, there is the loading area for outgoing goods. This is the area where vehicles are loaded by the driver. The loading area is not equipped with any cooling system and it is at ambient temperature. To preserve the quality of the frozen products, it is necessary that the loading of a pallet takes place in the shortest possible time and especially that no more than one pallet to be loaded per driver is send.

The company already makes use of two key software for the production process. One software is the ERP (Enterprise Resource Planning), which manages major daily activities such as product management, order gathering, and invoicing. The second software is the WMS (Warehouse Management System), which is used to control, coordinate, and optimize the movements, processes, and operational steps that take place within the cold storage rooms. In particular, it deals with the allocation of goods within the cold rooms according to type, characteristics, and size. Finally, the WMS is also entrusted with the management of outgoing goods: including coordinating order preparation operations, picking carried out by operators in the cold room, pallet assembly, and dispatch to the shipping area. Unfortunately, the WMS used by the company does not provide IT support for loading products onto vehicles, so it was decided to design and implement a software customized to the company's needs.

The two areas are connected by pallet handling system equipped with a descender/elevator that allows pallets to be moved from the shipping area to the loading area at floor -1. To ensure better control over the loading operations and minimise the time that frozen products are exposed to higher temperatures, the company has interconnected the pallet handling system to the company's information system, integrating it into the logic of the new IT system that manages the loading operations. Through this connection it was possible to add a smart functionality that allow the device to send a pallet to the loading area only when a series of conditions are satisfied.

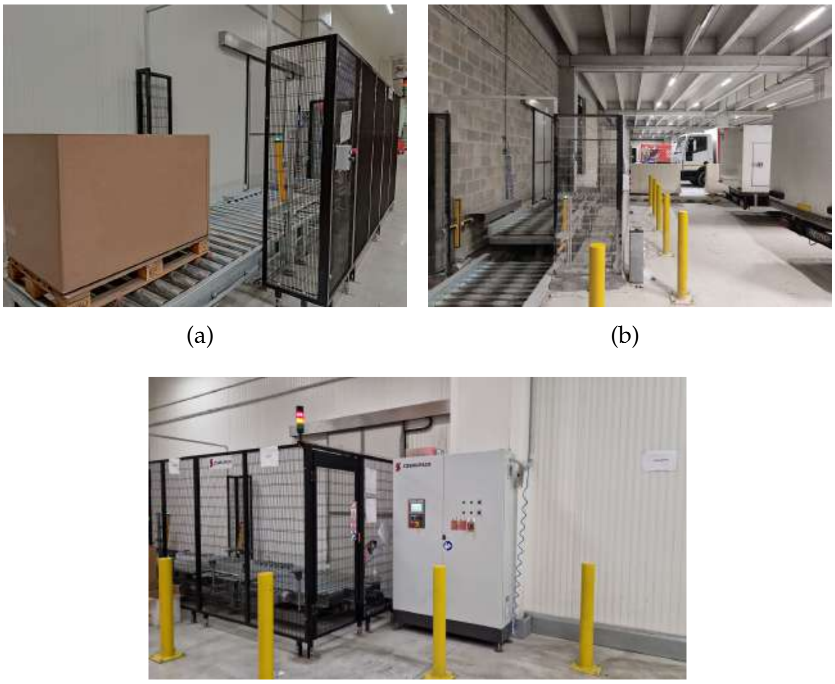
Description of the machinery and proposed solution

The pallet handling system, manufactured by Cosmapack[6], consists of two roller conveyors, one installed on the ground floor and one on the lower floor, connected to a column where a lift is installed. At the ends of the roller conveyors are two loading/unloading points where pallets are placed/picked up using a pallet truck. The roller conveyors are logically divided into stations, we have 3 stations on the upper floor and 4 stations on the lower floor. Each station is equipped with presence sensors that can detect the transition of pallets from one station to another. The whole system is controlled by an Omicron CJ2M PLC on which there is a Modbus TCP/IP server for data exchange.

The PLC allows us to access the following information for each station (PS1, PS2, PS3 on the upper floor and PI4, PI3, PI2, PI1 on the lower floor) in read mode:

- Pallet presence: the memory location will be valued with 1 if the station contains a pallet, 0 otherwise;
- Pallet ID: the memory location will be valued with the pallet ID (32bit integer) in case a pallet is present, 0 otherwise.

[6]Cosmapack website: https://www.cosmapack.it/



(a) (b)

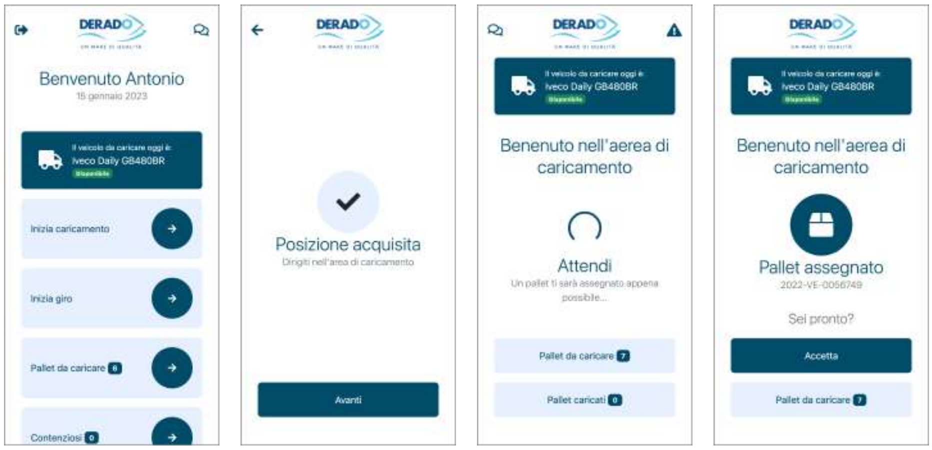
(c)

FIGURE 3.9: roller conveyor at shipping area (a); roller conveyor at loading area (b); wiring cabinet with PLC and HMI (c).

In addition, we have the ability to write to a memory location the ID of the pallet placed on the loading station on the upper floor. The machinery has been configured in such a way that it cannot move a pallet until the memory location is written with the pallet ID that is to be sent. This condition is necessary to prevent pallets from being sent to the lower floor unsupervised.

To meet the requirement of integration with the information system, cloud-based software, called IceTrack, was developed with the aim of organizing, managing and

FIGURE 3.10: State of the pallet moving system from the HMI. PS1, PS2 and PS3 are the upper floor stations. The lift position is represented with a value between 0 and 6895. PI4, PI3, PI2 PI1 are the lower floor stations.



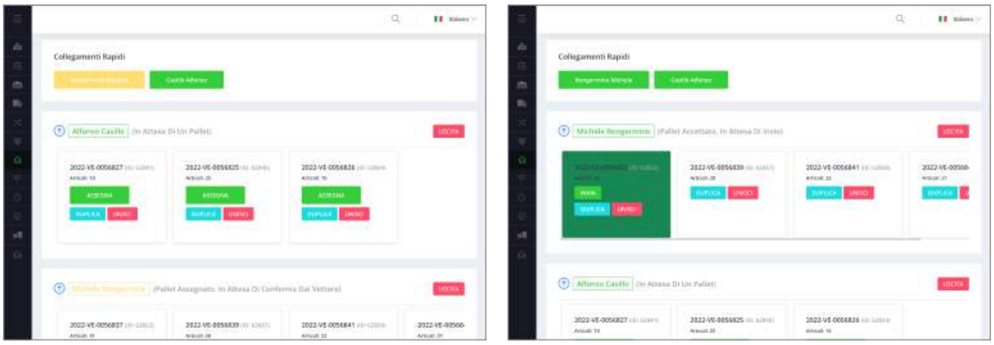
(a) (b) (c) (d)

FIGURE 3.11: IceTrack main menu (a); Entering to the loading area (b); A worker is waiting for a pallet (c); A pallet was assigned and must be accepted (d).

collecting data on the loading phase, where products are loaded into refrigerated vehicles. The machinery is installed on the company's local network. On the same network a server is installed on which the Modbus service, previously described, is running. Because IceTrack software runs in an external cloud, it was necessary to configure a port forwarding rule on the corporate firewall that allows us to publicly expose service API end-points over the Internet. For additional security, the firewall is configured to accept incoming connections only from a set of predefined IP addresses.

Each day the orders received from the ERP system are transmitted to the warehouse through the WMS, which is responsible for grouping the orders according to the goods to be picked and shipped. Each time a pick list is created by the WMS it will be associated with the carrier who will load it onto the vehicle and make delivery the next day. When a warehouseman picks the goods from the cold rooms and assembles the pallet the picking mission is fulfilled. When the mission is processed, a pallet with information about the items and the carrier is communicated to IceTrack.

Starting from the afternoon, carriers returning from deliveries must enter the loading zone to start the afternoon session, where vehicles are loaded with new products to be delivered the next day. Each driver, equipped with a smartphone, login to the application (fig. 3.11(a)) and communicates their entry into the loading



(a) (b)

FIGURE 3.12: IceTrack for warehouse. A pallet can be assigned (a); A pallet was accepted and is ready to send (b).

zone to the system (fig. 3.11(b)). When this is done, the carrier starts waiting for a pallet (fig. 3.11(c)). On the upper floor, the personnel in charge of product dispatch login to the system and perform operations related to their role by using a tablet. Operators working at the descender are able to see in their screen all the carriers who have accessed the loading area and for each of them the list of pallets ready to be sent to the lower floor.

Before actually sending pallets, the person operating at the descender performs a pre-assignment of the pallets to waiting drivers (fig. 3.12(a)), who receive a notification on their devices. Only when a driver accepts the assigned pallet and he/she sends a confirmation the pallet changes status and becomes ready for dispatch (fig. 3.11(d)). This step is important to prevent a pallet sent to the lower floor from not being picked up because the driver is distracted by other activities.

