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IEM Teaching and Research at the Crossroads of Innovation, Digitalisation and Sustainability

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Bernd M. Zunk
Amila Omazic

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Preface

Dear EPIEM conference participants!
Dear IEM colleagues!

For the EPIEM (European Professors of Industrial Engineering and Management) network – and its goal to initiate and foster collaboration between IEM academics across Europe – annual conferences are of vital importance. Thus, it is a great honour and pleasure for me as the current President of EPIEM, to present the proceedings of the 14th EPIEM Conference 2021 hosted by Graz University of Technology.

Considering the background of the ongoing Covid-19 pandemic, this EPIEM conference had to be organized in a virtual environment. And I am all the more pleased that you – the members of the IEM community and the contributors to this EPIEM conference proceedings – took this opportunity to attend this conference, to submit a research paper in order to present it and to discuss the implications of your research with the conference participants.

This kind of exchanging knowledge and sharing experiences is very important for us as a scientific community as EPIEM conferences should open the doors between motivated professors, lecturers, scientists and mindful thinkers in the field of IEM. Therefore, it is an honour for me to invite you already now to the upcoming 15th EPIEM Conference 2022 at Graz University of Technology (note: details you may find online at www.epiem.org) and to participate actively in our constantly growing EPIEM network.

At this point I would also like to take the opportunity to thank the members of the program committee as well as the members of the scientific committee of this 14th EPIEM Conference for their great help, inputs and contributions. In particular, I would like to thank Ms. Amila Omazic, BSc MSc whose organisational skills and prudence made many things happen in a unique way.

Graz, 1st of June 2021

Prof. Dr. Bernd M. Zunk
President of EPIEM

Trends and Proposals for European Industrial Engineering

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Abstract
This article analyses the trends in scientific publications (Web of Science) in the field of industrial engineering (IE) from 1950 to the present. Specifically, it presents the evolution of the emergence of 'concepts' associated with IE for decades, their quantitative or qualitative nature and the prominence of the different world regions in their origin. The analysis reveals a decline in the capacity of the academe and the industry to propose new 'concepts' during the last 20 years, a considerable variation of the leading role of world regions in IE and significant changes in the preponderance of IE 'concepts' with a quantitative or qualitative character. To foster the capacity of the IE academe in contributing to European industrial development, the transformations that the industry will have to face during the next decades are proposed as areas of development of the research activity. Enhancing training and research on the consequences of digitisation on industrial management, enlarging the optimization scope from company to value chain and industrial ecosystems and prioritizing research aimed at developing new 'concepts', methodologies and tools are suggested as some of the future paths for IE.

Keywords: Industrial Engineering, Research, Trends, Value chain

Introduction

Since the late 19th and early 20th centuries up to the present, with the contributions of F.W. Taylor (1911) on the scientific organisation of work, an area of research, knowledge and applications that straddle engineering and management without clear borders with other disciplines, has arisen. This area was termed industrial engineering (IE).

The evolution of industry, technologies and the needs of society (Hazarika et al., 2019) as well as the emergence of new production methods, techniques and philosophies have been transforming the role of IE in companies and the training and research carried out in universities. In turn, Universities have contributed to transforming the productive fabric of countries.

Despite the difficulties of 'acceptation' and the 'lack of recognition of the academic value' of the research carried out (Brustolin & Jonker, 2012), history tells us that European Industrial Engineering has managed to grow into highly productive research teams and as a source of innovation. Although the aforementioned difficulties generate nuances to the observation of issues addressed by the scientific production in IE, such observation allows us to reflect on the irruption of new 'concepts' in the academe and the industry. Moreover, the analysis of these ‘concepts’ helps us perceive some macro trends. In this article, these trends are presented and some possible development areas for IE are outlined.

Methodology

In this article, the term ‘concepts’ includes the frameworks, systems, models, maps, processes, procedures, techniques and tools associated with IE as defined by Shehabuddeen et al. (1999). To analyse the evolution of publications about the ‘concepts’, information was obtained through an exploration of the Web of Science database. The searching process in Web of Science was made in the fields Title, Abstract, Author’s Keywords and KeyWords Plus®, which generates keywords from the citations of the article.

The ‘concepts’ considered in the research process are the following ones: AQL based on MIL-STD-105D, Methods-Time MTM, MRP, TOC, ISO 9.000 Series, TQM, Six sigma, Hoshin Kanri, Cell Layout planing (JIT), Kanban (JIT), Poka Yoke, 5S, SMED (JIT), TPM, Supplier Development, Kaizen teams, Lean Production, Logistics (OR, etc.), QFD, Digitization Industry 4.0, Management models (EFQM, etc.), Quantitative Methods (Simulation), Project Management (PERT, GANTT,…), Seven Basic Quality Tools, Assembly Line Balancing, Queuing Theory, Skills Matrix, Computerized Maintenance Management Systems, Value Stream Mapping, Taguchi – Dis. of Experim., Innovation management, Ergonomics and Circular Economy.

For each of the ‘concepts’ considered, several aspects have been defined, including ding 1) the search terms; 2) the year of the first publication found; 3) the region of the world where the ‘concept’ first originated: and 4) the ‘concept’s fundamentally quantitative or qualitative nature. For 3), the ‘concept’ was classified as ‘International’ in case it was promoted by an international entity or emerged in a parallel way in different regions of the world. For 4), a ‘concept’ was considered quantitative if it aims at a precise calculation, is strongly based on numerical calculations or requires necessary computational assistance.
The process of defining search terms in English and some specific terms in Japanese was carried out through iterations in order to achieve a balance between finding the largest number of publications related to a ‘concept’ and, at the same time, avoiding the inclusion of publications related to other disciplines. Debugging of the terms was performed by reviewing the first 50 results of the searches obtained following roughly the first steps of the process proposed by Thomé et al. (2016) for a systematic literature review. Altogether, 73,729 publications were collected and classified.

The methodology used has some limitations for which corrective measures were taken. Firstly, for each of the 33 ‘concepts’ analysed, the number of publications identified per year was obtained, from the year of first appearance to the present. Taking into account the possible bias derived from access to only some databases and the initial period of data availability for some of them, this article analysed the percentage weight of the different ‘concepts’ and not the absolute value number of publications in each year. Secondly, depending on the scope, ‘concepts’ of a more global nature were included along with more specific ones. The grouping of search results for partial ‘concepts’ was considered to compensate for the grouped search for global ‘concepts’. Lastly, it is difficult to establish the precise boundary of disciplines associated with IE with respect to other disciplines. The fields identified by the American Institute of Industrial Engineers (IIE, 2006) to cover the scope of industrial engineers’ focus areas were taken as a reference. These include project management, manufacturing, production and distribution, supply chain management, productivity, methods and process engineering, quality measurement and improvement, programme management, ergonomics / human factors, technology development and transfer, strategic planning, management of change and financial engineering. The identification of the concepts covering these fields was carried out in three iterations by a group of university professors of Industrial Engineering with more than 25 years of teaching and research experience in the field. Considering the fuzzy boundaries of EI, this research could be extended by including other participants in the identification of terms from industry, consultancy as well as other representatives of industrial engineering.

Results

Figure 1 below shows the evolution of the appearance of new ‘concepts’ from 1950 to the present. It shows a progressive increase in proposals between the 1950s and 1990s and, subsequently, a drastic reduction in such proposal capacity.

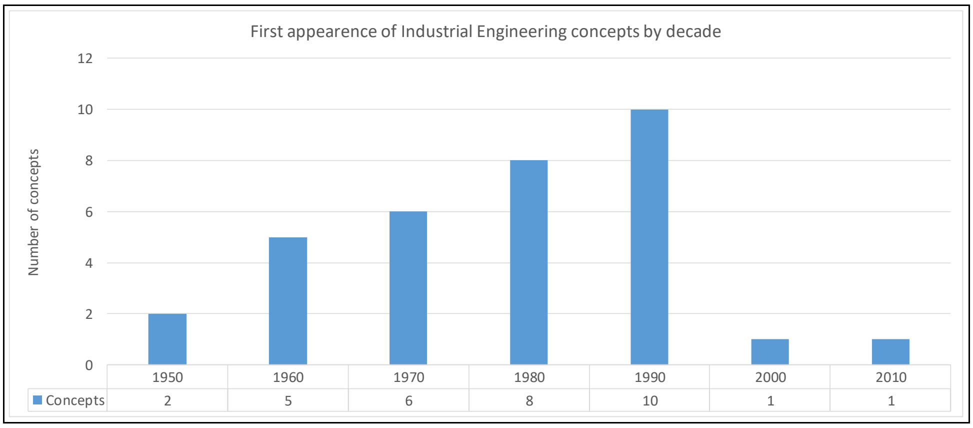

Fig. 1. First appearance of IE ‘concepts’ by decades.

A period of effervescence is also observed between 1980 and 1999, when the first publications related to 18 ‘concepts’ appeared (54% of the total). During these years, aspects related to just-in-time, quality improvement tools from Japan (QFD, Poka Yoke, Taguchi, Kaizen, etc.), TPM, the quality management systems ISO 9000, Six Sigma, lean production and their associated techniques, including VSM, Theory of Constraints or more philosophical aspects such as the importance of respect and the participation of people in the competitiveness of companies (Kaizen, Hoshin Kanri, Skills matrix), emerged. This period (1980–1999) represented a strong activity of incorporation into the IE profession of these ‘concepts’ through university training, continuous training and in research or consulting.

As shown in Figure 2, where the evolution of the percentage of publications by IE ‘concepts’ and by region of origin is represented, the increase in appearance of new ‘concepts’ coincides with a strong increase in the prominence of the manufacturing model from Japan, represented in a paradigmatic way - though not unique - by the automotive company Toyota.

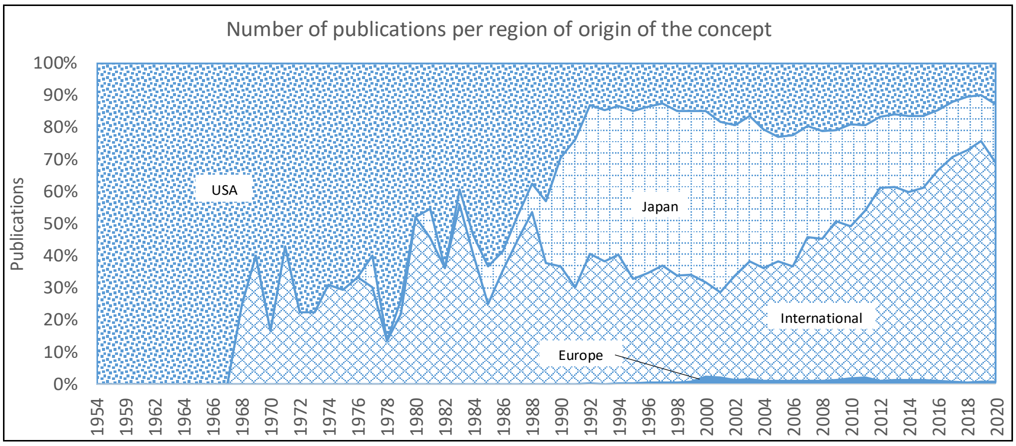

Fig. 2. Evolution of the percentage of publications by region of origin of the ‘concept’.

