TESIS DOCTORAL

AÑO 2021/2022

STRATEGIES TO IMPROVE THE INDUSTRY 4.0 ADOPTION AND KNOWLEDGE TRANSFER FOR SMALL AND MEDIUM ENTERPRISES

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Acknowledgment

GRACIAS

a EIDUNED (Escuela Internacional de Doctorado de la Universidad Nacional de Educación a Distancia), en especial a los profesores Miguel Ángel Sebastián Pérez y Cristina González Gaya por su apoyo a esta investigación.

a mi mujer Simone por ayudarme a ser cada día una mejor persona y por darme el mayor regalo de mi vida: mi hija Carlotta.

a mi familia y amigos por sacar lo mejor de mí y apoyarme cada segundo.

Abstract

The 4th Industrial Revolution opened a new era which prompts unlimited opportunities and challenges for the manufacturing industry and for the small and medium-sized enterprises (SME). Industry 4.0 technologies like Internet of Things and Cloud Computing are changing the business and manufacturing structures in profound ways. Literature review during this research showed three main gaps:

1. Recent research works fail to address the implementation of Industry 4.0 technologies in SMEs from a practical viewpoint.
2. The few existing roadmaps for the implementation of Industry 4.0 lack a focus on SMEs.
3. A collaborative Industry 4.0 knowledge transfer platform or hub designed for SMEs is missing.

To this end, a simple six-step roadmap is proposed that includes real implementations of Industry 4.0 in SMEs to cover the first two gaps. Additionally, related to the third gap, this research aims to enhance Industry 4.0 knowledge transfer through the development of a collaborative, web-based knowledge transfer Industry 4.0 platform.

The outcome of this research is firstly a collection of practical examples to demonstrate that SMEs can access several Industry 4.0 technologies with low-cost investments using the six-step roadmap. Secondly a developed collaborative Industry 4.0 knowledge transfer platform that will be referred to as Industry 4.0 HUB.

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Table 1. Abbreviations, Acronyms, and Definitions of Terms

Abbreviation	Description
AR	Augmented Reality
CRM	Customer-Relationship-Management
DT	Digital Transformation
DVPM	Digital Visual Project Management
DX	Digital Transformation
ERP	Enterprise Resource Planning
EU	European Union
GDP	Gross domestic product
IfM	Institute for Manufacturing
IIoT	Industrial Internet of Things
IoT	Internet of Things
IoT	Internet of Things
IS	Information Systems
JOP	Jumping-off Point
KM	Knowledge Management
KPI	Key Performance Indicator
KT	Knowledge Transfer
MMH	Manual Material Handling
MR	Mixed Reality
MRP	Material Requirements Planning
PYME	Pequeña y Mediana Empresa
PTL	Pick to Light
R&D	Research and Development
RFID	Radio-frequency identification
ROI	Return of Investment
SAL	Smart Assembly Line
SCM	Supply Chain Management
SDG	Sustainable Development Goals
SME	Small and Medium sized Enterprises
SOP	Standard Operation Procedure
UK	United Kingdom
UNIDO	United Nations Industrial Development Organization
VR	Virtual Reality

1 INTRODUCTION

1.1 Industry 4.0

1.1.1 Four revolutions

The world has experienced during the last two decades continuous technological disruptions. Some of the disruptions are affecting human interactions, meeting in the 90s meant to set a time and place using the desk phone or during a chat, and everyone would have appeared on time. Since the emerge of the social media platforms and apps, there is no meet up without WhatsApp, Zoom, Instagram or Facebook driving the interactions.

But the technological disruption does not only affect our social interactions but also how we work, and the businesses related to it. As we see in the Table 1, several companies listed in the early 2000s in the Fortune 500, do not exist anymore. 52 % of the Fortune 500 companies, have either gone bankrupt, been acquired, or disappeared within the last 20 years [1]. Amazon, Apple and Alphabet, and their technological disruptions, have taken their places.

Table 2. Fortune 500 [largest United States corporations by total revenue], Top 10

Ranking	2000	2010	2021
1	General Motors	Wal-Mart Stores	Walmart
2	Wal-Mart Stores	Exxon Mobil Corporation	Amazon
3	Exxon Mobil Corporation	Chevron Corporation	Apple
4	Ford Motor	General Electric Company	CVS Health
5	General Electric Company	Bank of America Corporation	UnitedHealth Group
6	International Business Machines Corporation	ConocoPhillips	Berkshire Hathaway
7	Citigroup	AT&T	McKesson
8	AT&T	Ford Motor Company	AmerisourceBergen
9	Philip Morris Companies	J.P. Morgan Chase & Co	Alphabet
10	The Boeing Company	Hewlett-Packard Company	Exxon Mobil

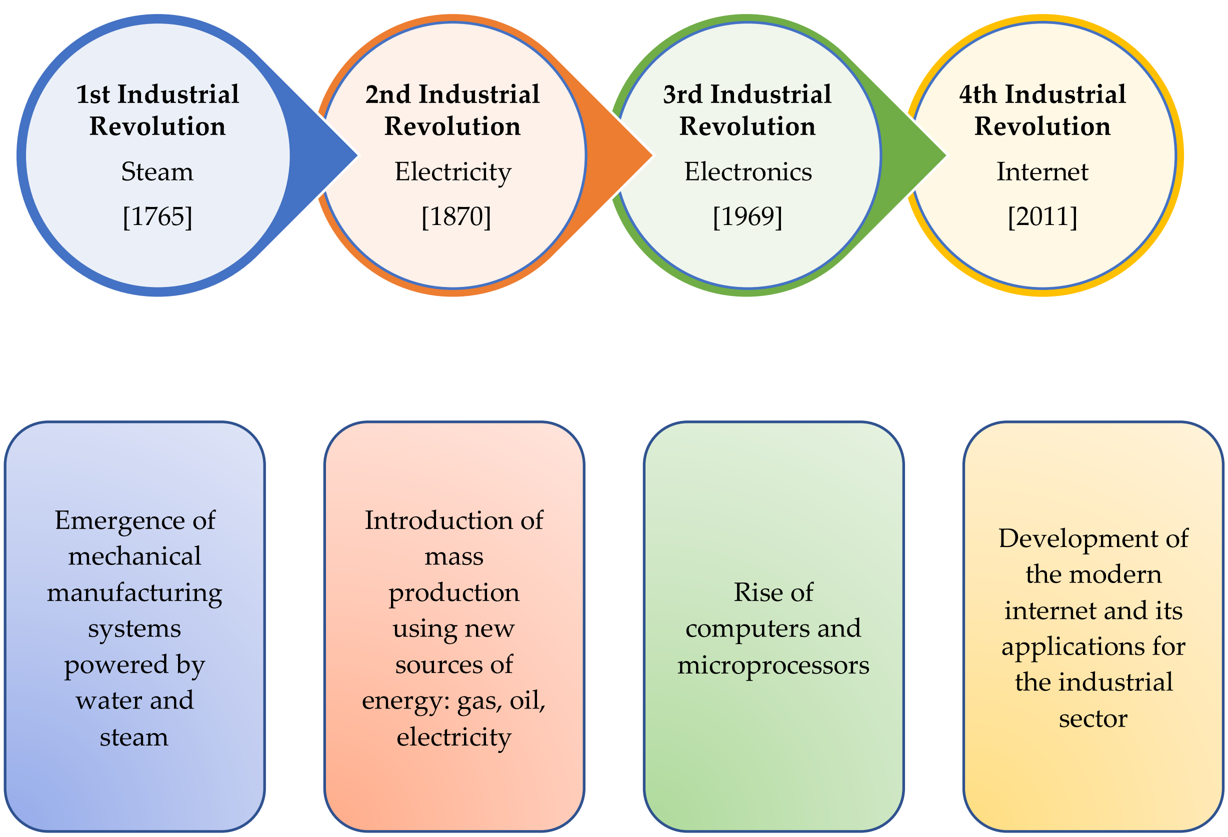
Source: Created by the author based on the data retrieved from fortune.com

The industry has also been affected by the technological revolution faced during the last two decades and the changes have not been less important:

- Digital Transformation and Cloud Computing: data has been stored for years in a physical way (tons of paper) in the basement of most companies. Nowadays a company in Berlin, stores its data in a cloud server physically located in Bangalore.
- Internet of Things and Machine Learning: Sensors, among other technologies, have changed profoundly the manufacturing lines. Automated assembly lines, generating real-time data which improves the productivity of the machines and robots using Machine Learning.

The above-mentioned examples of changes in the industry belong to revolution that has been called by the experts: the 4th Industrial Revolution or the Industry 4.0. This revolution was preceded in the past by other three revolutions, as we can see in Figure 1.

Figure 1 – Four industrial revolutions



Source: Created by the author

1.1.2 Origins

Professor Klaus Schwab, Founder and Executive Chairman of the World Economic Forum, coined the phrase “4th Industrial Revolution” in 2015, in an article published by Foreign Affairs [2] [3], which was also the subject of his book published in 2017.

On the other side, “Industrie 4.0” (Industry 4.0 in German) was launched in 2011 by the Communication Promoters Group of the Industry-Science Research Alliance. The Industry 4.0 aims to drive digital manufacturing forward by increasing digitization and the interconnection of products, value chains and business models. Industry 4.0 is pursued over a 10-15-year period and is based on the German government’s High Tech 2020 Strategy [4]. The German Chancellor at that time, Angela Merkel, highlighted very well the importance of this new industrial revolution for the German economy [5]:

"We must - and I say this as the German chancellor in the face of a strong Germany economy - deal quickly with the fusion of the online world and the world of industrial production. In Germany, we call it Industrie 4.0, because otherwise, those who are the leaders in the digital domain will take the lead in industrial production. We enter this race with great confidence. But it's a race we have not yet won."

1.1.3 Components of Industry 4.0

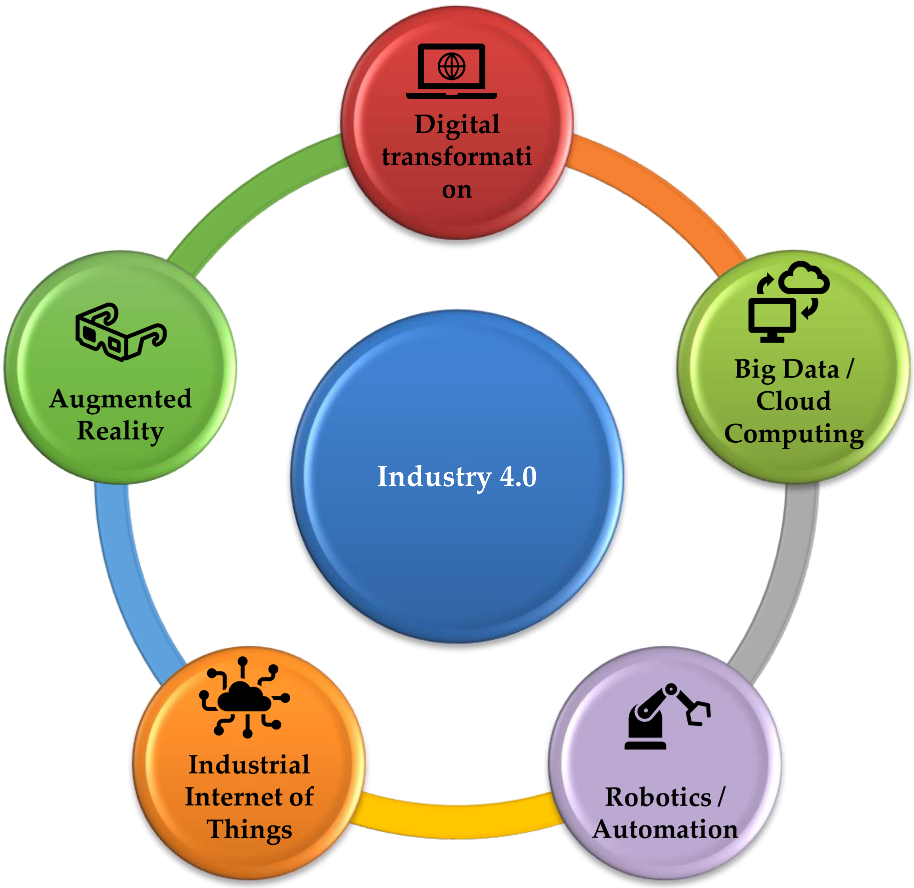
Industry 4.0 is a multifaceted term consisting of many components and growing constantly in complexity. Those components are extensive and each one requires an individual field research, but many authors conclude that all of them are interconnected [6] and a basics understanding of them is necessary to successfully implement an Industry 4.0 transformation. In the following sections some key technologies related to the industrial sector, as represented in Figure 2, considered during this research will be briefly introduced to ease the comprehension of the following chapters. Additionally, some applications and future trends will be presented.

1.1.3.1 Digital transformation

Digital transformation (DT, DX) is the use of digital technologies to transform every domain of business strategy of the companies.

Many companies face some issues understanding the exact definition of DT. Important differences exist across DT definitions with regards to the types of technologies. But despite the differences, similarities exist across definitions, for instance using common terms such as digital technologies [7]. Digital technologies change the way companies operate, because their usage reshape five key domains of strategy: customers, competition, data, innovation, and value [8]. Examples of digital technologies used in production are: Industrial Internet of Things, Artificial Intelligence, Big Data, Cloud Computing and Augmented Reality and Cybersecurity.

Figure 2 – Components of Industry 4.0 reviewed and used during this research



Source: Created by the author

1.1.3.1.1 Government initiatives for the Industry 4.0 and the Digital Transformation

The European Commission has identified the importance of the digital transformation and proposed the creation of the first-ever Digital Europe Programme, which will invest EUR 9.2 billion to align the next long-term EU budget (2021–2027) with increasing digital challenges [9, 10, 11].

Along with the Digital Europe Programme, the European Commission presented on 9 March 2021 a vision and avenues for Europe's digital transformation by 2030, the so-called Europe's Digital Decade: digital targets for 2030 [12]. But the Digital Europe Programme and the Europe's Digital Decade are not the only initiatives pursuing the digital transformation, other countries like China, Australia, Singapore, and Saudi Arabia have rolled out plans and strategies with the same purpose [13]. For instance, Australia is investing almost $1.2 billion during 2021-2022 in Australia's digital future through the Digital Economy Strategy [14] and Singapore plans to spend up to S$3.8 billion during 2021 to accelerate the digitalisation [15, 16]. The objectives and the key technologies of the Digital Europe Programme, the Australia's Digital

Economy Strategy and the Digital Government Transformation in Singapore, among others [17, 18], are shown in Table 3.

Table 3. Government initiatives promoting Digital Transformation and Industry 4.0

Initiative	Objectives	Key Technologies
Digital Europe Programme 	• Make Europe a world-leader in high-performance computing (HPC), by raising its scientific potential and industrial competitiveness. • Boost deployment of Artificial Intelligence-based solutions in critical areas like climate change or health. • Invest in cybersecurity to ensure the resilience, integrity and trustworthiness of European critical networks, infrastructures, and services. • Promote advanced digital skills, in key technologies deployed by the programme. • Widen the adoption and best use of key digital technologies to make Europe more competitive and address major societal challenges.	• Supercomputing • Artificial Intelligence • Cybersecurity

Europe's Digital Decade: digital targets for 2030

	The Digital Compass for the EU's digital decade evolves around four cardinal points:
	• Skills
	  o ICT Specialists: 20 million + Gender convergence
	  o Basic Digital Skills: min 80% of population
	• Digital transformation of businesses
	  o Tech up-take: 75% of EU companies using Cloud/AI/Big Data
	  o Innovators: grow scale ups & finance to double EU Unicorns
	  o Late adopters: more than 90% of SMEs reach at least a basic level of digital intensity
	• Secure and sustainable digital infrastructures
		• Digitalization
		• Cloud & Edge Computing
		• Artificial Intelligence
		• Big Data

Initiative	Objectives	Key Technologies
	○ Connectivity: Gigabit for everyone, 5G everywhere ○ Cutting edge Semiconductors: double EU share in global production ○ Data - Edge & Cloud: 10,000 climate neutral highly secure edge nodes ○ Computing: first computer with quantum acceleration • Digitalisation of public services ○ Key Public Services: 100% online ○ e-Health: 100% of citizens having access to medical records ○ Digital Identity: 80% citizens using digital ID	
Digital Economy Strategy 	• Building the foundations to grow the digital economy • Building capability in emerging technologies • Setting Digital Growth Priorities to lift our ambition	• Artificial Intelligence • Internet of Things • Data Analytics • Blockchain • Quantum Computing
Digital Government Transformation 	• From delivering digital services to developing Singapore into a Smart Nation, this initiative advocates innovative technology to shape the way business is done in the government	• Cybersecurity • Data Science • Artificial Intelligence • Internet of Things
High Value Manufacturing Catapult 	• To grow your business and the contribution of the manufacturing sector to the UK economy. • Investigate innovative technologies or scale up new products and processes to prove they have achieved manufacturing readiness	• Advanced Assembly • Automation • Digital Manufacturing • Biotechnology

Initiative	Objectives	Key Technologies
	• Work with academic partners to build on research at Universities and Research establishments in the UK and beyond • Use our expertise to help shape UK manufacturing policy. • Work with UK Government and others, to develop high quality training provision to meet industry needs.	
Produktion 2030 	• Resource- efficient production: To minimise the resource consumption and environmental impact of production systems and products. • Flexible production: To further develop manufacturing processes to keep pace with the products of the future. • Virtual production development: To convert information and data into knowledge and input for decision-making in virtual and physical production systems. • Humans in the production system: To strengthen cooperation between humans and automation in order to enhance people's performance and increase productivity and flexibility. • Circular production systems and maintenance: To develop competence and service-based products. • Integrated product and production development: To strengthen product development processes and tools for innovative product development.	• Automation • Digitalization

Source: Created by the author based on [9, 10, 11, 14, 15]

The Table 3 helps also to understand that the DT and Industry 4.0 are not about just one technology, they are about a strategy to deploy several technologies, such as Internet of Things or Artificial Intelligence. It is also important to mention that the initiatives are not limited to just improving the industrial sector, but also other relevant sectors of the society like urban mobility, mobile networks, government services, digital economy, etc.

1.1.3.2 Big Data / Cloud Computing

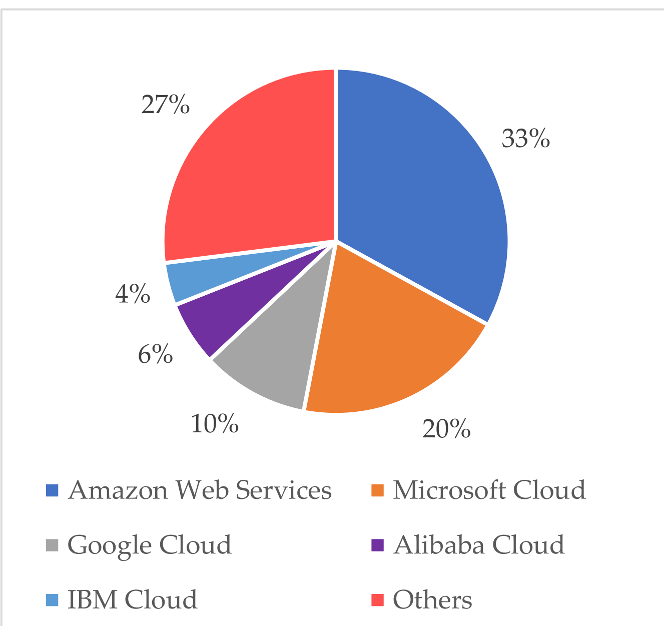
Big Data is the process of generating, capturing and analysing data coming from all kinds of sources [19]. Data sets are growing rapidly, the total amount of data created, captured, copied, and consumed globally is forecasted to increase rapidly. The total amount of data reached 64.2 zettabytes in 2020 and over the next five years, up to 2025, is projected to grow to more than 180 zettabytes [20].

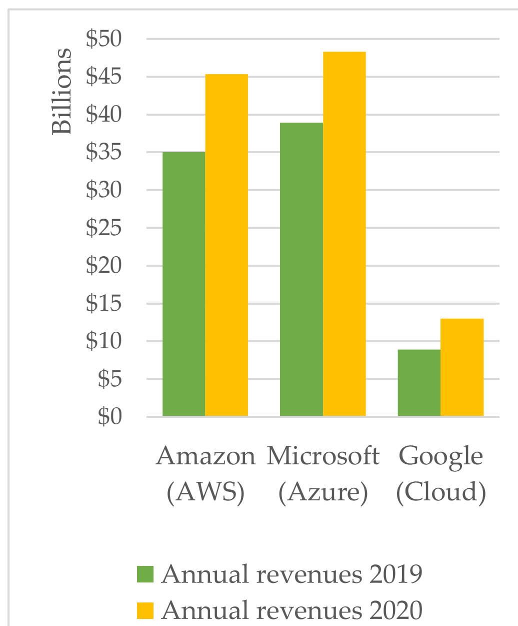
Big Data and Cloud Computing are closely related to each other. Big Data is more about extracting value while cloud computing focuses on scalable, elastic, on-demand and pay-per-use self-service models [21].

Nowadays, companies do not have the ability to store big amount of data internally, therefore they turn to Cloud Computing, which helps them to get an on-demand availability of computer system resources, without direct active management by the user. Cloud Computing is still a developing technology, some research works show that the general trend seems to be towards making use of infrastructure from multiple providers and decentralising computing away from resources currently concentrated in data centers [22].

There are three main companies dominating the market in Cloud Computing with more than 60% market share: Amazon Web Services, Microsoft Cloud and Google Cloud, as shown in Figure 3 [23, 24]. The market is expanding, and revenue growth rates show the immense profit for the companies [2020 to 2019: Amazon 23%, Microsoft 19%, Alphabet 32%] [25, 26, 27]. Because of this, the EU wants to address the current dominance of American and Chinese cloud giants, providing a federated and secure data infrastructure ecosystem, a European alternative to the existing cloud platforms [28].

Figure 3 – Cloud Market Share and Annual Revenues 2019/2020 from the top 3 companies





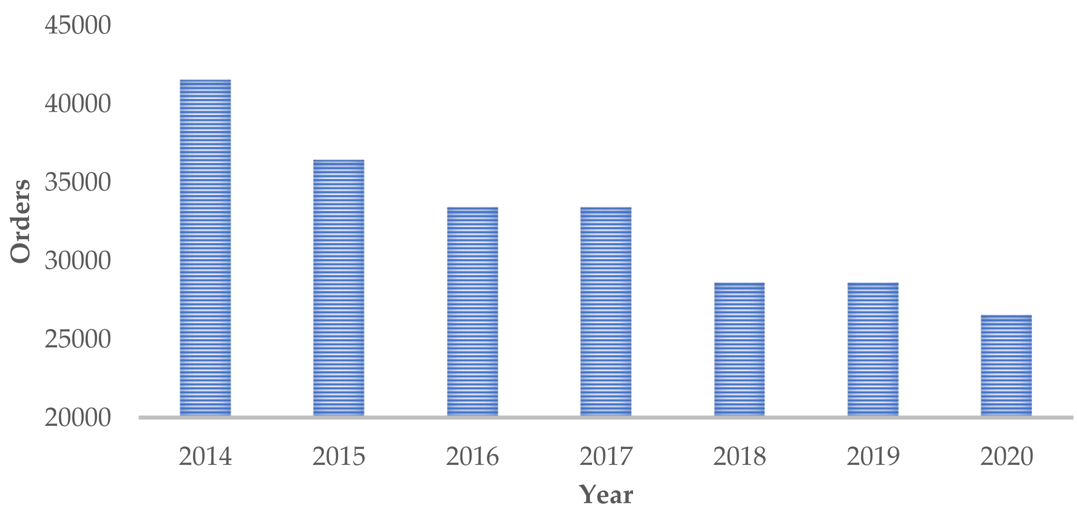
Source: Created by the author based on [23, 24]

1.1.3.3 Robotics / Automation

Robotics involves design, construction, and operation of robots. The usage of robots in the manufacturing generates a technology, knows as automation, by which a process or procedure is performed with minimal human assistance [29]. The robotics market has moved from some single players (ABB, Mitsubishi Electric, B+M Surface Systems GmbH, FANUC Robotics) to a global market shared by thousands of companies, especially Chinese manufacturers. In 2011 exploded the Chinese eager to buy robots, willing to automate all their factories, the country is currently on track to take delivery of 45% of all shipments between now and the beginning of 2022 [30].

This astonishing development led to the creation of domestic manufacturers. Nearly half of all industrial robots sold in China are domestically made by 2020 [30]. As a result of this evolution there are European companies like ABB, that are feeling the Chinese impulse as a reduction of the sales and orders, as shown in Figure 4.

Figure 4 – ABB's orders



Source: Created by the author based on the annual reports retrieved from [31]

Inside of the robotics market, there is an area that is rapidly expanding: collaborative robots, known as cobots. The cobots interact physically with humans in a shared workspace to complete tasks such as manipulation or object handovers. Cobots enable optimal combinations of the skills of machines, such as lifting heavy assemblies or performing tasks at high-speed or high temperature, with the skills of humans [32, 33, 34].

1.1.3.4 Internet of Things / Industrial Internet of Things

Industrial Internet of Things (IIoT) refers to the interconnection between sensors, instruments, work benches, test equipment and any other device used in the manufacturing [35]. It enables data collection, exchange and later analyse using for instance Big Data and Cloud Computing. As Siemens proclaims in its website [36]:

"Without the Internet of Things, there would be no Industry 4.0, no 5G, very few industrial AI applications and less work for cybersecurity experts to do"

Internet of Things (IoT) is a buzzword and its younger brother IIoT is growing exponentially and will be responsible for the market growth the next years. The IoT technology reached 100 billion dollars in market revenue for the first time in 2017, and forecasts suggest that this figure will grow to around 1.6 trillion by 2025 [37]. Gartner, Inc. forecasted that the IIoT market will grow to 5.8 billion endpoints in 2020, a 21% increase from 2019 [38]. As this research focuses on the Industry 4.0 and therefore on industrial applications, IIoT is the technology that will be analysed and used during the research.