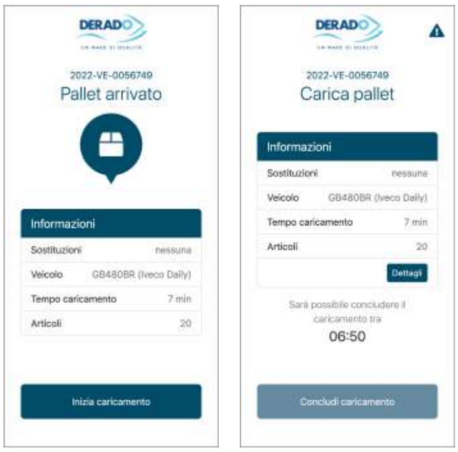
Through its screen the operator on the upper floor can see which pallets have been accepted and are ready to be sent. Once the pallet to be sent has been identified it will be moved from the location where it was stored and loaded onto the roller conveyor. After this operation the operator will return to his/her application and send the pallet via the button shown on the screen (fig. 3.12(b)). At this point the application will query the machinery to receive confirmation that the pallet has been placed on the roller conveyor, and if successful it will write the pallet ID to the start position. At this point the operator can start the conveyor system by pressing the start button next to the roller conveyor.

During pallets handling, the machinery control system will constantly update

FIGURE 3.13: Monitors installed in the loading area where delivery staff can see which pallets are traveling on the roller conveyor.

information about each station of the roller conveyor which allows us to know in real time the position of each pallet. The data read from the PLC are used to show in real-time information about the roller conveyor on the lower floor via a monitor installed in the loading area (fig. 3.13).

When a pallet reaches the picking station it can be picked up by the driver and its ID will be removed from the machine. Finally, the driver through his application can start the loading (fig. 3.14(a)). The loading operation has a predetermined minimum duration depending on the pallet weight and the number of items that are communicated by the WMS, the minimum times are: 3, 5, 7 minutes. Before this time, the driver cannot finish the loading operation and return to the waiting state (fig. 3.14(b)). To prevent the driver from starting the loading operation before the pallet is actually picked up a control is performed on all the IDs of the pallets that are traveling on the roller conveyor, in case it is still traveling the start of loading operation will generate an error.



(a) (b)

FIGURE 3.14: A pallet is arrived and can be loaded (a); Loading operation in progress (b).

Chapter 4

Cultural Heritage and Digitization for museums

4.1 Cultural Heritage in the Digital Era

In a broad sense, Cultural Heritage is both a process and a product. In its core, it is the cultural legacy inherited from the past, experienced in the present and passed down for the benefit of future generations. It includes not only tangible heritage, but also natural and intangible ones. In all its forms, cultural heritage needs policies and development models that not only could be able to respect and preserve its diversity, but also to provide tools for a continuous innovation of its promotion in the territory.

Cultural heritage is the cultural capital of our societies. It represents their diversities and identities, generating a continuous valorization of both. It also provides inspirations for creativity and innovation by transmitting expertise, skills and knowledge from the past which could be reinvented and reused in our present. Last but not least, it generates a great economic income, because of its link with the tourist sector, and it fosters access to and enjoyment of cultural diversity. For all these reasons and their importance, a proper management of cultural heritage requires approaches that focuses on sustainability, which could guarantee a right balance between benefiting from cultural heritage today and preserving it for future generations.

In this panorama, digital technologies provide the best opportunity to preserve cultural heritage and to make it more accessible to all audiences. Indeed, cultural organizations and museums that embrace technology can create innovative experiences for visitors and users, as well as let the public have a remote access to exhibitions.

In the past years, many applications designed for museums, and more in general for cultural heritage, were developed. In (Amato et al., 2013; Chianese et al., 2013) authors show some case studies of a smart guide for art exhibitions where visitors who use this application can get information about the artefacts nearby. In (Bonacini, 2015) authors describe the use of Google Business Photos/Street View Indoor, to map the entire museum and give the possibility to the users to virtually visit the place. In (Allegra et al., 2018), the authors propose a robotic museum guide to assist visitors.

In the last decades, most of the musealization processes took the advantage of 3D modelling and scanning. In (Alberghina et al., 2017), Morgantina Silver Treasure is acquired and analysed; then, 3D models and analysis results are made available through an ad-hoc web platform. In (Stanco et al., 2017), the authors conduct a study about Kouros of Lentinoi and propose a web application to make it accessible to the users. Other applications are developed to get benefits from augmented reality (AR), where users are able to interact with ancient artefacts, digitized through the use of 3d, with mobile devices. Using AR for Cultural Heritage education generates a positive impact on motivation for topics related to art, history, the sciences, etc. AR can be applied in formal environments like classrooms and informal environments such as museums, parks, archeological sites, cultural heritage sites, and so forth. In (González Vargas et al., 2020), it was observed that the use of this technology allows information that is relevant to a student to be complemented, and it improves the student's learning experience in topics related to Cultural Heritage studies.

3D models are a key resource for preservation, study and presentation. By combining the results of this technology with other concepts such as serious games, it is possible to achieve highly engaging user experiences. In (Smith, Walford, and Jimenez-Bescos, 2019) authors show how it was possible to reconstruct a site from plans and its transfer into four game engines in order to construct a system for independent navigation around the virtual building. This approach is at the base for a development of a serious game with a consistent historical setting. Game-based learning and in general, serious games, represent an attempt in contributing to the preservation of both tangible and intangible Cultural Heritage by raising awareness of its importance. They are an attempt to bring cultural heritage closer to a younger user population through interesting, interactive and educational content (Ćosović and Brkić, 2020).

The importance of this process of transformation has emerged with even greater prominence following the pandemic emergency caused by the spreading of SARSCov-2 virus. Over the last three years, society has had to reinterpret many aspects of daily life such as travels, work in the offices, entertainment, and cultural events. A deep reorganization was needed, and the concepts of digitization became a key factors in that process. The school system transferred education from face-to-face into remote teaching, while companies in the business world had to quickly find solutions to allow employees to access all the work resources from home.

The same overwhelming phenomenon affected the world of Cultural Heritage and the industry of museums. From an analysis conducted on the trends of Google searches, we can notice how the period during the first lockdown corresponds to an increase in Google searches related to museums and digital access as shown in fig. 4.1. This burdened especially university museums, because they strictly depend on the activity of universities, but these institutions were closed for almost one year. Furthermore, museums, particularly those belonging to universities and those regarding scientific contents, are not only places for education and entertainment, but also centres of research. Their collections are used for training students in the field of scientific investigations and are object of new research topics or projects. Thus, during the pandemic arose the necessity to find a way to continue these activities even with museums being closes. And again, this has been obtained thanks to the digital method, all over the world.

Fortunately, the transition to the digital method in Cultural Heritage began many years before the pandemic caused by Covid-19, although the crisis generated as a result of the epidemic accelerated the transformation process. In recent years, most digitization processes have exploited digital techniques such as 3D modeling, Augmented Reality (AR), Virtual Reality (VR), and the development of digital platforms to create new tools for Cultural Heritage as we have seen in the previous paragraphs.

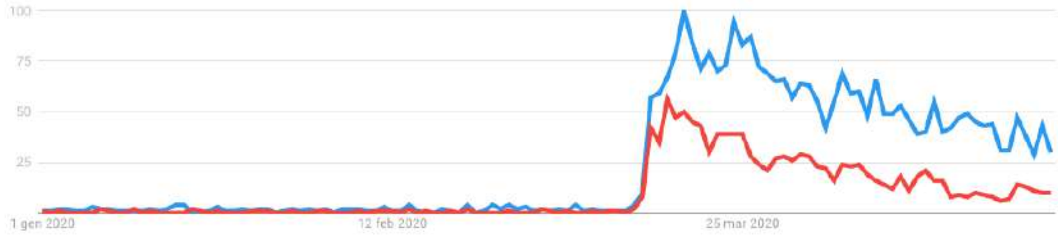


FIGURE 4.1: The growth of the number of google searches for ”museum virtual tour” (in blue) and ”virtual museum” (in red) from 01/01/2020 to 01/05/2020 exacted from Google Trends.

Following these premises, in this chapter we will describe three different digital tools that have been implemented for Museums of the University of Catania in order to respond to the necessity of preserving their cultural heritage and making its fruition easier, as well as available online. These three tools are related with three different digital concepts:

- a web application interacting with a database which could offer the visitors two different ways of exploring the museum collection. This was called I-PETER: Interactive Platform to Experience Tours and Education on the Rocks and it was implemented for the Museum of Mineralogy, Petrography and Volcanology of the University of Catania.
- a serious game for the dissemination of mineralogic and petrographic science, which can allow a player to learn how to use a petrographic microscope, recognise a rock by analysing the single minerals that constitute it and, therefore, identify the rock itself.
- a digital twin for the Foucault pendulum experiment installed at Città della Scienza that make possible at any time to check the status of the experiment even out of the building of the museum by a web application connected with the physical device.

4.2 Web application: a tool for interaction with museums and its collections

By now, mobile applications play a key-role in daily human activities, since they allow to easily access services related to multiple domains such as communication, gaming, assistance, job and so on. Moreover, in the last decade, the wide spreading of mobile devices, affected by the low cost and the relative ease-of-use, led most of the people to use such devices as the main mean to access internet and digital services. We use mobile applications for many different purposes: reading newspapers, online shopping, social networking and so on, and most of these services have features like tagging, comments, reviewing systems, etc. that permit to establish a bidirectional connection with other users or products we are interested in. For this reason, we decided to explore this area with the intention of bringing these features into the digital visit of a museum.

In this section, we discuss how with the Museum of Mineralogy, Petrography and Volcanology of the Department of Biological, Geological and Environmental Sciences of the University of Catania, we developed a new interactive system in order to facilitate the diffusion of its cultural contents towards a broader range of visitors, of different ages, countries and cultural background. Although the principle is not new, the innovation can be find in realisation modality. The fundamental principle of our approach is to make the visitor at the centre of the visit (Hein, 2002). He/she/they will experience actively the visit as main actor, having the possibility to customise the tour and internalise the multitude and fascinating aspects of the geological world. The total accessibility is furthermore guaranteed by the difficulty level options that the visitor can choose, together with the preferred language. The idea is to give to all users, regardless of their educational level, the possibility to learn by playing.