If initially the role of the United States in IE through its military and automobile industry was unquestionable (methods and times, balancing of assembly lines, statistical process control, project management, MRP, etc.) between 1950 and 1980, from the 1980s onwards, this leadership has declined in favour of Japan and the subsequent ‘concepts’ generated more internationally.

Figure 2 illustrates that the globalisation of industrial activity has brought with it an almost simultaneous appearance of new ‘concepts’ throughout the world. An example of this worth mentioning is the appearance in Europe of the Industry 4.0 ‘concept’, with a translation having various nuances in the United States under the name of Advanced Manufacturing or in Japan as Connected Industries. This trend will certainly remain in the following decades.

As it appears in Figure 3, the general appearance of techniques from Japan increased the importance of more qualitative or even philosophical ‘concepts’. Western companies needed time to understand and absorb these techniques very much related to Japanese culture. For this, certain terminological, philosophical and cultural adaptations were necessary.

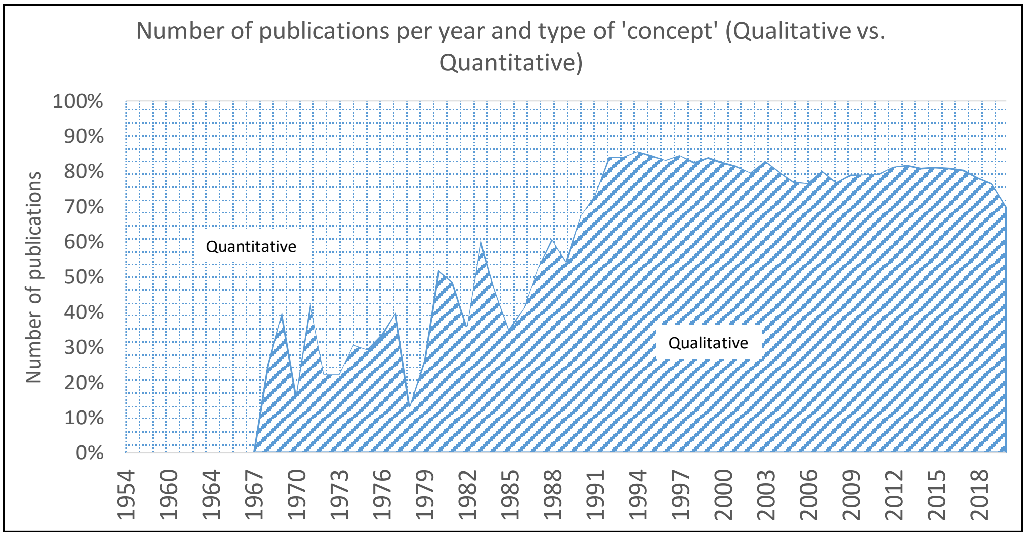

Fig. 3. Evolution of the percentage of publications by type of ‘concept’ (Qualitative vs. Quantitative).

On the other hand, the difficulties of homologation of research in IE with respect to the rest of the disciplines are known (Brustolin, 2012), especially in the qualitative aspects. Thus, the weight of qualitative ‘concepts’ by measuring publications in high-level journals is probably underestimated.

As can be seen in the figure, there has been a slight recovery in recent years in the research carried out on quantitative aspects, probably driven by the generalised automation and digitisation of the industry.

Conclusion

An analysis of the results reveals that, mainly, the ‘concepts’ associated with IE have come from the industry (military and automotive) and have subsequently been conceptualised and researched by the academe. During the last 20 years, there has been a decline in new proposals by the industry or the academe, and yet the industry is facing great transformations that will undoubtedly require techniques or methodologies for their optimisation. Among the major new trends that are expected to influence European industry in the coming years or decades, massive digitisation, energy transition, circular economy, climate neutrality or a strengthening of strategic value chains (European Commission, 2019; European Commission, 2020a) will certainly be addressed.

Digitisation of the industry, enhanced data analytics and artificial intelligence open a new field of action for the optimisation of business operations. These opportunities will make it possible to promote the appearance of quantitative tools to improve company performance (Moynihan, 2020). Industrial engineers are very well positioned to be the protagonists of these opportunities. For this, enhancing their training and related research in numerical tools (simulation, artificial intelligence, enhanced data analytics, etc.) associated with digitisation will be necessary.

Furthermore, in this context, in addition to seeking the optimisation of operations within the company, the industrial engineer will have to do so with a systemic vision of the value chain and industrial ecosystems (European Commission, 2020b). This perspective is especially true for addressing the challenges of energy transition, circular economy or back shoring. In this sense, being able to identify the opportunities derived from industrial cooperation alliances with other companies or organisations will be a key competence. For example, supplier development programmes, strengthening the local value chain or collaborative innovation can be areas for future development.

Complementary to improving existing techniques already applied, the future of the IE discipline will depend largely on the ability of the academe to conceptualise and propose new methodologies, ‘concepts’ and tools to the industry that will allow them to adapt efficiently to the new reality that awaits them. Research oriented to generating new approaches should be prioritised. Action research could be an appropriate methodology to promote addressing the operational realities experienced by practicing managers while simultaneously contributing to knowledge (Coughlan & Coghlan, 2002; Cauchick, 2010).

Butuner (2015) proposes that the most significant development in IE in the next 50 years will be systematic planning as a means to teach people how to arrive at decisions better. The new ‘concept’ proposals from IE should contribute to that purpose.

These approaches could make it possible to reactivate the lagging proposal capacity and contribute to an enrichment of training, research and transfer activities. Considering the limitations of this research, a deeper analysis from other perspectives of the trends and the future role of IE academe to contribute to European transformation processes is necessary. This article is just a partial contribution to this important discussion.

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Edge Computing in IEM Education

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Abstract
Increasing the processing power of edge computing components enables the development of new approaches for data processing and OT/ICT architectures. Edge computing components like IoT/IIoT/PLC have possibilities for new approaches in data processing that enable industrial systems to improve their business performance and productivity. In data processing, one of the new approaches is using Edge computing. Edge computing enables the collection and analysis of data at the edge (near its source). This characteristic enables that some problems can be quickly eliminated before they cause any effect on the production. Because of that, the knowledge about Edge computing has to be a part of today's IEM engineering education. To overcome the potential lack of knowledge of how to apply the Edge computing architecture in practice, it is important to change curriculums for IEM. In this paper are described some of the experiences in applying this approach to IEM curricula carried out at the University of Novi Sad.

Keywords: Edge computing, IEM, IoT/IIoT/PLC, Industry 4.0

Introduction

These days, business is being rapidly transformed by digitization. Digitization and big data rank high on the industrial system timetable everywhere because the rapid transformation has an impact on all industries and services. Digital transformation is an ongoing process and it will change the whole industrial automation and manufacturing industry in the next 5-10 years. This process includes different architectures and it is one of the main drivers of the concept of Industry 4.0 and it is irreversible (Wang et al., 2020, Stankovski et al., 2021). This is very important to the better understanding concept of Industry 4.0 or the Fourth industrial revolution. The only remaining question is how fast digital transformation will be implemented into real industrial systems. Industry 4.0 has many synonyms, like a smart factory, factory of the future, or smart manufacturing (Sittón-Candanedo et al., 2019; Stankovski et al., 2019). Label smart (or intelligent) in these synonyms just show that future industrial systems will be based on how data will be processed. Data start to be the key factor of the industrial systems in the Fourth industrial revolution. Typically, the explanation for industrial revolutions starts with, the First revolution which happened when steam power changed the whole concept of manufacturing and mechanization. The Second revolution happened when electric motors started to change assembly lines for mass production. The Third revolution happened with massive automation based on industrial computers or Programmable Logical Controllers (PLC). The Fourth revolution is an ongoing process and means the current trend of processing of collected data from different elements in systems (Buyya et al., 2019; Stankovski et al., 2019; Stankovski et al., 2020).

Industrial systems are constantly challenged to stay in tune with the ever-changing world of innovation and new demands. AI (Artificial Intelligence), ICT (Information and Communications Technology), IoT (Internet of Things), robotics, new materials, manufacturing design are some of the areas that bring challenges in the research and development of industrial systems. Also, industrial systems are under constant pressure to improve their business performance and productivity. Furthermore, in the last decade, we had exponential growth of the Internet of Things and Industrial Internet of Things (IIoT). Predictions for these technologies are promising and show that their growth will continue in the coming years (Lueth, 2014; Stankovski et al., 2020). Also, every new IoT/IIoT device also brings the growth of data. This trend requires new approaches in the data processing. Edge computing is one of these new approaches. Edge computing enables the collection and analysis of data at or near its source, and it can be very useful in industrial and non-industrial systems (Ostojic et.al, 2013; Ostojic et.al, 2015; Tegeltija et.al, 2016; Wang et.al, 2020; Prodanovic et.al, 2020; Stankovski et.al, 2020; Oros et.al, 2021). Processing potential risk situations at the edge enable quickly detected these situations and respond with the right real-time decision before any incorrect behavior of devices/systems. Making real-time decisions at the place of the data source is one of the main features of Edge computing. Actually, Edge computing can be part of architecture with main computers/industrial computers or Cloud computing. IoT/IIoT/PLC and other edge devices are the base of Edge computing with significant computing power. This computing power is needed to have real-time processing of data with complex algorithms, including AI algorithms, at or near its source. In the same time, we don’t have decreasing of the main functionality of edge devices and control systems (Kukolj et.al, 2018; Zečević et.al, 2018; Nemet et.al, 2019; Baranovski et.al, 2020; Stankovski et.al, 2020). For example, an application for predictive maintenance based on deep learning algorithms, which require analysis of big data, can be executed in real-time (Buyya et al., 2019; Stankovski et.al, 2020).

In the chapters that follow, it will be described in more detail challenges with introducing the Edge computing IEM (Industrial Engineering and Management) education.