The IIoT enables the interconnection of all areas and factors in the production: machines, material, and workers. The data generated can be sensed reliably and can also be transmitted in real time. This creates a smart interconnection, which properly used, brings several opportunities: preventive maintenance, real time problem solving, increased productivity.

A key breakthrough for the success of the IIoT and its future growth is the 5G, the fifth-generation technology standard for broadband cellular networks, which cellular phone companies began deploying worldwide in 2019. Several research studies agree on the importance of 5G technology, as it will play a key role as a communication framework to make smart manufacture an effective element in the increase of flexibility and productivity in industries around the world [39, 40, 41].

1.1.3.5 Augmented Reality

Augmented Reality (AR) is used to describe a combination of technologies that enable real-time mixing of computer-generated content with live video display [42]. AR enhances the reality [43] and has several applications [44], such as:

- In the industry to substitute paper manuals with digital instructions which are overlaid on the manufacturing operator's field of view, reducing mental effort required to operate [45].
- In the medicine to deliver clinical care to patients, in operating rooms, surgery and in education and training of emergency care providers [46].
- AR can also be used for human-robot collaboration, for instance for the remote manipulation of a robot [47].

The concept AR can also be broadened to virtual reality (VR) and mixed reality (MR), as AR is based on techniques developed in VR and MR. AR can be also subdivided in different categories, to enhance the definition of the technology is worth to highlight the classification presented in the research work [44]:

1. Display: the essential requirement discriminating AR displays from ordinary computer displays consists in the necessity to merge reality and virtuality.
2. Tracking: includes systems that perform the virtual object registration in a real environment.
3. User Interaction: includes a specific branch of human-computer interaction, uses alternative means to traditional 2D user inter-faces such as a mouse, keyboard, and touch screen input.
4. Application: includes existing solutions and technologies that innovate in a specific domain of application.

5. System: includes integrated AR solutions that are innovative because exploit existing AR technologies in a novel way but are not specifically designed to be adopted in various industry domains.

The global AR, VR and MR market is forecast to reach 30.7 billion U.S. dollars in 2021, rising to close to 300 billion U.S. dollars by 2024 [48]. Based on the analysis of the AR patents filled during the last years [44], all big organizations are developing new AR business opportunities: Microsoft, Google, Siemens, Amazon, etc.

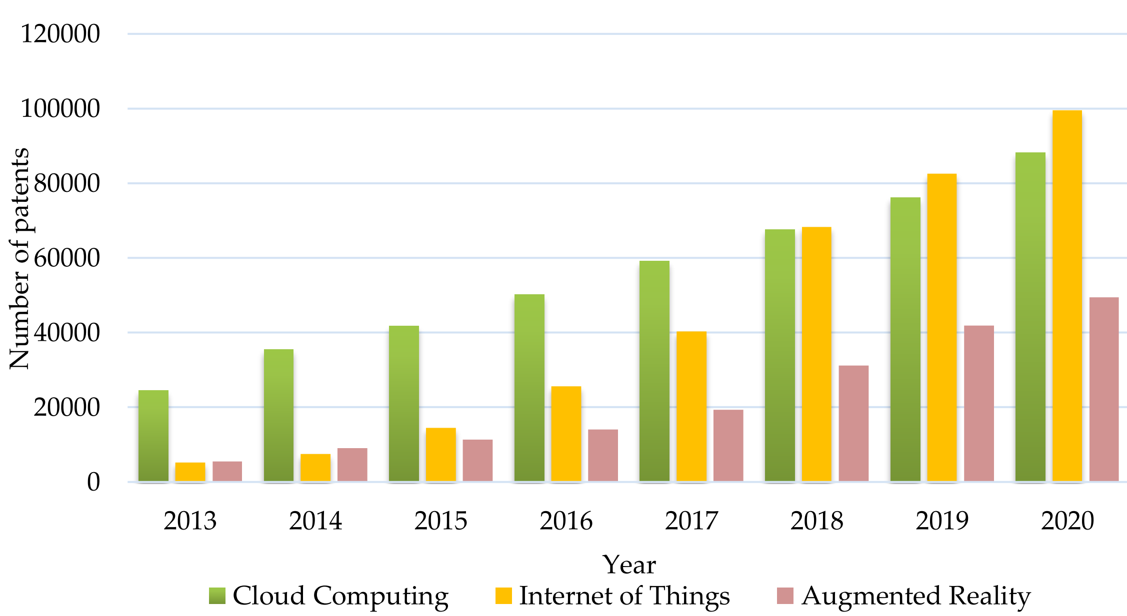
1.1.3.6 Industry 4.0 outlook

Industry 4.0 components and technologies are evolving fast. These changes are driving the world towards a future of production characterized by autonomous, self-organizing factories and integrated production systems.

The outlook for the following years shows that the change is still not over:

- The numbers of patents in any of the Industry 4.0 fields selected for this research are still growing every year, as shown in Figure 5.
- Countries all around the world are including Industry 4.0 policies in their political programmes [10, 49].
- All forecasts foresee a rise in all Industry 4.0 technologies investment. Companies expect Industry 4.0 to generate significant benefits and are investing big amounts [50, 38, 37].

Figure 5 – Number of patents by Industry 4.0 component

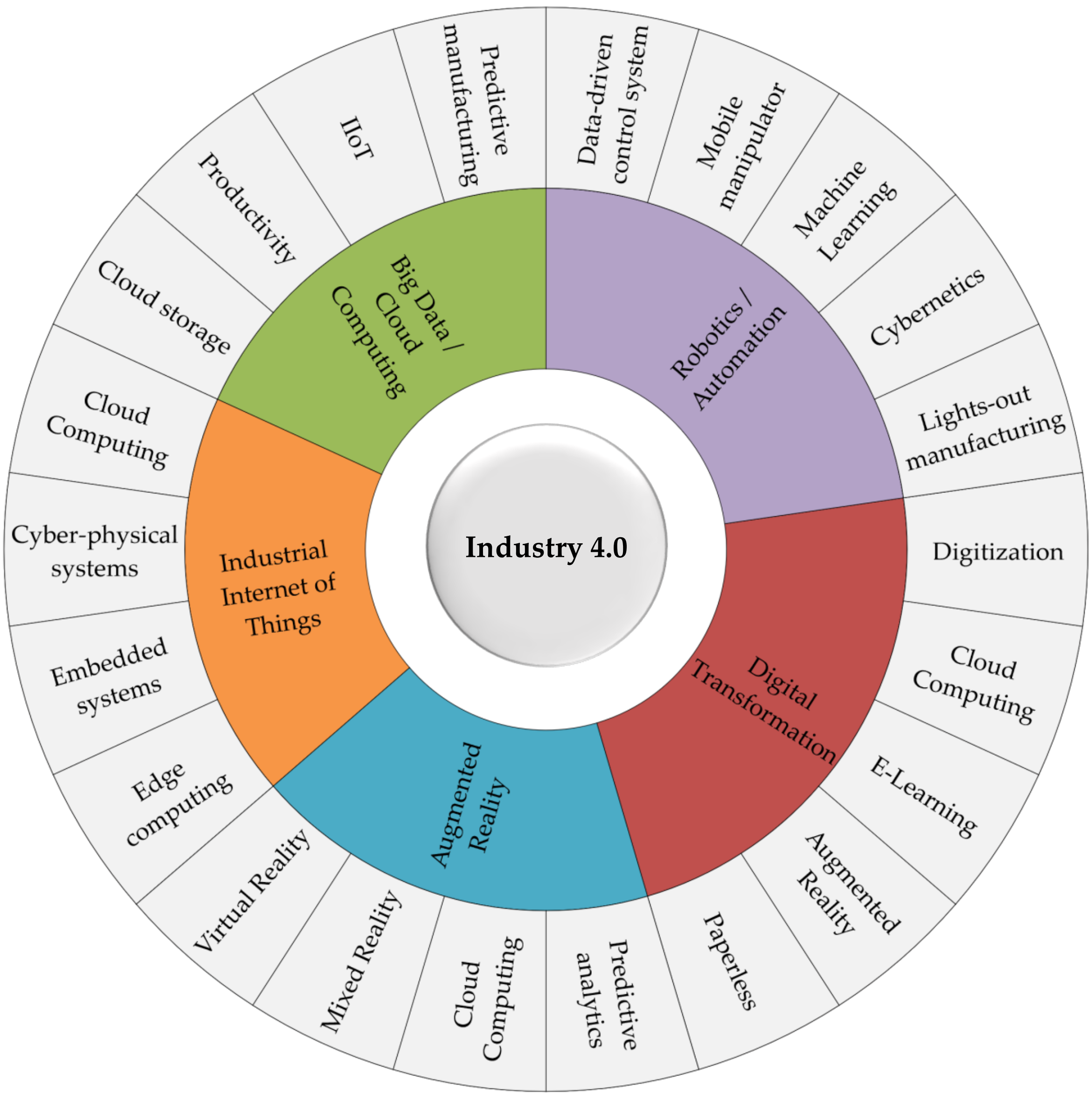


Source: Created by the author retrieving the data from https://worldwide.espacenet.com/patent/

1.1.3.7 Other components and interconnection

It is important to mention that there are lot of other technologies and components which can be interconnected and related to the Industry 4.0, like: 3D printing, machine learning, human-machine interfaces, etc.

Figure 6 – Sunburst and interconnection of the Industry 4.0 components



Source: Created by the author

The Industry 4.0 transformation has for every company a different meaning and a different path to be achieved, but at the same time, every company needs to comprehend the different components and tools offered in order to define the right business strategy. Those components are interconnected and serve different areas of the company. The interconnection of the different components of the Industry 4.0 is shown in the Figure 6 as some branches (inner circle) are replicated in some stems/leaves (outer circle).

1.2 Small and Medium Enterprises and their Supply Chain

1.2.1 SMEs in Europe

The European Commission defines three SME enterprise categories [51] as shown in Table 4:

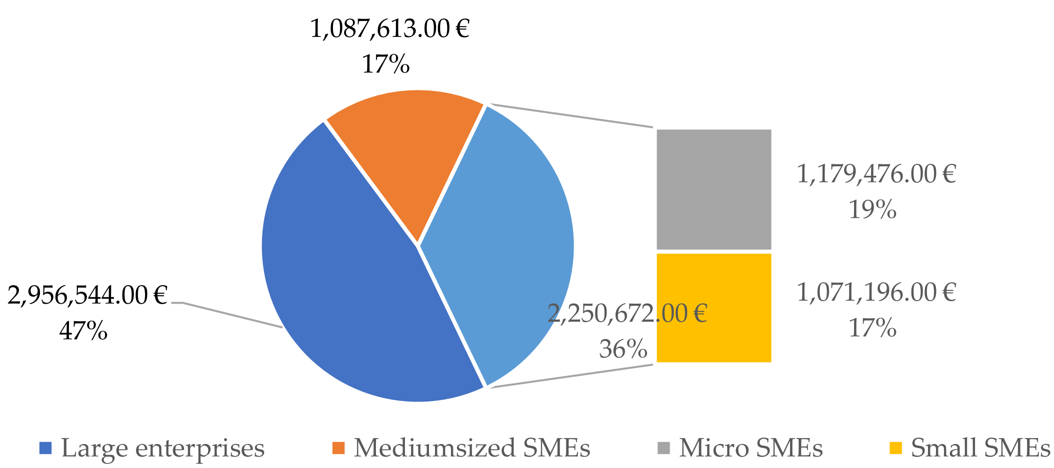
Table 4. Commission Recommendation concerning definition of SMEs

Enterprise Category	Employees	Turnover
Micro SME	0 to < 10	< €2 million
Small SME	10 to < 50	< €10 million
Medium-sized SME	50 to < 250	< €50 million

Source: Created by the author based on [51]

There were slightly more than 22 million enterprises in the EU-27 in 2020, of which 99.8% were SMEs and 0.2% large enterprises. Digging into the numbers, 99% of all enterprises are either micro-SMEs or small SMEs. All SMEs generated 53.0% of the value added, as represented in Figure 7, and 65.0% of the employment in 2020 [52]. These facts show the importance of the SMEs, especially micro and small SME, in the European economy and development.

Figure 7 – Value added (€) of the three different enterprise categories in 2020



Source: Created by the author based on [51]

1.2.2 Supply Chain in SMEs

1.2.2.1 Introduction and future trends

Likewise, the manufacturing sector plays a crucial role in Europe, serving as a key driver of economic growth and accounting for 80% of all exports, 25 % of the GDP and 65% of all innovations [53, 54, 55]. One key element of the manufacturing sector is its supply chain.

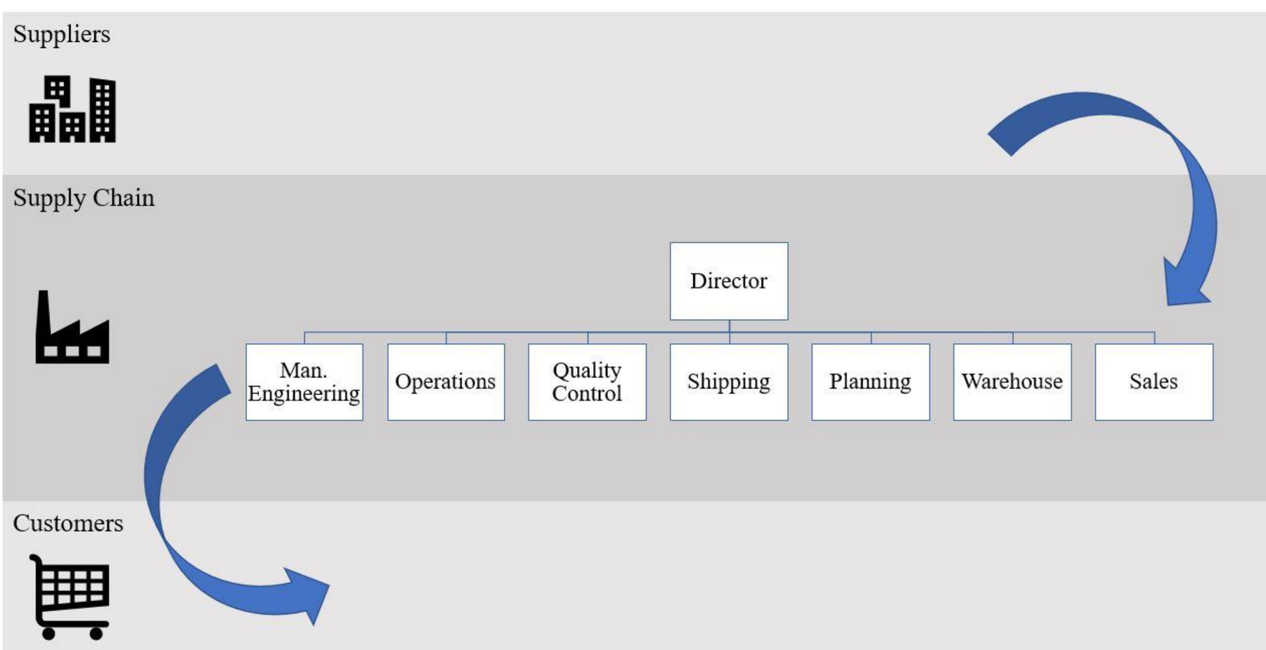
Supply chain is a system of organizations, people, activities, information, and resources involved in supplying a product or service to a consumer. Supply chain activities involve the transformation of natural resources, raw materials, and components into a finished product that is delivered to the end customer [56, 57, 58].

Supply chain is the heart of a company's operations, and it is facing tremendous challenges, which requires a digital transformation driven by the industry 4.0. New digital technologies have the potential to take over supply chain management entirely are disrupting traditional ways of working [59].

1.2.2.2 Organizational structure

As shown in Figure 8, supply chain has a flat organizational structure, due to fast decision making is required. Time matters and the information needs to flow quick and easily through the departments. A supply chain organization is a multifunctional and complex enterprise, which comprises several departments and roles:

Figure 8 – Supply chain organization



Source: Created by the author

Manufacturing Engineering

- Creation of the manufacturing work instructions
- Troubleshooting in the shop floor
- Implementation of the design changes coming from R&D
- Creations and documentation of the manufacturing processes
- Development and support of new technologies and lean tools

Operations

- Manufacturing of the product
- Implementation of lean tools
- Securing the quality of the product

Quality Control

- Creation of the qualification plan and report
- Validation and auditing of the manufacturing processes
- Securing the quality of the product
- Incoming inspection of the single parts and subassemblies
- Final inspection of the finished products

Shipping

- Packaging of the finished goods
- Shipment of the finished goods

Planning

- Creation of the work orders
- Planning of the raw material consumption
- Forecasting
- Implementation of Kanban systems and Min/Max systems

Warehouse

- Management of the material in the warehouse
- Movement of the material from incoming inspection to warehouse
- Picking material for the manufacturing line (operations)

Sales

- Frame contract discussions

- Price agreements
- Supplier selection

Some small SMEs and most medium-sized SMEs in the manufacturing sector, have a similar structure as the one described above. Micro SMEs, due to the lack of resources, have less roles and departments, which are covering more competencies.

1.2.2.3 ERP as starting point for the digitalization of SMEs and their SCM

Enterprise resource planning (ERP) is the integrated management of main business processes. Companies use ERP solutions to collect, store, manage and interpret data from many business activities [60, 61, 62]. ERP solution might cover business areas such as Human Resources (HR), Supply Chain Management (SCM), Manufacturing (PLM), Procurement/Sales (SRM), Customer Services (CRM), and Finance, as represented in Figure 9:

Figure 9 – ERP Modules

Source: Created by the author

There are two big players in the ERP market: SAP and Oracle. The two together control more than 40 % of the market, leaving the rest for the competitors like Sage, Microsoft, and Infor [63].

The solutions are very capable and cover all areas of the supply chain presented in the section 1.2.2.2. ERP solutions are the starting point for the digitalization of the companies and therefore for the Industry 4.0 transformation. The information and resources of the company must be available in an integrated management software.

During the last ten years, all companies have moved their ERP solution to the cloud, enlarging their capabilities by using cloud computing and enabling SMEs to start using ERP as Software as a service (SaaS) [64, 65]. But there are still some reasons preventing the SMEs to access to the ERP solutions: high prices, complexity, necessity of training and support after the purchase, applicability for several departments, capabilities of the solutions offered are higher than the requirements to be fulfilled [66].

Each vendor claims that using its product will give an enterprise a competitive advantage. Large companies can afford to invest in ideas that may bring them a competitive advantage, for instance implementation full ERP solutions from Oracle or SAP. The SMEs do not have this luxury. They are pretty much sceptical about the change in their working style unless and until they are sure about the effectiveness of the new technology in terms of bottom-line results. This causes in most of the cases a make decision; the SMEs decide to manage its supply chain using the software tools which are already available (e.g.: Excel, partial implementation of Oracle or SAP, small vendors covering some of their needs…).

1.3 Access to the Industry 4.0 for SMEs

Europe, as well as other economies like United States, Japan, India, or China rely on their manufacturing sector, to continue the economic expansion and to ensure the well-being of their citizens. SMEs are facing tremendous challenges since 2011 due to the 4th Industrial Revolution, in the form of emerging Industry 4.0 technologies and their applications for the industrial sector [67, 68, 69].

SMEs are crucial to the growth in European regions, and they must participate in the benefits. SMEs are the backbone of the European economy, and their importance for jobs and growth in European regions, as shown in 1.2.1, cannot be underestimated. To reach the Digital Compass 2030 target, at least 90% of SMEs of the EU should have a basic level of digital intensity. In 2020, only 60% of SMEs were at that level in the adoption of digital technologies. Denmark and Finland are already very close to the EU target with 88%, while Bulgaria and Romania are lagging far behind (33%) [70, 71]. To enable SMEs to benefit from the opportunities of digitalisation, their participation in collaborative research programmes with other SMEs and large companies must be facilitated.

As some experts already highlighted, some organizations might be unable to adapt to the Industry 4.0 [2] and SMEs are the first victims. SMEs need to adapt to the digital transformation and all other Industry 4.0 technologies, but Industry 4.0 is not only about technology, it is about strategy and new ways of thinking [8].

The responses of the Flash Eurobarometer 486 showed that in 2020 just a quarter of EU-27 SMEs had already introduced advanced digital technologies such as Industry 4.0 technologies or were planning to do so [52]. There is still a big gap to close.

Literature review in recent years showed that SMEs must be considered separately from large enterprises regarding Industry 4.0 implementation, because they are less capable of coping with the financial, technological, and staffing challenges than large companies [72, 73, 74]. This is something that has been identified not only in research works, but also in government initiatives, like Industrie 4.0 in Germany, which have highlighted this issue [4].

This has resulted in technology-transfer projects specifically for SMEs to pass on Industry 4.0 solutions, and in extensive research works, as shown in Table 5 concerning SMEs and Industry 4.0 especially in the first two of the three following areas:

- Identification of key Industry 4.0 technologies, challenges and the associated benefits for SMEs (1)
- Maturity level of implementation or classification based on the level of Industry 4.0 implementation in SMEs (2)
- Process model or roadmap for the implementation of Industry 4.0 technologies (3)

Table 5. Literature review to identify the gaps regarding the access to the Industry 4.0 for SMEs

Title	Area	Focus on SMEs	Type of paper	Reference
Industry 4.0: Adoption challenges and benefits for SMEs	1	Yes	Survey / Statistical Analysis	[75]
Industry 4.0 technology implementation in SMEs - A survey in the Danish-German border region	1	Yes	Survey / Statistical Analysis	[76]
Three Stage Maturity Model in SMEs towards Industry 4.0	2	Yes	Conceptual	[77]
The future of manufacturing industry: a strategic roadmap toward Industry 4.0	3	No	Conceptual	[78]
A Maturity Level-Based Assessment Tool to Enhance the Implementation of Industry 4.0 in Small and Medium-Sized Enterprises	2	Yes	Conceptual	[79]
Classification of Small- and Medium-Sized Enterprises Based on the Level of Industry 4.0 Implementation	4	Yes	Conceptual	[80]
Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges	1	No	Literature review / Conceptual	[81]
Process model for the successful implementation and demonstration of SME-based industry 4.0 showcases in global production networks	3	Yes	Conceptual	[82]

Title	Area	Focus on SMEs	Type of paper	Reference
A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs)	2	Yes	Literature review	[83]
Literature Search of Key Factors for the Development of Generic and Specific Maturity Models for Industry 4.0	2	Yes	Literature review	[84]
Challenges of Industry 4.0 Technology Adoption for SMEs: The Case of Japan	1	Yes	Conceptual	[85]
Problems with the Implementation of Industry 4.0 in Enterprises from the SME Sector	1	Yes	Conceptual / Survey	[69]
Roadmap Industry 4.0 – Implementation Guideline for Enterprises	3	No	Conceptual	[86]

Source: Created by the author

1.4 Industry 4.0 Knowledge Transfer

The 4th Industrial Revolution is profoundly changing the structures and processes within companies. Industry 4.0 is a one-time event that brings opportunities and challenges for large-sized enterprises, as well as for SMEs [75, 85]. Big companies have deployed investment plans, roadmaps, and worldwide investigation groups to support the transition toward Industry 4.0. The close relationship between a large-sized enterprise and an SME requires both advancing and progressing at the same speed. Therefore, SMEs must adapt to Industry 4.0 developments proposed by large companies. To cope with this transformation and be able to adopt Industry 4.0 innovations, SMEs must demonstrate flexibility and adaptability. However, many SMEs still find it difficult to know which Industry 4.0 technologies to invest in [69, 87, 88].

The Industry 4.0 could end up being an obstacle to support firm competitiveness and productivity if the SMEs' peculiarities are not properly identified and supported. To gain a better insight into the characteristics of SMEs adopting Industry 4.0 technologies, a systematic literature review was performed to understand the challenges and problems that SMEs are facing during the Industry 4.0 transformation. Some authors refer to financial resources and technology awareness as the primary challenges that the SMEs are facing.

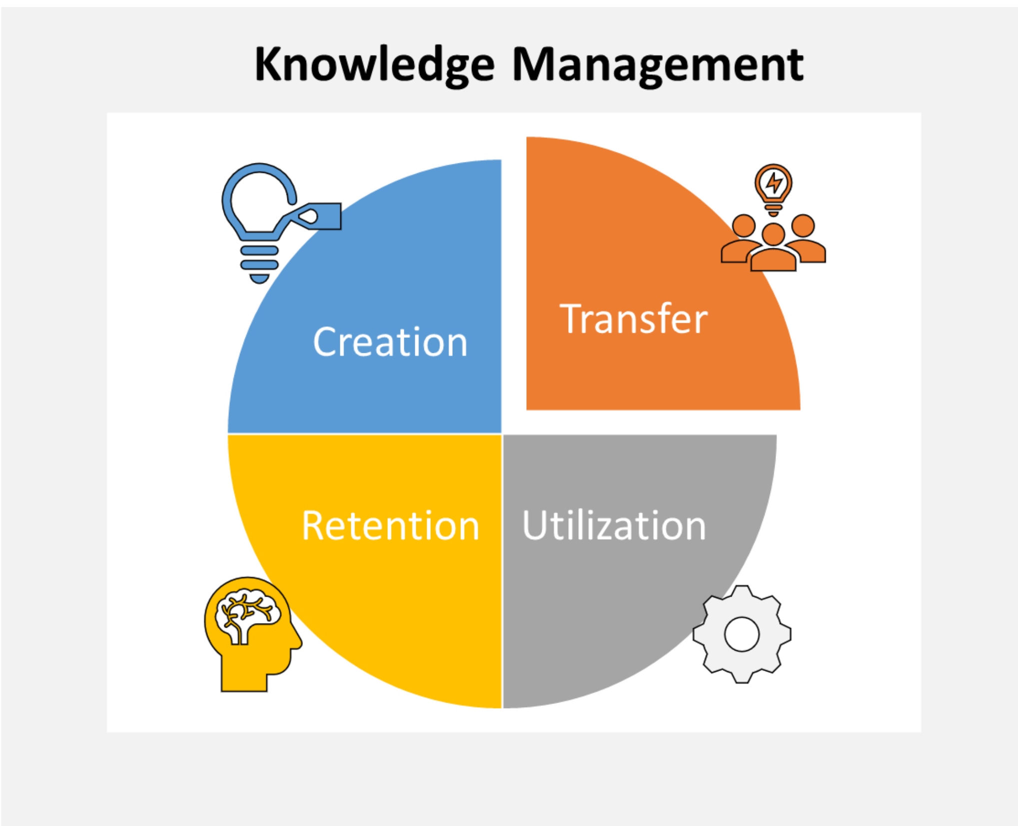
Other research points out high costs, a lack of information, complexity, and the abundance of technologies as the key challenges and problems. However, all of them agree on one challenge: a lack of knowledge [75, 85, 69, 87, 88, 89, 90]. SMEs have problems accessing Industry 4.0 knowledge due to the lack of knowledge management and transfer.