Using these guidelines we developed an interactive application called I-PETER (Interactive Platform to Experience Tours and Education on the Rocks). The application, available at `http://iplab.dmi.unict.it/ipeter`, consists of a virtual system for the understanding and the dissemination of mineralogical-petrographic science, based on the new methodological approach of the visitors' personal experience.

At this stage, our platform, shows some representative samples of the museum linked with some important monuments in Catania. The museum, thanks to this pilot project, will be able to guarantee the accessibility to scientific knowledge and its methodological approach to everybody, promoting cultural tourism and increasing the city's cultural awareness.

Thanks to these new functionalities I-PETER can cover all the aspects that pivot around a visit to the museum: visitors can enjoy a tool for a digital approach to scientific collections, researchers can have a public access to structured and well-organised information in mineralogy, petrography and heritage sciences, and finally museum staff can benefit from a novel tool for data analytics.

4.2.1 The history of the museum and its collections

Today's Museum of Mineralogy, Petrography and Volcanology was inaugurated on the 21 October 1949 after the reorganisation carried out by the Director Professor Salvo Di Franco. The collections, indeed, have undergone numerous movements among different locations and suffered serious damages because of the Second World War. The history of the collections is marked by the activities of the Institutes that hosted them and the various relocations that have caused the unfortunate deterioration of some minerals and rocks with the partial loss of the tags provided.

In 1781 the famous naturalist and volcanologist Giuseppe Gioeni donated to the University of Catania precious collections of minerals and rocks from Monte Etna, as well as fossils of Sicilian origin. Thanks to this donation, in the same year, the Museum of Natural History was established, whose chair was assigned to Gioeni himself. In 1841, the University of Catania acquired 5,984 specimens from the collections of "natural productions" of land and sea origin, previously stored since 1779 in the "house-museum" of Giuseppe Gioeni (Finocchiaro and Alberghina, 2007). Few years later, in 1844, consequently to these acquisitions, the naturalist and volcanologist Carlo Gemmellaro, the former director of the Museum of Natural History, ordered the acquisition of 6,000 labels, some of which are still present at the museum.

With the annexation to the Kingdom of Italy in 1864, Carlo Gemmellaro bought the *"Collezione di rocce di tutti i terreni della crosta del Globo"*, from the Comptoir de

Mineraux of Heidelberg, which consists of as many as 910 specimens, classified according to the Leonhard System (Finocchiaro and Alberghina, 2007).

In 1872 the museum was divided into:

1. Mineralogy and Geology Museums, where terrestrial natural productions were exhibited;

2. Museum of Zoology, where the marine productions were exhibited.

Professor Lorenzo Bucca, during his direction at the Institute of Mineralogy, took care of ordering the mineralogical, petrographic and palaeontological collections, beside bringing together in a single collection those of Giuseppe Gioeni and Carlo Gemmellaro. This collection was enriched even more by some other acquisitions of samples of local and foreign provenance. In 1919 the Higher Council of Public Education founded in Catania the first chair of Volcanology, which was assigned to Professor Gaetano Ponte, who was able in a short time to set up important and rich collections of volcanic rocks and minerals from the Hyblean area, Etna and Aeolian Islands.

In 1999 the collections of Mineralogy, Petrography and Volcanology, after various movements, have been reorganised in the current disposition, in the Museum of Mineralogy, Petrography and Volcanology, inaugurated as said before in 1949.

The samples are today exposed in the following sections:

- General section of Mineralogy, including minerals and native elements, with a focus on pigments;

- General section of Petrography, constituted by sedimentary (e.g., clastic, chemical, biochemical origin), magmatic (effusive and intrusive) and metamorphic rocks;

- Mineralogical, petrographic and volcanologic section of Monte Etna, Aeolian Islands and Vesuvio;

- Collection of minerals from the Sicilian sulphur quarries;

- Collection of Marbles and Jaspers;

- Collection of Gems and Pearls;
- Collection of Archaeological artefacts

Due to the historical vicissitudes of the collections, it appeared necessary to verify the classification of all the samples stored. A verification is being carried out with regards to the definitions and the attributions of classes indicated in the inventory and/or in the tags provided. The analysis of the mineralogical and chemical compositions of the specimens is being performed, in order to confirm previous identifications, and to correctly reclassify mistaken attributions, if needed.

Since the museum doesn't have enough spaces, it has often been necessary to choose the materials to be exhibited. Currently, about 1,300 samples are exposed in the museum, while the other 500 are stored in the warehouse. Another focal point of this work is to make accessible to the community the whole cultural patrimony of the Department, that otherwise would remain unknown.

4.2.2 Web application development

Using the state-of-the-art technology (MySQL database, Apache server, PHP Framework, HTML5) we developed the proposed virtual system as a web-based application. Figure 4.2 shows the web architectural design of the proposed application through a block diagram. Using a web browser, a user can make a request, via the internet, to the web server that hosts the application. Since the developed application is a dynamic web site, after a user's request the web server makes a request to the database in order to get the dynamic content of the requested web page. After the web server receives all the data from the database, it is able to compose the web page using the application interface based on a responsive HTML template. Finally, the web browser receives all the source code of the requested page and it will display it to the user.

The choice of this architecture allowed us to enlarge the number of devices compatible with the proposed application. This is because the system is available on both Android and iOS devices, and more in general for every device with a web browser installed. Few years ago, the use of web applications instead of native applications would have been a limit for features which are strictly connected to the operative

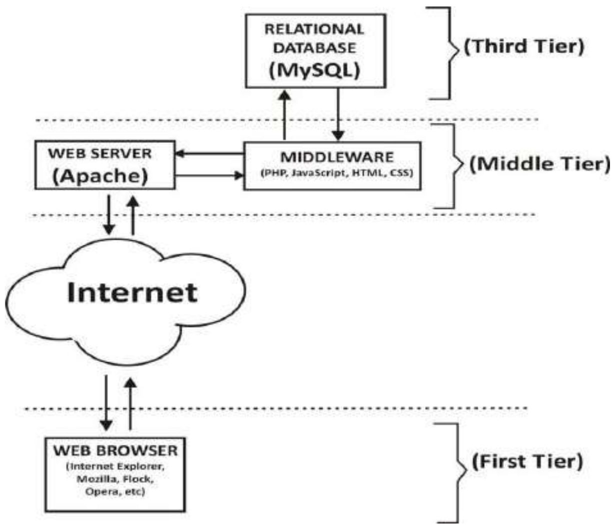


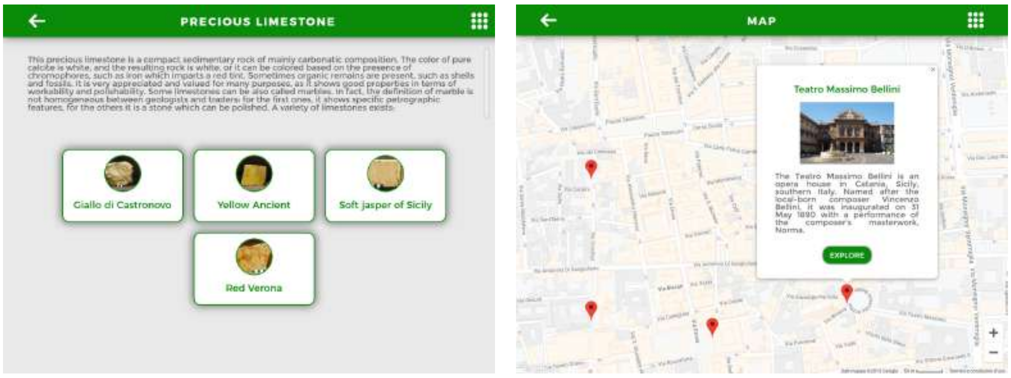
FIGURE 4.2: General web application architecture.

system of the device, such as: GPS position, access to camera or microphone, sensors; today, thanks to the use of modern web programming languages one is able to use these functionalities on the proposed application even if it is accessible through a web browser.

The first time that a user starts our application, he/she/they has/have to provide to the system some information about his language and his age range. Specifically, the system asks the user to choose between two options, namely: "Child tour" and "Adult tour". We use this information to get our visitors a better experience with tailor-made contents.

The landing page of the application is a menu with several buttons:

- "Discover the Collections" brings the user to the list of categories of the samples;
- "Go to the City" allows to navigate the collections by exploring the monuments of the city where one of the sample of the collections is used;
- "History of the Museum" brings the user to a section where it is possible to know the history of the museum and its collections;
- "Leave a comment" allows the user to leave a review;
- then there are two buttons to change the mode and the language.



(a) (b)

FIGURE 4.3: Screenshots from the I-PETER application: a) exploring the collection in classic mode; b) exploring the collection by the monuments located in the city map.

As mentioned above, the platform offers to visitors two different approaches of fruition of the museum collections: a classical visit, provided by the curator of the museum, where a user can navigate the contents through a hierarchical schema (Solima, 2011) starting from the exposed sample toward their investigation (fig. 4.3(a)); a second mode involving the interaction with a city map where the visitor can choose a monument, from which starting to investigate the stones and minerals visible on it, towards those correlated with the museum collections (fig. 4.3(b)).

When a user chooses the first mode he/she/they finds/find a view where he/she/they can select between two categories: rocks or minerals. After this choice, there is a second level where multiple typologies of each class are shown. Rocks have an extra classification by sub-classes: sedimentary rocks, magmatic rocks and metamorphic rocks. The last layer of the hierarchical schema is represented by the list of the samples that are physically exposed at the museum that belong the chosen typology.

After the choice of a sample, the application brings the user to the "Investigation mode", where the user can find all the information about the specimen.

Going to the "Investigation mode", a user is brought to the sheet of the sample (level two) (fig. 4.4). Then, he/she/they is/are allowed to navigate through four different views that go from the microscopic analysis, like the thin section (level one), to the macroscopic level represented by a monument or a building where the material is used (level three and four). Links are created also with all the other uses, in particular in relation to the world of art. Pigments, as malachite and azurite, are linked with their traditional use as pigments in paintings, or clays as raw materials to create ceramic, linking that with some archaeological remains that enrich even more the digital collection of the proposed app. Navigation can be performed through two buttons to simulate the zoom in and out from the sample.