Challenges with edge computing

The global Edge computing market size was valued at 3.5 billion US $ in 2019, registering a Compound Annual Growth rate (CAGR) exceeding 37% from 2020 to 2027 which is shown in a report on https://www.grandviewresearch.com/industry-analysis/edge-computing-market. Also, in the report the global Edge computing market is segmented in following industry vertical outlook:

- Industrial,
- Energy & Utilities,
- Healthcare,
- Agriculture,
- Transportation & Logistics,
- Retail,
- Data Centers,
- Wearables and
- Smart Cities, Smart Homes, Smart Buildings.

Obviously, with this wide market size segmentation, challenges in the implementation of Edge computing are differentiated from the segment to the segment. Of course, a lot of common challenges can be observed. Let start with three-layer Edge Computing basic architecture which can be used for all Edge computing applications. This three-layer Edge Computing basic architecture is given in Sittón-Candanedo et al., 2019). Besides, common basic architecture, common 10 challenges that Edge computing can tackle are (Money Control, 2018; Williams, 2020):

1. **Latency:** Any device connected to the Internet has to be responsive in a matter of milliseconds. Any lag in the communication between network and devices is termed as latency. Edge computing can eliminate latency issues as it works on the principle of a more distributed network, makes sure there is no disconnect in real-time information processing and gives a more reliable network.
2. **Security:** In an Edge architecture, any outage would be limited to the edge computing device and the local applications on that device.
3. **Real-time data:** Edge computing sites send real-time data and alerts without any disturbances. An efficient monitoring system can prevent and rectify issues even before they arise.
4. **Cost:** Edge computing minimizes the capital outlay and operating expenses.
5. **Governance:** Every company wants to build a culture of information technology at par with industry standards, complying with data regulations.
6. **Scale:** Each remote Edge computing location requires multiple monitors to understand the health and status of each IT component from physical access, power and cooling to the servers and network devices. This makes it difficult to visualize and understand the state of the entire Edge computing environment and the impact each Edge computing component has on others.
7. **Performance:** Monitoring and managing the Edge computing performance in real-time to/from the consumer/end-point and to/from the Edge computing to the cloud/data center.
8. **Control:** Edge computing locations run ‘lights out’ resulting in challenges to manage physical access, control IT equipment, manage the environment (power/cooling), track equipment and assess, isolate and remediate issues especially when the network is impacted or unavailable.
9. **Organization:** Managing Edge computing, the same way as a traditional data center with different teams responsible for ‘slices’ of the infrastructure creates significant inefficiencies in respect to support, costs, skills, resources and business availability
10. **Heterogeneity:** Infrastructure diversity (different IT and environment equipment) creates fragmented visualization, control and management resulting in high costs (including skills, resources, resolution time) and the creation of Edge computing equipment ‘silo’s’. Complexity will increase exponentially with every custom Edge computing location added.

All above mention challenges have their solutions and some of them are given. From a practical point of view, probably the biggest challenge is heterogeneity when introducing Edge computing in existing systems.

Integration of individual Edge computing device can be a very demanding task which requires multidisciplinary knowledge and expertise. Actually, multidisciplinary knowledge is obligatory if we want to implement Edge computing. Process of implementation of Edge computing in the field of industrial automation depends and how IEM engineering understand this computer architecture. Therefore, it is important to permanently improve the IEM curriculums at universities. The next chapter will be present how IEM curriculums is improved at the University of Novi Sad in order to overcome challenges with Edge computing in industrial practice.

Edge computing in IEM education

University of Novi Sad (UNS), Faculty of Technical Sciences (FTS) have almost six decades of experience with IEM study programs (Faculty of Technical Sciences, 2021). In order to prepare students to find solutions for challenges that Edge computing has, some of the subjects have to improve or change their structure. According to the challenges which are mention in second chapter, we recommend changing the structure of the following subjects:

- Design of Information Systems (DIS)
- Automatic identification system (AIS),
- Programmable logic controllers (PLC),
- Artificial Intelligence (AI),
- Computer integrated manufacturing (CIM)

In these subjects, students have to get knowledge and learn how to overcome issues with digital transformation. This process of upgrading the structure of subjects includes a minimum following piece of knowledge:

- **Enterprise IT architecture:** Students have to learn how to design three-layer Edge computing architecture in the enterprise. This knowledge can be part of the following subjects: DIS, PLC and CIM.
- **Software as a service (SaaS):** Students have to learn how to access an application that is hosted and managed in the cloud by the service provider. This knowledge can be part of the following subjects: DIS, AIS, PLC and CIM.
- **Platform as a service (PaaS):** Students have to learn how to deploy applications in the cloud environment and manage certain configuration settings for the platform. This knowledge can be part of the following subjects: DIS, AIS, PLC and CIM.
- **Infrastructure as a service (IaaS):** Students have to learn how to manage the compute, storage, networking, operating system, and application components, in the case when the service provider is responsible for managing the underlying physical infrastructure and the data center. This knowledge can be part of the following subjects: DIS, AIS, PLC and CIM.
- **Predictive maintenance**: Students have to learn how to develop algorithms and programs for the prediction of fault detections of devices in automated systems. This knowledge can be part of the following subjects: DIS, AI, PLC and CIM.
- **Identification technology:** Students have to learn how to develop/implement identification technology for product/part tracking during the whole life cycle. This knowledge can be part of the following subjects: DIS, AIS, PLC and CIM.
- **Protocols for IoT/IIoT data collection:** Students have to learn how to integrate protocols (like MQTT (Message Queuing Telemetry Transport) protocol) in IoT/IIOT projects. This knowledge can be part of the following subjects: DIS, AIS, PLC and CIM.

Upgrading the structure of subjects with the above recommendations, will also solve demands for increased collaboration between OT (Operational Technology)/IT (Information Technology) experts and IEM engineering, in order to each side understanding and supporting the needs of the other.

Conclusion

Digital transformation is the key factor for almost every industrial system. Edge computing is part of digital transformation and its role is to bridging the gaps between different users across the system by collecting, managing, and analyzing data at or near its source in order to increase efficiencies of the system.

In this paper are given recommendations on how to upgrade subjects in the IEM curriculum in order to overcome challenges with Edge computing in practice for future IEM engineers.

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Teaching and Learning Transversal Competences in Management Engineering

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Abstract
The role and education of engineers are widely discussed in recent years, because of the increasing relevance of technology and technological knowledge for the future sustainable economic development. Engineering programs should be able to provide students with the desirable level of vertical specialisation, and also with multi- and inter-disciplinarity, non-traditional, horizontal competences and soft skills. To this aim, a "situated" or "embedded teaching" approach could be helpful. An example is reported in which such an approach has been applied to a bachelor and a master program in management engineering at LIUC Università Cattaneo. Three transversal paths have been introduced on sustainability, critical thinking and fieldwork, in which a set of theoretical and practical activities are totally embedded not only into a real context, but also into the set of laws, language and symbols typical of the traditional specialization engineering disciplines.

Keywords: transversal competences, engineering programs, embedded teaching, sustainability, critical thinking, fieldwork

Introduction

The role and education of engineers are widely discussed in recent years, because of the increasing relevance of technology and technological knowledge for the future sustainable economic development. "Engineers are the ideal problem solvers" for the needs of the future society (Morell, 2010).

Several factors make the education of engineers increasingly complex and challenging. No doubt there is an increasing relevance of competences not traditionally included in engineering programs: soft skills, professional skills, ethics, sustainability, critical thinking, creative thinking, self-management, team-working, communication, problem solving, global mindset, awareness of social and human issues. These competences are also coherent with the increasing need for multi-disciplinarity and inter-disciplinarity, as innovation and development are often linked to the ability to integrate knowledge coming from different fields. So, in some way, there is a claim for a wider and open education of engineers (OECD, 2011; Shuman et al., 2005, Graham, 2018). But at the same time, there is an increasing specialization in the production of knowledge which, in turn, would suggest an increasing specialization of engineering programs.

It can be argued that there is an increasing tension generated by the above trends, which is especially relevant in the design of engineering programs.

The problem is: how to design engineering programs able to provide management engineering students with the desirable level of vertical specialisation, multi- and interdisciplinarity, non-traditional, horizontal competences? How to do that without losing the traditional (and always very much appreciated) scientific rigour in engineering studies?

This paper aims at sharing the real experience of the School of Industrial Engineering of LIUC Università Cattaneo in dealing with this complex question.

Theoretical background

The need for transversal competences in management engineering

There is recently a huge amount of literature concerning the need for transversal competences for all engineers, which is originated in academic communities and in practitioners' ones (among others, Kamp, 2016; Graham, 2018; World economic Forum, 2020).

The engineering community and, more generally, the community of academics, professionals and students in the "technology" field are strongly engaged in a process of reflexion and study on the type of education needed in the future. The Italian Conference for Engineering (named COPI) has recently proposed a position paper, Ingegneria 2040, in which it is claimed the need for a significant change in the education of engineers, in order for them to be able to positively contribute to the future of societies, territories, technologies, organisations. This paper is currently under discussion within several important Schools of Engineering in Italy and is stimulating innovation in engineering programs and in teaching and evaluation methods.

The literature strongly emphasises the growing importance of "other" skills than the more traditional scientific, technical and highly specialized competences; among these, in particular:

- soft and "professional" skills, such as team-working, leadership, creativity, curiosity, autonomy, the ability to function on multi-disciplinary teams, the ability to communicate effectively (OECD, 2011; Shuman et al., 2005)
- capacity to understand the impact of engineering solutions in a global, economic, environmental, and societal context (Shuman et al., 2005); this refers to the need for a more "social-education" (Graham, 2018), in which scientific and technological competencies are closely linked to contextual characteristics (economic, social, political, cultural) and to the main societal grand challenges (Klaassen, 2019);
- ability to embrace, and give value to, diversity in a very broad sense, including diversities in gender, geography, discipline, culture, abilities, possibilities, social context etc. (Crosthwaite, 2019)
- ability to be open minded, flexible, and adaptable (Morel, 2010).

Developing these types of skills implies for the need to invest also in abilities typical in human sciences education programs (UCL, 2018) and in social sciences.

While many authors and several Schools of engineering substantially agree on the need to help future engineers to develop the above competences, there isn't any agreement on how to do that.

Teaching transversal competences in management engineering programs: an embedded approach

As claimed in the introduction, designing education programs for future engineers implies for managing trade-offs and tensions, generated by the need for contemporary working on specialisation, multi-disciplinarity, interdisciplinarity, soft skills, creativity, scientific rigour, autonomy, critical thinking, social awareness. Furthermore, when asked, most professors in engineering would say that it is not possible to add anything in the challenging and already intense bachelor and master programs in engineering.