Knowledge management (KM) is a field of study that has existed for more than four decades [91]. It can be defined as the process of creating, sharing, using, and managing the knowledge and information of an organization [92, 93]. KM has four primary activity areas or knowledge flows, as shown in Figure 10: knowledge creation, retention, transfer, and utilization [94, 95].

Knowledge Transfer (KT), sometimes also known as knowledge sharing (KS), refers to sharing knowledge from one individual or group of individuals (e.g., an SME) to another individual or group of individuals. KT pursues to create, organize, and distribute knowledge between different users and seeks to ensure its availability to future users [93, 94, 95, 96]. KT is a complex field because of the plurality of sources, including individuals, organizations, the internet, and books. Some aspects hindering successful KT are communication issues, a lack of networking and difficulty accessing the knowledge [97, 98]. The ability to transfer knowledge effectively in the networks of SMEs is of paramount importance for supporting the transition to Industry 4.0.

Several studies suggest the development of online platforms to optimize KT [99, 100]. These kinds of platforms promote a knowledge-sharing culture through discussion forums and other transfer tools so that SMEs contribute to the overall success.

Figure 10 – Knowledge management and the four knowledge flows.



Source: Created by the author

1.5 Sustainable Development Goals

1.5.1 2030 Agenda for Sustainable Development

The 2030 Agenda for Sustainable Development was adopted by all United Nations Member States on 25 September 2015.

The target of this agenda was to provide a shared master to stimulate action over the next fifteen years in areas of critical importance for humanity and the planet: people, planet, prosperity, peace, partnership. At its heart are the 17 Sustainable Development Goals (SDGs), logo shown in the Figure 11, which are an urgent call for action by all countries - developed and developing - in a global partnership.

They recognized that ending poverty and other deprivations must go together with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests [101].

Figure 11 – Sustainable Development Goals

Source: logo retrieved from https://www.un.org/sustainabledevelopment/news/communications-material/

1.5.2 Interconnection between Industry 4.0 and SDGs

The agency UNIDO of the United Nations specialized in industrial development for poverty reduction, inclusive globalization, and environmental sustainability, reported in 2016 from an expert discussion the following key conclusions [102]:

- The importance of building awareness of the Industry 4.0 consequences for inclusive and sustainable industrial development and providing access to know-how, skills, education, and technology.
- The great potential of innovation management standards to help developing countries and economies in transition to leapfrog into Industry 4.0. These guiding frameworks would be relevant for all types of organizations, including SMEs.

1.5.3 Goals for this research

This research is aligned with the following Sustainable Development Goals, as shown in Figure 12:

- **Industry, Innovation and Infrastructure**

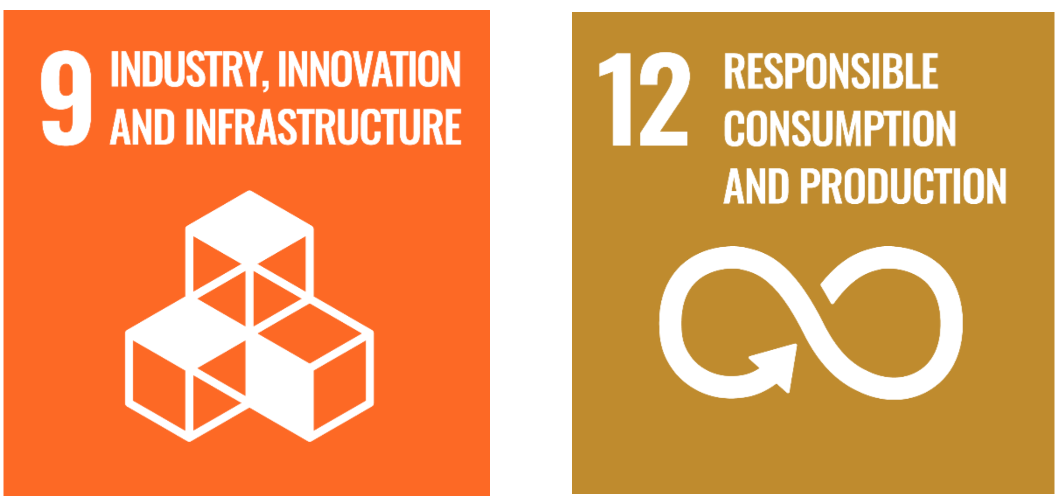
This goal seeks to build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

The Industry 4.0 technologies can transform a developing region in a developed region. Almost every government is investing in Industry 4.0, willing to provide its residents a profound skillset and know-how, capable to transform a society.

- **Responsible Consumption and Production**

This goal pursues to ensure sustainable consumption and production patterns. The digital transformation, as part of the Industry 4.0, enables the adoption of a new strategy in the supply chain to go paperless to reduce the carbon footprint.

Figure 12 – Goals for this research



Source: logos retrieved from https://www.un.org/sustainabledevelopment/news/communications-material/

1.6 Gaps

The broad scope of the Industry 4.0 makes its implementation challenging. For every SME has the Industry 4.0 transformation a different meaning and a different path to be achieved, but at the same time, every company needs to comprehend the different components and tools offered in order to define the right business strategy.

As described in the section 1.3, most of these research works aim to investigate SMEs from a theoretical point of view. There is, however, a gap in the practical viewpoint, which is greatly needed for business-oriented implementations, as shown also in the Table 5. Additionally, the few roadmaps described for the implementation of Industry 4.0 lack the focus on SMEs, which leads to a second gap in this area, as highlighted in the Table 5.

Moreover, based on the literature review described in the section 1.4, this research focuses on Industry 4.0 KT within SMEs, as this was the primary challenge identified during the literature review.

2 AIMS AND OBJECTIVES

Access to Industry 4.0 technologies must be simplified for SMEs, especially for microenterprises. SMEs can't afford to lose money; they need to choose very carefully how to invest it. SMEs need to hit the target when choosing technologies for the transformation to Industry 4.0 and this research focuses initially on developing a roadmap to implement Industry 4.0 components in an assembly line, describing some practical examples for each technology, turning an outdated manufacturing line into a Smart Assembly Line (SAL).

Additionally, two aspects must be considered as crucial for the success of SMEs: the improvement of the access to Industry 4.0 knowledge and Industry 4.0 KT. Therefore, this research aims to enhance Industry 4.0 KT through the development of a collaborative, web-based knowledge transfer Industry 4.0 platform.

Both research objectives are aligned with the two SDGs previously described in the section 1.5.

2.1 Definition of 1st research question

How to adopt the disruptive and productive technologies offered of the Industry 4.0 in SMEs and where to start?

2.2 1st Research objective

This research has its focus on developing a roadmap for the implementation of Industry 4.0 components in an assembly line, describing some practical examples for each technology, turning an old-fashion manufacturing line into a SAL.

The 1st research question attempts to fulfil the following objectives:

1. Study the state-of-the-art Industry 4.0 technologies and their possible implementation in SMEs.
2. The definition of a roadmap helping SMEs through the different steps of the Industry 4.0 transformation.

2.3 Definition of 2nd research question

How to enable the access to Industry 4.0 for SMEs providing a collaborative Industry 4.0 knowledge transfer platform?

2.4 2nd Research objective

This research has its focus on starting the development of a collaborative Industry 4.0 knowledge transfer platform. The platform attempts to fulfil the following objectives:

1. Analyse the existing KT initiatives and platforms supporting the Industry 4.0 transition within SMEs.
2. Propose a new collaborative online platform to improve Industry 4.0 KT between SMEs.

3 METHODOLOGY

3.1 Introduction

In this chapter the methods used to develop the two main results of this research, Industry 4.0 Roadmap and Industry 4.0 HUB, are described. Moreover, this chapter will define and justify all the research decisions made, as well as describe the research strategy and procedures followed.

The first section 3.2 presents the methodology in three stages utilized to create, test, and validate the Industry 4.0 Roadmap. It begins with a literature review of Industry 4.0 implementations for SMEs and ends up producing a singular roadmap for the implementation of Industry 4.0 technologies in SMEs. Through this chapter, the lector will gain an overview on the development of the Industry 4.0 Roadmap, which it is the foundation to review and understand the qualitative and quantitative results presented later in the chapter 4.

Secondly, the section 3.3 introduces the methodology in two phases applied to the creation of the Industry 4.0 HUB. The initial literature review to understand the existing Industry 4.0 knowledge transfer platforms leads to the development of a newly web-based platform to promote the collaboration between SMEs. In this section, the lector will get an insight into the current Industry 4.0 knowledge transfer platforms and the programming languages used for the development of the Industry 4.0 HUB. Subsequently in the chapter 5, the functionalities and advantages of the Industry 4.0 HUB will be presented.

3.2 Industry 4.0 Roadmap

For the first research objective, the following research method in three stages was used:

1. Literature review conducted in 2019 and the start of 2020 to:
    - identify the situation of SMEs in Europe
    - benchmark the transformation towards Industry 4.0 of large enterprises
    - understand Industry 4.0 concepts and technologies and estimate their costs
2. Development of the roadmap for SMEs and shaping the concept of Smart Assembly Line (SAL) in 2019.
3. Testing and validation of the roadmap by using different Industry 4.0 technologies in 2020 and 2021.

3.2.1 Background

3.2.1.1 Industry 4.0 technologies

The analysis of different Industry 4.0 technologies was carried out by reviewing some European guidelines; for instance, those proposed by The Mechanical Engineering Industry Association (VDMA), and the compilation of practical examples created by this association since 2019 [103] [104]. Additionally, benchmarking was performed through internet research, to obtain a preliminary view of the top Industry 4.0 performers. Best practices have been identified in companies like Volkswagen, Amazon, Siemens, etc. [105] [106] [107] [108].

There is extensive literature about technologies related to Industry 4.0 [81] [4] [73] [103] [109]. Industry 4.0 can be implemented in every industrial sector, from shipbuilding to aerospace and medical devices. Transformation to Industry 4.0, however, means different things to each company in these sectors, with different ways to achieve this. At the same time, every company needs to understand the different components and tools offered in order to define the right business strategy [110].

Considering the large number of technologies related to Industry 4.0, four of these technologies were selected to perform a deep dive into the literature review: Cloud Computing, IoT, Digital Transformation (DT) and VR.

Some authors consider IoT and Cloud Computing the key technologies of Industry 4.0 [81]; others, cannot imagine a transition to the 4th industrial revolution without considering several Industry 4.0 pillars at the same time [111]. Several authors highlight the advantages that Cloud Computing offers, for instance, it saves costs and delegates liabilities to third-party providers [112].

Moreover, the development of the IoT is a crucial moment in the history of humanity because it is changing our mindset, culture, and the way we live or manufacture. Just like with the internet age, there will be a pre-IoT world and a post-IoT world. The IoT era will not be an instantaneous transition, but a gradual and continuous shift during which evolution will never stop [113]. Sensor technologies, which are a key element of the IoT, have experienced an incredible development in recent times and still have some challenges ahead, like proper standardisation [114]. This development has been driven by the advent of high-speed and low-cost electronic circuits, a change in the way we approach signal processing, and corresponding advances in manufacturing technologies [115]. Likewise, the DT provides business the ability to digitize, automate and integrate processes, which enables them to shift away from analog approaches [116].

Additionally, there are some research works and conference proceedings that believe that VR will greatly support the accessibility of smart manufacturing [117] [118] [119].

Based on the abovementioned literature review, following conclusions are worthy to be mentioned:

- IoT has experienced tremendous cost reduction in the past few years and the technologies offered have multiplied.
- DT is the foundation of a successful implementation of Industry 4.0 technologies. It brings powerful benefits to the businesses and enables them to adapt to a changing market
- Cloud Computing is, nowadays, a well-established technology offered at a low-cost price.
- VR is a very flexible technology that can be implemented in several areas of production.

Moreover, the outlook for the coming years according to the number of patents as represented in Figure 5, shows that Industry 4.0 growth is still ongoing. This will lead to cost reduction and will enable access to these technologies by more companies.

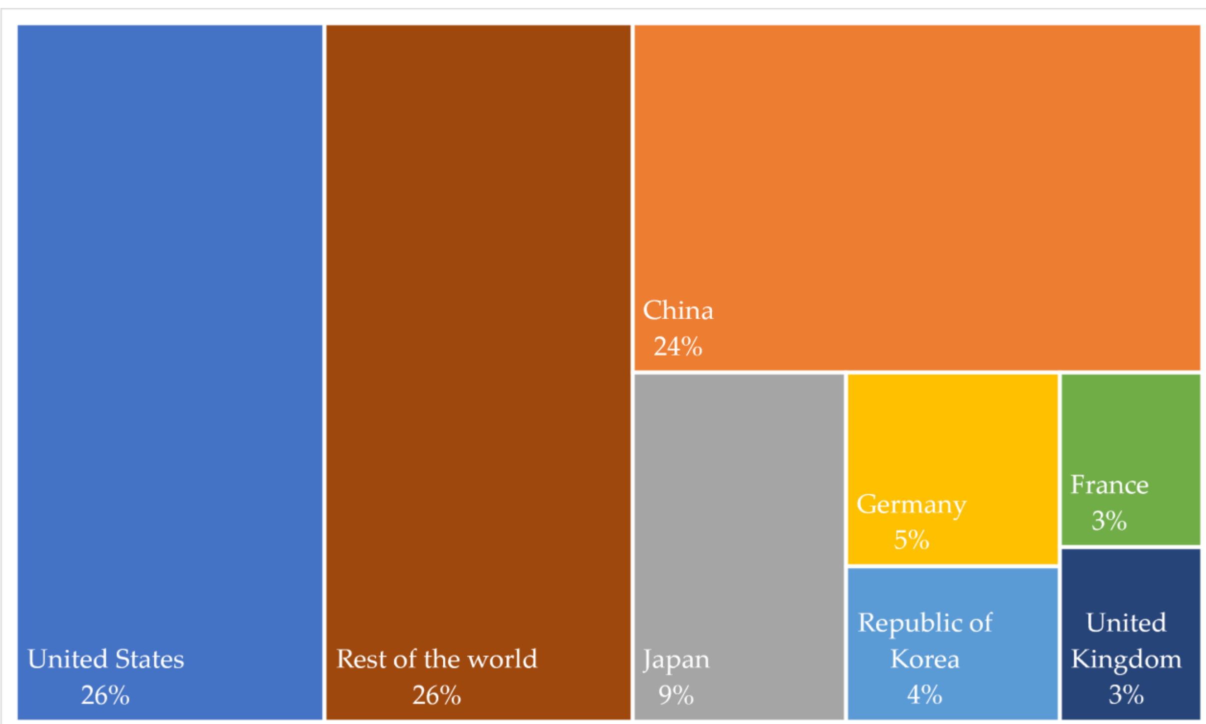
3.2.1.2 Regional and global disparities in industrial digitization

There is an important aspect to be considered while implementing Industry 4.0 technologies: the already existing economic divergence between low and high performing regions and states in Europe. Low performing regions in Europe, as regions with lower GDP per capita, have commonly fewer large enterprises than high performing regions. SMEs are their main contributor to the economic growth [120, 121, 122, 52].

Industry 4.0 and its new technologies might widen economic disparities between regions if SMEs in low performing regions are not able to catch up with the industrial transformation [122]. European policies must address this issue and promote a convergence driven by Industry 4.0 implementation in SMEs. While some EU countries are at the global forefront of digital transformation, others risk being left behind. Some organizations, like the European Investment Bank, have highlighted the importance of this convergence [123].

Moreover, the disparities are to be seen also on a global level: one representative example is the spending on IoT. United States, China and Western Europe account for roughly three quarters of all IoT spending [124, 125], as shown in Figure 13. Although the three regions will have similar spending totals initially, China's spending will grow at a faster rate than the other two regions, as some forecasts are predicting.

Figure 13 - Geographical distribution of spending on Internet of things, 2019



Source: Created by the author based on [124, 125]

3.2.1.3 Private investment in Industry 4.0 – Large-sized companies

Large-sized companies in Europe have rolled out investment plans and roadmaps for DT and IoT lasting until 2022-2023 [105, 107, 108].

These companies are willing to digitalize business processes, implement agile working methods, help reduce the burden on employees, improve productivity and speed up processes. Tasks that used to be performed manually are to be simplified through improved IT [105]. Personal relationships between the company and the customer are to be made online and this development will lead to the development of new professions that do not currently exist [126].

No matter the business sector (telecommunications, banking, automobile industry, food industry, technology, medical devices, insurance or clothing, etc.), every large-sized company has a roadmap for digital transformation and the implementation of Industry 4.0 technologies, and they are on their way to digitizing the supply chain, customer services and finances.

3.2.1.4 Private investment in Industry 4.0 – SMEs

SMEs do not have the economic resources to implement Industry 4.0 technologies. For this study, microenterprises and small enterprises are targeted, based on the definitions given in Table 4, with the selected turnover range being between €0.5 million and €10 million.

The average profit margin of SMEs in 2019 was 7.4%. Of this profit, the average re-investment in innovations was 10% [127]. The assumption is that SMEs are willing to re-invest between €3,700 and €74,000 in innovations. The cost of the tools used for this study, based on the three technologies, shall fall within this range and, at best, be less than €14,800 to cover the complete range of microenterprises which have a turnover between €0.5 million and €2 million.

3.2.1.5 COVID-19, key technologies supporting remote working

Since the beginning of the COVID-19 pandemic, the role and perception of digitalisation in our society and for the SMEs has radically changed and it has become an imperative need. The vulnerabilities of many SMEs have been exposed: lack of digitalisation and new digital technologies weakness.

The pandemic has also shown the importance of companies embracing remote working and digitalisation [128]. Three technologies selected during this research support the digitalisation of SMEs:

- In order to enable remote working, the company's information and resources must be available in an integrated management software, and companies must embrace DT in the form of Cloud Computing.
- IoT enables machines and working cells installed in the production line of SMEs to send data to the gateways for further data analysis at the edge or on the cloud. This provides not only real-time visibility of the operations but also enables remote monitoring of production.
- VR solutions empower the companies to perform activities such as training or prototype verification in a remote environment.

3.2.2 Roadmap

All research works addressing these roadmaps make no distinction between large companies and SMEs, as mentioned in section 1.6, considering a large company structure and expertise for Industry 4.0 roadmaps, means ending up involving several departments and teams, such as: strategic management, procurement, human resources, industry 4.0 transition teams or production. SMEs, however, do not have these kinds of structures; they are single-layer companies. Microenterprises, for instance, have less than ten employees and every single employee, not teams, should be able to use the roadmap. Many different approaches to roadmapping have been developed, and roadmaps can take many shapes and forms. Generally, the roadmap focuses on a graphic representation that provides a strategic overview of the topic at hand. The templates and guidelines proposed by the Institute for Manufacturing (IfM) of the University of Cambridge [129] [130] [131] are selected for the basic development of this roadmap. This holistic roadmap framework links directly to the following fundamental questions that apply in any strategic context:

- Where do we want to go? Where are we now? How do we get there?
- Why do we need to act? What should we do? How should we do it? By when?

These questions are addressed during the first two steps of the six-step roadmap. Additionally, as the research wants to address the practical viewpoint, steps 2 through 5 present a business-oriented implementation strategy that takes into consideration the limitations of SMEs (e.g. budget, personnel, etc.). The six-step roadmap is shown in Figure 14 [132].

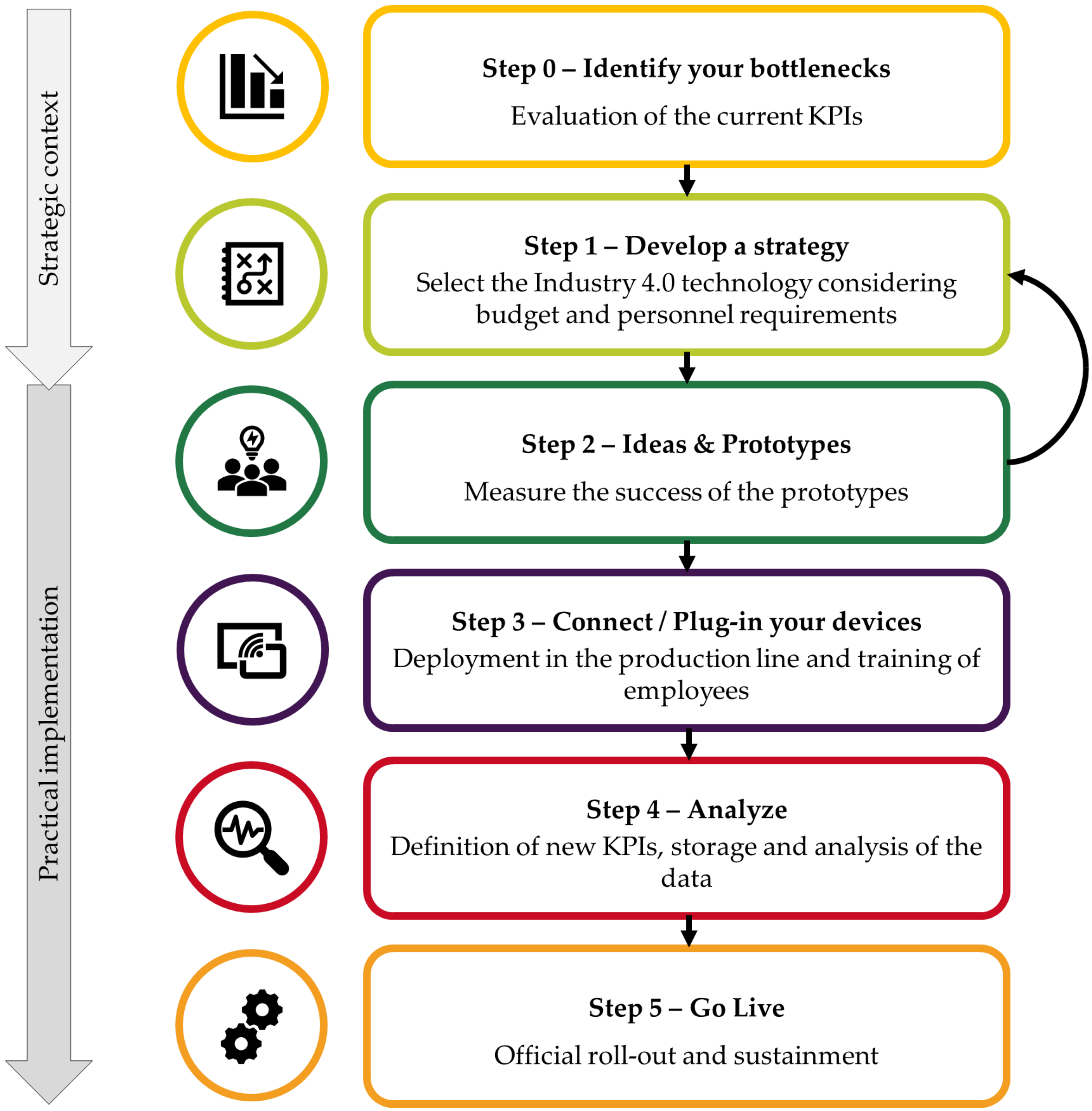
Step 0 – Identify your bottlenecks

The roadmap begins by identifying those areas of production that are hindering the overall efficiency. The search for bottlenecks consists of evaluating Key Performance Indicators (KPIs) throughout production. This evaluation will reveal the answers to the following questions: Why do we need to act? Where are we now?

Step 1 – Develop a strategy

Step 1 is a crucial stage for the proper development of the roadmap. During this step, the person in charge at the SME must propose possible long-term countermeasures for these bottlenecks using selected Industry 4.0 technologies [Cloud Computing, IoT, Digital Transformation or VR] that best suit this purpose. This person must also consider the maximum available budget for the SME when creating this strategy. This step provides an answer to the following questions: Where do we want to go? How do we get there? What should we do? By when?

Figure 14 - Roadmap for the 4th industrial revolution of SMEs



Source: Created by the author

Step 2 – Ideas and prototypes

The roadmap continues with the initial deployment of the tool selected in the production line. This initial roll-out begins with a prototype, not by installing the tool across the entire production line. The success of the prototype must be evaluated during a defined time span. If the prototype does not show promising results, the process must return to step 1, in order to propose different long-term countermeasures.

Step 3 – Connect / Plug in your devices

If the results during step 2 are satisfying, the process continues by deploying the solution across the entire production line. This phase starts by training the operators in the production line on how the tool is used, carrying out some dry runs. This step will improve acceptance of the selected Industry 4.0 technology by the operators.

Step 4 – Analyze

The original KPIs identified during step 1, and how they are measured, may no longer be adequate. During this process, additional KPIs must be proposed, and Cloud Computing must be ready to support the storage and analysis of data that the technology selected will generate.

Step 5 – Go Live

The final step is the official roll-out of the technology across the entire production line. This step focuses on monitoring the KPIs defined. The person in charge at the SME will control sustainment during a defined period.