For each sheet, we provide both, textual and multimedia contents. In this way, contents are dynamically selected using the preferences set by the user at the beginning of the digital visit. The different textual contents are provided by the curator of the museum with different levels of detail and complexity.

"Investigation mode" can be also accessed through a QR code, that is placed near every physical sample exposed at the museum. A QR code is a 2D image code that became popular after the introduction of cameras and scanning function in mobile devices (Okazaki, Hirose, and Li, 2011). The use of QR codes give to the users the opportunity to directly interact with the samples exhibited at the museum. This is possible thanks to the architecture of a web application; indeed, every sample inside I-PETER is reachable by a Uniform Resource Identifier (URI). So, if a visitor is interested in a sample, he/she/they can take a picture of its QR code, that contains the URI, and access to the "Investigation mode" of the sample quickly, without the need of navigating the various menus of the application.

FIGURE 4.4: Screenshot of the "Investigation mode" page of the Giallo di Castronovo sample exposed at the museum.

The city exploration mode allows visitors to digitally explore monuments and buildings where the materials exhibited at the museum are used, sketched in an interactive city map. When the application is running, the system will ask the permission to use the GPS position obtained from the user device. If the user grants the permission, the application will be also able to locate him/her inside the map of the city. Moreover, the system can provide some tips about what to see around the user. Once a monument has been chosen, a pop-up with general information appears; now the user can go deeper with the navigation and start the descendant analysis from the macroscopic level to the microscopic one. Thanks to this mode, the proposed application can be used even outside the museum to get accurate information of the monuments of the city.

Particular attention was dedicated also to the user experience design, in order to face some typical problems related to long and boring visit of museums, full of information acquired passively. We used colours that induce calm, in order to create a comfortable area of learning, where the visitors can decide to stop, come back, read again or skip information, if they are not interested. In this way, we tried to overcome the so called "museum fatigue" (Bitgood, 2000), which implies a decrease of the visitor's concentration with increasing tiredness.

4.2.3 I-PETER Dataset

Nowadays, machine learning and artificial intelligence are able to solve a significant number of tasks, such as clustering and classification. The main problem of these techniques is the high number of labelled data that they need to work properly. Datasets are often available online, but with some limitations in their usage due to copyright. For petrography and mineralogy, the biggest online dataset is Mindat.org[1], which contains more than 5,000 minerals and more than 2,000 rocks, with about 900,000 pictures. Unfortunately this database, such as other kinds of databases, is covered by database copyright (inside the European Union this is covered by directive 96/9/EC and others, but there are similar laws in the US and other countries) and this makes it difficult to access this information freely.

[1]Mindat.org is the primary outreach project of the Hudson Institute of Mineralogy. The mindat.org database is a key resource for education about rocks and minerals and their importance to society (https://www.mindat.org/).

As we know, museums have a lot of useful information, but as long as they are not digitised and organised they cannot be used by artificial intelligence algorithms. The way used to encourage the museum to digitise and label its data was the web application I-PETER. At the end of the digitisation process, I-PETER will host all the museum collections, in which every sample is represented by some pictures and its information, we estimate to have more than 1500 images in the main database.

Thanks to I-PETER's semantic structure, we are able to extract a dataset from the web application main database. The dataset is automatically generated by a routine, that can be executed after each update by the administrator, this allows to always have fresh information.

To generate the dataset we use the information provided by the hierarchical schema and the information showed in the "Investigation mode" at level two and level one. From the hierarchical schema we take: the unique identification number; the category, i.e. rock or mineral; the type of rock, that is provided only for rocks, and is one among magmatic, sedimentary or metamorphic; the name of the rock or mineral. From level two, that shows the museum sample, we have one or more pictures of the specimen, while from level one the image of the thin section of the specimen.

The dataset is publicly available and free to download for scientific research[2]. The dataset is made by two folders, that contain the pictures of the samples and the pictures coming from thin sections, each file is named using the unique identification number. A csv file is provided with the information about each image. The csv file is made by seven columns: ID is the unique identification number; TYPE depends from the type of the image, it can be a Museum Sample (MS) or a Thin Section (TS); NAME is the name of the sample; MAIN CLASS is the category; SUB CLASS is specified only for rocks and it represent the type of the rock; SAMPLE CLASS is the category of the rock or the mineral.

[2]Direct link for dataset download: http://iplab.dmi.unict.it/ipeter/dataset.php

4.3 Serious game: become a researcher in the mineral-petrographic field

Computer games are a powerful mechanism to engage the large public into an active state of learning where spectators are motivated to create their own knowledge rather than to receive information passively. Games with educational purposes – namely Serious Games – are now becoming more and more popular. Serious games provide amusing and compelling experiences and keep the player focused for long lasting sessions. For this reason are widely used in many learning context: mathematics and science (Schäfer et al., 2013; Wouters et al., 2016), computational thinking and computer programming (Kazimoglu et al., 2012), history, etc.

The previous experience of collaboration among geologists, conservators and computer scientists led to the implementation of a web application called I-PETER: Interactive Platform to Experience Tours and Education on the Rocks, a turning point for the Museum of Mineralogy, Petrography and Volcanology of the University of Catania, with the goal of promoting a new interactive system which could facilitate the diffusion of its cultural contents towards a broader range of visitors, of different ages, countries and cultural background using their smartphone or any device equipped with a web browser. Since I-PETER has had a good success among museum visitors, we decided to continue developing digital content for the museum.

In collaboration with museum personnel, a game was designed with the aim of dissemination the knowledge of mineralogic and petrographic science and research instruments and techniques that are used by researchers in this field. The game, in italian language, is free available on-line[3]. Users of our simulator are able to analyse different thin sections of rocks using a microscope equipped with a polarising filter in order to discover those minerals which compose the rock. Then, users can conduct different type of non-invasive analysis to identify the mineral.

[3]Simulator website: https://dreamin.unict.it/microscopio/

FIGURE 4.5: Microscope and observation of a basalt thin section at low magnification trough the eyepieces of the microscope.

4.3.1 Game design process

In order to make the simulation as real as possible we decided to reconstruct all the chain of actions that a researcher need to do when he/she/they performs/perform an analysis by using a specific instrumentation. Four kinds of analytical instrumentation, usually employed for investigating minerals and rocks, were considered. The petrographic microscope is the petrographic instrument for excellence, the most antique and the most used. It is an instrument that allows to observe objects at enlarged scale. It is possible to perform a series of operations which could reveal the optical characteristics of minerals, allowing their identifications. In case of rocks, the observation of thin sections of the sample will allow to identify the single minerals that constitute it, therefore to identify the rock itself (Peccerillo and Perugini, 2003). A thin section is a 20-30 microns thickness section, obtained by cutting a rock sample in order to make it observable by transmitted light.

A sequence of mandatory actions carried out to use a microscope for petrographic investigations is reported as example. The sequence has been simplified and schematised, as scientific investigations are always dependent on the characteristics of materials that is investigated. In fact a unique path, always valid, does not actually exist. The simplified sequence for investigations by petrographic microscope is hereafter reported:

1. Choose the thin section of a sample to investigate;

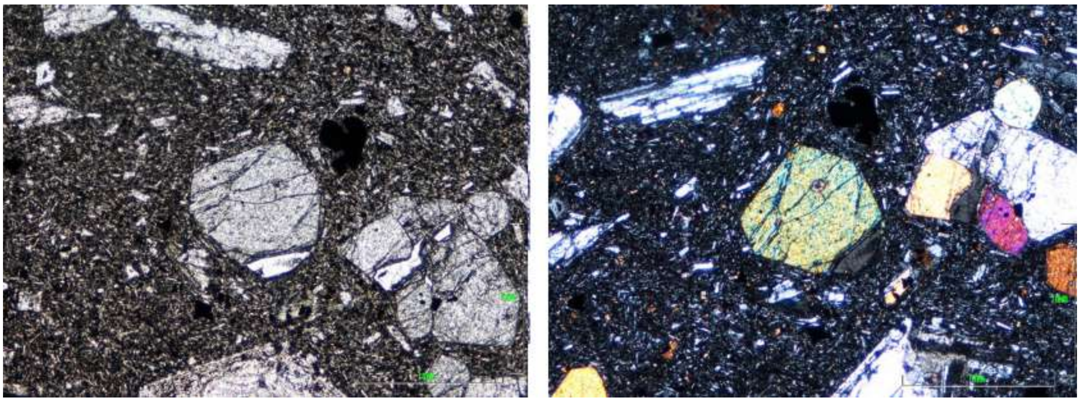


FIGURE 4.6: Images acquired with microscope in non-polarised light (left) and polarised light (right) of the Basalt thin section with the olivine in the centre.

2. Put the thin section on the microscope's rotating plate;
3. Turn on the light source;
4. Choose a microscope optic, in order to decide the level of magnification of the investigation;
5. Adjust the focus by using the specific knobs on the sides of the microscope.

Once these actions are completed, a researcher will be able to look through the eyepieces of the microscope and observe the structure of the sample. The microscope offers also the possibility to add a polarising filter, placed between the light source and the sample base. It can be activated or deactivated by means of a special lever. It allows to convert the light from non-polarises to polarises in order to collect univocal data for the recognition of the mineral. In order to observe the variables linked to the optic characteristics of the minerals observed in the sample, it could be useful/necessary to rotate the plate where the thin section is placed. In the example used for the microscope simulator, the thin section is a thin section of a Basalt rock, and looking inside through the microscope it is possible to recognise different kind of minerals, among which those centred in the image, which according to the observed features is hypothesised to be an olivine, as shown in fig. 4.6.