So, the question raises: how to develop engineering programs able to train students in all the necessary hard, soft, vertical and transversal competences and skills that are required for their future professional career and, most of all, for them to be able to positively contribute to the development of a sustainable society?

It is not only a matter of contents to be added. Because of the transversal nature of the skills and abilities mentioned above, there is the need to educate new types of engineers, who are strongly linked to their surrounding social environment, able to work in other fields than their specific technical one (Van de Beemt et al., 2017). This requires some reflexions on the way students learn this kind of skills and competences and, thus, on the way educators teach them. It is widely acknowledged that, with respect to “conventional teaching”, “embedded teaching” and “situated teaching” may stimulate the development of problem-solving skills and a more contextualised thinking and reasoning (Collins, 1989). Embedded teaching can be broadly intended as “learning of domain knowledge through expert-like activities and authentic problem solving in rich social, cultural and functional contexts” (Chen, 2001). This approach can stimulate students in developing not only the rigorous knowledge in their study domain, but also the ability to communicate their ideas according to the scientific rules of their knowledge domain, to set and solve problems properly, to involve them in real world situations, where it is necessary to integrate knowledge form other domains in their own one. Providing students with a real context in which declarative knowledge can be applied is fundamental for *doing* engineering (Doyle et al., 2019).

Following the above considerations, an “embedded” or “situated” teaching approach could be feasible to allow engineering students to acquire transversal competences and skills. In the following, a real experimental application example of this method is described.

A case study at LIUC Università Cattaneo

LIUC is a small University situated in the North of Italy, in the middle between Milano and the Switzerland borders. LIUC has two Schools: The School of Industrial Engineering and the School of Business Administration and Management.

The School of Industrial Engineering was engaged in 2020 in the re-design of its bachelor and master programs, following the suggestions coming from all the academic and practitioners’ literature mentioned in the previous sections. LIUC was also strongly stimulated in this direction by the external stakeholders, among which industry associations and companies, which were among the original founders of the University itself.

According to the main skills and competences needed for future engineers, LIUC decided to invest in three main transversal areas: sustainability, critical thinking and fieldwork. The related learning objectives are reported in Table 1:

Transversal areas of competences	**Learning goals**
Sustainability	Acquiring the tools for evaluating the environmental and social impact of (technological and managerial) decisions, in consideration of the grand social challenges.
Critical thinking	Learning how to analyse, synthesise and evaluate problems with standard reasoning procedures, considering also ethical issues.
Fieldwork	Learning by doing and develop several soft skills being involved into real-world problems: team-working, leadership, communication and relational skills, problem setting and solving, ability to work on multi and inter-disciplinary and complex issues, creativity, entrepreneurship.

Table 1: Transversal areas of competences and related learning goals at LIUC

Selecting the areas of investment was only the first step. The second one, and probably the most important, was to decide how to teach in these areas, or, to better say, how to build a learning path able to bring students to reach the desired learning outcomes. To this aim, the faculty board at LIUC took into consideration three main contributions. First, obviously, the literature on the topic. Second, the discussion held in academic contexts, such as SEFI (European Society for Engineering Education), COPI (the Italian Conference for Engineering), and AiIG, the Italian Society for Management Engineering. Third, a survey conducted among engineering students: students were asked about their interest in the transversal topics and more specific questions were asked about their preferences with respect to different teaching and learning alternatives. At the end of this work, and after discussing the issue in 4 Faculty Board meetings in 6 months, the choice of an "embedded teaching" approach was chosen. The idea was to plan the activities in the three transversal areas not with "stand alone" courses or projects, but, on the contrary, embedding the activities within the traditional programs and courses, as depicted in Figure 1.

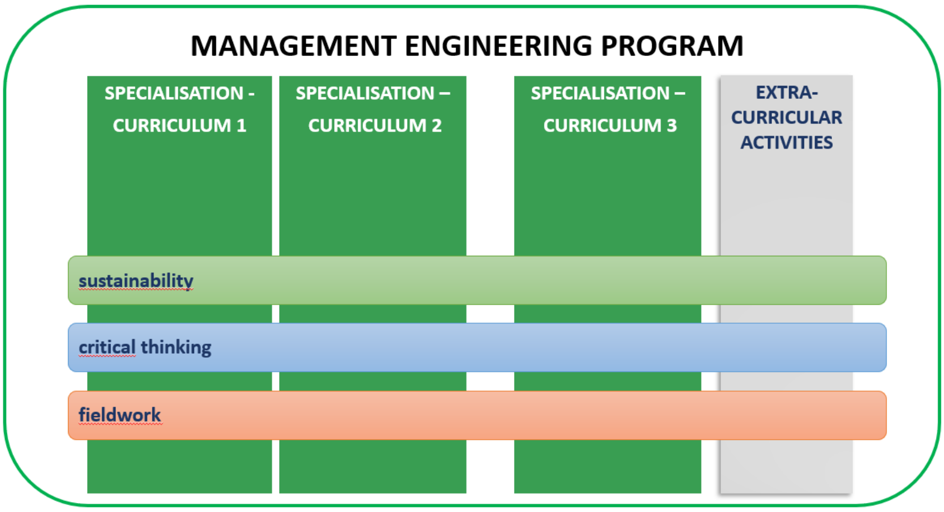

Figure 1: transversal paths for transversal competences at LIUC

As shown in the figure above, in both the Bachelor and the Master Program in Management Engineering, three transversal paths have been conceived, referred to the three areas of sustainability, critical thinking and fieldwork, each one intended to give students the opportunity to develop the "other" skills than engineering ones. Once embraced this kind of approach, the following step was to depict the specific learning paths. Learning paths "are defined as sets of one or more learning actions that lead to a particular learning goal" (Jensses et al., 2010).

At LIUC, the learning path for each transversal competence includes the following sets of activities:

- short theoretical modules, practical projects and team-works within traditional (mandatory) engineering courses;
- optional, elective dedicated courses that students can choose according to their preferences and interests;
- extra-curricular activities (such as for example societal-related contests, debates on topics related to the social grand challenges, projects aimed at facing a societal challenge of the surrounding territory) that students can choose according to their preferences and interests.

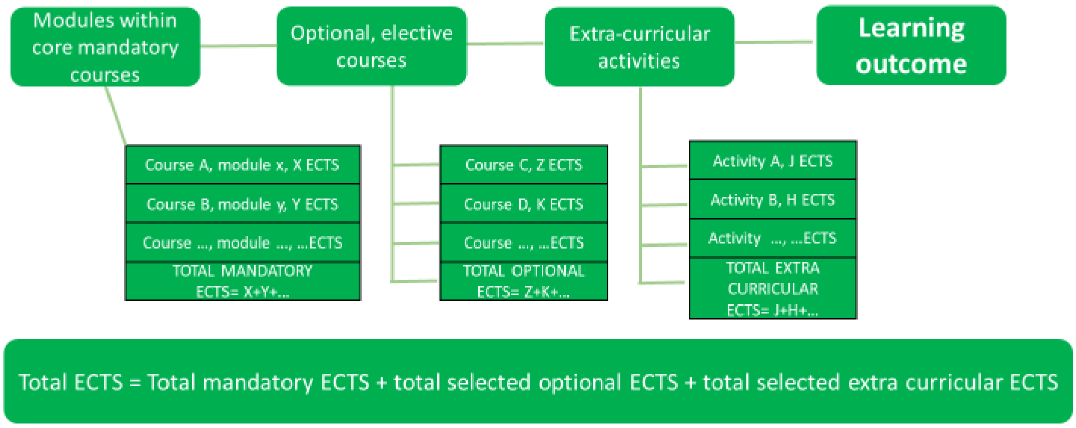

Figure 2: learning paths for transversal competences at LIUC

The structure of the learning paths, represented in Figure 2, is thus composed by a set of mandatory activities, by which all students acquire the minimum level of each transversal competence established for the engineering program, and by a set of optional, non-mandatory activities, among which students can select those more in line with their interests, attitudes and personal goals. The rules for introducing the various activities in the study plan are defined by the School, in consideration of the possible pre-requisites and avoiding overlapping of contents. Each student can thus decide the amount of effort he/she wants to put in each transversal area of competence, on top of the minimum imposed by the common mandatory program. The amount of effort will obviously determine the level of learning outcome achieved by each student, and allows students to personalise their curriculum. Hereafter an example of a learning path, for a generic transversal area of competence, represented by type of activity and by year.

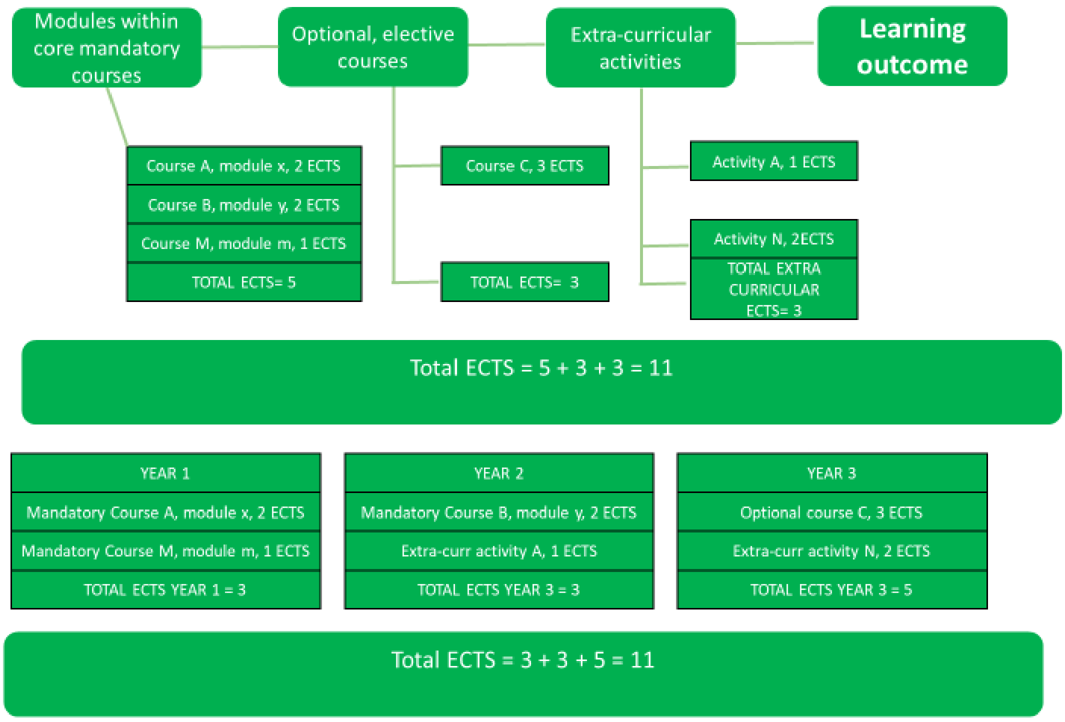

Figure 3: learning paths by type of activity and by year

It is worth notice that the LIUC situated teaching approach is aimed at "embedding" the transversal skills into the context of the traditional engineering knowledge domain, organising learning contents and activities around real problems, contexts and cases, situated within the specialisation engineering disciplines. Hence, the LIUC approach is "situated" (or "embedded") in a twofold way: situated into the context of a traditional engineering discipline and situated into a real and rich context.