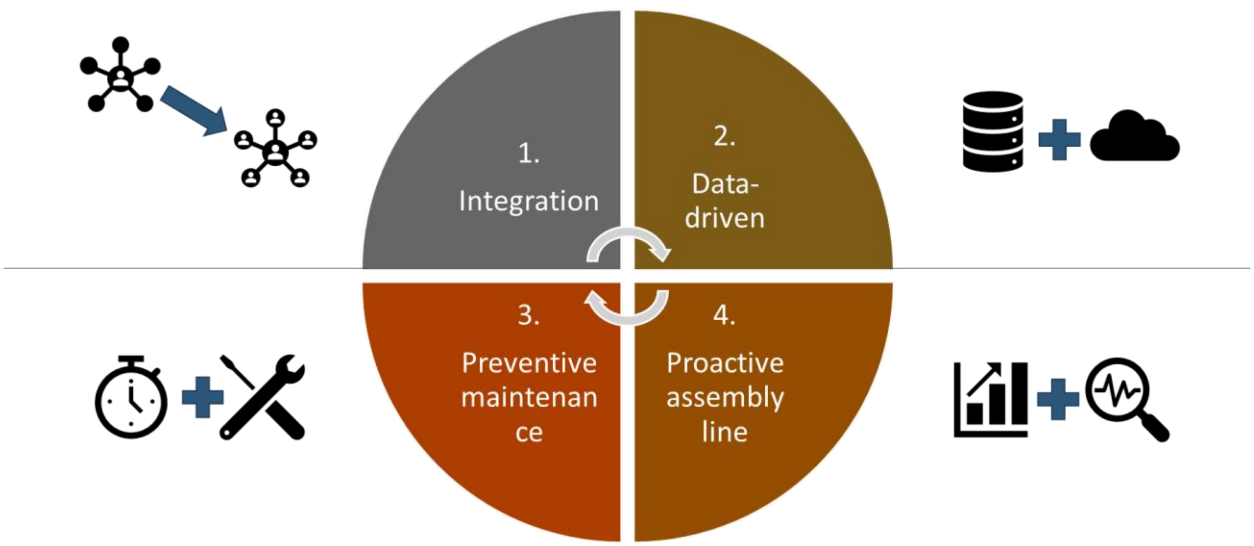
In short, access to Industry 4.0 technologies must be simplified for SMEs, and therefore, the proposed six-step roadmap aims to facilitate decision-making and access to Industry 4.0 technologies by the production area of SMEs. This roadmap has been verified in several examples of practical implementation in the supply chain of SMEs.

3.2.3 Smart Assembly Line (SAL)

SAL is a term shaped during this research, which further develops the Smart Production Line concept presented during a conference paper in 2017 [133]. The SAL aims to connect the theoretical point of view of Industry 4.0 with the four technologies (Cloud Computing, Digital Transformation IoT and VR) selected in this research, so that these technologies are not implemented in isolation but as a group. The four technologies are capable of fostering the four key characteristics of the SAL, as shown in Figure 15, and their implementation should share a common end goal: these technologies and solutions optimize production, enhance productivity and efficiency, and are implemented using the theoretical framework of the roadmap previously defined.

The SAL and the roadmap work together: every component of the technology will be selected and implemented using the roadmap; once the component is implemented in production, it will foster the characteristics promoted by the SAL, as represented in Figure 15 and Figure 16.

Figure 15 - Key characteristics of the Smart Assembly Line

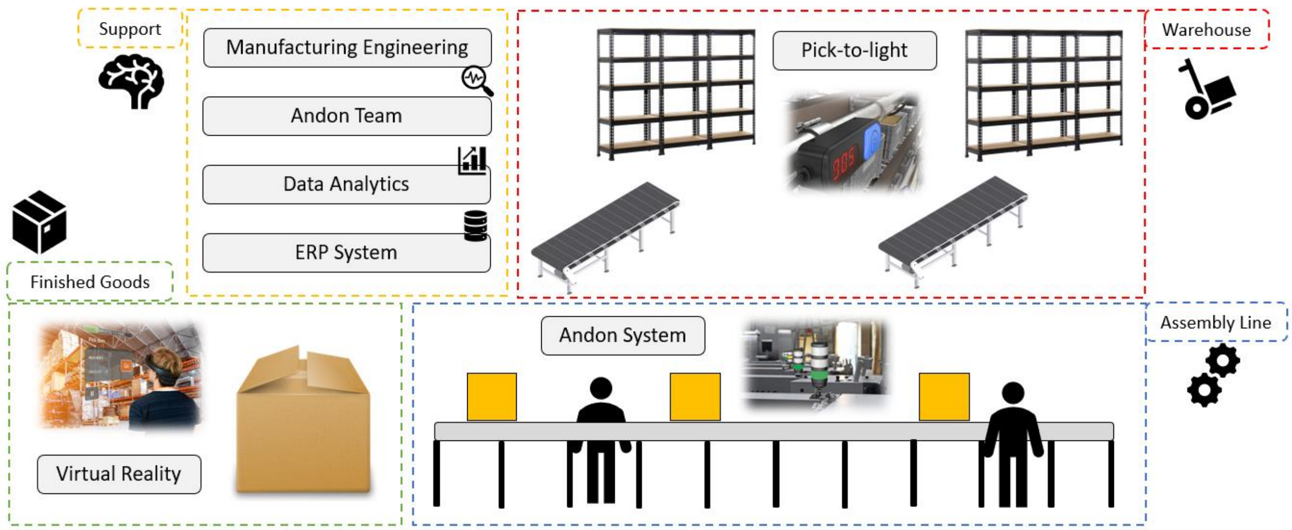


Source: Created by the author

The SAL has 4 key characteristics that set it apart from a traditional production line.

1. Collaboration: promotes integration of all equipment and personnel working in the assembly line. It transforms an assembly line in which all components are working in isolation into an interconnected assembly line.
2. Data-driven: the SAL generates real-time data and stores it in the cloud (manufacturing time, first pass yield, number of defective parts, etc.). This data can be retrieved at any time, from anywhere.
3. Preventive maintenance: data usage enables the implementation of preventive maintenance, in order to avoid down-times.
4. Proactive assembly line: the SAL identifies the efficiency of the resources and equipment used in the line in real time. If the assembly line is not working efficiently, the line itself will propose a new distribution of the resources to increase productivity.

Figure 16 - Overview of the Smart Assembly Line



Source: Created by the author

3.3 Industry 4.0 HUB

For the second research objective, a research approach in two phases was used:

1. Literature review conducted in 2019 and 2020 to evaluate current Industry 4.0 knowledge transfer initiatives and platforms.
2. By the end of 2020, the collaborative online platform Industry 4.0 HUB for knowledge transfer for SMEs was developed.

3.3.1 Background

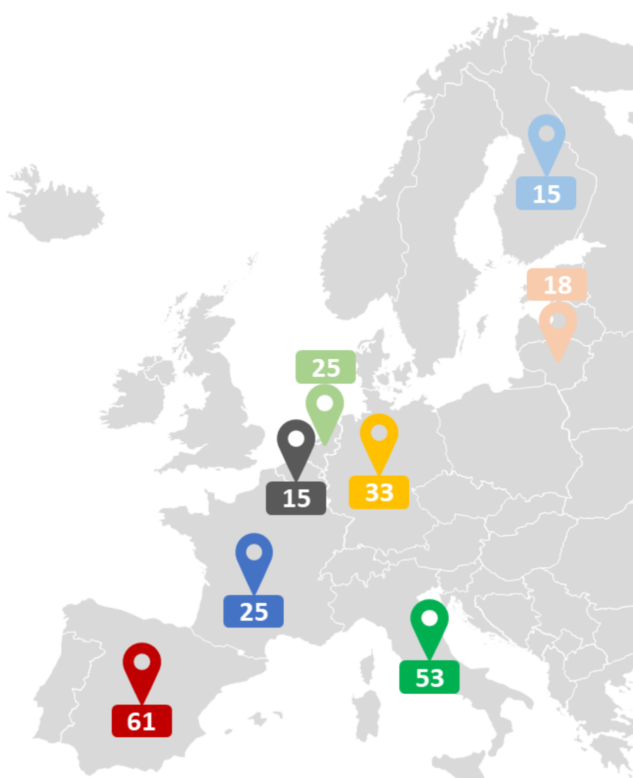
A systematic literature review was performed using several databases such as the Web of Science, Google Scholar, and Scopus to identify existing Industry 4.0 KT initiatives and platforms.

The foundation of Plattform Industrie 4.0 by several German associations with more than 6000 member companies in April 2013 was the first attempt to create a platform supporting industry KT and the further development of the recent trend in manufacturing technologies, termed as Industry 4.0. The platform, officially announced and kicked off at the Hannover Fair in 2013, seeks to promote the development of Industry 4.0 in Germany and thus strengthen the competitiveness of Germany as a production location [134, 135].

In this context, the excellent Industry 4.0 map is worth highlighting due to its transformation of knowledge related to successful and sustained Industry 4.0 test cases and support of other SMEs accessing Industry 4.0 technologies by providing already proven solutions and saving the initial trial and error phase. In addition, the SME Transfer Network submodule organizes meetings and workshops to promote KT within SMEs.

Using the benefits of the digital transformation, the Digital Innovation Hub (DIH) from the European Commission is another excellent initiative to further promote Industry 4.0 KT within SMEs. It intends to build a European network of DIHs that are one-stop shops to help companies improve their processes, products, and services by using digital technologies. DIHs provide access to technical expertise and experimentation by acting as knowledge transfer platforms [136, 137, 10]. The current numbers show the astonishing progress of the DIHs, as shown in Figure 17. By November 2021, there were 360 fully operational DIHs in Europe. Countries like Spain and Italy already have more than 50 DIHs fully operational, while other countries like Germany and France have more than 20 DIHs in preparation that will open their doors in the following months [138]. The Digital Europe Programme will foster the creation of new DIHs even further.

Figure 17 - Top 7 EU countries by number of fully operational DIHs

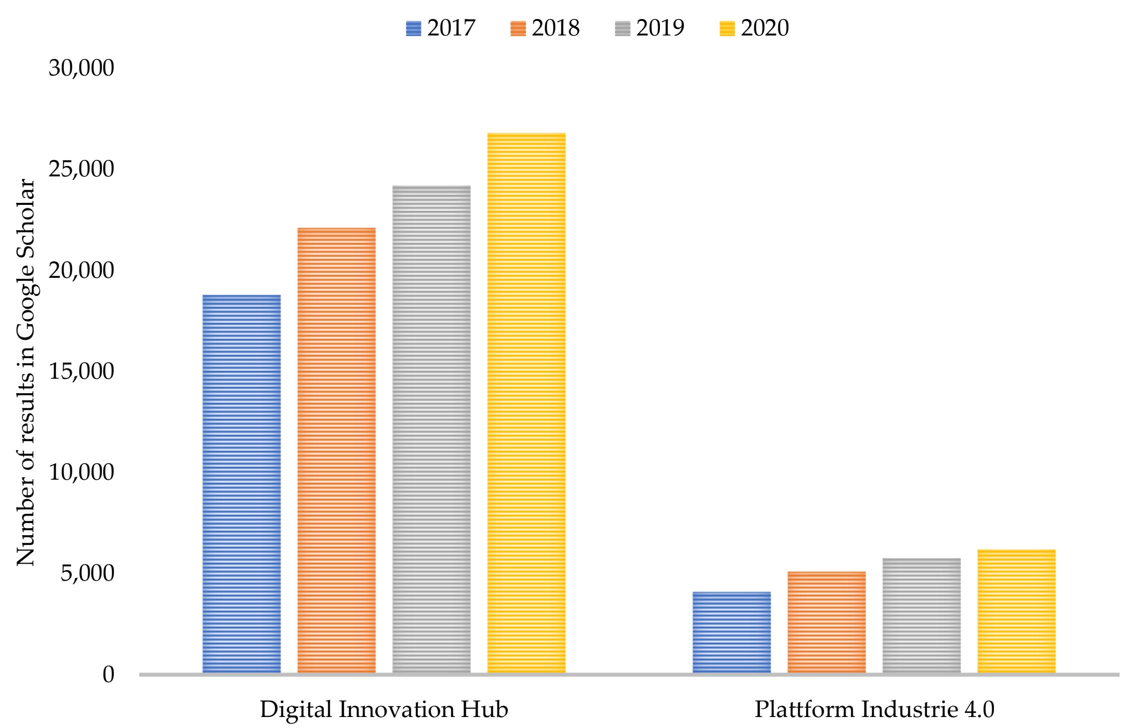


Country	In Preparation	Fully operational DIHs
Austria	5	10
Belgium	14	15
Bulgaria	5	0
Croatia	4	11
Cyprus	2	1
Czech Republic	3	9
Denmark	3	9
Estonia	2	4
Finland	4	15
France	24	25
Germany	24	33
Greece	5	10
Hungary	2	8
Ireland	5	6
Italy	15	53
Latvia	1	4
Lithuania	1	18
Luxembourg	4	1
Malta	2	0
Netherlands	18	25
Poland	7	7
Portugal	4	6
Romania	4	10
Slovakia	3	2
Slovenia	1	11
Spain	18	61
Sweden	6	11

Source: Created by the author based on [138]

During recent years, a new trend has been observed: some DIHs are getting connected and creating a cluster to expand their area of influence to a national level and to lead the development not only of a region, but also of a nation or even a pan-European area [139]. One example of this development is the cluster de:hub, which comprises twelve DIHs creating one digital ecosystem [11]. Furthermore, a relevant part of the DIHs is the project DIHNET.EU, which aims to create a sustainable pan-European network of networks to interconnect the regional DIHs and promote networking and collaboration [140]. This project might help to create a great online community to foster interaction among hubs, information exchange, and peer learning.

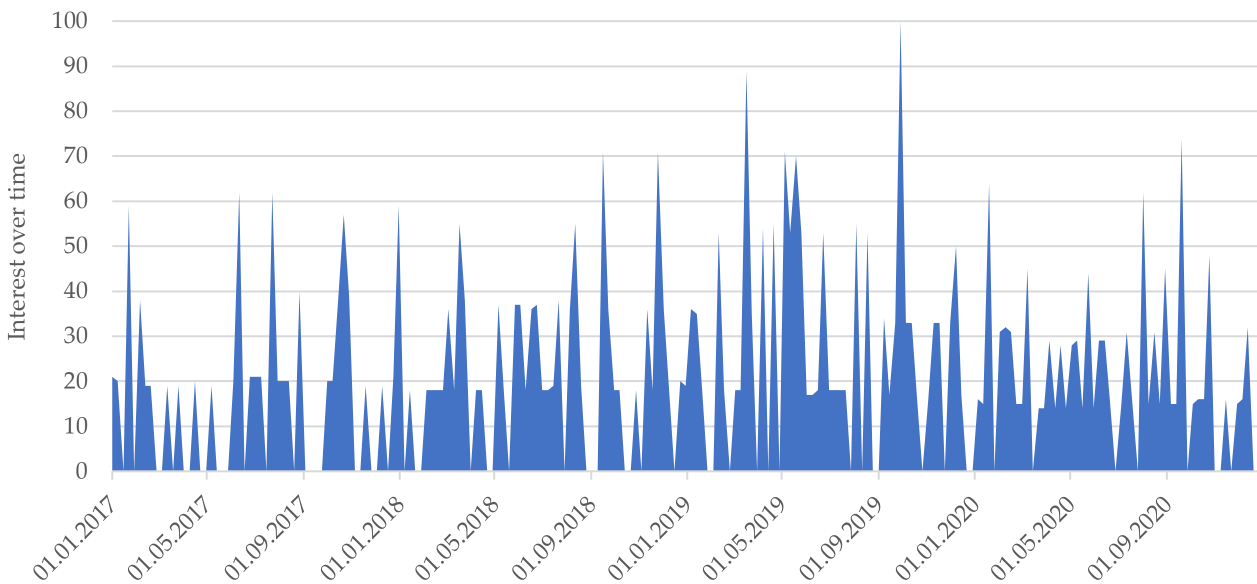
Figure 18 - Development during the last four years of the number of results in Google Scholar related to DIH and *Plattform Industrie 4.0*.



Source: Created by the author based on data retrieved from Google Scholar

To conclude, and to highlight the relevance of the abovementioned platforms, the interest and research in recent years on the DIH and Plattform Industrie 4.0 is growing, as shown in Figure 18. Moreover, the number of searches for DIH in Google in the last four years shows popularity peaks during the last two years, which emphasizes the need for Industry 4.0 knowledge transfer platforms, as shown in Figure 19.

Figure 19 - Interest over the last four years in DIH, generated via Google Trends.



Source: Created by the author based on data retrieved from Google Trends

3.3.2 Industry 4.0 HUB

In summation, SMEs are being supported by European initiatives in order to improve KT in regard to Industry 4.0. Moreover, there are even Industry 4.0 KT platforms, clusters, and hubs for SMEs, like the DIHs or Plattform Industrie 4.0, which will increase their influence and support SMEs in the following years through European investment plans [141].

In the case of DIHs, the European Commission is creating a complex, regional, multi-layered, and heterogeneous innovation ecosystem that will promote its expansion in the following years. Some studies have suggested the importance of addressing Industry 4.0 at a regional level to foster innovation locally [142, 143, 144]. However, given the number, the different focus, and the specialization of DIHs at the regional, national, and EU levels, new strategies to coordinate, control, and optimize communication through those levels are necessary. DIHs are regionally based, supporting the local industry. Nonetheless, collaboration and networking between the DIHs are essential to ensure that knowledge related to the best practices can be transferred.

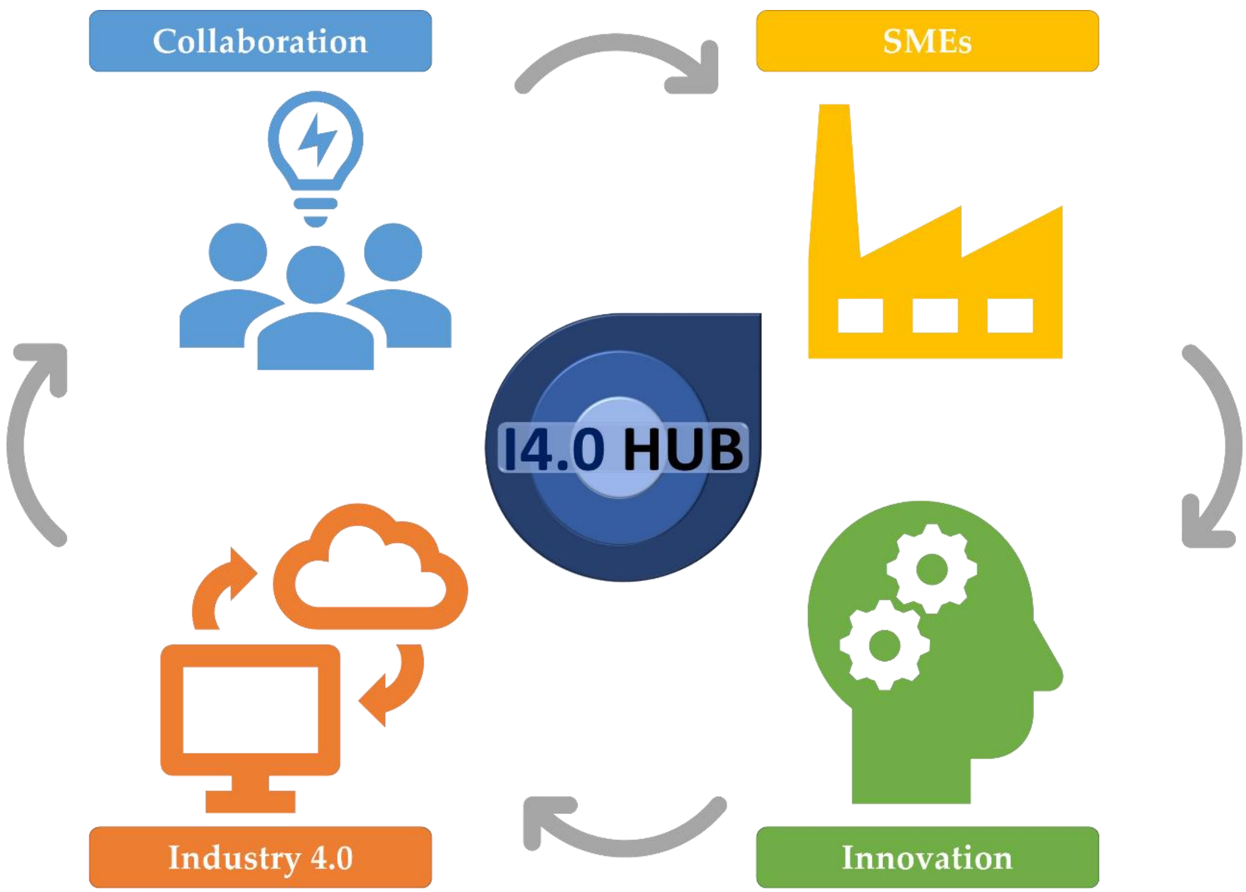
Industry 4.0 technologies are evolving fast, and knowledge must be collected in real time. Moreover, the inclusion of new technologies, and especially the advent of Industry 4.0, are facilitating collaboration while at the same time accelerating the development of innovation outcomes and setting new challenges for SMEs [136, 9, 139, 145]. New KT strategies must be developed considering the dynamics resulting from the implementation of Industry 4.0.

Consequently, promoting a collaborative atmosphere by boosting the synergies between SMEs and promoting networking through the different levels previously mentioned will enhance a culture of innovation.

When SMEs start the transition to Industry 4.0, first of all, they do not want to start from scratch, and secondly, it can be easy to get lost in the multitude of technologies and tools that are available in today's market. There is a lack of an essential Industry 4.0 collaborative knowledge platform for every SME at every level, as shown in Figure 20. There is a gap for providing a collaborative web application Industry 4.0 KT hub without borders and without the level of granularity that initiatives like DIHs have created (European countries, European regions, and specialized DIHs).

The KT of Industry 4.0 technologies and projects, as well as the networking of SMEs, can be facilitated via the creation of a collaborative hub. This research aims to fill this gap and has its focus on developing a collaborative, web based KT hub for the implementation of Industry 4.0 components in the supply chains of SMEs.

Figure 20 - Industry 4.0 knowledge transfer for SMEs.



Source: Created by the author

3.3.3 Development of the Industry 4.0 HUB

3.3.3.1 Origins of the Industry 4.0 HUB

Prior to the development of the web based KT hub, a first website development attempt was done during this research [146]. The mission was to develop a simple SCM web-based solution for the micro enterprises and its functions as described in section 1.2.2.2. The developed solution aimed to fulfil the following objectives:

- Get more experience developing web-based hubs
- Gain more insight into a full software stack platform (frontend, backend, and database)
- Identify key elements helping SMEs to start the 4th industrial revolution through digital transformation
- Compare existing off the shelf ERP solutions with a custom-made solution
- Possibility to expand in the future the SCM solution to integrate it in an ERP solution

The SCM web-based solution received the name Supply Chain Hub, and it is a full software stack platform (frontend, backend, and database). For the frontend development HTML, CSS, Bootstrap and JavaScript were used. On the other hand, PHP and JavaScript were used for the backend development and SQL was used for the database.

The Supply Chain Hub offers several SCM tools to help SMEs access the digital age. The tools interconnect departments, functions, and roles, as shown in Figure 21:

<u>Yamazumi Charts</u>

The tool Yamazumi chart is a stacked bar chart that shows the balance of cycle time workloads between several operators typically in an assembly line or work cell.

<u>Bill of materials</u>

The bill of materials is a list of materials, sub-assemblies or parts, and their quantities to manufacture and product.

<u>Stardard operating procedures</u>

The standard operating procedure (SOP) tool allows the users to create a step-by-step instruction designed to help the workers carry out complex manufacturing, packaging or quality operations. SOPs aim to improve the productivity and the quality of the products. A screenshot of the tool is shown in Figure 22.

<u>Takt Time</u>

This feature allows the user to calculate the takt time, which is the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand.

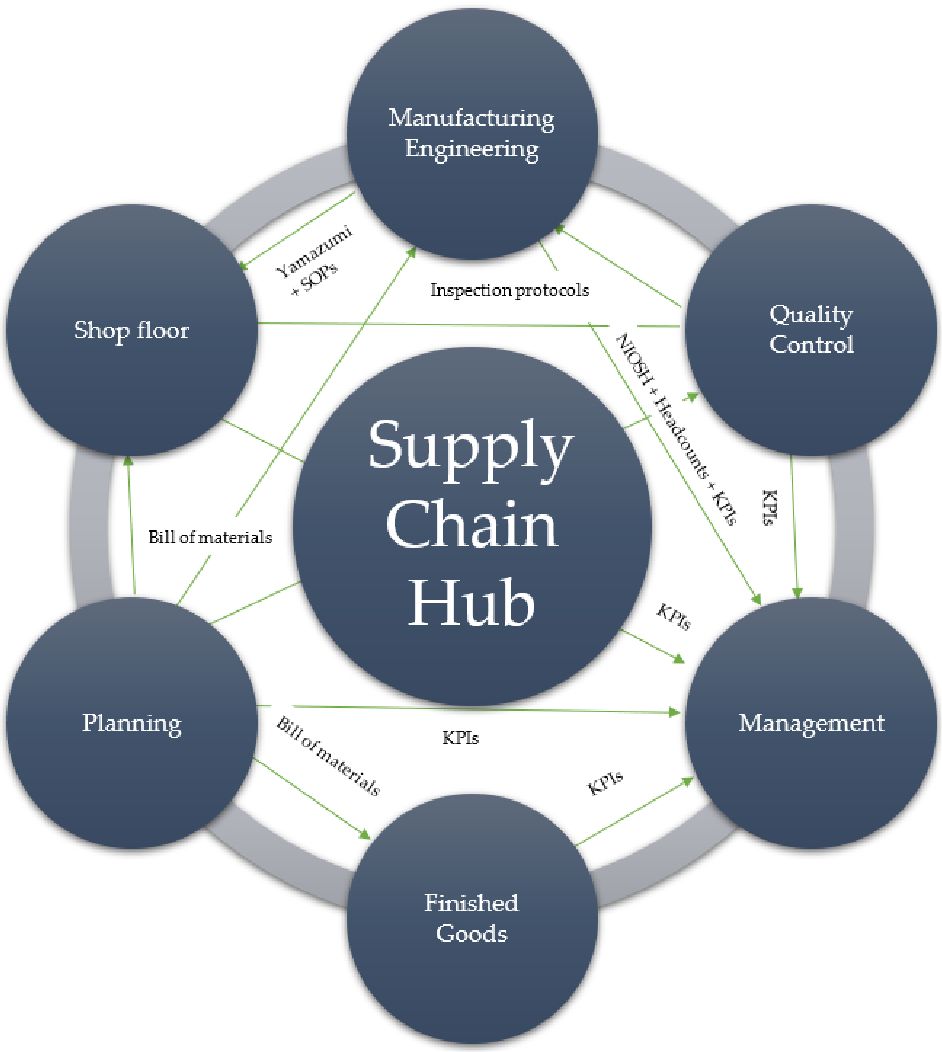
Headcounts

This tool provides a simple and fast feature to calculate the needed headcounts for the assembly line and work cells based on forecasting.