Further techniques that allow the characterisation of minerals and rocks are X-ray Fluorescence (XRF), Fourier-Transform Infrared-Spectroscopy (FTIR) and Raman Spetroscopy (Raman). For all these three analytical techniques the results are revealed as a spectrum, a linear image with peaks or bands that according to their

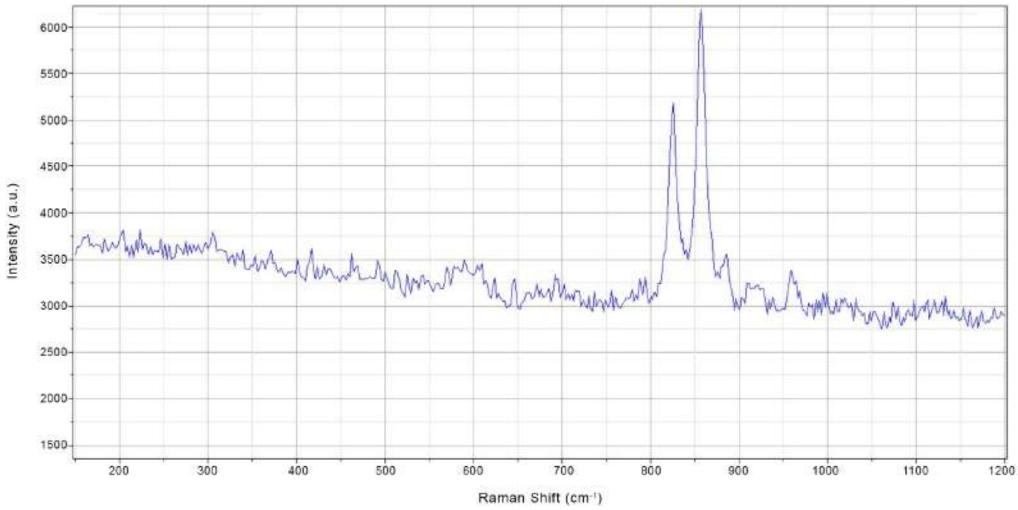


FIGURE 4.7: Example of an olivine spectrum acquired by using Raman spectroscopy.

position on the X-axis of the graph allows to understand their identity, and according to their value in the Y-axis allows to measure their relatively quantitative amount as shown in fig. 4.7. As well as XRF, FTIR and Raman spectroscopy could be performed both on prepared samples or on the surface of them in a non-invasive way. The last method is preferable when we are investigating objects of museum interest, as in the case of this study. If for the microscope a specific sequence of action has been defined and simulated, for XRF, FTIR and Raman, the analyses are simulated by simply virtually touching the instrument for starting the acquisitions, and then by observing the formation of the related spectrum on the monitor of the computer.

Because we want to develop a simulator with the same results that can be obtained from the real instruments we need to collected the real data from real analysis: for each thin section observed using the microscope we collect different images changing the rotation of the plate, the magnification level and the type of light (polarised and not). It means that for each thin section we need to acquire 288 images. This number is given by this formulation: $n = 2(360/\alpha) \cdot l$; where α is the number of degrees of difference between two rotations, l is the number of level of magnification. In our configuration we use $\alpha = 10$ and $l = 4$ (2.5x, 10x, 20x, 40x). For the chemical investigations, a representative analytical spectrum resulted by the analyses conducted on an olivine sample is reported.

FIGURE 4.8: A screenshot taken from the game where is possible to see on the left the side menu with the thin sections and on the right the main scene with the optical microscope and the light source control box (in italian language).

4.3.2 Game development

Since the development of a video game is a very complicated process that requires different skills, it was essential to make some choices that kept development costs low but that could nevertheless allow to have a simple and effective tool. The development is based on the Unity game engine (Messaoudi, Simon, and Ksentini, 2015), a tool used at all scales of video games development, from the large studio to the hobbyist bedroom, such that over half of all new video games are reportedly being made with Unity (Nicoll and Keogh, 2019). Another feature, that was fundamental in our choice of Unity as game engine was the large compatibility of video games made with Unity. There is indeed the possibility to export the final product on the most spread platforms: Windows, iOS, Android, WebGL. Thanks to the possibility of using WebGL we were able to develop a web based build compatible with the most modern operating systems and browsers such as Chrome and Safari for desktop devices, but without additional effort we were able to produce APK that can be free downloaded and installed on mobile Android devices for better compatibility since WebGL is on experimental stage on mobile devices at the moment.

Unity offers the possibility to develop games both in 3D and 2D: since the use of 3D requires expert modellers that have to reconstruct the game environments and instruments used in the laboratory using computer graphics and this wasn't possible

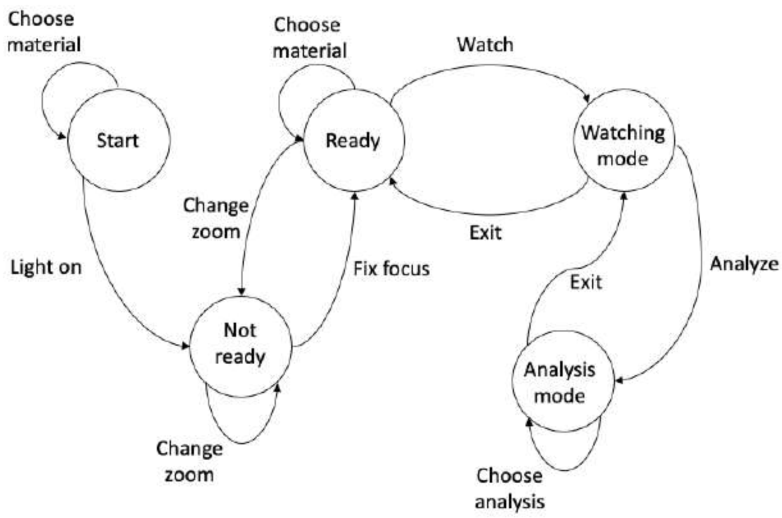


FIGURE 4.9: Design of game interaction.

due the large time request and high costs this solution, it was chosen to use a two-dimensional graphic with a point and click approach widely used in many graphic adventures loved by a large audience of gamers.

The user interface (UI) has two sections: a side menu where the thin sections are drag and dropped on the rotating plate of the microscope by the player and a main panel that contains the main elements of the scenes: the microscope, the detail of the revolver of the microscope, all the analysis instruments and monitor where consult the result of analysis. To keep the design of the UI simple and even for the target of the users of our simulator it was decided to use a graphic style where all the objects in the scene are hand-drawn, faithfully reproducing the real objects that are present in the university laboratory, with a style similar to a comic.

The game logic designed in collaboration with researcher of Departments of Biological, Geological and Environmental Sciences (DSBGA) is summarised in fig. 4.9. At the begin of the game the player can drag a thin section from the menu on the left and put it to the rotating plate of the microscope (fig. 4.8). Nevertheless, in order to proceed to the next scene it is mandatory that the player turns on the light source, as in the reality we cannot use the microscope since the light source is on. In scene two (fig. 4.10(a)), the microscope with all the interactive parts is presented, the player can click on the eyepieces to observe the sample, click on the revolving nose-piece to add or remove the polarising filter or change the level of magnification (fig. 4.10(b)), click on the knobs on the side of the microscope to adjust the focus. At the first time and after every change of magnification the player has to adjust the focus or a blur filter will applied to the image showed after the click on the eyepieces in order to simulate the lack of focus.

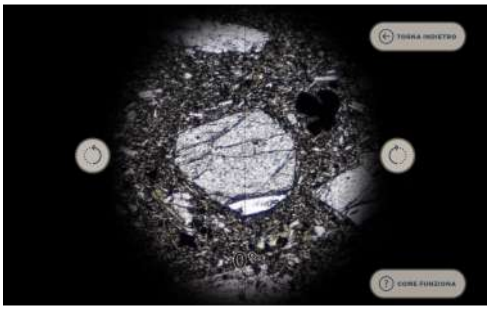
Scene three is where the real images obtained from the researchers can be observed (fig. 4.10(c)). To simulate the observation of the thin section through the eyepieces a black frame is overlapped to the original image. Since we know that rotation is a key factor to find out more details, especially with the polarised light filter, two control points are implemented in order to give the user the possibility to rotate the plate and observe the same material with a different angle. When the user clicks on a control point a different image is loaded, each image is taken with an rotation of 10 degrees. By clicking a mineral on the observed image it is possible to move to the laboratory to conduct further analysis and deeper the investigation.

The laboratory is presented in scene four (fig. 4.10(d)). In this scene is possible to see all the instruments used to carry out XRF, FITR and Raman investigations and a personal computer where it is possible to observe the results. To start an analysis an user has to choose one instrument by clicking on it and turn on the computer. Since the result of all the analysis is a bi-dimensional chart containing the spectrum, that is acquired during the analysis process taking about 60 seconds, we decided to put only the most representative steps. In this case, a set of 6 images is shown one after the other, after every 10 seconds until the completion of the analysis. To make the waiting time smaller, the time in game is speed up at the double of the real time. When the final chart is obtained, a popup with the name of the mineral is shown to complete the identification process.

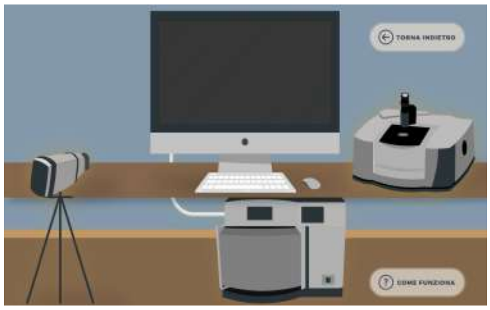
For a better user experience (UX) we tried to keep the difficulty as simple as possible, but we know that there are some sequences of actions that are not so intuitive. To help users, the game provides two different helps: the first one is given by suggesting all the objects in the scene which the user can interact simply adding a bright halo for a couple of seconds; the second one is a button with the help that can be consulted in every scene in which the player can find all the instruction to complete the sequence of action to get a result.

(a)

(b)



(c)



(d)

FIGURE 4.10: scene two: microscope with all the interactive parts (a); scene two: a detail of the revolving nose-piece to change the magnification level (b); scene three: observation of a real sample of basalt (c); scene four: the laboratory with all the research instruments (d).