For each transversal path, an academic coordinator has been identified, with the task to coordinate and plan the set of activities proposed by academics and by external stakeholders, to monitor ongoing activities and to assess the students' learning process.

Discussion and Conclusions

In this paper, it is argued that a situated or embedded teaching approach could be helpful for building engineering programs able to help students in developing the complex skills and competences needed for successfully operate as future professionals and technology managers. An example is reported in which such an approach has been applied to a bachelor and a master program in management engineering at LIUC Università Cattaneo. Three transversal paths have been introduced on sustainability, critical thinking and fieldwork, in which a set of theoretical and practical activities are totally embedded not only into a real context, but also into the set of laws, language and symbols typical of the traditional specialization engineering disciplines. The re-designed programs are planned to be launched since the academic year 2021-2022. Hence, so far it is only possible to discuss the planning elements, and a future work will be dedicated to on the real effectiveness, limits and advantages achieved in practice.

A first observation on the LIUC approach concerns the complexity of the whole program design: defining a balanced set of activities within each learning path is very complex, because of the need to embedded some of them within other courses and hence to introduce innovative ways of doing things into traditional courses. Furthermore, the need to balance curricular and extra-curricular activities is also complex, as the study program for engineers is already very intense and challenging, and so any addition should be carefully assessed. The traditional declarative knowledge is not enough and should be balanced with an epistemological basis (Doyle et al., 2019), but achieving the right balance is not easy. Furthermore, the possibility for students to personalise the learning path, thanks to the several optional and extracurricular activities, increases complexity even more. But personalisation of learning paths is considered fundamental as students may have different motivations, background, level of capacity and available time (Nabizadeh et al., 2020). And the LIUC approach allows to act on the three main parameters of learning path personalisation, related to the "why", the "what" and the "how" of learning (Nabizadeh, 2020).

A second observation concerns the coordination and management complexity: the task assigned to the three transversal path coordinators is really hard, as it requires clear communication to students, continuous relations with the persons who actually are responsible for each single activity, orientation activity and support to students (Van den Beemt et al., 2017).

A third crucial point is concerned with the assessment of the final skills and competences acquired by students. The practical abilities acquired by students, and thus the effectiveness of the programs, require a dedicated assessment, for which teachers and students should be prepared. But the literature is not yet well development from this perspective (Boix Mansilla et al., 2009; Richter & Paretti, 2009; Morell, 2010).

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Customer Success Management: Success Factors

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Abstract
B2C and B2B companies are increasingly changing their revenue streams from licensing to subscription based revenue streams. This change in revenue streams requires a new view on relationships between customer and supplier, and to bind the customer to the supplier company in the long term. That is why a new philosophy arises: the customer success management (CSM). However, despite its positive contribution to company success, companies are still struggling implementing this new approach. Against this backdrop, our paper firstly sheds light on the development of CSM and its requirements to customer and supplier. Secondly, based on a literature research and qualitative study, our paper reveals success factors that need to be considered by implementing CSM in companies.

Keywords: customer success management, success factors, customer engagement, proactive customer management, customer relationship management

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Customer success management – a new management discipline
The megatrend of digitalization offers new possibilities to companies and drives changes in well-established business models. Companies tend to provide services to their customers that require subscription based revenue models. Consequently, new challenges arise such as considerably reduced switching costs for customers and the necessity to create value on a recurring basis. However, traditional customer service and support are not meeting those sufficiently. Thus, companies need to establish the CSM approach: It allows companies to cooperate closer with their clients and creates a trustworthy relationship. Due to this, companies can better sense the needs of their customers and thus better satisfy their needs. That is how companies can reach high customer loyalty and successfully introduce their new business models to the market (Hochstein, Rangarajan, Mehta and Kocher, 2020). Further, the role of the customer success manager (CS Manager) becomes increasingly popular and is seen as the third most important future role (Zibi, Sieck, Hutchinson, Tierney and Ying, 2019). Accordingly, CSM is not a buzzword in today's business world but the most recent development status of customer management (Hilton, Hajihashemi,

Henderson and Palmatier, 2020): It improves a company's value creation, demonstrates better a solution's value, and gives the customer a voice within the seller company (Hochstein, Chaker, Rangarajan, Nagel and Hartmann, 2021).

Development of Customer Success Management

CSM has its origins in customer relationship management (CRM): While marketing was focused on customer transactions until the 1990s, this view evolved to relationship marketing in the early 1990 and early 2000s. This new view's main objective was to establish positive relationships with customers and ensure their satisfaction and loyalty. Later on, at the turn of the century, managers and academicians recognized that one should not only simply satisfy customers to ensure their loyalty. This laid the foundation for customer engagement: In this approach, customers are no longer a passive receiver of value but an active participant in the value creation process (Pansari and Kumar, 2017).

Central to this new view, which can be seen as the foundation of CSM, is the quality of relationships and maximizing customer value especially in the after sales phase (Pansari and Kumar, 2017). CSM can be seen as the next development stage of customer engagement and ensures a higher customer centricity of enterprises (Ulaga, 2018).

Customer, Supplier and Joint Sphere

The CSM can be divided into three dimensions: customer, supplier and joint sphere (Eggert, Ulaga and Gehring, 2020).

The first dimension describes the influence of the customer who has to be open towards new products and needs to have market knowledge (Challagalla, Venkatesh and Kohli, 2009). Since the supplier needs information about the customer, transparency about customer processes, challenges and strategies is important to the supplier (Prohl and Kleinaltenkamp, 2020; Zoltners, Sinha and Lorimer, 2019).

The second dimension concerns intraorganizational structures and processes of the supplier. Appropriately implementing CSM and establishing it as a company-wide mindset, requires support by managers and cross-functional incentivisation (Tuli, Kohli and Bharadwaj, 2007; Zoltners et al., 2019).

Lastly, in the third dimension, the value creation is conducted (Grönroos and Voima, 2013). This requires trustworthy employees as well as customer analysis and training (Prohl and Kleinaltenkamp, 2020; Zoltners et al., 2019).

Study Design

Our findings are based on a qualitative survey. After we had developed a semi-structured interview guideline, we gathered the interview data in the second half of the year 2020. Table 1 gives an overview of the characteristics of our participants. In total, we acquired 17 participants including twelve interviewees working in IT / Software as a Service (SaaS) sector, two in education and three in consulting.

All participants have already gained experience in the field of CSM or are CS Manager in their company. The duration of each interview was about one hour. We audio-recorded all interviews and conducted transcripts following Mayring's guidelines of qualitative content analysis (Mayring, 2016).

ID	Domain	Experience in CSM [years]	Sector	Turnover [€]	Employees (circa)
01	CS Manager	< 1	IT / SaaS	5-10 bn	10-20 k
02	CS Manager	1-2	IT / SaaS	> 100 bn	> 100 k
03	Senior CS Manager	> 5	IT / SaaS	10-15 bn	30-40 k
04	Head of CS	1-2	IT / SaaS	N/A	< 100
05	Head of CS	1-2	IT / SaaS	N/A	100-500
06	CS and Sales Manager	1-2	IT / SaaS	< 1 m	< 100
07	CS Manager	< 1	IT / SaaS	N/A	< 100
08	Senior CS Manager	> 5	IT / SaaS	5-10 bn	10-20 k
09	CS Manager	< 1	IT / SaaS	1-5 bn	5-10 k
10	Phd student	3-4	Education	N/A	N/A
11	Phd student	1-2	Education	N/A	N/A
12	Associate partner	< 1	Consulting	400-500 m	5-10 k
13	Senior partner	> 5	Consulting	500-600 m	1-5 k
14	CS Manager	1-2	IT / SaaS	100-200 m	1-5 k
15	CS Manager	1-2	IT / SaaS	500-600 m	5-10 k
16	Team Lead / CS Manager	3-4	IT / SaaS	800-900 m	5-10 k
17	CEO	> 5	Consulting	N/A	8

Table 1: Characteristics of the participants

Success Factors in Customer Success Management

The success factors are classified into the three dimensions as mentioned before: supplier, customer and joint. Figure 1 summarizes all confirmed success factors.

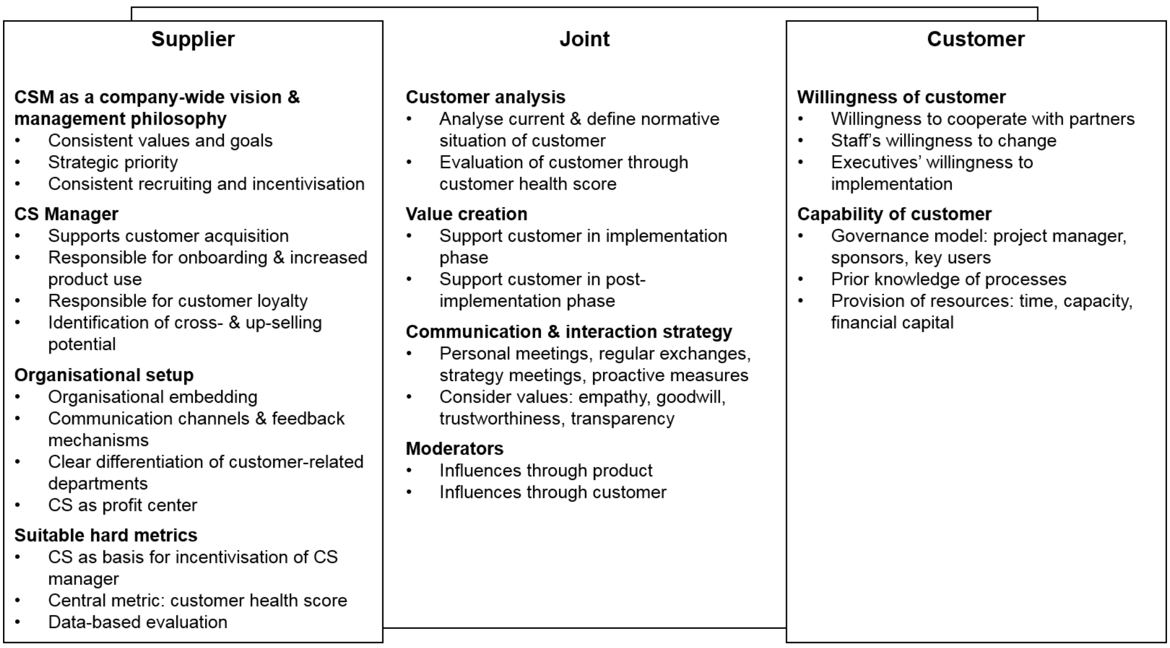

Figure 1: Success factors in CSM

The following three subsections outline the particularities and relationships between the individual success factors.