Dashboard

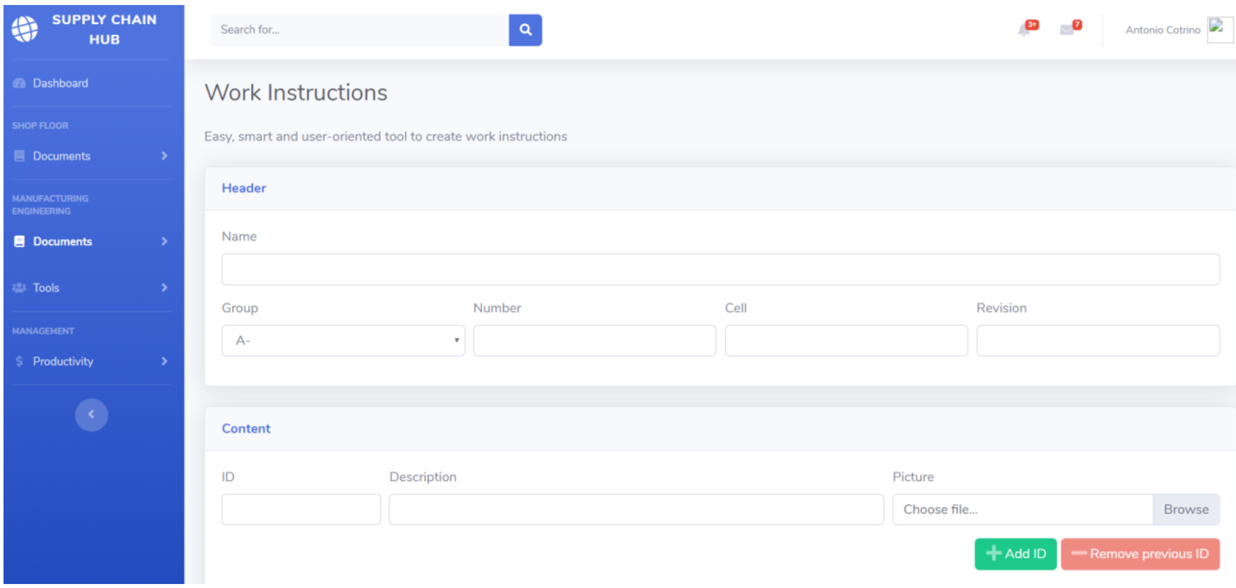
The dashboard provides at-a-glance views of key performance indicators (KPIs) relevant to the business process, as well as some general information and updates for the employees and management to keep them up to date. Additionally, it aims to provide real-time enterprise analytics for better decision-making.

Figure 21 – Different departments and roles of the Supply Chain interconnected through the Supply Chain Hub



Source: Created by the author

Figure 22 – Standard operating procedures (SOP)



Source: Created by the author

Given the complexity of a complete SCM solution and the multifaceted possible tools to be developed, the Supply Chain Hub reached just some positive results but a lot of room for improvement, as shown in Table 6. Additionally, some key elements for the digital transformation of the SMEs were identified.

Table 6. Positive results, improvements, and conclusions of the development of the Supply Chain Hub

Positive results	**Future improvements**
The Supply Chain Hub represents the beginning of a vision, where an integrated software solution helps SMEs to overcome the digital transformation, especially microenterprises	The dependency from Microsoft Office, ERP solutions and other SW remains, due to the level of capabilities of this software has not been reached
The Supply Chain Hub could significantly reduce the amount of paperwork in every SME	Real-time enterprise analytics provide by the Supply Chain Hub are still in its infancy
It enhances the collaboration across the supply chain	The connection between the Supply Chain Hub and the customers/suppliers is still to be developed

Conclusions
ERP solutions enable the adoption of a new strategy to go paperless and to manage the data digitally and in the cloud
The Supply Chain Hub was a positive experience to gain more insight into a full software stack platform
Existing off the shelf ERP & SCM solutions are very powerful, and their current prices are accessible to every micro enterprise
Nowadays the possibilities to develop a SCM custom-made solution in combination with Cloud Computing are unlimited
ERP solutions are a backbone to start the digital transformation of SMEs
SCM & ERP solution can enhance collaboration enterprise-wide and allow SMEs to embrace the development of a remote working environment

Source: Created by the author

3.3.3.2 Final development of the Industry 4.0 HUB

Following the Supply Chain Hub, the web based KT hub developed during this research is called Industry 4.0 HUB [147]. It is a full software stack platform (frontend, backend, and database). There are several alternatives of web application software stack solutions that might be selected based on different decision criteria for each project, including the project size, scalability, maintainability, and security [148].

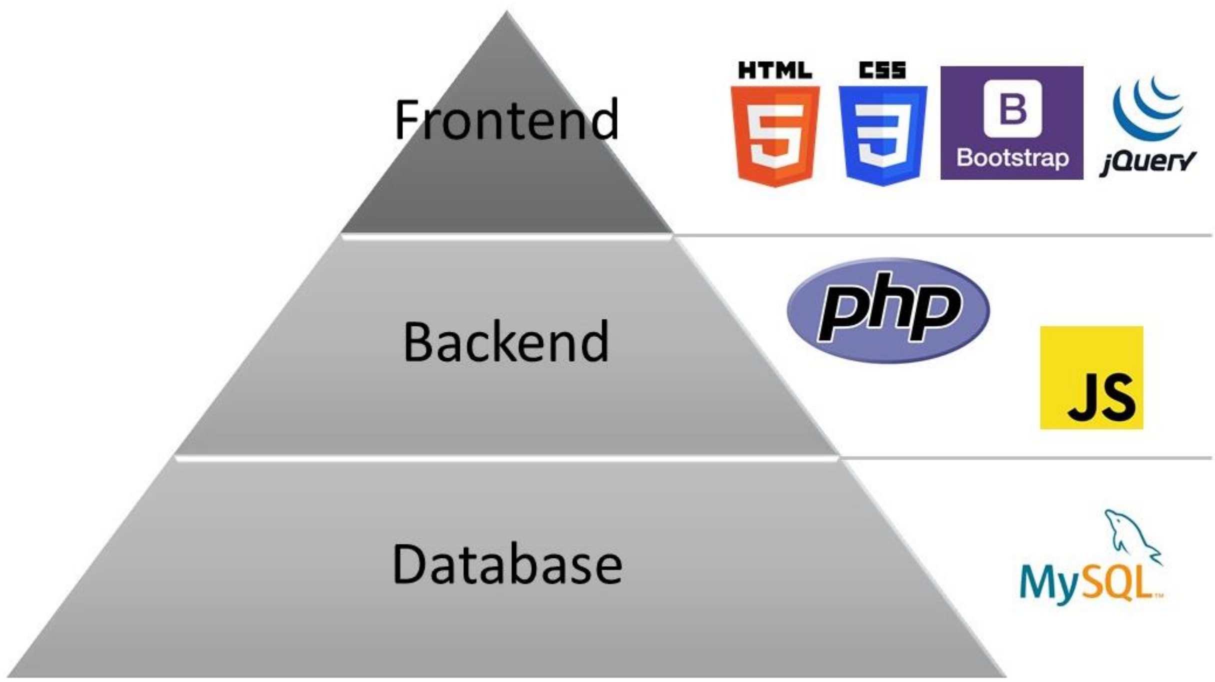
To support the decision-making, recent results from the Developer Survey 2020 from Stack Overflow were analysed. Nearly 65,000 developers from over 180 countries participated in the survey, and the results show that JavaScript, HTML or CSS, and SQL are the top three programming, scripting, and markup languages used [149]. As this project is still in its early stages, the following alternatives were selected based on the experience of the author and the current usage between web developers. Other than that, other criteria were not taken into consideration. For the frontend development, the following programming languages were used:

- HTML 5: the latest version of the markup language for web pages.
- CSS 3: a style sheet language used for describing the presentation of a document written in a markup language such as HTML.
- Bootstrap 4: HTML, CSS, and JavaScript framework for developing responsive web pages.
- The backend development was performed using the following programming languages:
- PHP: a server scripting language and a powerful tool for making dynamic and interactive web pages.

- JavaScript: high-level and multi-paradigm programming language.

Finally, MySQL was used for the creation of the database. Moreover, several libraries, such as the JavaScript library jQuery, were used to simplify the programming and expand the capabilities of the Industry 4.0 HUB. The full software stack architecture is shown in Figure 23.

Figure 23 - Frontend, backend, and database development.



Source: Created by the author

The source code editor used for the development was Visual Studio Code. The first phase of the development was performed locally on the laptops of the author on a local test server without interaction with a live server. Once the platform was running in a stable state and the first dry runs were completed, it was uploaded to a web server, and the Industry 4.0 HUB has been live since January 2021 from the following link: [i40-hub.com](i40-hub.com)

The code of the Industry 4.0 HUB is available in the Annex.

3.4 Recap

The initial literature review led to the conclusion that existing roadmaps make no distinction between large companies and SMEs. SMEs must be considered separately and to that purpose the six-step Industry 4.0 Roadmap, developed using the templates and guidelines proposed by the IfM of the University of Cambridge, was presented during this methodology chapter. The Industry 4.0 Roadmap is validated and verified in the following chapter 4, including several qualitative and quantitative results.

On the other hand, the two main existing Industry 4.0 KT platforms DIHs and Plattform Industrie 4.0 were extensively analysed through systematic literature review. The outcome was the aim to fill the existing gap with a new collaborative web application Industry 4.0 KT, the so-called Industry 4.0 HUB. This chapter described the selected programming languages for the development of the frontend, backend and database of the Industry 4.0 HUB. The result of the development and the different functionalities that the Industry 4.0 HUB offers are presented in the chapter 5.

4 INDUSTRY 4.0 ROADMAP FOR SMES

4.1 Introduction

During this chapter the qualitative and/or quantitative results obtained during the testing and validation of the Industry 4.0 Roadmap are presented. There are in total six Industry 4.0 solutions, which are based on various Industry 4.0 technologies such as IoT, Cloud Computing, VR and DT. The structure to present the solutions is the always the same through the different sections:

- Short introduction to get some insights into the technology and the problem which aims to be solved.
- Industry 4.0 Roadmap application following the six steps.
- Costs associated to the implementation of the solution.
- Qualitative and/or quantitative results obtained during the testing and validation.

The study of the Industry 4.0 solutions selected in this research, including testing and verification, was carried out at the Munich manufacturing site of a biomedical company. The Andon system [4.2] and the Digital Visual Project Management [4.5] have been completely rolled out in the production line and the results of the validation are conclusive. The Manipulator [4.6] and the RFID Kanban [4.7] are installed in the assembly line and the warehouse but the results of the validation are still on-going. The Mixed reality [4.3] and Pick-to-light [4.4] technologies are still at the analysis stage of the six-step roadmap; therefore, no quantitative results are yet available and only qualitative results of the first prototype are presented.

4.2 Andon system – IoT applied to quality control

Quality is the main driver of an exceptional production plant. Non-conformances shall be kept under control in order to provide customers with the best quality, and to maintain favourable productivity.

Real-time visibility and immediate intervention regarding waste are needed to manage non-conformances. Furthermore, tracking trends in performance over time is also crucial to improve the efficiency of the operations in the assembly line.

Andon is a term that refers to a system which notifies a quality or processing problem. An Andon system is one of the elements described in the Jidoka quality control method pioneered by Toyota as part of the Toyota Production System and belongs to the lean production approach [150].

The Andon system proposed within this research uses a TL70 Modular Tower Light with a wireless radio base connected to a DXM700 Wireless Controller. The data will be pushed to the Banner Cloud Data Services (CDS) to create a dashboard and perform cloud computing activities.

The Andon system uses two of the technologies highlighted in the section 1.1.3: IoT and Cloud Computing. Implementation following the roadmap is described in Table 7.

Table 7. Andon system – roadmap application

Step number	Step description	Application for this solution
0	Identify your bottlenecks	The number of quality non-conformances has been increasing for a long time. Quality failures shall be detected immediately, and countermeasures shall be applied as soon as possible.
1	Develop a strategy	Every work cell in the assembly line will get a traffic light that is manually switched to notify quality non-conformances. It will generate real-time data and will allow employees to resolve the issues in a short period of time.
2	Ideas & Prototypes	Think big but start small. A model work cell was created, where the first prototype was tested.
3	Connect / Plug in your devices	Traffic light was installed, connected to the controller, dashboard was set, and the Andon team was ready to analyze the data. Some dry runs were performed until the system ran stable.
4	Analyze	Andon team ran daily KPIs to control the evolution of quality non-conformances and analyze the results. Am I winning or am I losing?
5	Go Live	Once the results were verified and the Andon system has proven that IoT can help track and reduce quality non-conformances, the Andon system went live and is ready to be extended to another work cells.

Source: Created by the author

Total investment for the Andon system is $1,194 (implementing a single Tower Light), but is easily extendable by acquiring new Tower Lights (each $315) [151]:

- TL70 Modular Tower Light [$315]
- DXM700 Wireless Controller [$579]
- Banner Cloud Data Services (CDS) – Starter [$300 – Annually]

<u>Quantitative results</u>

The Andon system was installed in January 2020 in the Munich manufacturing site of a biomedical company as shown in Figure 24. The success of the solution was evaluated using two KPIs for six months, and presented in the Table 8:

- Number of non-conformances: measures the amount of non-conformances created in the production line and incoming inspection areas during a month. The number of non-conformances went down by 63% since the introduction of the Andon system.

- Savings: the processing of a non-conformance takes on average 10 working hours (root-cause analysis, definition of countermeasures, implementation of countermeasures, etc.). Savings are measured in working hours based on the jumping-off point (JOP), which was February 2020.

Table 8. Andon system – Quantitative results

Month / 2020	Savings to JOP	Number of non-conformances
February	-	145
March	270 h	118
April	650 h	80
May	720 h	73
June	850 h	60
July	920 h	53

Source: Created by the author

Figure 24 - Implementation of the Andon system

Source: Created by the author

4.3 Mixed Reality for manufacturing and shipping processes

HoloLens coupled with the software solution Microsoft 365 Guides is a hands-free computer for the operator that:

- Displays the manufacturing instructions as interactive Standard Operating Procedures (SOP) and renders high-definition holograms that respond like physical objects. It goes where you go, sees what you see, and does what you say.
- Displays digital pick lists. Order details are automatically assigned and sent to each picker, where they can follow instructions on their HoloLens for a more efficient process. A digital picking list can more easily include additional information such as product images, serving as an additional quality control check and as a validation that the picker is grabbing the correct item.

Mixed reality uses one of the technologies presented in section 1.1.3: VR. Implementation following the roadmap is described in Table 9.

Table 9. Virtual reality – roadmap application

Step number	Step description	Application for this solution
0	Identify your bottlenecks	Work orders for shipping are often picked incorrectly; paper-based pick lists are getting lost, or not properly reported to the database.
1	Develop a strategy	2 shipping orders per day, consisting of 10/20 items, need to be prepared and commissioned. One pair of mixed reality glasses, that can be shared out between the operators is needed. Additionally, the pick lists must be digitized.
2	Ideas & Prototypes	Standard shipping will be used for the prototype. It consists of 15 items [10 crates and 5 boxes]. The pick list needs to include: customer information, date and time of the order, order number, product location in the warehouse, product locator and a photograph of the product.
3	Connect / Plug in your devices	One HoloLens is ready to be used and the digital pick list is accessible. One operator is trained on the usage of the mixed reality glasses, and he will perform a couple of dry runs.
4	Analyze	Control the picking time: it shall be shorter. Correct possible mistakes: missing items in the picking list, ergonomics not properly controlled, etc.
5	Go Live	Once the final quantitative results are available, the tool will be ready to go live and to be extended to all shipping orders.

Source: Created by the author

The total investment for the mixed reality system is $3,520 [152]:

- HoloLens 2 [$3,455]
- Microsoft 365 Guides [$65 per user/month]

Quantitative results

The results of mixed reality implementation are not available at this point in the research. The initial qualitative results gained from the operators in the Munich manufacturing site are presented in section 6.

4.4 Pick-to-light – boosting productivity in the picking and kitting processes

Manual picking processes that are not properly carried out can lead to significant monetary losses. Operators need experience to know the exact location of the bins or storage racks for the different work orders in the production line.

The Pick-to-light (PTL) system provides an extraordinary solution: the front of each bin or storage rack is equipped with a numerical display with buttons. These devices or nodes are controlled by software. This software lights up the display, prompting the operator to remove goods from the bin or storage rack, and indicates how many units of the article in question to pick on the screen.

Once the operator has finished extracting the corresponding units, he or she presses a key to confirm the operation has been carried out. This informs the software, and the light is turned off.

PTL Solution Kits consist of several PTL Devices connected to a DXM700 Controller, which is configured via touch screen.

The PTL uses two of the technologies selected in the section 1.1.3: IoT and Cloud Computing. Implementation following the roadmap is described in Table 10.

Table 10. Pick-to-light – Implementation process

Step number	Step description	Application for this solution
0	Identify your bottlenecks	Work orders are often picked incorrectly, working processes are inefficient, picking time is rocketing and the increasing number of materials in the warehouse has worsened visibility.
1	Develop a strategy	Based on the number and complexity of the work orders to be picked, 10 lights and a controller are needed to improve the picking process in the warehouse.
2	Ideas & Prototypes	The most-picked work orders were selected.
3	Connect / Plug-in your devices	Pick-to-lights were installed, connected to the controller, dashboard was set, and the warehouseman was ready to analyze performance of the picking process based on the lights. Some dry runs were performed until the system ran stable.

Step number	Step description	Application for this solution
4	Analyze	KPI was set to control evolution of the picking time and analyze the results. Am I winning or am I losing?
5	Go Live	Once the final quantitative results are available, the tool will be ready to go live and be extended to other warehouse areas.

Source: Created by the author

Total investment for the PTL system is $2,648 (just one PTL), easily extendable by purchasing additional PTL devices [153]:

- PTL110S-TD3-QP150 [$149]
- SOLUTIONSKIT-PTL [$2,499]

Quantitative results

PTL results are not available at this point in the research. The initial qualitative results gained from the operators in the Munich manufacturing are presented in the next section 6.

4.5 Digital Visual Project Management

The COVID-19 pandemic has shown the importance of companies embracing remote working and digital transformation. With the aim of ensuring the business continuity several companies had to move from an on-site project management to a remote project management. Companies all around the world had to bring teams to work together, anytime, anywhere [154, 128].

A project management software helps the teams plan, organize, and manage resource tools and develop resource estimates. Several project management tools have become during 2020 more visible and all large enterprises have adopted them as their primary solution to help teams organize, track, and manage their work. The alternatives nowadays are unlimited: Trello, Asana, Monday.com, Jira, Wrike, Microsoft Planner, Smartsheet, ProofHub, etc. [155]

The solution presented during this research is the so called Digital Visual Project Management (DVPM), which seeks to transition from the traditional physical visual project management to a digital version.

The DVPM uses one of the technologies selected in the section 1.1.3: Digital Transformation. Implementation following the roadmap is described in Table 11.

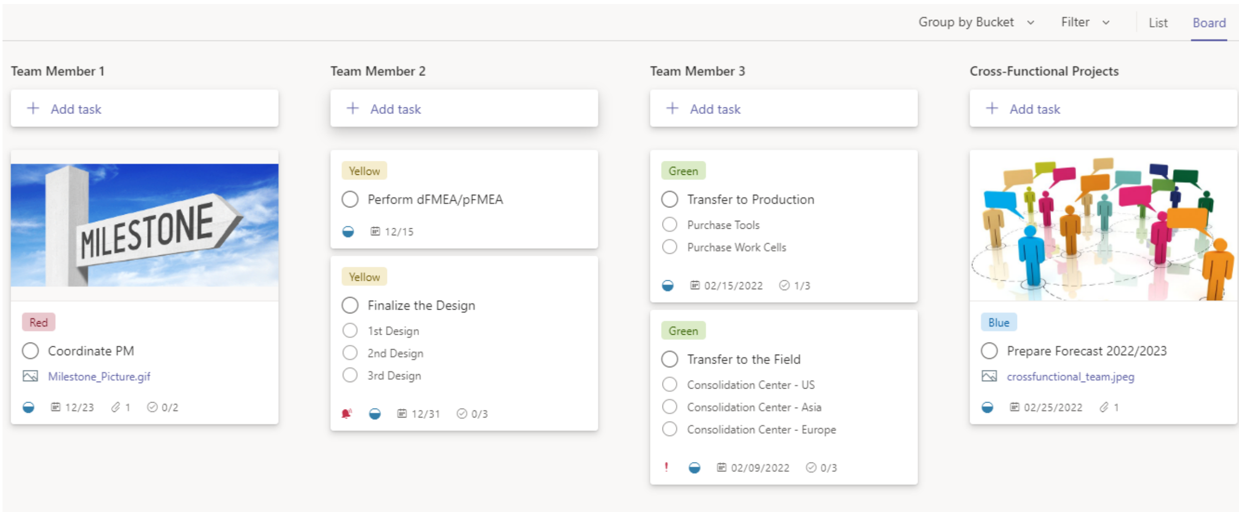
Table 11. Digital Visual Project Management – Implementation process

Step number	Step description	Application for this solution
0	Identify your bottlenecks	Teams are not continuously available on-site, the work environment is moving towards a hybrid model, where some employees are working remote and some employees on-site. Old project management strategies, where projects were tracked on-site using visual project management boards are not valid anymore.
1	Develop a strategy	A project management software must be selected to replace the traditional Post-it-based boards. Different project management software tools were used during some months to select the most appropriate one. Microsoft Planner was selected, as the tool is part of Microsoft Teams, which is already used in the business.
2	Ideas & Prototypes	A trial DVPM has been created to start gaining some experience, as shown in Figure 25.
3	Connect / Plug-in your devices	The first official DVPM was set to help the manufacturing engineering team organize the tasks.
4	Analyze	A new KPI was set to control the number of closed tasks every month. Am I winning or am I losing?
5	Go Live	The tool is ready to go live and be extended to other departments of SCM, such as manufacturing quality and materials & planning

Source: Created by the author

The total investment for the DVPM is $57 a month/user for the Microsoft 365 E5 license, which provides access not only to Microsoft Teams, where Microsoft Planner [Tasks by Planner and To Do] is integrated, but also to other Microsoft 365 Apps such as PowerPoint, Word and Excel [156].

Figure 25 - Trial DVPM created using Microsoft Planner [Tasks by Planner and To Do]



Source: Created by the author

<u>Quantitative results</u>

The DVPM started in June 2020 in the Munich manufacturing site of a biomedical company. The success of the solution was evaluated using two KPIs for six months, and presented in the Table 12:

- Number of closed tasks: measures the number of tasks closed in the manufacturing engineering team during a month. The number of open tasks went down by 36% since the introduction of the DVPM.
- Savings: 20 tasks need on average a headcount fulltime to manage them. Savings are measured in reduction of headcounts based on the JOP, which was June 2020.

Table 12. DVPM – Quantitative results

Month / 2021	**Savings to JOP [Number of headcounts]**	**Number of open tasks/closed tasks**
June	-	75
July	0.1	73/2
August	0.5	65/8
September	0.55	64/1
October	1.1	53/11
November	1.3	48/5

Source: Created by the author

4.6 Manipulator – Ergonomics, Safety and Productivity Improvement

Manual material handling (MMH) contributes to a large percentage of musculoskeletal disorders (MSDs) reported annually in Europe. The MSDs can result in pain, disability, medical treatment, and financial stress [157]. Additionally, MSDs are the leading cause of work disability, sickness absence from work and loss of productivity across all the EU member states. It is estimated that the total cost of lost productivity attributable to MSDs among people of working age in the EU could be as high as 2% of gross domestic product (GDP) [158]. Cobots and industrial manipulators have been introduced to answer a need for more ergonomics and safety in MMH [159, 160].

The solution presented during this research is the manipulator, which improves ergonomics and safety and enhances the productivity. The manipulator instead of the cobot has been selected because it was an off the shelf solution: programming not needed, cheaper and easier to implement.

The manipulator uses one of the technologies selected in the section 1.1.3: Robotics and Automation. Implementation following the roadmap is described in Table 13.

Table 13. Manipulator – Implementation process

Step number	Step description	Application for this solution
0	Identify your bottlenecks	MMH is a health risk in the assembly line. Operators must manually lift and assemble heavy subassemblies (from 5 kg up to 40 kg). It contributes to MSDs and poor ergonomics scores. Additionally, two headcounts instead of one have to be planned for some stations of the assembly line in order to lift and assemble the 40 kg sub-assemblies, which decreases the productivity.
1	Develop a strategy	The existing International safety standards for MMH [EN 1005 and OSHA and NIOSH] were reviewed to fully understand the health risks associated to the MMH and to identify maximum lifting weight manually allowed [161, 162, 163, 164]. Some trade fairs, such the International trade fair for automation in production and assembly in Stuttgart (MOTEK) were visited to gather ideas [165].
2	Ideas & Prototypes	Several cobots and industrial manipulators solutions were analyzed and investigated to solve improve ergonomics.
3	Connect / Plug-in your devices	The industrial manipulator Liftronic Easy [166] from the company Scaglia Indeva was selected and installed in the assembly line, as shown in Figure 26.

Step number	Step description	Application for this solution
4	Analyze	Two KPIs were set to control the success of the industrial manipulator.
5	Go Live	The manipulator is ready to go live and to improve the manufacturing processes and ergonomics in the assembly line.

Source: Created by the author

Figure 26 – Industrial Manipulator – Liftronic Easy

Source: Created by the author

The total investment for the Manipulator is $46,000.