4.4 Digital twin: the Foucault Pendulum experiments become digital

A digital twin is a virtual representation of a physical entity, living or non-living, of a person or system, even a complex one, connected to a physical part (Saddik, 2018) with which it can exchange data and information, either synchronously (in real time) or asynchronously (at later times). The digital twin can evolve to become a true digital replica of potential and actual physical resources (physical twin), processes, people, places, infrastructures, systems and devices that can be used for various purposes. The digital component can include all the life-cycle information of the physical elements it represents.

In general terms, the main features of the digital twin are:

- the set of data and information in any way referable to the entities represented by the digital twin;

- the connection between the elements of the physical component with the corresponding virtual part;
- the exchange of data and information between the virtual (cyber) component and the physical component, using sensors and actuators.

The concept of the digital twin can be compared to other concepts (cross-reality environments, co-spaces, mirror models), which aim, in general, to model part of the physical world, e.g. an object or place, with its cyber representation, which can be an abstraction of some aspect of the physical world (Loke et al., 2015). Digital twins can integrate the internet of things, artificial intelligence, machine learning and data analysis. They can create digital simulation models that update and change when their physical counterparts change.

The data representing the digital twin can be derived from the most diverse sources: from sensors transmitting various aspects of its operating conditions; historical data on past conditions; data provided by human experts, such as engineers, technicians, doctors, with specific and relevant knowledge; data collected from other similar machines, or from the systems and environment of which it may be a part; information retrieved from any database accessible through the Internet. The digital twin can also use machine learning and artificial intelligence systems to process data and produce new knowledge.

The term digital twin is particularly popular in industry, where it is specifically used to refer to the virtual reproduction of a real process or service realised through data collected by sensors. In the museum sector, this can be imagined as the digital copy of works or installations with which visitors can interact by modifying their state.

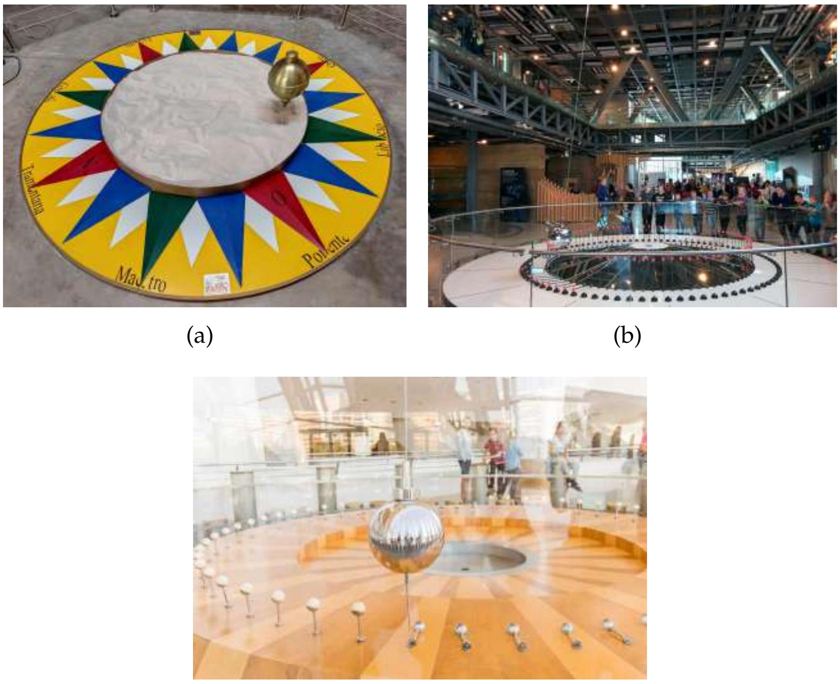
In collaboration with Città della Scienza and the Department of Physics and Astronomy (DFA), it was decided to digitise the Foucault pendulum experiment installed at Città della Scienza by means of a digital twin. The aim of this activity was to make the development of the experiment accessible outside the museum via the Internet. By means of a web application, it is possible at any time to check the status of the physical device installed at the museum. The physical installation and the web interface of the digital twin are shown in fig. 4.11 .

4.4.1 Digital Twin design

The Foucault Pendulum, named after the French physicist Jean Bernard Léon Foucault, was conceived as an experiment to demonstrate the rotation of the Earth through the effect of the Coriolis force. It is a pendulum free to swing in any direction for approximately 24 hours. The first Foucault Pendulum was presented to the public in 1851, and consisted of a 28 kg sphere suspended from the dome of the Pantheon in Paris by a 67 m long wire. In an inertial system, it would have drawn lines always in the same direction, but this was not the case. At every latitude of the Earth, except along the line of the equator, the pendulum's plane of oscillation is observed to rotate slowly. At the North and South Poles, the rotation occurs on a sidereal day: the pendulum's oscillating plane stands still while the Earth rotates, in accordance with Newton's law of motion. At our latitude, the pendulum installed at Citta della Scienza takes about 39 hours to complete one complete cycle. Since the observation times for this experiment are very long, it was decided to offer museum visitors the possibility of following the evolution of the experiment over time even outside the museum building.

Regarding the installation of the pendulum experiment at Città della Scienza (fig. 4.12(a)) the evolution of the experiment can be observed by means of a trace left on

FIGURE 4.11: The digital twin of the Foucault pendulum installed at Città della Scienza.



(a) (b) (c)

FIGURE 4.12: Foucault's Pendulum experiment at three different museums: Città della Scienza - Catania (a), Centrum Nauki Kopernik - Warsaw (b), Museu de les Ciències - Valencia (c).

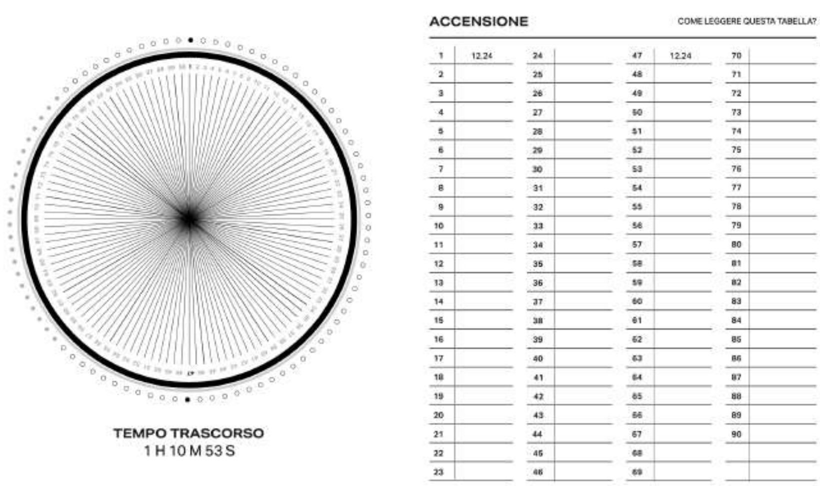
the sand by a metal spike. In our case, the virtualisation of the entire system should therefore have concerned two main components, which are the movement of the sphere and the history of the execution of the experiment represented by the trace in the sand. From the study of the same experiment, installed at other museums, it was possible to observe how the evolution of the experiment over time was not represented using the sand, but in another way. The passage of the sphere at a given point of the circumference is demonstrated through a rod which is dropped, when bumped by the sphere. This system, which is preferable to using sand, is used for example in the Copernicus Science Museum in Warsaw (fig 4.12(b)) and at the Museums of Scienze of Valencia (fig. 4.12(c)). Indeed, the use of sand between each pendulum launch requires levelling the previous grooves. This operation is more complex to carry out than the repositioning of the rods that occurs in other cases.

Since it would have been preferable to eliminate the need for the use of sand in our case as well, in addition to the electronic device for detecting the passage of the sphere, a visual method was designed to communicate the passages of the sphere from certain points by using RGB LED lighting. At this point, it was also possible to define the method of representing the state of the virtual experiment, which was to be accessible to visitors once they had left the museum. The digital representation is, in fact, a transposition of the LED strip physically installed on the outer edge of the sandbox. Since our goal was to have a user-friendly system, the digital twing access is via a QR code with a direct link to a web page, where the same result shown by the LEDs installed at the museum is represented with a specially designed interface (fig. 4.13).

In order to avoid elements that could spoil the harmony of the installation, the detector device had to act without the need for physical contact with the sphere and be positioned in an area not visible to users. For this reason, it was decided to use magnetic sensors to detect the pendulum passage. At the end of the sphere, the spike was replaced by a small magnet that interacted with the magnetic switches installed inside the detector, which is positioned in the centre of the structure covered by sand.

4.4.2 The development of the Digital Twin

The digital twin consists of three interacting elements: detector, LED strip, web interface. A MySQL database is used to synchronise the status between the various components. The detector consists of a disc with a diameter of 40 centimetres, in which 90 normally-open magnetic reed switches are installed. When the reed switch interacts with a magnetic field, the switch inside is closed and this generates a high type signal (5V) that is sent to an Arduino microcontroller. The microcontroller used



1	12.24	24		47	12.24	70	
2		25		48		71	
3		26		49		72	
4		27		50		73	
5		28		51		74	
6		29		52		75	
7		30		53		76	
8		31		54		77	
9		32		55		78	
10		33		56		79	
11		34		57		80	
12		35		58		81	
13		36		59		82	
14		37		60		83	
15		38		61		84	
16		39		62		85	
17		40		63		86	
18		41		64		87	
19		42		65		88	
20		43		66		89	
21		44		67		90	
22		45		68			
23		46		69			

FIGURE 4.13: The design of the web version of the digital twin.