Success Factors in the Supplier's Sphere

The success factors are classified into four areas: CSM as a company-wide vision and management philosophy, CS Manager, organisational setup, and suitable hard metrics.

As a company-wide vision and management philosophy, CSM defines a number of values and goals, each of which is prioritised on each level and implemented and lived as a mind-set. When CSM is introduced, it is recommended that it is done so via a top-down approach. Managers should be capable of coaching their employees in the implementation of CSM.

The role of CS Manager is new within the organisation and is the intersection between marketing, sales, support, and product development departments, and should aim to achieve value for the customer. The areas of CSM responsibility within the organisation should be precisely defined. CSM supports the onboarding of customers and facilitates customer perceptions of the product's expected benefits in the introduction and use phases. It also identifies cross- and up-selling potential and establishes customer loyalty. The CS manager should have the opportunity to further their development and improve upon their empathy and soft skills, as well as be able to explain the often complex products in a comprehensible manner. Moreover, analytical skills are necessary in order to understand the business model of the customer and derive the potential solutions which can be offered to the customer to guarantee their success.

It is fundamentally important to determine the conditions of the organisational framework, which comprise efficient communication channels and feedback mechanisms. CSM should be thought of as a profit centre. To secure efficiency in the coordination, specific teams should be established for each customer company in the process flow and the roles between customer-related departments must be clearly differentiated.

The basis for the calculations should be the CSM measures that add value to the customer, in addition to incentivising the CS Manager. Customer success metrics monitor customer health, the customer health score is a set of indicators and key figures which describe the health of the customer and ensure transparency of any changes. For the recording and evaluation of data, CSM uses the data-based possibilities of new technologies, as well as actively using data for validating its own current activities and better aligning future activities with customer success.

Success Factors in the Joint Sphere

A good point from which to begin in supporting the customer is customer analysis. Better understanding the customer and his added value facilitates a description of the initial situation. Thus, a picture can be formed of the target situation of the customer. Then, customers should be evaluated based on appropriate indicators including frequency of use, customer satisfaction, customer contact points, customer status, cross- and up-sell successes and the direct economic effect.

The second factor to consider is the creation of value by the customer. The activities extend into the implementation phase, from identifying key users, to training, onboarding, gamification, and regular coordination meetings. It is essential in the post-implementation phase to demonstrate the value of generating potential.

Customer analysis and value generation measures are supported via comprehensive communication and interaction measures, these include personal meetings at the outset of the relationship with the customer, regular exchanges, strategy meetings, and other selective, proactive measures. Moreover, interaction values are also identified as important for success, in particular the terms empathy, trustworthy interaction, transparency, and goodwill attract attention.

However, different moderators influence these measures, which need to be included as they are relevant to success. Two influencing factors were found: the customer and the product. The first moderator is the customers, who are primarily checked via customer potential, but customer characteristics are also considered, such as information intensity, the interest of the customer and the need for communication. The second moderator is the product: CSM measures are influenced by the type of product as well as its stage in the life cycle.

Success Factors in the Customer Sphere

Customer success engagement should be prioritised to companies interested in working with the offering company and the CS Manager. This necessitates open and transparent communication, as well as the workforce being willing to redesign processes and support assertive executives. Sharing information with the CS Manager allows the provider to set up and further develop his business model in a customer-centric manner.

Additionally, the customer should be in possession of particular skills. It is necessary to have a functioning governance model which includes a project manager, sponsors, and key users, especially where particularly complex products are involved and where there is a high requirement for change to implement the product. Prior knowledge of technical details, one's own processes, and successful change management processes are also advantageous. Moreover, for a successful implementation all participants need to have sufficient time and financial resources.

Discussion and conclusions

Globally, CSM and the related position of CS Manager are in high demand. While this topic has traditionally been addressed primarily by IT and SaaS companies, more traditional industries now recognise the added value and are beginning to introduce CS departments. The determined success factors offer insights into the design and implementation of CSM. As a management approach, CSM is recommended when the company sells complex, consultation-intensive products, and is also relevant to long-term success in the goal of building long-term customer relationships, subscription revenue models and customer proximity. CSM is not only a company function but is used on the company's strategy agenda and is a company-wide philosophy.

The study illustrates the starting points for adjusting your own company to CSM and creating appropriate framework conditions for customer success to be achieved. The division into the three spheres clarifies the prerequisites which must be created to ensure that CSM is noticeable to customers. In the joint and customer sphere, the CS manager must have a clear understanding of tasks and roles required and the close monitoring of customers. CSM drives essential necessities which are required as a result of changes in digitisation, customer behaviour, new competitors, and new business models. The practice has embraced CSM and it is now time to include it in research.

There have been only initial attempts to define and delimit CSM, even if there is a need for a systematic review of the existing literature in related research areas. There has been almost no work in the quantitative research field. Therefore, this work creates a foundation for further research into CSM.

Most companies surveyed operated within the software and IT environment. The position of CS Manager already exists in other industries; it is therefore recommended to extend the survey to include also other branches of industry. Besides that, it would be of high practical relevance to determine which organisational changes should be performed within companies to enable the successful implementation of customer success management and the roles of the CS Manager.

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Developing an Industry 4.0 Mobile Training Unit for Industrial Engineering Education

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Abstract
To remain abreast of the latest and ever developing technologies and paradigms of Industry 4.0, workers, students and trainers must continuously train and gain new skills and knowledge. Training content and methods are therefore required which effectively support knowledge transfer. From research previously carried out, via a questionnaire reaching over 200 participants, it has emerged that learners wanting to gain knowledge in Industry 4.0 topics have an active learning style. An active learning style means that learners learn best when they experience a situation and tend to retain and understand information best by doing something active with it such as in a laboratory or demonstration session. This coupled with the increasing difficulties of teaching and learning within industrial engineering education means that there is a need for an innovative solution to tackle this problem. This research work has therefore resulted in an Industry 4.0 mobile training unit which can complement the traditional training content and allow the learners to embark on a participative experience, hence leading to a more effective knowledge transfer.

Keywords: Industry 4.0, Engineering Education, Skills, Pedagogy, Demonstrator

Introduction
Developments relating to the Industry 4.0 revolution are driving technology and new concept development within industry at such a fast pace that even Higher Education Institution (HEI) educators are finding difficulties to catch up with these changes. Industrial engineering professionals need not only keep abreast of the latest industrial engineering technologies, but also learn new techniques and skills from the digital aspect, such as machine learning, Internet-of-Things (IoT), and cybersecurity concepts. These skills mismatches currently existing within HEIs imply that difficulties are being encountered in transferring knowledge effectively to a new generation of learners.

Furthermore, new paradigms of education are required to match the learning styles and preferences of a new generation of learners who are not necessarily engaged in the traditional “ex-cathedra” approach to knowledge transfer. From the research carried out as part of the ICARUS Erasmus+ project (icarusproject.edu.mt) it was concluded that learners wanting to gain knowledge in Industry 4.0 have an active learning style. This emerged as part of wider-ranging questionnaire which was distributed amongst over 230 participants with an industrial engineering background in various European countries. A predisposition to an active learning style means that they learn best when they experience a situation and tend to retain and understand information best by doing something active with it, such as in a laboratory or demonstration session.

It is here therefore being hypothesised that a new generation of learners within HEIs, who are accustomed to easy access to information via the internet, need to be engaged into gaining a deeper knowledge and understanding of industrial engineering concepts by being engaged in a real-time as well as participative use and demonstration of key-concepts and technologies.

In order to develop this active and engaging learning experience, training content and methods are therefore required which effectively support knowledge transfer. Therefore, the aim of this work is to develop an Industry 4.0 mobile training unit which could complement the training content and allow the learners to embark on a participative experience, hence leading to a more effective knowledge transfer.

Literature Review: A State of the Art of Training Systems for Industry 4.0

The concept of active learning within manufacturing is not a new one and has been discussed and approached differently within industrial engineering education. A number of approaches have been developed to encourage participative learning and effective knowledge transfer such as the learning factory concept. A number of these learning factory concepts have been well documented by Abele et al. (Abele et al. 2015) and can be used to address various requirements not strictly limited to education. One of the main concepts of the learning factory is that learners can train in a realistic training environment, as well as bringing the learning experience closer to an industrial scenario. An excellent implementation of this concept is presented by Matt et al. (Matt, Rauch, and Dallasega 2014) as the “Mini-Factory” at the Free University of Bolzano. This implementation demonstrates a number of industrial engineering concepts, from planning and assembly task analysis to robot programming and control. Another implementation of the learning factory within an educational environment is the “Automated Class Room” at the University of Applied Sciences Emden/Leer (Wermann et al. 2019). That said, learning factory approaches are typically limited to particular environments and do not allow for portability of a setup. Furthermore, their main objectives is to provide a hands-on learning approach in the lab, rather than providing a pedagogical approach to active learning in the classroom.

In a bid to improve training effectiveness researchers have also used Industry 4.0 technologies such as Virtual Reality and Data Mining to develop training systems (Roldán et al. 2019). In this case though, the approach is best suited for task training by operators within industrial environments, rather than targeted towards effective knowledge transfer of Industry 4.0 concepts in the HEI classroom. A number of works have also developed technology demonstrator type setups, but these are typically limited to a particular technology rather to provide training in over-arching Industry 4.0 concepts. One example of such an implementation is the robot process planning approach developed by (Erős et al. 2021). Whilst this is a good example of a technology demonstrator it is very limited to a particular application.

This literature review of the state of the art in training demonstrators for Industry 4.0 shows that there is a lack of portable demonstrators which effectively integrate training material in a range of applications and Industry 4.0 technologies. The aim of this research is therefore to develop an Industry 4.0 mobile training unit for effective and active industrial engineering education.