Quantitative results

The Manipulator was installed in September 2021 in the Munich manufacturing site of a biomedical company. The success of the solution is being evaluated using two KPIs for six months, and presented in the Table 14:

- Number of Reported Accidents & Incidents
- Savings: one headcount instead of two can be planned for some stations of the assembly line to lift and assemble the 40 kg sub-assemblies, which improves the productivity. Savings are measured in reduction of headcounts based on the JOP, which was September 2021.

Table 14. Manipulator – Quantitative results

Month / 2021	**Number of Reported Accidents & Incidents**	**Savings to JOP [Number of headcounts]**
September	0	-
October	0	0.7
November	0	1

Source: Created by the author

4.7 RFID Kanban

The Japanese word Kanban means visual board or sign. The Kanban system is part of the Toyota Production System (TPS), which was created in the late 1940s to control inventory levels and the production and supply of components. The Kanban system can be thought of as a signal and response system. When an item is running low at the manufacturing shop floor, there will be a visual sign, usually a card, specifying how much to order from the supply. The person using the parts makes the order for the quantity indicated by the Kanban card and the supplier provides the exact amount requested [167, 168, 169, 170].

The Kanban technology has evolved from traditional handwritten cards to automated ordering systems using Radio-frequency identification (RFID). The solution presented during this research is the RFID Kanban, which is a system for managing the replenishment of production material in manufacturing industries. The basis is an insensitive chip with antenna, the so-called RFID tag or RFID transponder, which is attached to the object used in the shop floor as a label on the Kanban bin and is movable. Each tag is identifiable by a unique number for data security. The RFID Kanban system also consists of a reading device for detecting the transponder and the sending unit for data transmission or for the automated reordering of parts for production [171, 172]. There are several ways to trigger the order, for example:

- Turning the 2-part Kanban bins
- Pressing a button
- Weighing technology, which constantly monitors the fill level in the container and triggers the demand when the reorder level is reached

- The empty Kanban bin is dropped into the RFID box
- The empty Kanban bins are transported through the RFID gate
- The empty Kanban bins are placed on a RFID mat

The abovementioned solutions enable automated repeat orders without the need for scanning or manual entry. The RFID Kanban uses one of the technologies selected in the section 1.1.3: Internet of Things. Implementation following the roadmap is described in Table 15.

Table 15. RFID Kanban – Implementation process

Step number	Step description	Application for this solution
0	Identify your bottlenecks	Managing the replenishment of production material in the manufacturing is time-consuming and leads to human errors. The whole process is not efficient: - human errors are mitigated through the conduction of regular physical inventories - warehouse workers must manually check all Kanban cards and Kanban bins and they need to enter the orders manually in the ERP system
1	Develop a strategy	Physical Kanban cards were a standard in the 2000s but is not state of the art technology to be used to manage the material replenishment.
2	Ideas & Prototypes	Different Kanban systems from different vendors such as Würth and Keller & Kalmbach were analyzed, as well as the different ways to trigger the order.
3	Connect / Plug-in your devices	The dropLOG® Kanban system from Keller & Kalmbach was selected and installed for the material replenishment of fasteners and connecting components (small parts), as shown in Figure 27.
4	Analyze	KPIs were set to control evolution of the missing parts and to measure the time invested to replenish the material. Am I winning or am I losing?
5	Go Live	Once all quantitative results are gathered, the RFID Kanban will be ready to go live and to improve the replenishment process, introducing an automated ordering system.

Source: Created by the author

Figure 27 – RFID Kanban

Source: Created by the author

The total investment for the RFID Kanban system is $2,528, without including the prices of the material bins [171, 172, 173]:

- Zebra RFID Labels [$117]
- Zebra RFID printer [$1428]
- Rack with material bins [$900]
- DropLOG Lease [$75/monthly]

Quantitative results

The RFID Kanban was installed in July 2021 in the Munich manufacturing site of a biomedical company. The success of the solution is being evaluated using two KPIs for six months, and presented in the Table 16:

- Number of missing parts: incorrectly material replenishment leads to missing parts in the assembly line.
- Savings: traditional material replenishment management for fasteners and connecting components (small parts) using handwritten Kanban cards requires on average 40 working hours a month, plus the additional countermeasures needed due to the missing parts. Savings are measured in working hours based on the jumping-off point (JOP), which was July 2021.

Table 16. RFID Kanban – Quantitative results

Month / 2021	Savings to JOP	Number of missing parts
July	3 h	13
August	4 h	13
September	4 h	11
October	6 h	11
November	7 h	9

Source: Created by the author

4.8 Recap

This chapter presented the results of the six Industry 4.0 solutions implemented in the SME manufacturing site following the strategy of the Industry 4.0 Roadmap. The testing and verification of the Industry 4.0 Roadmap shows the suitability to successfully roll out Industry 4.0 technologies in SMEs.

Moreover, this chapter 4 pretended to highlight the practiced-oriented focus of the Industry 4.0 Roadmap and therefore real solutions, which are currently in used are described.

5 INDUSTRY 4.0 HUB FOR SMES

5.1 Introduction

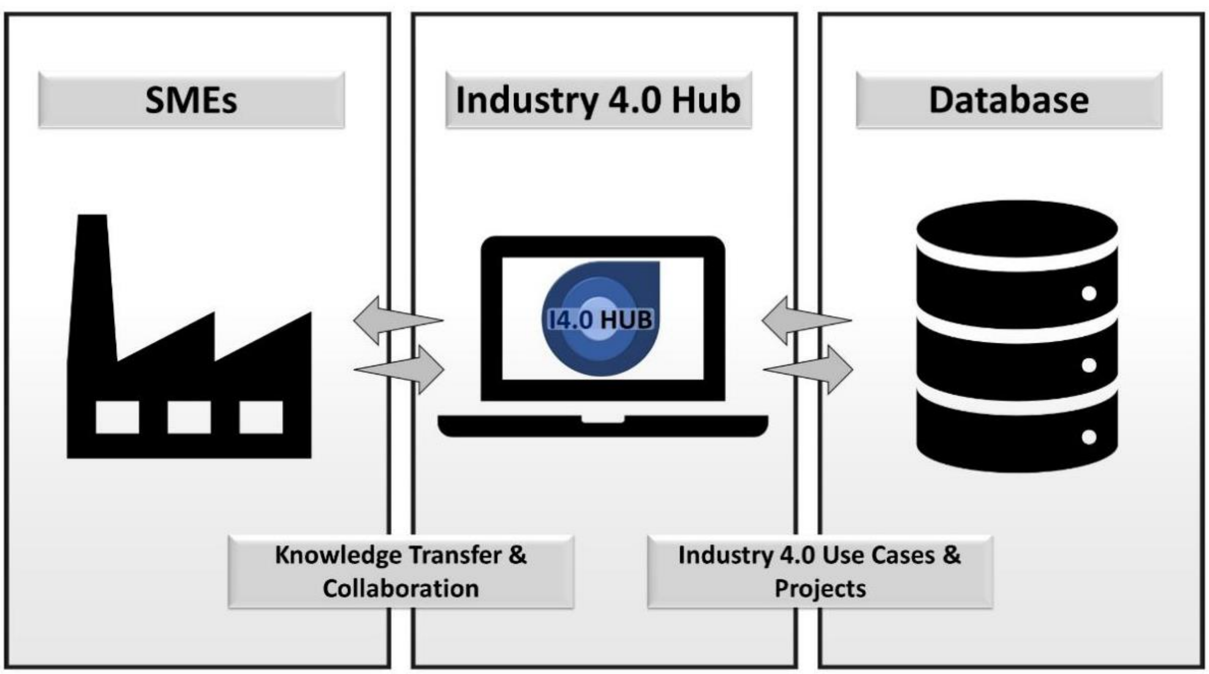
This chapter aims to present the collaborative Industry 4.0 KT platform called Industry 4.0 HUB. It starts with a guideline to understand how the platform works and how the different functionalities are interconnected. Subsequently, the different modules of the website and their capabilities are detailed presented.

5.2 Industry 4.0 HUB

The Industry 4.0 HUB is a website that aims to support SMEs in selecting the appropriate Industry 4.0 technologies and projects. The website intends to work as an SME collaborative network for KT, where SMEs can access the latest knowledge, expertise, and technology to access Industry 4.0. The Industry 4.0 HUB wants to eliminate impediments to accessing Industry 4.0 knowledge; it wants to offer open access to Industry 4.0 knowledge.

This platform does not pretend to gather single Industry 4.0 technologies, but instead collects Industry 4.0 use cases, real solutions, and projects in SMEs. The Industry 4.0 HUB is based on three pillars: the SMEs accessing the platform, the website offering the front-end capabilities, and a database, as the backend, where Industry 4.0 use cases are stored, as shown in Figure 28. The Industry 4.0 HUB is designed with a modular architecture that guarantees great advantages in terms of flexibility and extensibility. The Industry 4.0 HUB offers four modules, which will be explained in the following subsections.

Figure 28 - Industry 4.0 HUB architecture



Source: Created by the author

5.3 The HUB

This module is the core of the KT. The HUB enables the SMEs to access the Industry 4.0 database and gain the information and awareness necessary to implement Industry 4.0 use cases. Each use case is presented from a practical viewpoint, with a detailed dataset including the fields presented in Table 17.

Table 17. Dataset of the Industry 4.0 use cases.

Field	Description
Name of the Industry 4.0 Project	Unique identification of the Industry 4.0 use case, which is used as a key for the SQL database.
Industry 4.0 Technology	The literature about technologies related to Industry 4.0 is extensive [109, 103, 104, 81]. Considering the large number of technologies related to Industry 4.0, six of these technologies were selected to classify the use cases: Internet of Things, machine learning, automation, big data, cloud computing, augmented reality, and other.
Description	Short introduction of the Industry 4.0 solution, including the use case of the project and the improvement achieved. With this information, other SMEs can gain a quick understanding of and easily and quickly comprehend the key usage of the solution and implement it in their organizations.
Budget	Several research works have highlighted that SMEs do not have the economic resources to implement Industry 4.0 technologies [88, 132]. For the Industry 4.0 HUB, this category is included so that microenterprises and small enterprises with turnover ranges between EUR 0.5 million and EUR 10 million can carefully select the solution based on the costs and the investment.
Picture	This allows the user to upload a picture of the use case to support rapid visual recognition.
Additional Information (Link)	This is a field to include links to provide additional information, such as the website of the vendor of the technologies used.

Source: Created by the author

This dataset in the database aims to describe in a nutshell the abovementioned key elements to understand how an Industry 4.0 use case has been implemented in a SME.

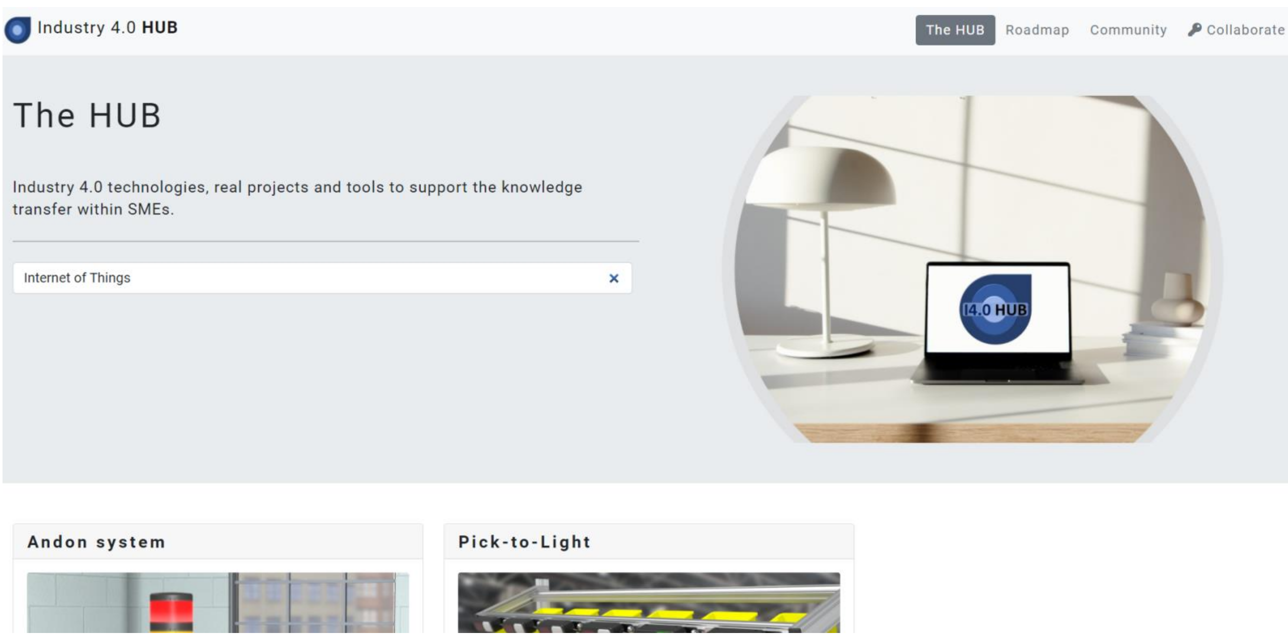
Additionally, this module has a search bar, which allows the user of the SME to search for:

- Industry 4.0 technologies

- Budget
- Specific use cases
- Keywords

Some examples of Industry 4.0 use cases in SMEs, related to the IoT, presented using the abovementioned dataset are shown in Figure 29.

Figure 29 - Industry 4.0 HUB desktop user interface.



Source: Created by the author

5.4 Roadmap

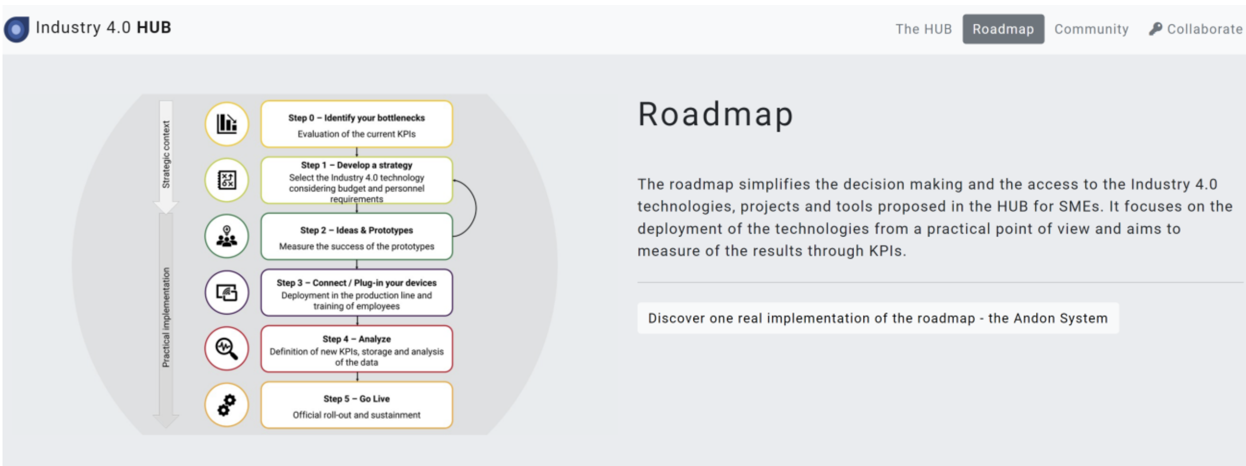
The HUB enables Industry 4.0 KT and allows SMEs to gain the Industry 4.0 practical knowledge required to implement the projects in their facilities. However, the implementation could be tortuous sometimes, and therefore, an additional module was provided in the Industry 4.0 HUB to support the SMEs: Roadmap.

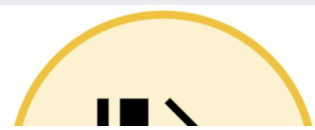
This module connects the two main results of this research: the Industry 4.0 Roadmap described in the chapter 4 and the website Industry 4.0 HUB. The first objective of this module is to be a theoretical guideline to understand how to implement the strategy of the Industry 4.0 Roadmap. Secondly, some successful solutions, implemented in SMEs using the Industry 4.0 Roadmap as described in the previous chapter, are also presented in this module.

The Industry 4.0 Roadmap aims to facilitate decision-making and access to Industry 4.0 technologies by the production areas of the SMEs.

The main differences between the roadmap proposed within this research and the roadmaps presented in previous research, as previously described in the chapter 4, are its focus on SMEs and the practical viewpoint. The initial dashboard of this module is shown in Figure 30.

Figure 30 - Industry 4.0 HUB – Module Roadmap





Source: Created by the author

5.5 Community

Following the networking trend being observed during recent years in other platforms like DIH, the Industry 4.0 HUB proposes a module called Community. The importance of community is becoming greater as we address the challenges that SMEs are facing nowadays to implement Industry 4.0 technologies. This module aims to be a forum where SMEs can share experiences on Industry 4.0 implementation and where collaboration can appear.

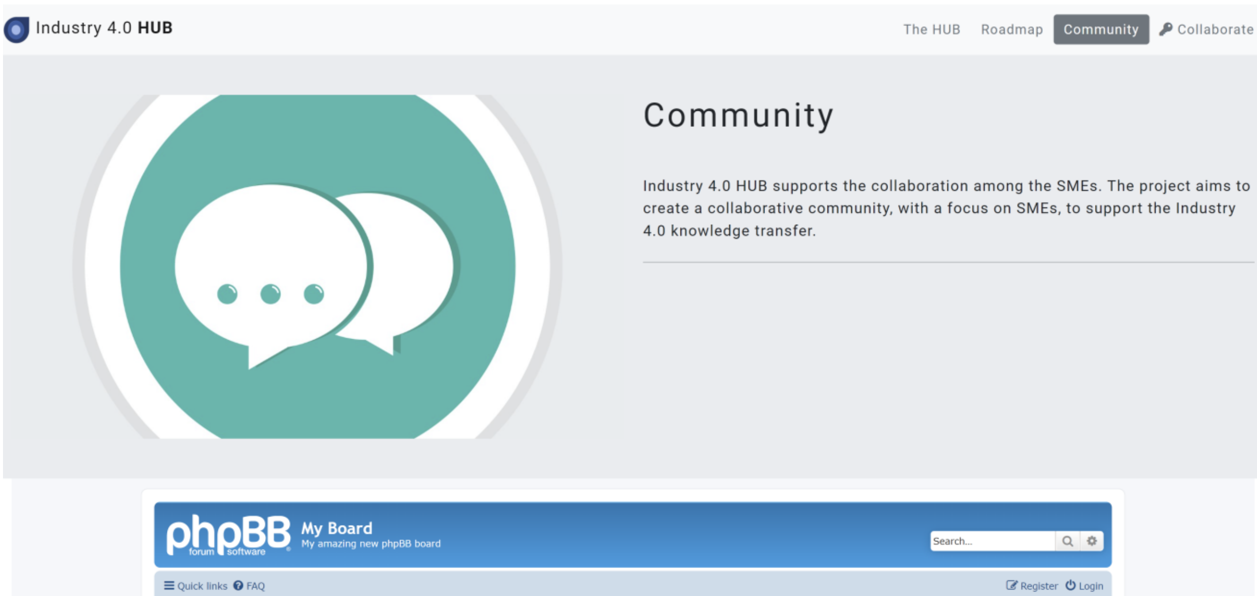
But fruitful cooperation between the SMEs of the Industry 4.0 HUB requires effective collaboration, and therefore the following module 5.6 is required to foster the community. This module is shown in the Figure 31.

5.6 Collaborate

This module allows SMEs to contribute to the Industry 4.0 HUB, introducing use cases, real projects, and implementations of SMEs in the database. Every DIH has a different focus and specialization on a regional level, which makes access to the knowledge for SMEs from other regions or nations within the European Union and outside of it difficult. On the other hand, Plattform Industrie 4.0 focuses mainly on the use cases in Germany. Both platforms have already defined structures and procedures. Single users or SMEs are not able to collaborate; they cannot transfer Industry 4.0 knowledge with other SMEs.

The Industry 4.0 HUB aims to create a platform without regional or national barriers and where everyone has the right to share Industry 4.0 knowledge and experience. Effective collaboration offers the means for improving the access to the Industry 4.0 to the SMEs. It is also important for reducing inequality nationally and internationally along the EU.

Figure 31 - Industry 4.0 HUB – Module Community



Source: Created by the author

5.7 Recap

Through this chapter, the lector gained an overview on the capabilities of the Industry 4.0 HUB including its different modules.

6 DISCUSSIONS

6.1 Industry 4.0 Roadmap

6.1.1 Roadmap comparison

As described earlier in section 3.2.2, the proposed roadmap aimed to simplify access by SMEs to Industry 4.0 technologies. The main differences between the roadmap proposed within this paper and roadmaps presented in previous research works are its focus on SMEs and the practical viewpoint. To highlight this extended approach, the following three criteria will be used in a weighted decision matrix Table 18:

- Task-oriented: SMEs do not have the same structures as large enterprises and, therefore, the roadmap must be task-oriented, not team-oriented. A roadmap that focuses on the completion of particular tasks makes it possible to create a roadmap with a single headcount, without involving several departments. This reduces the resources required to create the roadmap.
- Investment considerations: the roadmap will take into account the monetary limitations of SMEs for implementation.
- Practical implementation: the roadmap should not conclude with a theoretical development of the strategy; instead, it should continue with its deployment in practice and the subsequent measurement of the results through KPIs.

The fulfilment of the abovementioned criteria is represented in the following table Table 18 [green circle: fulfilled, red circle: not fulfilled].

Table 18. Roadmap comparison

Proposed roadmap	Task-oriented	Practical implementation	Investment considerations
[86]	🔴	🔴	🔴
[78]	🔴	🔴	🔴
[82]	🔴	🟢	🔴
This research [3.2.2]	🟢	🟢	🟢

Source: Created by the author

6.1.2 Data obtained during usage of the roadmap

Based on the quantitative results presented in section 4.2 and on the qualitative results gained during the prototype phase, the Andon system improves the operation as follows:

- The key benefit of the Andon system is that it makes the condition of manufacturing processes readily and easily visible to plant managers, operators, and maintenance personnel, improving cross-functional collaboration.
- In addition, it makes it far easier to ensure processes are being carried out efficiently and productively.
- Andon boards can also act as an early warning device, improving visibility. When abnormal conditions are noted, they will appear on the Andon board, giving operators and managers time to correct problems before they begin in some cases.

The qualitative results gathered during the prototype phase show that the implementation of a PTL system reaps great benefits:

- It makes the operations far more flexible by decreasing the number of operator movements. In addition, it takes advantage of the time previously spent on reading, writing down and checking information to prepare more orders, thereby increasing employee productivity.
- It drastically decreases errors made in order preparation.
- Assistive picking technology requires the least training for new hires. This facilitates the onboarding of operators in your facilities.
- It consists of a mature technology that has incorporated increasing possibilities regarding the design of the devices and the nature of the messages it displays. This, consequently, provides enhanced customization options.

The qualitative results gained during the prototype phase show that usage of mixed reality glasses promotes the following benefits:

- It reduces the gap between rookies and veterans in many professions, due to the fast-learning curve.
- Improved Resource Management
- It simplifies complex problems/situations through the usage of high-definition holograms, increasing the productivity of operators.

Moreover, the quantitative results gathered during this research and presented in section 4.5, in addition with the qualitative results, show that the DVPM improves how teams collaborate:

- The data and progress of each project is available in just one place, in just one tool. It makes easier to delegate tasks and to manage the resources. The DVPM facilitates keeping team members in the loop about everything happening in the project.
- Improved visibility regarding tasks and resources, makes possible to optimize the resources management and distribute them efficiently. It generates headcounts savings, as shown in Table 12, due to the increased productivity.
- The DVPM comes with customizable dashboards for real-time reporting, which improves the visibility not only towards team members, but also towards management.

The quantitative results related to the Manipulator, which are still being carried out, presented in section 4.6, in addition with the qualitative results, show that the industrial Manipulator improves ergonomics and productivity:

- The manipulator effectively improves the operator wellness and achieves ergonomic safe handling operations. It eliminates the strain during load lifting, but also the inertia during acceleration, braking or direction changes.
- The Liftronic Easy Manipulator has an electronic control, which has many advantages compared to a traditional pneumatic manipulator: auto-weight sense, less maintenance costs, and noise reduction.
- The manipulator also generates savings, it improves the productivity, reducing the headcounts, as shown in Table 14.

Finally, the quantitative results obtained during the usage of the RFID Kanban, presented in section 4.7, in addition with the qualitative results, show that the RFID Kanban, or similar modern types of Kanban, automates the management of the material replenishment and increases the productivity:

- The RFID Kanban allows the Materials & Planning department to precisely control the inventory levels in real time.
- It eliminates the need for manual data entry and simplifies the ordering and replenishment process and data transfer.
- The RFID Kanban system is easy to implement in old-fashioned warehouses, as it is an upgrade of traditional Kanban system, with increases the acceptance, reduces the fears of the operators and no change of existing processes is required.
- The solution generates savings: eliminates manual data entries and the reduces missing parts due to the reduction of the human error as shown in Table 16.

To summarize, the proposed roadmap brings the following benefits:

- The roadmap helps SMEs enter the new era of manufacturing using a simple process that does not require complex expertise or big teams. The proposed roadmap covers one of the gaps highlighted in the section 1.6.
- The six Industry 4.0 technologies selected (Cloud Computing, Digital Transformation, IoT, Robotics, Automation and VR) are available for every company, no matter the number of employees or its revenue. According to another gap identified in section 1.6, this research has shown the implementation of Industry 4.0 technologies from a practical point of view using the roadmap.
- The initial investment is affordable for every SME. Five out of the six results presented cost less than €4,000, just the manipulator exceeds the range presented in section 3.2.1.4; the solutions have evolved to low-cost products that generate great productivity improvements.

Moreover, the key characteristics of the SAL presented in section 3.2.3 are visible in the six technologies presented during this paper Table 19.