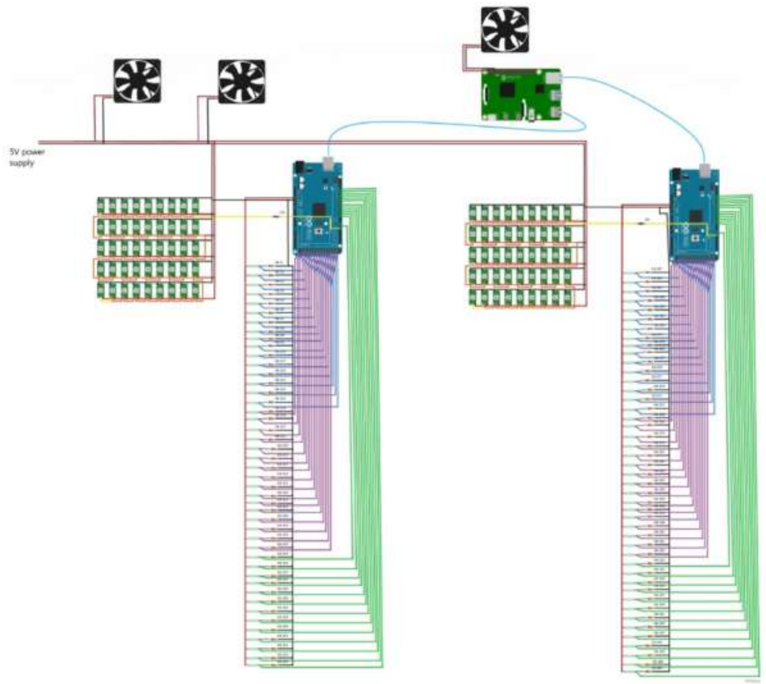


FIGURE 4.14: Electrical diagram of the detector device and led lighting system.

is an Arduino Mega 2560 Rev3. This microcontroller has 54 digital pins, 16 analogue input pins and 4 serial ports. Since it had to drive 90 reed switches in this case, it was necessary to use two Arduino Mega, each of which drives 45 reed switch detectors and 45 RGB LEDs. Since the Arduino Mega does not have a network connection, it was necessary to add a Raspberry Pi, a single-board computer developed in the UK by the Raspberry Pi Foundation, to connect the two Arduino Megas via a USB serial port and to listen to the signals sent by the microcontrollers. Each time a contact on a reed switch is detected, the Raspberry PI transfers this information to a cloud server where it will be stored in a database. The connection diagram is shown in fig. 4.14.

The code written for the microcontroller, developed in C/C++ using the Arduino IDE, consists essentially of two main functions: setup and loop. The setup contains the code needed to initialise the LEDs, which are all initially switched on in white, and to establish the serial connection with the Raspberry Pi for sending information. The loop, on the other hand, contains the control function that is executed indefinitely. The control function can be described by the following pseudo-code:

```
BEGIN
FOR i IN 1 TO 45
```

```
    IF SWITCH[i] IS TRUE
        LED.SET(i, GREEN)
        SERIAL.OUT(i)
    ENDIF
ENDFOR
END
```

When a high signal is detected on a digital pin of the microcontroller, we turn on the corresponding LED with a green light and send a message to the Raspberry Pi via serial connection. The Raspberry Pi has the task of executing a Python script that remains in data download on the serial port. When a message is received (containing the identifier of the activated switch, between 1 and 90) a second function will write the sensor identifier and timestamp to a remote database. When the Raspberry Pi starts up, a signal is sent to the remote server that empties the database in order to initialise the system and make it ready for a new pendulum launch.

4.5 Achieved results

In recent years, digital technology has revolutionised many areas of society. Now museums are also looking to digitalise their institutions. They want to win over new visitors and establish innovative communication platforms that will accommodate digital participation and presence on all levels. Museums allow us to discover and learn new things. In their rooms, we can get up close to collections and artefacts that have been preserved, researched and put on show to educate and create experiences. Being public places, museums also provide us with an opportunity to socialise, to meet people and to share thoughts. Our work is therefore not only focussing on what we can achieve through digital media. It also aims to find out what makes a trip to the museum a shared experience. We want to know what forms of social interaction are the key to this. Furthermore, we are looking for ways to interconnect physical and virtual aspects. This will allow us to create new interpersonal communication platforms where you can enjoy museums without actually walking into a building. Until now, if you wanted to explore a museum, there was a clear boundary between digital and physical experiences. True hybrid formats and technical infrastructures that link the real and virtual worlds to enable shared experiences do not exist (yet). Digital technologies make possible the trasformation of a museum from a physical place that can be turned into hybrid entities that combine physical locations, virtual experiences and venues for social interaction. Every tool developed was designed following exactly this model.

Through the I-PETER web app, the museum has been able to bring the beauty of its collections outside its walls. Visitors can use I-PETER before, during, and after the visit. Using it before the visit allows visitors to better prepare for the visit itself; it is also possible to find out what the museum's collections have to offer from home. During the visit, the application is used as an in-depth look at the minerals and rocks on exhibits. In this case, QR codes allow direct access to the objects. Finally, the app can be used after the visit to expand or recall what was seen at the museum. Unlike a simple audio guide or catalog, I-PETER offers also logically linked content. The user experience is designed in a way that allows users to take a journey from the micro, looking at thin sections, to the macro, discovering where that material can be applied within buildings or monuments in the city.

Serious games carry the huge advantage of acquire information in an active playful environment that makes the learning process more interesting and less difficult compared with traditional methods such as listening or reading. Exploiting our simulator, users can easier assimilate knowledge in petrography and mineralogy and about laboratory instruments in a more interactive way following the principles of learn by doing. Users have the possibility to deep investigate how rocks are made and how to correctly recognise them, which tools are used everyday in research and what are the main functions of each of them. At this stage, all the software functionalities and the game logic passed the validation of researchers and developers. In the next phase, we can finally start to collect further real data in our lab in order to implement analysis of new rocks inside our simulator. The objective is to provide at least one mineral for each classification (e.g. one carbonate mineral, one silicate mineral and so on...). Then, we can easy import the new data in our simulator and provide and essential but useful database for investigation in mineralogy. Thanks to this effort students and young researchers will have the possibility to access real data that can't be easy find even in the enormous vastness of internet. Moreover, simulator provides chemical and spectroscopic analysis results that can be performed only inside professional laboratories with expensive instruments, difficult to find in primary or middle schools.

Digital twins allow us to break the boundary between physical and virtual. Thanks to these tools, physical objects, equipped with appropriate sensors, can be reproduced in their components and states digitally. The application of this technology at Science City has allowed us to make usable an experience that until now could only be observed physically by going to the museum. With access through a website possible to add multimedia content to the experience to help users better understand the experiment.

Chapter 5

Final conclusions

In this work, we analyzed how digital transformation affects industries and cultural heritage sector. For each scenario, in the first instance, the needs and expected goals were analyzed, then an analysis was conducted on implementable technologies, and finally solutions were developed.

In particular, when it comes to the industrial sector, the current scenario was analyzed in terms of both technological and regulatory aspects. Regulatory aspects are to be considered fundamental in the perspective in which companies investing in digitization want to use the aid and credit instruments put in place by various governments. This leads to the main problem addressed in this thesis: capital goods and the requirements for such investments from the Italian national Industry 4.0 plan.

To meet the requirement of bidirectional interconnection, a framework that makes it possible to dialogue with machines that meet determined requirements has been developed. Thanks to its web API, it allows us to have a layer that is practically compatible with all kinds of applications. Finally, in order to meet the requirement of automated integration, two case studies were presented where the previously elaborated framework was applied and software solutions were developed to meet the needs of the production process of the various companies. Both cases presented successfully showed an improvement in the production process and/or in quality standards through the use of digital solutions and 4.0 machinery.

Although with different purposes, the problem of digitization of the cultural heritage sector was addressed. Again, an overview of needs was given, and then three tools were proposed to try to meet some of these needs.

A web app was developed to create a digital experience before, during, or after a museum visit. Information from individual items were combined to create a narrative that would add value to the app when compared to a website or audio guide. Through the use of serious games, it was possible to develop tools for the dissemination of research in mineralogy and petrography. Through the use of the simulator, players can play the role of a researcher and perform analyses on rocks and minerals. The use of games allows us to overcome the limitation imposed by passive assimilation of information. Through gaming, information is conveyed through an interactive and entertaining channel. Finally, digital twins have allowed us to virtually take an experiment, that of Foucault's Pendulum, closely linked to a physical dimension, out of the museum. The use of these tools enabled us to link physical and virtual aspects to create "augmented" experiences.

As time goes on, digital will become more central to our daily lives; what we can do now is to understand how these tools can benefit us from what we already know and put into practice every day.

Bibliography

Alberghina, M.F. et al. (2017). "Integrated three-dimensional models for noninvasive monitoring and valorization of the Morgantina silver treasure (Sicily)". In: *Journal of Electronic Imaging* 26.1. DOI: 10.1117/1.JEI.26.1.011015.

Allegra, D. et al. (2018). "Experiences in using the pepper robotic platform for museum assistance applications". In: *International Conference on Image Processing*, pp. 1033–1037. DOI: 10.1109/ICIP.2018.8451777.

Amato, Flora et al. (2013). *The Talking Museum Project*. Elsevier, pp. 114–121.

Ashton, Kevin et al. (2009). "That 'internet of things' thing". In: *RFID journal* 22.7, pp. 97–114.

Bergerman, Marcel et al. (Mar. 2015). "Robot Farmers: Autonomous Orchard Vehicles Help Tree Fruit Production". In: *IEEE Robotics & Automation Magazine* 22.1, pp. 54–63. DOI: 10.1109/mra.2014.2369292. URL: https://doi.org/10.1109/mra.2014.2369292.

Bitgood, S. (2000). "The role of attention in designing effective interpretive labels". In: *Journal of interpretation Research* 5.2, pp. 31–45.

Bonacini, E. (2015). "The "Paolo Orsi" Syracuse Archaeological Museum Pilot Project: A 360° Tour with Google Indoor Street View". In: *2015 11th International Conference on Signal-Image Technology Internet-Based Systems (SITIS)*, pp. 833–840.

Brennen, J. Scott and Daniel Kreiss (Oct. 2016). *Digitalization*. DOI: 10.1002/9781118766804.wbiect111. URL: https://doi.org/10.1002/9781118766804.wbiect111.

Chianese, A. et al. (Dec. 2013). "SmARTweet: A Location-Based Smart Application for Exhibits and Museums". In: *2013 International Conference on Signal-Image Technology Internet-Based Systems*, pp. 408–415. DOI: 10.1109/SITIS.2013.73.