Research Methodology

In order to address this gap, and as part of the ICARUS project, an Industry 4.0 Mobile Training Unit is being developed. The systematic research methodology being employed is based on the User Centered Design Approach (Gulliksen et al. 2003). As shown in Figure

1, the first step of this approach is to adopt a structured approach to understand the user needs. For this work two types of users where considered. One set of user is the target of the training unit, i.e. the industrial engineering learner in an HEI. The other set of users are the trainers who will make use of the setup in a training environment. A set of design requirements are then developed based on user input in order to effectively develop a training unit which targets the actual user needs. This analysis of the requirements leads to the design of an Industry 4.0 Mobile Training Unit. The next and final step of this work will be to build the demonstrator and evaluate it with learners in a participative learning activity.

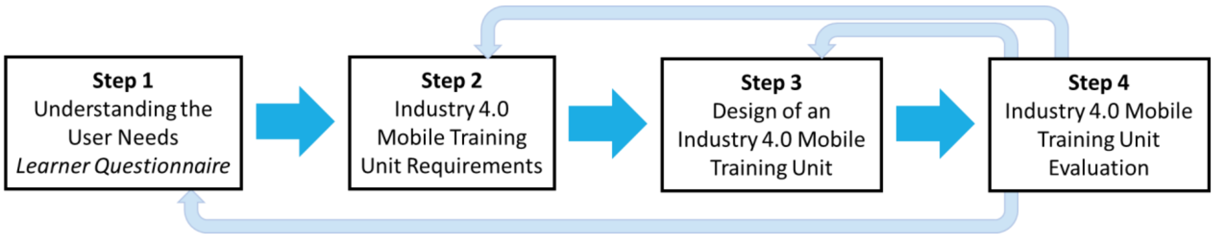

Figure 1: User Centered Design Approach

Mobile Training Unit Requirements

To understand better the user needs for a mobile training unit an online questionnaire was designed. This questionnaire which was distributed amongst a number of potential Industry 4.0 learners from European countries for a total of 231 respondents. The respondents overwhelmingly (96%) prefer an active training unit which allows them to interact in real-time with the technology.

Furthermore, a majority (63%) of the trainers responding to the questionnaire would also need to transport this mobile training unit not only within their own institution but also to other entities or to participate in specific training events. From these respondents the choice of vehicle to be used for transportation is a mix of private vehicles (40%) and rental vans (60%). These requirements provide an input in terms of the modularity and dimensions and weight of the training unit.

Based on an analysis of the questionnaire results as well as the aims of this project the specifications for an Industry 4.0 mobile training unit were drawn up. These are described in Table 1.

Active	The unit must allow active learners to interact in real-time with the setup during the learning experience.
Integrated	The Mobile Training Unit capabilities must be integrated/paired with the learning content on specific technologies/concepts.
Demonstrate	Topics such as Collaborative Robotics, Cyber Security and Data Integration and analysis needs to be implemented to allow for various Industry 4.0 approach and technology demonstration.
Transportable	The system must be transportable both internally and externally within the institution. Dimensions and weight therefore have to suite the transportation requirements.
Modular	Allow for a degree of modularity to allow customisability depending on the training or transportation needs.

Table 1: Specifications of an Industry 4.0 Mobile Training Unit

Results: The Design of an Industry 4.0 Mobile Training Unit

An Industry 4.0 mobile training unit was therefore designed in order to meet these specifications. This mobile training unit has been designed to demonstrate a number of Industry 4.0 technologies such as Collaborative Robotics, 3D Printing, Augmented Reality, Industrial Internet of Things (IIoT) and Artificial Intelligence. As shown in Figure 2 a UR3 robot by Universal Robots is used for the collaborative robotics aspect.

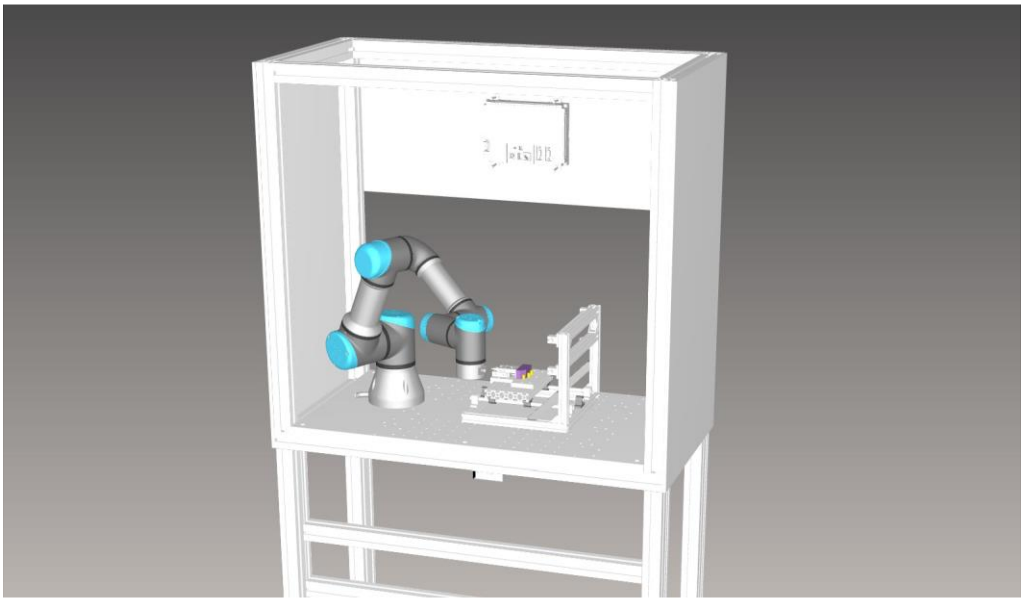

Figure 2: Concept of Modular Industry 4.0 Mobile Training Unit

This robot has been selected and is at the centre of this design as it can demonstrate a number of Industry 4.0 technologies and concepts including:

- Collaborative robotics and human robot interaction
- Robot programming and task planning
- Cybersecurity demonstrations and exercises
- Safety engineering methodologies and concepts

Further to the UR3 robot a desktop 3D Printer by Creality for the 3D printer. Industrial Ethernet protocols are used to connect the robot and 3D printer to a PLC (OMRON NX102). AR and VR models of the setups and products loaded onto the machine have also been developed in order to demonstrate the functionality of these technologies. These selections have been made to demonstrate the concepts of IIoT, data mining and cloud-based systems for real-time data collection and analysis from various PLCs and controllers via the OPC-UA communications protocol.

Discussion

The conceptual design solution as described in the previous section is the main contribution of this work. It is aimed at achieving the objective of this research, i.e. an Industry 4.0 mobile training unit for effective and active industrial engineering education. A number of Industry 4.0 technologies are implemented within the training unit, hence the aim of demonstrating a range of technologies is achieved.

The training unit is also coupled with the congruent training material for the different technologies and Industry 4.0 concepts such as AI, data mining, collaborative robotics, AR and VR. Both this Industry 4.0 training unit as well as the training material have also been developed as an open-source project, and these will be made available under an academic free license for other HEIs to develop and customise accordingly to their specific user requirements. Furthermore, as a systematic and guided approach, trainers can utilise the user centred design approach proposed by this work to customise the training unit to the specific needs and requirements of their industrial engineering learners, be these currently undergoing training in HEIs or as well in industry.

That said at this stage of this research the effectiveness of this training approach can still not be quantified and determined, since the actual training unit has not been implemented and tested within an actual training environment. Therefore, to confirm whether the overall aim and objectives of this research have been achieved this Industry 4.0 training unit would have to be used in a classroom set up to see whether not only have the design requirements been met, but whether the active training approach being proposed here is more effective than the traditional training methods.

A further note has to also be said about the actual design solution proposed here and the limitations of this research. As proposed by the user centred design approach the design solution is constrained or dependent on the users who were part of the study. Whilst a good sample size was adopted, it still could skew the design to a particular notion or direction, and hence lack generalisation for every training situation or user. There are still learners who prefer and perform better within a traditional approach to teaching were the student is more passive towards receiving knowledge and information from the professor. That being said, this approach to developing active training and pedagogical approaches aimed at increasing the effectiveness of knowledge transfer can be used as a guide for the development of innovative training practices.

Conclusion

Whilst as discussed in the previous section the Industry 4.0 training module here presented is still to be implemented and evaluated in a learning context, it is expected that this approach of integrating learning content with an active demonstrator will improve the effectiveness of the training content.

Furthermore, by making this setup portable it can be used within classrooms and everyday teaching, in order to demonstrate Industry 4.0 technologies to HEI students, as well as making it transportable to Industry for specific training sessions.

In future work this research will continue to develop new and innovative knowledge transfer approaches which will complement this test bed in order to move away from the traditional “ex-Cathedra” lecturing approaches used in HEIs, and implement active and participative training methods.

Acknowledgements

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Digitalization of Practical Laboratory Teaching in Learning Factories in the Age of Covid-19

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Abstract
The Covid-19 pandemic has led to major social and economic changes worldwide. In a time characterized by social distancing, educational institutions also had to adapt their infrastructures and processes to the new circumstances. In addition to general restrictions and distance learning, this also had a particular impact on practical training at schools and universities. In this paper, we highlight an example of the digitalization of practical laboratory instruction in a learning factory environment of an undergraduate engineering course. In addition to reporting experiences, we also look ahead to future challenges in practical lab teaching in a post-Corona era.

Keywords: Covid-19, Corona, Learning Factory, Teaching, Engineering Education 4.0, Industry 4.0

Introduction

The outbreak of the Corona pandemic in early 2020 caused hospitals, the economy, and even educational institutions to come to a virtual standstill almost worldwide within a short period of time. E-learning has become the mandatory component of all educational institutions like schools, colleges, and universities in and around the world due to the pandemic crisis of COVID-19. This deadly situation has flipped out the offline teaching process (Radha et al., 2020). Online teaching and learning imply a certain pedagogical content knowledge, mainly related to designing and organising for better learning experiences and creating distinctive learning environments, with the help of digital technologies (Rapanta et al., 2020). Teaching staff have had to prepare and deliver their classes from home, with all

the practical and technical challenges this entails, and often without proper technical support (Hodges et al., 2020).
In our post-digital reality, one can argue that ‘online’ is a helpful descriptor for students’ actual experiences (Fawns, 2019), especially in the rich parts of the world, where Internet-connected devices are in such regular use, and the boundaries between learning and other activities in everyday life have become so soft. However, the same cannot yet be said for ‘online teaching’ which comprises intentional support for other people’s learning, mediated by the Internet. The rapid closing-off of face-to-face educational work, in response to the Covid-19 pandemic, gave teachers the possibility to sense and test the difference between online teaching and off-line teaching (Rapanta et al., 2020).