Table 19. SAL – expectations fulfilled

Tools	Collaboration	Data-driven	Preventive Maintenance	Proactive assembly line
Andon System	✓	✓	✓	✓
Mixed reality	✓	✓	✗	✓
PTL	✓	✓	✗	✓
DVPM	✓	✓	✗	✓
Manipulator	✓	✗	✓	✓
RFID Kanban	✓	✓	✓	✓

Source: Created by the author

6.2 Industry 4.0 HUB

The result of this research is the Industry 4.0 HUB platform, which has been completely developed and online since January 2021 at the following link: i40-hub.com. This research presents the qualitative advantages of using the collaborative KT platform Industry 4.0 HUB:

- The Industry 4.0 HUB creates a single source for Industry 4.0 KT for SMEs. Every SME willing to implement Industry 4.0 technologies does not need to seek hundreds of papers, books, and platforms as everything is available in just one website, which covers the lack of knowledge highlighted in Section 1.6. Additionally, the resources needed to start the Fourth Industrial Revolution are minimized.
- The HUB provides real-time SME access to an immense collection of Industry 4.0 use cases.
- The Collaborate and Networking modules allow SMEs to enter use cases and share Industry 4.0 knowledge and resources, creating a collaborative network.

- The Roadmap module helps SMEs enter the new era of manufacturing using a simple process that does not require complex expertise or big teams.

Industry 4.0 KT must be simplified for the SMEs, especially for the microenterprises, and therefore, a single source platform like the Industry 4.0 HUB could provide the solution to the deficiency identified. As was previously mentioned, DIHs and Plattform Industrie 4.0 are great initiatives and key enablers for the transition toward Industry 4.0 and digital transformation for European SMEs. The European network of DIHs will help companies to improve their processes, products, and services using digital technologies, and they will provide access to technical expertise and experimentation, but within this research a different way to improve the Industry 4.0 KT between SMEs is proposed. Table 20 highlights some of the differences between the Industry 4.0 HUB, the Plattform Industrie 4.0, and the DIHs. In conclusion, the Industry 4.0 HUB supports the transition toward Industry 4.0 for SMEs by using a different approach than the one used in Plattform Industrie 4.0 and the DIHs. The Industry 4.0 HUB aims to eliminate unnecessary barriers and to simplify Industry 4.0 KT.

Table 20. Comparison between Industry 4.0 HUB, DIH, and *Plattform Industrie 4.0.*

Platform	Scalability	Resources	Networking	Technical Expertise	Specialization
DIH	✗	✗	✓	✓	✓
Plattform Industrie 4.0	✓	✗	✗	✓	✓
Industry 4.0 HUB	✓	✓	✓	✗	✗

Source: Created by the author

7 CONCLUSIONS

7.1 Conclusions about research objectives

As described in the section 2, this research has identified two significant objectives, which were studied and developed within this thesis.

Firstly, the research aimed to improve the adoption of disruptive and productive Industry 4.0 technologies in Small and Medium sized Enterprises (SMEs), as well as to define the strategy and the starting point for the implementation. To this purpose:

- The state-of-the-art Industry 4.0 technologies were analyzed, focusing on their capabilities, development, pricing, and ease of implementation for SMEs. The outcome of the analysis was the selection of five technologies, which are in an optimal maturity level for the adoption in SMEs: Internet of Things, Digital Transformation, Robotics, Cloud Computing and Virtual Reality.
- A six-step Industry 4.0 Roadmap for the specific purposes of SMEs was developed, including six practical examples to implement new Industry 4.0 technologies using the proposed strategy.

Secondly, the research targeted to simplify and to enhance the access to Industry 4.0 technologies for SMEs by providing a collaborative Industry 4.0 knowledge transfer platform. To this matter:

- The existing knowledge transfer initiatives and platforms [Digital Innovation Hub and Industrie 4.0 Plattform] supporting the Industry 4.0 transition within SMEs were reviewed and evaluated.
- A new collaborative online platform to improve Industry 4.0 knowledge transfer between SMEs was developed: Industry 4.0 HUB and their functionalities and capabilities were presented within this research.

The abovementioned results represent an advance in Industry 4.0 knowledge and enhance the existing strategies and tools for the access of SMEs to the Industry 4.0 revolution.

7.2 General conclusions

The fourth industrial revolution marks the beginning of a new era that brings unlimited possibilities and many challenges for SMEs. On one hand, technologies that are part of Industry 4.0, such as the Internet of Things and Cloud Computing, are radically changing the way it is produced and the methods of doing business, as well as increasing the productivity and the margins of many manufacturers. On the other hand, many SMEs are unable to adapt to the Industry 4.0 revolution, for instance the majority of SMEs in Europe have not introduced advanced digital technologies such as Industry 4.0 technologies yet.

As highlighted during this research, SMEs are the backbone of the European economy, and their importance for jobs and growth in European regions must be considered when rolling out EU programmes to promote the Industry 4.0 transformation. The results presented during this thesis constitute an improvement in the strategies and tools for the access of SMEs to the Industry 4.0. The Industry 4.0 Roadmap and its practical examples demonstrated that Industry 4.0 technologies are nowadays accessible to SMEs, because they are related to low-cost investment and easy implementations.

Additionally, this research also showed that the problem accessing Industry 4.0 technologies for SMEs often lies in the lack of information and in the poorly knowledge transfer within SMEs and with large enterprises. To this purpose, the Industry 4.0 HUB is a reliable platform to access the Industry 4.0 information and to improve the knowledge transfer.

In addition to this thesis, as already mapped out by government initiatives like the Digital Europe Programme and the Europe's Digital Decade, a clear path towards a common vision and actions is needed to succeed in the digital transformation and in the Industry 4.0 transformation. The involvement and commitment of the public, supporting the SMEs, is also crucial to achieve a successful digital transformation. The Industry 4.0 HUB, The Industry 4.0 Roadmap, and government initiatives as the Digital Europe Programme and the Digital Innovation Hubs will enable SMEs to benefit from the opportunities of digitalisation and the fourth industrial revolution, but there is still a big gap to close.

7.3 Further research

The next step in this research would be to develop further the Industry 4.0 HUB towards an e-commerce platform that provides guidance to the SMEs to access the Industry 4.0 technologies. The SMEs could select, based on artificial intelligence and algorithms, the best possible solutions based on the requirements, number of employees, areas of the production and budget available and finally right away purchase them online. This development would require the main Industry 4.0 technologies suppliers to offer their products in the marketplace, as well as a profound development of the artificial intelligence skills.

Such a future Industry 4.0 HUB platform would simplify tremendously the access to the Industry 4.0 technologies, providing not only knowledge transfer between SMEs but also one-click buying capabilities of the most suitable technologies proposed.

On the other hand, the examples of Industry 4.0 technologies implemented using the Industry 4.0 Roadmap showed the great capabilities and productivity in standalone areas that the technologies offer for a low-cost investment. A future research area would be the integration of the various Industry 4.0 technologies used in different areas of manufacturing and business planning processes within a SME, to offer an end-to-end solution across the entire supply chain of the SMEs.

Moreover, another future research subject would be the inclusion of cybersecurity aspects when implementing Industry 4.0 technologies using the Industry 4.0 Roadmap. Many SMEs are facing security breaches, that are affecting the industrial manufacturing processes. It is necessary to propose a cybersecurity framework and strategy when accessing the Industry 4.0.

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ANNEX – Industry 4.0 HUB Programming

Index – HTML

```
<!DOCTYPE html>
<html lang="en">

<head>

  <meta charset="utf-8">
  <meta name="viewport" content="width=device-width, initial-scale=1, shrink-to-fit=no">
  <meta name="description" content="Industry 4.0 HUB">
  <meta name="author" content="Alberto Cotrino">

  <title>Industry 4.0 HUB</title>
  <link rel="shortcut icon" type="image/jpg" href="img/logo_t.png"/>

  <!-- Bootstrap 5 CSS -->
  <link href="vendor/bootstrap/css/bootstrap.min.css" rel="stylesheet">

  <!-- Custom fonts for this template -->
  <link href="vendor/fontawesome-free/css/all.min.css" rel="stylesheet">
  <link href="vendor/simple-line-icons/css/simple-line-icons.css" rel="stylesheet" type="text/css">
  <link href="https://fonts.googleapis.com/css?family=Roboto:300,400,700,300italic,400italic,700italic" rel="stylesheet" type="text/css">

  <!-- Custom styles for this template -->
  <link href="css/style.css" rel="stylesheet">

</head>

<body>

  <!-- Navigation -->

  <nav class="navbar navbar-expand-lg navbar-light bg-light">
```

```
  <a class="navbar-brand" href="index.html">
   <img src="img/logo_t.png" width="35" height="35" class="d-inline-block align-top" alt="">
   Industry 4.0 <b>HUB</b>
  </a>
  <button class="navbar-toggler" type="button" data-bs-toggle="collapse" data-bs-target="#navbarSupportedContent" aria-controls="navbarSupportedContent" aria-expanded="false" aria-label="Toggle navigation">
   <span class="navbar-toggler-icon"></span>
  </button>

  <div class="collapse navbar-collapse justify-content-end" id="navbarSupportedContent">
   <ul class="navbar-nav mr-auto">
    <li class="nav-item">
     <a type="button" class="btn btn-outline-secondary border-0" href="hub_search.php">The HUB</a>
    </li>
    <li class="nav-item">
     <a type="button" class="btn btn-outline-secondary border-0" href="roadmap.html">Roadmap</a>
    </li>
    <li class="nav-item">
     <a type="button" class="btn btn-outline-secondary border-0" href="community.html">Community</a>
    </li>
    <li class="nav-item">
     <a type="button" class="btn btn-outline-secondary border-0" href="collaborate/hub_create.html">
      <i class="fas fa-key"></i>
      Collaborate</a>
    </li>
   </ul>
  </div>
 </nav>

  <!-- Carousel -->
  <header class="text-center">
   <div id="carouselExampleCaptions" class="carousel slide" data-bs-ride="carousel">
    <div class="carousel-indicators">
     <button type="button" data-bs-target="#carouselExampleCaptions" data-bs-slide-to="0" class="active" aria-current="true" aria-label="Slide 1"></button>
```

```
      <button type="button" data-bs-target="#carouselExampleCaptions" data-bs-slide-to="1" aria-label="Slide 2"></button>
    </div>
    <div class="carousel-inner">
      <div class="carousel-item active">
        <img src="img/bg-masthead.jpg" class="d-block w-100" alt="...">
        <div class="carousel-caption d-none d-md-block">
          <h1>Industry 4.0 HUB</h1>
          <p>Industry 4.0 for Small and Medium-Sized Enterprises</p>
        </div>
      </div>
      <div class="carousel-item">
        <img src="img/bg-masthead2.jpg" class="d-block w-100" alt="...">
        <div class="carousel-caption d-none d-md-block">
          <h1>Knowledge Transfer within SMEs</h1>
          <p>SMEs require new collaborative Industry 4.0 knowledge transfer platforms</p>
        </div>
      </div>
    </div>
    <button class="carousel-control-prev" type="button" data-bs-target="#carouselExampleCaptions" data-bs-slide="prev">
      <span class="carousel-control-prev-icon" aria-hidden="true"></span>
      <span class="visually-hidden">Previous</span>
    </button>
    <button class="carousel-control-next" type="button" data-bs-target="#carouselExampleCaptions" data-bs-slide="next">
      <span class="carousel-control-next-icon" aria-hidden="true"></span>
      <span class="visually-hidden">Next</span>
    </button>
  </div>
 </header>

<!-- Quote & Icons -->
<section class="features-icons bg-light text-center">
 <div class="container-fluid">
  <div class="row">
    <div class="col-lg-12">
```

```
          <figure class="text-center">
            <blockquote class="blockquote">
              <p>Organizations might be unable to adapt to the 4th Industrial Revolution</p>
            </blockquote>
            <figcaption class="blockquote-footer">
              Professor Klaus Schwab <cite title="Source Title">Founder and Executive Chairman of the World Economic Forum</cite>
            </figcaption>
          </figure>
        </div>
      </div>
      <div class="row">
        <div class="col-lg-6">
          <div class="features-icons-item mx-auto mb-5 mb-lg-0 mb-lg-3">
            <div class="features-icons-icon d-flex">
              <i class="icon-book-open m-auto text-primary"></i>
            </div>
            <h4>Hub</h4>
            The HUB serves as an Industry 4.0 knowledge transfer platform for SMEs
          </div>
        </div>
        <div class="col-lg-6">
          <div class="features-icons-item mx-auto mb-5 mb-lg-0 mb-lg-3">
            <div class="features-icons-icon d-flex">
              <i class="icon-graph m-auto text-primary"></i>
            </div>
            <h4>Roadmap</h4>
            The roadmap helps SMEs to enter the 4th Industrial revolution using a simple process
          </div>
        </div>
      </div>
    </div>
  </section>

  <!-- Image Showcases -->
```

```
  <section class="showcase">
   <div class="container-fluid p-0">
    <div class="row no-gutters">

     <div class="col-lg-6 order-lg-2 text-white showcase-img" style="background-image: url('img/bg-showcase-1.jpg');"></div>
     <div class="col-lg-6 order-lg-1 my-auto showcase-text">
      <h4>Industry 4.0 for SMEs</h4>
      The Industry 4.0 brings opportunities to improve the productivity for small and medium-sized enterprises (SME), however at the same time the 4th Industrial Revolution brings some challenges as well. New knowledge management strategies promoting a collaborative atmosphere between SMEs are needed. Networking through the different regional, national and EU levels are required to foment the innovation.
     </div>
    </div>
    <div class="row no-gutters">
     <div class="col-lg-6 text-white showcase-img" style="background-image: url('img/bg-showcase-2.jpg');"></div>
     <div class="col-lg-6 my-auto showcase-text">
      <h4>Industry 4.0 - HUB</h4>
      There is a gap to provide a collaborative Industry 4.0 knowledge transfer hub in a European level, without borders, without the level of granularity and regionality proposed in the current initiatives. This platform "Industry 4.0 - HUB" aims to fill this gap and has its focus on developing a collaborative web-based knowledge transfer hub for the implementation of Industry 4.0 technologies in the supply chain of SMEs.
     </div>
    </div>
   </div>
  </section>

 <!-- Footer -->
 <footer class="footer bg-light">
  <div class="container-fluid">
   <div class="row justify-content-center">
    <div class="col-6">
     <ul class="nav">
      <li class="nav-item">
       <a class="nav-link" href="about.html">About</a>
      </li>
      <li class="nav-item">
       <a class="nav-link" href="contact.html">Contact</a>
```

```
          </li>
        </ul>
      </div>
      <div class="col-6 text-end">
        <a href="www.linkedin.com/in/albertocotrino">
          <i class="fab fa-linkedin fa-2x fa-fw"></i>
        </a>
      </div>
    </div>
    <div class="row text-center">
      <h5 class="text-muted">&copy; Industry 4.0 - HUB 2019-2021</h5>
    </div>
  </div>
</footer>

<!-- Bootstrap core JavaScript -->
<script src="vendor/jquery/jquery.min.js"></script>
<script src="vendor/bootstrap/js/bootstrap.bundle.min.js"></script>

</body>

</html>
```

The HUB Search 1 – PHP

```
<!DOCTYPE html>
<html lang="en">

<head>

  <meta charset="utf-8">
  <meta name="viewport" content="width=device-width, initial-scale=1, shrink-to-fit=no">
  <meta name="description" content="Industry 4.0 HUB">
  <meta name="author" content="Alberto Cotrino">

  <title>Industry 4.0 HUB</title>
```

```
  <link rel="shortcut icon" type="image/jpg" href="img/logo_t.png"/>

  <!-- Bootstrap 5 CSS -->
  <link href="vendor/bootstrap/css/bootstrap.min.css" rel="stylesheet">

  <!-- Custom fonts for this template -->
  <link href="vendor/fontawesome-free/css/all.min.css" rel="stylesheet">
  <link href="vendor/simple-line-icons/css/simple-line-icons.css" rel="stylesheet" type="text/css">
  <link href="https://fonts.googleapis.com/css?family=Roboto:300,400,700,300italic,400italic,700italic" rel="stylesheet" type="text/css">

  <!-- Custom styles for this template -->
  <link href="css/style.css" rel="stylesheet">

</head>

<body>

  <!-- Navigation -->

  <nav class="navbar navbar-expand-lg navbar-light bg-light">
    <a class="navbar-brand" href="index.html">
      <img src="img/logo_t.png" width="35" height="35" class="d-inline-block align-top" alt="">
      Industry 4.0 <b>HUB</b>
    </a>
    <button class="navbar-toggler" type="button" data-bs-toggle="collapse" data-bs-target="#navbarSupportedContent" aria-controls="navbarSupportedContent" aria-expanded="false" aria-label="Toggle navigation">
      <span class="navbar-toggler-icon"></span>
    </button>

    <div class="collapse navbar-collapse justify-content-end" id="navbarSupportedContent">
      <ul class="navbar-nav mr-auto">
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0 active" href="hub_search.php">The HUB</a>
        </li>
        <li class="nav-item">
```

```
        <a type="button" class="btn btn-outline-secondary border-0" href="roadmap.html">Roadmap</a>
      </li>
      <li class="nav-item">
        <a type="button" class="btn btn-outline-secondary border-0" href="community.html">Community</a>
      </li>
      <li class="nav-item">
        <a type="button" class="btn btn-outline-secondary border-0" href="collaborate/hub_create.html">
          <i class="fas fa-key"></i>
          Collaborate</a>
      </li>
    </ul>
  </div>
</nav>

<!-- Section Title -->
<section class="sectitle">
    <div class="container-fluid">
      <div class="row g-4 justify-content-center">
        <div class="col-md-6">
          <h6 class="mb-5">The HUB</h6>
          <p>Industry 4.0 real projects and tools to support the knowledge transfer within SMEs.</p>
          <hr class="my-4">
        </div>
        <div class="col-md-6">
          <img src="img/hub_overview.jpg" class="img-fluid" alt="The HUB">
        </div>
      </div>
      <div class="row justify-content-center">
        <form class="d-flex">
            <div class="col-md-6 p-3 mb-3">
              <input class="form-control me-2" id="search" type="search" placeholder="Search here..." autocomplete="off" aria-label="Search">
            </div>
            <div class="col-md-6 p-3 mb-3">
              <select class="form-select" id="search2" aria-label="Search2">
```

```
        <option selected>or choose the Industry 4.0 technology...</option>
        <option value="1">Machine Learning</option>
        <option value="2">Internet of Things</option>
        <option value="3">Automation</option>
        <option value="4">Cloud Computing</option>
        <option value="5">Big Data</option>
        <option value="6">Augmented Reality</option>
       </select>
      </div>
     </form>
   </div>
  </div>
</section>

<!-- Results / Card -->
<section class="resultshub">
 <div class="container-fluid">
  <div class="row g-4 justify-content-center">
   <div class="col-12">
    <div class="result"> </div>
   </div>
  </div>
 </div>
</section>

<!-- Footer -->
<footer class="footer bg-light">
 <div class="container-fluid">
  <div class="row justify-content-center">
   <div class="col-6">
    <ul class="nav">
     <li class="nav-item">
      <a class="nav-link" href="about.html">About</a>
     </li>
```

```
          <li class="nav-item">
            <a class="nav-link" href="contact.html">Contact</a>
          </li>
        </ul>
      </div>
      <div class="col-6 text-end">
        <a href="www.linkedin.com/in/albertocotrino">
          <i class="fab fa-linkedin fa-2x fa-fw"></i>
        </a>
      </div>
    </div>
    <div class="row text-center">
      <h5 class="text-muted">&copy; Industry 4.0 - HUB 2019-2021</h5>
    </div>
  </div>
 </footer>

 <!-- Bootstrap core JavaScript -->
 <script src="vendor/jquery/jquery.min.js"></script>
 <script src="vendor/bootstrap/js/bootstrap.bundle.min.js"></script>

</body>

</html>

<!---jQuery ajax live search --->
<script type="text/javascript">
  $(document).ready(function(){
    // fetch data from table without reload/refresh page
    loadData();
    function loadData(query){
      $.ajax({
        url : "livesearch.php",
        type: "POST",
```

```
          chache :false,
          data:{query:query},
          success:function(response){
            $(".result").html(response);
          }
        });
      }

      // live search data from table without reload/refresh page
      $("#search").keyup(function(){
        var search = $(this).val();
        if (search !="") {
          loadData(search);
        }else{
          loadData();
        }
      });
    });
</script>

<script type="text/javascript">
    $(document).ready(function(){
      // fetch data from table without reload/refresh page
      loadData();
      function loadData(query){
        $.ajax({
          url : "categorysearch.php",
          type: "POST",
          chache :false,
          data:{query:query},
          success:function(response){
            $(".result").html(response);
          }
        });
```

```
    }

    // live search data from table without reload/refresh page
    $("#search2").keyup(function(){
     var search2 = $(this).val();
     if (search2 !="") {
      loadData(search2);
     }else{
      loadData();
     }
    });
  });
</script>
```

The HUB Search 2 – PHP

```
<?php
         // include database connection file

         // Database configuration
  $servername = "localhost";
  $username = "root";
  $password = "";
  $dbname = "toolboxdb";

     // Create connection
     $conn = new mysqli($servername, $username, $password, $dbname);
     // Check connection
     if ($conn->connect_error) {
      die("Connection failed: " . $conn->connect_error);
     }

         // fetch data from prueba table..

         $output = "";
         if (isset($_POST['query'])) {
```

```
                $search = mysqli_real_escape_string($conn, $_POST['query']);
                $sql = "SELECT * FROM prueba WHERE Name LIKE '%$search%' || Number LIKE '%$search%' ||
                                Description LIKE '%$search%' || Budget LIKE '%$search%' || Picture LIKE '%$search%'";
        }else{
                $sql = "SELECT * FROM prueba ORDER BY Name DESC";
        }

        $query = mysqli_query($conn, $sql);
        if (mysqli_num_rows($query) > 0) {
                $output="
    <div class='row'>";

     while($row = mysqli_fetch_assoc($query)) {
     $name = $row['Name'];
     $number = $row['Number'];
     $description = $row['Description'];
     $budget = $row['Budget'];
     $picture = $row['Picture'];
     $link = $row['Link'];

      $output.=
      "<div class='col-lg-4'>
        <div class='card mb-3'>
          <h4 class='card-header'>$name</h4>
            <div class='card-body'>
              <img src='img/$picture' class='card-img-top'>
            </div>
              <ul class='list-group list-group-flush'>
              <li class='list-group-item'><h5>Industry 4.0 Technology: $number</h5></li>
              <li class='list-group-item'><h5>$description</h5></li>
              <li class='list-group-item'><h5>Budget: €$budget</h5></li>
              </ul>
            <div class='card-body'>
              <a href='$link' class='card-link'>Additional Info [External Link]</a>
```

```
            </div>
          </div>
        </div>";
      }
    $output.="</div>";
    echo $output;
            }else{
                        echo "<h5>No record found</h5>";
            }

?>
```