Coreynen, Wim, Paul Matthyssens, and Wouter Van Bockhaven (Jan. 2017). "Boosting servitization through digitization: Pathways and dynamic resource configurations for manufacturers". In: *Industrial Marketing Management* 60, pp. 42–53. DOI: 10.1016/j.indmarman.2016.04.012. URL: https://doi.org/10.1016/j.indmarman.2016.04.012.

Ferrari, Paolo et al. (July 2018). "Impact of Quality of Service on Cloud Based Industrial IoT Applications with OPC UA". In: *Electronics* 7.7, p. 109. DOI: 10.3390/electronics7070109. URL: https://doi.org/10.3390/electronics7070109.

Finocchiaro, Paolo and Mario Alberghina (2007). *Idee, cultura e storia per la Città della Scienza*. G. Maimone.

Frenzel-Piasentin, Adeline et al. (June 2021). "Digitization or Digitalization? – Toward an Understanding of Definitions, Use and Application in IS Research". In: *AMCIS 2021 Proceedings*. Vol. 18.

González Vargas, Juan Camilo et al. (2020). "Survey: Using Augmented Reality to Improve Learning Motivation in Cultural Heritage Studies". In: *Applied Sciences* 10.3. ISSN: 2076-3417. DOI: 10.3390/app10030897. URL: https://www.mdpi.com/2076-3417/10/3/897.

Hein, G. E. (Sept. 2002). "The Constructivist Museum". In: *Learning in the Museum*. Routledge, pp. 165–189.

Iwanitz, Frank and Jorgen Lange (Jan. 2010). *OPC Fundamentals, Implementation and Application*. New Delhi, India: Laxmi Publications.

Kalender, Murathan et al. (2019). "Additive Manufacturing and 3D Printer Technology in Aerospace Industry". In: *2019 9th International Conference on Recent Advances in Space Technologies (RAST)*, pp. 689–694. DOI: 10.1109/RAST.2019.8767881.

Kazimoglu, Cagin et al. (2012). "A Serious Game for Developing Computational Thinking and Learning Introductory Computer Programming". In: *Procedia - Social and Behavioral Sciences* 47, pp. 1991–1999. DOI: 10.1016/j.sbspro.2012.06.938. URL: https://doi.org/10.1016/j.sbspro.2012.06.938.

Liaw, Chya-Yan and Murat Guvendiren (2017). "Current and emerging applications of 3D printing in medicine". In: *Biofabrication* 9.2. DOI: 10.1088/1758-5090/aa7279. URL: https://dx.doi.org/10.1088/1758-5090/aa7279.

Loke, Seng W. et al. (July 2015). "The La Trobe E-Sanctuary: Building a Cross-Reality Wildlife Sanctuary". In: *2015 International Conference on Intelligent Environments*. IEEE. DOI: 10.1109/ie.2015.36. URL: https://doi.org/10.1109/ie.2015.36.

Mahnke, Wolfgang, Stefan-Helmut Leitner, and Matthias Damm (2009). *OPC Unified Architecture*. Springer Berlin Heidelberg. DOI: 10.1007/978-3-540-68899-0. URL: https://doi.org/10.1007/978-3-540-68899-0.

Mell, P M and T Grance (2011). *The NIST definition of cloud computing*. Tech. rep. DOI: 10.6028/nist.sp.800-145. URL: https://doi.org/10.6028/nist.sp.800-145.

Messaoudi, Farouk, Gwendal Simon, and Adlen Ksentini (Dec. 2015). "Dissecting games engines: The case of Unity3D". In: *2015 International Workshop on Network and Systems Support for Games (NetGames)*. IEEE. DOI: 10.1109/netgames.2015.7382990. URL: https://doi.org/10.1109/netgames.2015.7382990.

Modbus organization (n.d.). URL: https://modbus.org/.

Mohurle, Savita and Manisha Patil (2017). "A brief study of wannacry threat: Ransomware attack 2017". In: *International Journal of Advanced Research in Computer Science* 8.5, pp. 1938–1940.

Nicoll, Benjamin and Brendan Keogh (2019). "The Unity Game Engine and the Circuits of Cultural Software". In: *The Unity Game Engine and the Circuits of Cultural Software*. Cham: Springer International Publishing, pp. 1–21. ISBN: 978-3-030-25012-6. DOI: 10.1007/978-3-030-25012-6_1. URL: https://doi.org/10.1007/978-3-030-25012-6_1.

Okazaki, Shintaro, Morikazu Hirose, and Hairong Li (2011). "QR Code Mobile Promotion: An Initial Inquiry". In: *Advances in Advertising Research (Vol. 2)*. Gabler, pp. 405–420. DOI: 10.1007/978-3-8349-6854-8_26. URL: https://doi.org/10.1007/978-3-8349-6854-8_26.

Peccerillo, Angelo and Diego Perugini (2003). *Introduzione alla Petrografia Ottica*. Perugia: Morlacchi Editore. ISBN: 8888778276.

Ring, Tim (2015). "Connected cars – the next target for hackers". In: *Network Security* 2015.11, pp. 11–16. ISSN: 1353-4858. DOI: https://doi.org/10.1016/S1353-4858(15)30100-8. URL: https://www.sciencedirect.com/science/article/pii/S1353485815301008.

Ross, Jeanne (2019). "Don't Confuse Digital with Digitization". In: *Who Wins in a Digital World? Strategies to Make Your Organization Fit for the Future*. Chap. 1, pp. 3–7.

Rüßmann, Michael et al. (2015). "Industry 4.0: The future of productivity and growth in manufacturing industries". In: *Boston consulting group*, pp. 54–89.

Saddik, Abdulmotaleb El (Apr. 2018). "Digital Twins: The Convergence of Multimedia Technologies". In: *IEEE MultiMedia* 25.2, pp. 87–92. DOI: 10.1109/mmul.2018.023121167. URL: https://doi.org/10.1109/mmul.2018.023121167.

Santarcangelo, Vito et al. (2018). "IoT made in Sud". In: *Esperienze di Ricerca e Sviluppo applicate alle brillanti realtà del nostro sud*. RCE Multimedia. Chap. 2, pp. 13–30. ISBN: 9788883991134.

Schäfer, Andreas et al. (June 2013). "From boring to scoring – a collaborative serious game for learning and practicing mathematical logic for computer science education". In: *Computer Science Education* 23.2, pp. 87–111. DOI: 10.1080/08993408.2013.778040. URL: https://doi.org/10.1080/08993408.2013.778040.

Small, Executive Agency for and Medium sized Enterprises. (2018). *Digital transformation scoreboard 2018, EU businesses go digital: opportunities, outcomes and uptake.* Publications Office. DOI: 10.2826/691861. URL: https://data.europa.eu/doi/10.2826/691861.

Smith, Matthew, Nigel Stephen Walford, and Carlos Jimenez-Bescos (2019). "Using 3D modelling and game engine technologies for interactive exploration of cultural heritage: An evaluation of four game engines in relation to roman archaeological heritage". In: *Digital Applications in Archaeology and Cultural Heritage* 14. ISSN: 2212-0548. DOI: https://doi.org/10.1016/j.daach.2019.e00113. URL: https://www.sciencedirect.com/science/article/pii/S221205481830050X.

Solima, Ludovico (Jan. 2011). "Nuove tecnologie per la valorizzazione dei beni culturali". In: *Mezzogiorno & beni culturali. Caratteristiche, potenzialità e policy per una loro efficace valorizzazione*. Cuzzolin Editore, pp. 271–294. ISBN: 978-88-87479-36-2.

Souza, Marcelo Tramontin et al. (2020). "3D printed concrete for large-scale buildings: An overview of rheology, printing parameters, chemical admixtures, reinforcements, and economic and environmental prospects". In: *Journal of Building Engineering* 32. ISSN: 2352-7102. DOI: https://doi.org/10.1016/j.jobe.

2020.101833. URL: https://www.sciencedirect.com/science/article/pii/S2352710220334665.

Stanco, F. et al. (Jan. 2017). "Virtual anastylosis of Greek sculpture as museum policy for public outreach and cognitive accessibility". In: *Journal of Electronic Imaging* 26.1. DOI: 10.1117/1.JEI.26.1.011025.

Tiraboschi, Michele and Francesco Seghezzi (2016). "Il Piano nazionale Industria 4.0: una lettura lavoristica". In: *Labour & Law Issues* Vol 2, N° 2 (2016). DOI: 10.6092/ISSN.2421-2695/6493. URL: https://labourlaw.unibo.it/article/view/6493.

Vidas-Bubanja, Marijana and Iva Bubanja (2017). "The challenge of going digital". In: *Journal of Engineering Management and Competitiveness* 7.2, pp. 126–136. DOI: 10.5937/jemc1702126v. URL: https://doi.org/10.5937/jemc1702126v.

Webel, Sabine et al. (Apr. 2013). "An augmented reality training platform for assembly and maintenance skills". In: *Robotics and Autonomous Systems* 61.4, pp. 398–403. DOI: 10.1016/j.robot.2012.09.013. URL: https://doi.org/10.1016/j.robot.2012.09.013.

Wouters, Pieter et al. (May 2016). "The effect of surprising events in a serious game on learning mathematics". In: *British Journal of Educational Technology* 48.3, pp. 860–877. DOI: 10.1111/bjet.12458. URL: https://doi.org/10.1111/bjet.12458.

Zhong, Ray Y. et al. (July 2015). "A big data approach for logistics trajectory discovery from RFID-enabled production data". In: *International Journal of Production Economics* 165, pp. 260–272. DOI: 10.1016/j.ijpe.2015.02.014. URL: https://doi.org/10.1016/j.ijpe.2015.02.014.

Ćosović, Marijana and Belma Ramić Brkić (2020). "Game-Based Learning in Museums—Cultural Heritage Applications". In: *Information* 11.1. ISSN: 2078-2489. DOI: 10.3390/info11010022. URL: https://www.mdpi.com/2078-2489/11/1/22.