Roadmap – Index

```
<!DOCTYPE html>
<html lang="en">

<head>

  <meta charset="utf-8">
  <meta name="viewport" content="width=device-width, initial-scale=1, shrink-to-fit=no">
  <meta name="description" content="Industry 4.0 HUB">
  <meta name="author" content="Alberto Cotrino">

  <title>Industry 4.0 HUB</title>
  <link rel="shortcut icon" type="image/jpg" href="img/logo_t.png"/>

  <!-- Bootstrap core CSS -->
  <link href="vendor/bootstrap/css/bootstrap.min.css" rel="stylesheet">

  <!-- Custom fonts for this template -->
  <link href="vendor/fontawesome-free/css/all.min.css" rel="stylesheet">
  <link href="vendor/simple-line-icons/css/simple-line-icons.css" rel="stylesheet" type="text/css">
  <link href="https://fonts.googleapis.com/css?family=Roboto:300,400,700,300italic,400italic,700italic" rel="stylesheet" type="text/css">
```

```html
  <!-- Custom styles for this template -->
  <link href="css/style.css" rel="stylesheet">

</head>

<body>

  <!-- Navigation -->

  <nav class="navbar navbar-expand-lg navbar-light bg-light">
    <a class="navbar-brand" href="index.html">
      <img src="img/logo_t.png" width="35" height="35" class="d-inline-block align-top" alt="">
      Industry 4.0 <b>HUB</b>
    </a>
    <button class="navbar-toggler" type="button" data-bs-toggle="collapse" data-bs-target="#navbarSupportedContent" aria-controls="navbarSupportedContent" aria-expanded="false" aria-label="Toggle navigation">
      <span class="navbar-toggler-icon"></span>
    </button>

    <div class="collapse navbar-collapse justify-content-end" id="navbarSupportedContent">
      <ul class="navbar-nav mr-auto">
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="hub_search.php">The HUB</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0 active" href="roadmap.html">Roadmap</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="community.html">Community</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="collaborate/hub_create.html">
            <i class="fas fa-key"></i>
            Collaborate</a>
        </li>
```

```
    </ul>
   </div>
  </nav>

  <!-- Section Title -->
  <section class="sectitle">
    <div class="container-fluid">
      <div class="row g-4 justify-content-center">
        <div class="col-md-6">
          <img src="img/roadmap2.jpg" class="img-fluid" alt="roadmap">
        </div>
        <div class="col-md-6">
          <h6 class="mb-5">Roadmap</h6>
          <p>The roadmap simplifies the decision making and the access to the Industry 4.0 technologies, projects and tools proposed in the HUB for SMEs.
            It focuses on the deployment of the technologies from a practical point of view and aims to measure of the results through KPIs.</p>
          <hr class="my-4">
          <form class="form-inline my-2 my-lg-0">
            <a href="#andon" class="btn btn-light btn-lg">Discover one real implementation of the roadmap - the Andon System</a>
          </form>
        </div>
      </div>
    </div>
  </section>

  <!-- Steps roadmap -->
    <div class="container-fluid">
      <div class="row g-4 align-items-center">
        <div class="col-8 text-center">
          <h2>0 - Identify your bottlenecks</h2>
          <p>The roadmap begins by identifying those areas of production that are hindering the overall efficiency. The search for bottlenecks consists of evaluating Key Performance Indicators (KPIs) throughout production.</p>
        </div>
        <div class="col-4">
          <img src="img/bottlenecks.JPG" class="img-fluid">
```

```
 </div>
</div>
<hr class="my-4">
<div class="row g-4 align-items-center">
 <div class="col-4">
  <img src="img/strategy.JPG" class="img-fluid">
 </div>
 <div class="col-8 text-center">
  <h2>1 - Develop a strategy</h2>
  <p>Step 1 is a crucial stage for the proper development of a roadmap. During this step, the person in charge at the SME must propose possible long-term countermeasures for these bottlenecks using Industry 4.0 technologies (e.g.: Cloud Computing, IoT or VR) that best suit this purpose. This person must also consider the maximum available budget for the SME when creating this strategy.</p>
 </div>
</div>
<hr class="my-4">
<div class="row g-4 align-items-center">
 <div class="col-8 text-center">
  <h2>2 - Ideas & Prototypes</h2>
  <p>The roadmap continues with the initial deployment of the tool selected in the production line. This initial roll-out begins with a prototype, not by installing the tool across the entire production line. The success of the prototype must be evaluated during a defined time span. If the prototype does not show promising results, the process must return to step 1 in order to propose different long-term countermeasures.</p>
 </div>
 <div class="col-4">
  <img src="img/prototypes.JPG" class="img-fluid">
 </div>
</div>
<hr class="my-4">
<div class="row g-4 align-items-center">
 <div class="col-4">
  <img src="img/connect.JPG" class="img-fluid">
 </div>
 <div class="col-8 text-center">
  <h2>3 - Connect / Plug-in your devices</h2>
```

```html
      <p>If the results during step 2 are satisfying, the process continues by deploying the solution across the entire production line. This phase starts by training the operators in the production line on how the tool is used and carrying out some dry runs. This step will improve the acceptance of the selected Industry 4.0 technology by the operators.</p>
     </div>
    </div>
    <hr class="my-4">
    <div class="row g-4 align-items-center">
     <div class="col-8 text-center">
      <h2>4 - Analyze</h2>
      <p>The original KPIs identified during step 1, and how they are measured, may no longer be adequate. During this process, additional KPIs must be proposed and Cloud Computing must be ready to support the storage and analysis of data that the technology selected will generate.</p>
     </div>
     <div class="col-4">
      <img src="img/analyze.JPG" class="img-fluid">
     </div>
    </div>
    <hr class="my-4">
    <div class="row g-4 align-items-center">
     <div class="col-4">
      <img src="img/golive.JPG" class="img-fluid">
     </div>
     <div class="col-8 text-center">
      <h2>5 - Go Live</h2>
      <p>The final step is the official roll-out of the technology across the entire production line. This step focuses on monitoring the defined KPIs. The person in charge at the SME will control sustainment during a defined period.</p>
     </div>
    </div>
   </div>
  </section>


  <!-- Section Title -->
  <section class="sectitle" id="andon">
   <div class="container-fluid">
    <div class="row g-4 justify-content-center">
     <div class="col-md-6">
```

```
<h6 class="mb-5">Andon system – IoT applied to quality control</h6>

<p>Quality is the main driver of an exceptional production plant. Non-conformances shall be kept under control in order to provide customers with the best quality, and to maintain favorable productivity.

Real-time visibility and immediate intervention regarding waste are needed to manage non-conformances. Furthermore, tracking trends in performance over time is also crucial to improve the efficiency of the operations in the assembly line.

Andon is a term that refers to a system which notifies a quality or processing problem. An Andon system is one of the elements described in the Jidoka quality control method pioneered by Toyota as part of the Toyota Production System and belongs to the lean production approach.

The Andon system implemented within this project uses a TL70 Modular Tower Light with a wireless radio base connected to a DXM700 Wireless Controller. The data will be pushed to the Banner Cloud Data Services (CDS) to create a dashboard and perform cloud computing activities. </p>

<hr class="my-4">

</div>

<div class="col-md-6">

<img src="img/andon.jpg" class="img-fluid" alt="The HUB">

</div>

</div>

</div>

<div class="accordion accordion-flush" id="accordionFlushExample">

<div class="accordion-item">

<h2 class="accordion-header" id="flush-headingOne">

<button class="accordion-button collapsed" type="button" data-bs-toggle="collapse" data-bs-target="#flush-collapseOne" aria-expanded="false" aria-controls="flush-collapseOne">

0- Identify your bottlenecks

</button>

</h2>

<div id="flush-collapseOne" class="accordion-collapse collapse" aria-labelledby="flush-headingOne" data-bs-parent="#accordionFlushExample">

<div class="accordion-body">The number of quality non-conformances has been increasing for a long time. Quality failures shall be detected immediately, and countermeasures shall be applied as soon as possible.</div>

</div>

</div>

<div class="accordion-item">

<h2 class="accordion-header" id="flush-headingTwo">

<button class="accordion-button collapsed" type="button" data-bs-toggle="collapse" data-bs-target="#flush-collapseTwo" aria-expanded="false" aria-controls="flush-collapseTwo">

1- Develop a strategy

</button>
```

```
</h2>
<div id="flush-collapseTwo" class="accordion-collapse collapse" aria-labelledby="flush-headingTwo" data-bs-parent="#accordionFlushExample">
<div class="accordion-body">Every work cell in the assembly line will get a traffic light that is manually switched to notify quality non-conformances. It will generate real-time data and will allow employees to resolve the issues in a short period of time.</div>
</div>
</div>
<div class="accordion-item">
<h2 class="accordion-header" id="flush-headingThree">
<button class="accordion-button collapsed" type="button" data-bs-toggle="collapse" data-bs-target="#flush-collapseThree" aria-expanded="false" aria-controls="flush-collapseThree">
2- Ideas & Prototypes
</button>
</h2>
<div id="flush-collapseThree" class="accordion-collapse collapse" aria-labelledby="flush-headingThree" data-bs-parent="#accordionFlushExample">
<div class="accordion-body">Think big but start small. A model work cell was created, where the first prototype was tested.</div>
</div>
</div>
<div class="accordion-item">
<h2 class="accordion-header" id="flush-headingFour">
<button class="accordion-button collapsed" type="button" data-bs-toggle="collapse" data-bs-target="#flush-collapseFour" aria-expanded="false" aria-controls="flush-collapseFour">
3- Connect / Plug-in your devices
</button>
</h2>
<div id="flush-collapseFour" class="accordion-collapse collapse" aria-labelledby="flush-headingFour" data-bs-parent="#accordionFlushExample">
<div class="accordion-body">Traffic light was installed, connected to the controller, dashboard was set, and the Andon team was ready to analyze the data. Some dry runs were performed until the system ran stable.</div>
</div>
</div>
<div class="accordion-item">
<h2 class="accordion-header" id="flush-headingFive">
<button class="accordion-button collapsed" type="button" data-bs-toggle="collapse" data-bs-target="#flush-collapseFive" aria-expanded="false" aria-controls="flush-collapseFive">
```

```
4- Analyze
</button>
</h2>
<div id="flush-collapseFive" class="accordion-collapse collapse" aria-labelledby="flush-headingFive" data-bs-parent="#accordionFlushExample">
<div class="accordion-body">Andon team ran daily KPIs to control the evolution of quality non-conformances and analyze the results. Am I winning or am I losing?</div>
</div>
</div>
<div class="accordion-item">
<h2 class="accordion-header" id="flush-headingSix">
<button class="accordion-button collapsed" type="button" data-bs-toggle="collapse" data-bs-target="#flush-collapseSix" aria-expanded="false" aria-controls="flush-collapseSix">
5- Go Live
</button>
</h2>
<div id="flush-collapseSix" class="accordion-collapse collapse" aria-labelledby="flush-headingSix" data-bs-parent="#accordionFlushExample">
<div class="accordion-body">Once the results were verified and the Andon system has proven that IoT can help track and reduce quality non-conformances, the Andon system went live and is ready to be extended to another work cells.</div>
</div>
</div>
</div>
</section>

<!-- Footer -->
<footer class="footer bg-light">
<div class="container-fluid">
<div class="row justify-content-center">
<div class="col-6">
<ul class="nav">
<li class="nav-item">
<a class="nav-link" href="about.html">About</a>
</li>
<li class="nav-item">
<a class="nav-link" href="contact.html">Contact</a>
```

```
        </li>
       </ul>
      </div>
      <div class="col-6 text-end">
       <a href="www.linkedin.com/in/albertocotrino">
        <i class="fab fa-linkedin fa-2x fa-fw"></i>
       </a>
      </div>
    </div>
    <div class="row text-center">
      <h5 class="text-muted">&copy; Industry 4.0 - HUB 2019-2021</h5>
    </div>
   </div>
  </footer>

  <!-- Bootstrap core JavaScript -->
  <script src="vendor/jquery/jquery.min.js"></script>
  <script src="vendor/bootstrap/js/bootstrap.bundle.min.js"></script>

</body>

</html>
```

The HUB Create 1 – HTML

```
<!DOCTYPE html>
<html lang="en">

<head>

  <meta charset="utf-8">
  <meta name="viewport" content="width=device-width, initial-scale=1, shrink-to-fit=no">
  <meta name="description" content="Industry 4.0 HUB">
  <meta name="author" content="Alberto Cotrino">

  <title>Industry 4.0 HUB</title>
```

```
  <link rel="shortcut icon" type="image/jpg" href="img/logo_t.png"/>

  <!-- Bootstrap 5 CSS -->
  <link href="/vendor/bootstrap/css/bootstrap.min.css" rel="stylesheet">

  <!-- Custom fonts for this template -->
  <link href="/vendor/fontawesome-free/css/all.min.css" rel="stylesheet">
  <link href="/vendor/simple-line-icons/css/simple-line-icons.css" rel="stylesheet" type="text/css">
  <link href="https://fonts.googleapis.com/css?family=Roboto:300,400,700,300italic,400italic,700italic" rel="stylesheet" type="text/css">

  <!-- Custom styles for this template -->
  <link href="/css/style.css" rel="stylesheet">

</head>

<body>

 <!-- Navigation -->

 <nav class="navbar navbar-expand-lg navbar-light bg-light">
  <a class="navbar-brand" href="index.html">
   <img src="img/logo_t.png" width="35" height="35" class="d-inline-block align-top" alt="">
   Industry 4.0 <b>HUB</b>
  </a>
  <button class="navbar-toggler" type="button" data-bs-toggle="collapse" data-bs-target="#navbarSupportedContent" aria-controls="navbarSupportedContent" aria-expanded="false" aria-label="Toggle navigation">
   <span class="navbar-toggler-icon"></span>
  </button>

  <div class="collapse navbar-collapse justify-content-end" id="navbarSupportedContent">
   <ul class="navbar-nav mr-auto">
    <li class="nav-item">
     <a type="button" class="btn btn-outline-secondary border-0" href="hub_search.php">The HUB</a>
    </li>
```

```
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="roadmap.html">Roadmap</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="community.html">Community</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0 active" href="collaborate/hub_create.html">
            <i class="fas fa-key"></i>
            Collaborate</a>
        </li>
      </ul>
    </div>
  </nav>

  <!-- Section Title -->
  <section class="sectitle">
    <div class="container-fluid">
      <div class="row g-4 justify-content-center">
        <div class="col-6">
          <h6 class="mb-5">Collaborate</h6>
          <p>Help expand the HUB, including your Industry 4.0 technologies, real projects and tools to support the knowledge transfer within SMEs.</p>
          <hr class="my-4">
        </div>
        <div class="col-lg-6">
          <img src="/img/collaboration.jpg" class="img-fluid" alt="Collaborate">
        </div>
      </div>
    </div>
  </section>

  <!-- Introduce new tool -->

  <section class="addtool text-center">
```

```
<div class="container-fluid">
 <form class="row mx-auto g-3" method="post" action="/send.php" enctype="multipart/form-data">
  <div class="col-md-6">
   <label for="inputname" class="form-label">Name of the Industry 4.0 Project</label>
   <input type="text" class="form-control" name="inputname" placeholder="e.g. Augmented Reality for Picking Processes">
  </div>
  <div class="col-md-6">
   <label for="inputarea" class="form-label">Industry 4.0 Technology</label>
   <select name="inputarea" class="form-select">
    <option selected>Choose...</option>
    <option>Cloud Computing</option>
    <option>Internet of Things</option>
    <option>Big Data</option>
    <option>Automation</option>
    <option>Machine Learning</option>
    <option>Augmented Reality</option>
    <option>Other</option>
   </select>
  </div>
  <div class="col-12">
   <label for="inputdescription" class="form-label">Description</label>
   <textarea class="form-control" name="inputdescription" rows="3" placeholder="Short description so that other SMEs can easily implement the same project. Include also any necessary external links to e.g. vendors."></textarea>
  </div>
  <div class="col-md-6">
   <label for="inputbudget" class="form-label">Budget</label>
   <div class="input-group mb-3">
    <span class="input-group-text">€</span>
    <input type="text" class="form-control" name="inputbudget" aria-label="Amount (to the nearest euro)">
   </div>
  </div>
  <div class="col-md-6">
   <label for="inputimage" class="form-label">Picture</label>
   <input type="file" class="form-control" name="inputimage">
  </div>
```

```html
      <div class="col-md-12">
        <label for="inputlink" class="form-label">Additional Infos [Link]</label>
        <div class="input-group mb-3">
          <span class="input-group-text" id="basic-addon3">https://example.com/IIoT/</span>
          <input type="text" class="form-control" name="inputlink" aria-describedby="basic-addon3">
        </div>
      </div>
      <div class="col-12">
        <button type="submit" name="image" class="btn btn-secondary btn-lg"><i class="fas fa-save"></i> Save to The HUB</button>
      </div>
    </form>
  </div>
</section>

<!-- Footer -->
<footer class="footer bg-light">
  <div class="container-fluid">
    <div class="row justify-content-center">
      <div class="col-6">
        <ul class="nav">
          <li class="nav-item">
            <a class="nav-link" href="/about.html">About</a>
          </li>
          <li class="nav-item">
            <a class="nav-link" href="/contact.html">Contact</a>
          </li>
        </ul>
      </div>
      <div class="col-6 text-end">
        <a href="www.linkedin.com/in/albertocotrino">
          <i class="fab fa-linkedin fa-2x fa-fw"></i>
        </a>
      </div>
    </div>
```

```
    <div class="row text-center">
      <h5 class="text-muted">&copy; Industry 4.0 - HUB 2019-2021</h5>
    </div>
  </div>
</footer>

<!-- Bootstrap core JavaScript -->
<script src="/vendor/jquery/jquery.min.js"></script>
<script src="/vendor/bootstrap/js/bootstrap.bundle.min.js"></script>

</body>

</html>
```

The HUB Create 2 – PHP

```
<!DOCTYPE html>
<html lang="en">

<head>

  <meta charset="utf-8">
  <meta name="viewport" content="width=device-width, initial-scale=1, shrink-to-fit=no">
  <meta name="description" content="Industry 4.0 HUB">
  <meta name="author" content="Alberto Cotrino">

  <title>Industry 4.0 HUB</title>
  <link rel="shortcut icon" type="image/jpg" href="img/logo_t.png"/>

  <!-- Bootstrap 5 CSS -->
  <link href="vendor/bootstrap/css/bootstrap.min.css" rel="stylesheet">

  <!-- Custom fonts for this template -->
  <link href="vendor/fontawesome-free/css/all.min.css" rel="stylesheet">
  <link href="vendor/simple-line-icons/css/simple-line-icons.css" rel="stylesheet" type="text/css">
  <link href="https://fonts.googleapis.com/css?family=Roboto:300,400,700,300italic,400italic,700italic" rel="stylesheet" type="text/css">
```

```
    <!-- Custom styles for this template -->
    <link href="css/style.css" rel="stylesheet">

</head>

<body>

  <!-- Navigation -->

  <nav class="navbar navbar-expand-lg navbar-light bg-light">
    <a class="navbar-brand" href="index.html">
      <img src="img/logo_t.png" width="35" height="35" class="d-inline-block align-top" alt="">
      Industry 4.0 <b>HUB</b>
    </a>
    <button class="navbar-toggler" type="button" data-bs-toggle="collapse" data-bs-target="#navbarSupportedContent" aria-controls="navbarSupportedContent" aria-expanded="false" aria-label="Toggle navigation">
      <span class="navbar-toggler-icon"></span>
    </button>

    <div class="collapse navbar-collapse justify-content-end" id="navbarSupportedContent">
      <ul class="navbar-nav mr-auto">
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="hub_search.php">The HUB</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="roadmap.html">Roadmap</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="community.html">Community</a>
        </li>
        <li class="nav-item">
          <a type="button" class="btn btn-outline-secondary border-0" href="collaborate/hub_create.html">
            <i class="fas fa-key"></i>
            Collaborate</a>
```

```
      </li>
    </ul>
  </div>
</nav>

<!-- Section Title -->
<section class="sectitle">
    <div class="container-fluid">
      <div class="row g-4 justify-content-center">
        <div class="col-md-6">
          <h6 class="mb-5">The new tool/project has been introduced in The HUB, thanks for supporting this initiative!</h6>
          <p>What do you want to do next?</p>
          <hr class="my-4">
          <form class="form-inline my-2 my-lg-0">
            <a type="button" href="hub_create.html" class="btn btn-secondary btn-lg">Create another tool/project in The HUB</a>
            <a type="button" href="hub_search.php" class="btn btn-secondary btn-lg">Search in The HUB</a>
          </form>
        </div>
        <div class="col-md-6">
          <img src="img/thankyou.jpg" class="img-fluid" alt="Collaborate">
        </div>
      </div>
    </div>
</section>

<!-- Footer -->
<footer class="footer bg-light">
  <div class="container-fluid">
    <div class="row justify-content-center">
      <div class="col-6">
        <ul class="nav">
          <li class="nav-item">
            <a class="nav-link" href="about.html">About</a>
          </li>
```

```
        <li class="nav-item">
          <a class="nav-link" href="contact.html">Contact</a>
        </li>
      </ul>
    </div>
    <div class="col-6 text-end">
      <a href="www.linkedin.com/in/albertocotrino">
        <i class="fab fa-linkedin fa-2x fa-fw"></i>
      </a>
    </div>
  </div>
  <div class="row text-center">
    <h5 class="text-muted">&copy; Industry 4.0 - HUB 2019-2021.</h5>
  </div>
 </div>
</footer>

<?php

// define variables and set to empty values
$inputname = $inputarea = $inputdescription = $inputbudget = $inputimage = $inputlink = "";

if ($_SERVER["REQUEST_METHOD"] == "POST") {
 $inputname = test_input($_POST["inputname"]);
 $inputarea = test_input($_POST["inputarea"]);
 $inputdescription = test_input($_POST["inputdescription"]);
 $inputbudget = test_input($_POST["inputbudget"]);
 $inputimage = test_input($_FILES["inputimage"]["name"]);
 $inputlink = test_input($_POST["inputlink"]);
}

function test_input($data) {
 $data = trim($data);
 $data = stripslashes($data);
```

```
  $data = htmlspecialchars($data);
  return $data;
}

?>

<?php
  $servername = "localhost";
  $username = "root";
  $password = "";
  $dbname = "toolboxdb";

    // Create connection
    $conn = mysqli_connect($servername, $username, $password, $dbname);
    // Check connection
    if (!$conn) {
      die("Connection failed: " . mysqli_connect_error());
    }

    $sql = "DELETE FROM prueba WHERE Name IS NULL";

    $sql = "INSERT INTO prueba (Name, Number, Description, Budget, Picture, Link)
    VALUES ('$inputname', '$inputarea', '$inputdescription', '$inputbudget', '$inputimage', '$inputlink')";

?>


<?php
$target_dir = "img/";
$target_file = $target_dir . basename($_FILES["inputimage"]["name"]);
$uploadOk = 1;
$imageFileType = strtolower(pathinfo($target_file,PATHINFO_EXTENSION));

// Check if image file is a actual image or fake image
```

```
if(isset($_POST["image"])) {
 $check = getimagesize($_FILES["inputimage"]["tmp_name"]);
 if($check !== false) {
  $uploadOk = 1;
 } else {
  $uploadOk = 0;
 }
}

// Check if file already exists
if (file_exists($target_file)) {
 $uploadOk = 0;
}

// Check file size
if ($_FILES["inputimage"]["size"] > 500000) {
 $uploadOk = 0;
}

// Allow certain file formats
if($imageFileType != "jpg" && $imageFileType != "png" && $imageFileType != "jpeg"
&& $imageFileType != "gif" ) {
 $uploadOk = 0;
}

// Check if $uploadOk is set to 0 by an error
if ($uploadOk == 0) {
// if everything is ok, try to upload file
} else {
 if (move_uploaded_file($_FILES["inputimage"]["tmp_name"], $target_file)) {
 } else {
 }
}
?>
```

```
 <?php

   if ($conn->query($sql) === TRUE){
    if($uploadOk == 1) {
     $message = "New record created successfully";
     echo "<script type='text/javascript'>alert('$message');</script>";
     }
   }  else {
     $messageerror = "Error. Please contact the admin";
     echo "<script type='text/javascript'>alert('$messageerror');</script>";
    }

 ?>

 <!-- Bootstrap core JavaScript -->
 <script src="vendor/jquery/jquery.min.js"></script>
 <script src="vendor/bootstrap/js/bootstrap.bundle.min.js"></script>

</body>

</html>
```

The HUB Community – PHP

```
<!DOCTYPE html>
<html lang="en">

<head>

 <meta charset="utf-8">
 <meta name="viewport" content="width=device-width, initial-scale=1, shrink-to-fit=no">
 <meta name="description" content="Industry 4.0 HUB">
 <meta name="author" content="Alberto Cotrino">
```

```
 <title>Industry 4.0 HUB</title>
 <link rel="shortcut icon" type="image/jpg" href="img/logo_t.png"/>

 <!-- Bootstrap core CSS -->
 <link href="vendor/bootstrap/css/bootstrap.min.css" rel="stylesheet">

 <!-- Custom fonts for this template -->
 <link href="vendor/fontawesome-free/css/all.min.css" rel="stylesheet">
 <link href="vendor/simple-line-icons/css/simple-line-icons.css" rel="stylesheet" type="text/css">
 <link href="https://fonts.googleapis.com/css?family=Roboto:300,400,700,300italic,400italic,700italic" rel="stylesheet" type="text/css">

 <!-- Custom styles for this template -->
 <link href="css/style.css" rel="stylesheet">

 <script type="text/javascript">
  var framefenster = document.getElementsByTagName("iFrame");
  var auto_resize_timer = window.setInterval("autoresize_frames()", 400);
  function autoresize_frames() {
   for (var i = 0; i < framefenster.length; ++i) {
     if(framefenster[i].contentWindow.document.body){
      var framefenster_size = framefenster[i].contentWindow.document.body.offsetHeight;
      if(document.all && !window.opera) {
       framefenster_size = framefenster[i].contentWindow.document.body.scrollHeight;
      }
      framefenster[i].style.height = framefenster_size + 'px';
     }
   }
  }
 </script>

</head>

<body>
```

```
<!-- Navigation -->

<nav class="navbar navbar-expand-lg navbar-light bg-light">
 <a class="navbar-brand" href="index.html">
  <img src="img/logo_t.png" width="35" height="35" class="d-inline-block align-top" alt="">
  Industry 4.0 <b>HUB</b>
 </a>
 <button class="navbar-toggler" type="button" data-bs-toggle="collapse" data-bs-target="#navbarSupportedContent" aria-controls="navbarSupportedContent" aria-expanded="false" aria-label="Toggle navigation">
  <span class="navbar-toggler-icon"></span>
 </button>

 <div class="collapse navbar-collapse justify-content-end" id="navbarSupportedContent">
  <ul class="navbar-nav mr-auto">
   <li class="nav-item">
    <a type="button" class="btn btn-outline-secondary border-0" href="hub_search.php">The HUB</a>
   </li>
   <li class="nav-item">
    <a type="button" class="btn btn-outline-secondary border-0" href="roadmap.html">Roadmap</a>
   </li>
   <li class="nav-item">
    <a type="button" class="btn btn-outline-secondary border-0 active" href="community.html">Community</a>
   </li>
   <li class="nav-item">
    <a type="button" class="btn btn-outline-secondary border-0" href="collaborate/hub_create.html">
     <i class="fas fa-key"></i>
     Collaborate</a>
   </li>
  </ul>
 </div>
</nav>

<!-- Section Title -->
<section class="sectitle">
  <div class="container-fluid">
```

```
<div class="row g-4 justify-content-center">
 <div class="col-md-6">
  <img src="img/forum.jpg" class="img-fluid" alt="roadmap">
 </div>
 <div class="col-md-6">
  <h6 class="mb-5">Community</h6>
  <p>Industry 4.0 HUB supports the collaboration among the SMEs. The project aims to create a collaborative community, with a focus on SMEs, to support the Industry 4.0 knowledge transfer.</p>
  <hr class="my-4">
  <form class="form-inline my-2 my-lg-0">
   <a href="#andon" class="btn btn-light btn-lg">Discover one real implementation of the roadmap - the Andon System</a>
  </form>
 </div>
</div>
</div>
</section>

<!-- 1:1 aspect ratio "https://connect.i40-hub.com/"-->
<div class="container-fluid">
 <div class="row">
  <div class="col-12">
   <div class="embed-responsive embed-responsive-1by1">
    <iframe class="embed-responsive-item" src="https://connect.i40-hub.com/" onload="this.style.height=(this.contentDocument.body.scrollHeight+45) +'px !important';" scrolling="no" style="width:100%;min-height:800px;border:none;overflow-y:hidden;overflow-x:hidden;"></iframe>
   </div>
  </div>
 </div>
</div>

<!-- Footer -->
<footer class="footer bg-light">
 <div class="container-fluid">
  <div class="row justify-content-center">
   <div class="col-6">
    <ul class="nav">
```

```
          <li class="nav-item">
            <a class="nav-link" href="about.html">About</a>
          </li>
          <li class="nav-item">
            <a class="nav-link" href="contact.html">Contact</a>
          </li>
        </ul>
      </div>
      <div class="col-6 text-end">
        <a href="www.linkedin.com/in/albertocotrino">
          <i class="fab fa-linkedin fa-2x fa-fw"></i>
        </a>
      </div>
    </div>
    <div class="row text-center">
      <h5 class="text-muted">&copy; Industry 4.0 - HUB 2019-2021</h5>
    </div>
  </div>
 </footer>

 <!-- Bootstrap core JavaScript -->
 <script src="vendor/jquery/jquery.min.js"></script>
 <script src="vendor/bootstrap/js/bootstrap.bundle.min.js"></script>

</body>

</html>
```