In this paper, we present the shift from analogue teaching to online teaching using the example of hands-on laboratory teaching in a learning factory lab. Learning factory labs are characterized by the fact that they are supposed to deepen the practical aspect of learning through practical on-site content in particular. As a result of the Covid-19 pandemic, many learning factory laboratories were faced with the challenge of digitizing their practical learning concepts and adapting them to distance learning.

Review of Learning Factory Teaching Concepts
A Learning Factory in a narrow sense is a learning environment specified by (Abele et al., 2019):

- processes that are authentic, include multiple stations, and comprise technical as well as organizational aspects,
- a setting that is changeable and resembles a real value chain,
- a physical product being manufactured, and
- a didactical concept that comprises formal, informal and non-formal learning, enabled by own actions of the trainees in an on-site learning approach.

Depending on the purpose of the Learning Factory, learning takes place through teaching, training and/or research. Consequently, learning outcomes may be competency development and/or innovation. An operating model ensuring the sustained operation of the Learning Factory is desirable (Abele et al., 2019).

In a broader sense, learning environments meeting the definition above but with (Abele et al., 2019):

- a setting that resembles a virtual instead of a physical value chain, or
- a service product instead of a physical product, or
- a didactical concept based on remote learning instead of on-site learning can also be considered as Learning Factories.

Learning Factories are becoming increasingly popular to teach students, how the methods and concepts learned in theory work in a hands-on and industry-related environment. In the last decades numerous learning factories have been built in industry and academia. The first examples of learning factories were established in the United States (Penn State University, in 1994). In recent years, many learning factories have been established and in most cases, these consist of demonstration lessons as well as the opportunity to design, test and optimize production systems and processes in practice. With the introduction of industry 4.0 also many learning factories adapted their education model as well as their offer in order to meet the expectations of students and companies towards technologies and methods of smart manufacturing (Rauch et al., 2019). Examples of learning factories are the Pilotfabrik at TU Vienna, the Center for Industrial Productivity (CIP at Darmstadt) or the LMS Learning Factory in Greece.

Practical Teaching at the Smart Mini Factory

The Smart Mini Factory lab was set up at the Free University of Bolzano to support applied research and practical teaching for students as well as for professionals. The focus of the learning factory lab is to teach and demonstrate the application of lean manufacturing principles as well as newest technologies and methods from Industry 4.0 and smart manufacturing aiming to accelerate the introduction of Industry 4.0 in local companies. According to the structure of local economy another focus of the lab is on small and medium sized enterprises (SME). Over the last years the lab developed several practice oriented training offers for undergraduate students as well as for lifelong learning. In lifelong learning the lab offers since 2018 different trainings to professionals from industry to qualify their existing workforce in Industry 4.0 topics.

With the lockdown restrictions as well as specific restrictions in education the Smart Mini Factory needed to adapt and change the learning concept for offering several trainings that are part of the undergraduate course. In one of the courses related to production system design the students normally were introduced in the lab equipment that consists in a manual assembly line, assembly tools, a collaborative robot, a digital worker assistance system for displaying worker instructions digitally on the worktable and other equipment for industrial logistics (lean and kanban shelves etc.).

In a next step the instructor presents the use case which consists in planning, designing and implementing the assembly of a real product, which in this use case is a pneumatic cylinder consisting of 22 different parts (Matt et al., 2014). Students analyse the product creating a bill of material, they analyse the process by conducting time measurements and methods time-measurement (MTM) and finally they plan a possible layout for the assembly line. After this they implement the planned assembly process in an 8-hour practical workshop in the Smart Mini Factory lab. During these 8 hours they stepwise optimise the performance and ergonomic situation of the assembly system and document the changes and modifications done as well as their impact (see Figure 1). The most significant advantages of this approach reported by students after this lab exercises lies in knowing how to apply methods learnt in theory, how an assembly process looks in practice and what kind of failures can occur and how different machines and tools can or cannot be used in practice (e.g. collaborative robot).

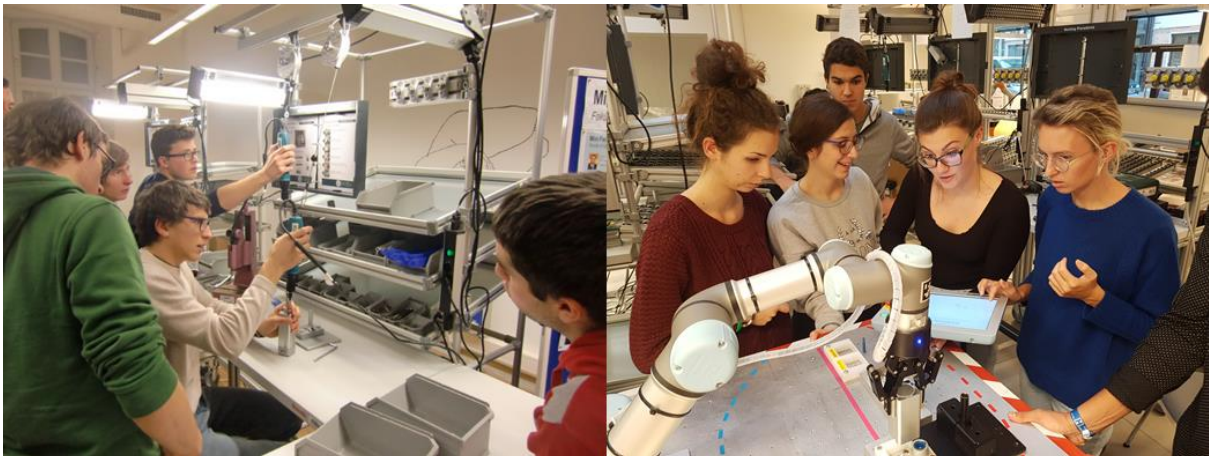

Figure 1: Practical workshop in the Smart Mini Factory under normal conditions

Experiences from Practical Teaching under Covid-19 Conditions

Due to the pandemic situation, the use case in the learning factory laboratory was adapted to distance learning. This required a great effort for preparation and for technical conversion.

Instead of the usual on-site demonstration of the available equipment, a Virtual Lab Tour was developed, which can now also be conducted independently of the course on the Learning Factory Lab website. For this purpose, the software matterport was selected and used as a technical tool. This software was originally developed for the real estate market to offer virtual tours through potential properties. For this purpose, about 60 all-round videos and photos were taken at various locations in the laboratory. These were finally merged by the software to a 3D spatial image, which enables a virtual tour of the laboratory (see also Figure 2). The individual machines and devices are marked with a blue interactive dot in the 3D tour. If the student clicks on this point, details about the equipment and demonstration videos are displayed.

Figure 2: Virtual Lab Tour through the 360° view matterport engine

A series of videos were shot in advance in the laboratory and viewed together via MS Teams to explain the product and the assembly process (see Figure 3).

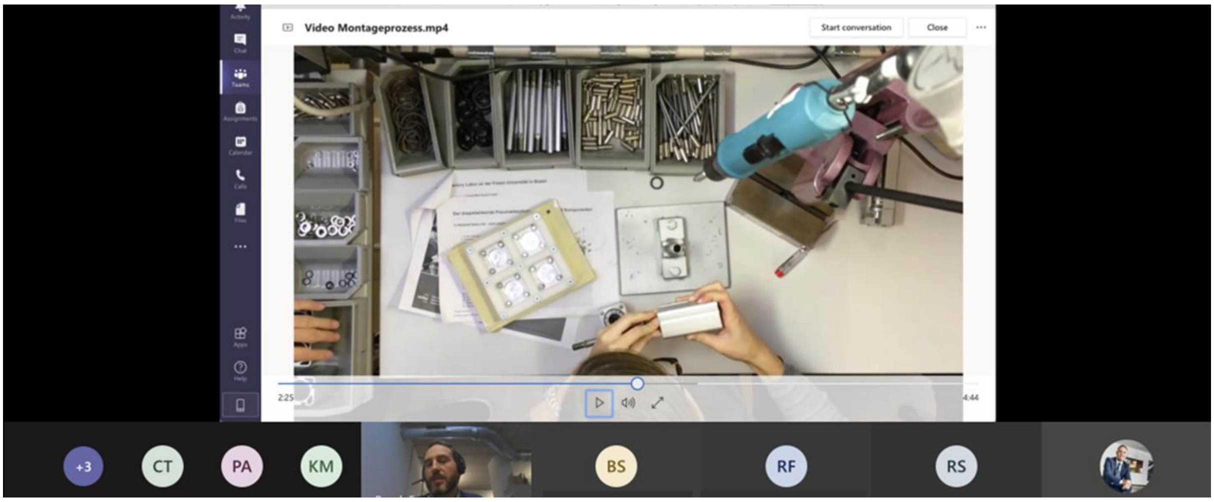

Figure 3: Off-Line practical exercises through video material and live-demonstrations

Outlook into a Post-Corona Era

The subsequent discussion with the students revealed that, given the situation, they were very satisfied with the way the laboratory exercise was implemented, but they strongly missed the direct interaction with the laboratory equipment. It was possible to convey the basic learning content and methods at a distance. However, many practical learning effects are lost through the pure implementation at a distance. In particular, “learning through mistakes” was only possible to a very limited extent via the virtual implementation of the laboratory case study. In a post-corona era, some aspects will be retained. For example, the Virtual Lab Tour has been integrated as a fixed component on the lab's website and is thus available not only to students but to all interested parties. This has also proven to be a useful tool for short lab presentations. The videos, which were recorded for the lab exercise, will be made available in the future especially to working students, who thus have the opportunity to participate in the lab group work. At the same time, it is important to explore further technical possibilities for the future, such as the implementation of real-time remote experiments in the field of robotics. For the coming year, it is planned to give students the possibility to directly execute the path movements programmed in the software by means of remotely connected and secured robots in real time and to display them via a camera system.

Conclusion

Overall, it has become apparent that the Covid-19 pandemic has generated a major challenge for education and, in particular, for practical training. However, instructors were forced to break new ground in terms of digital tools and to gain initial experience very quickly. Some of the measures under the Covid-19 pandemic will no longer be necessary in a post-Corona era, but will be continued and further developed as they significantly support the teaching and also allow working students to participate in a better way and more actively in the classroom.

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Resilience in Manufacturing During COVID-19 Through Digital Worker Assistance Systems

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Abstract
As the ongoing Covid-19 outbreak proved, pandemics affect not only health, mobility and social life of individuals, but have a strong impact also at systemic level of manufacturing industry. Many companies were forced to lockdown, many closed facilities voluntarily. The companies that continued or reopened their manufacturing needed to rapidly reorganize their operational processes to ensure the safety of their workers. For many companies it was a huge challenge to continue working efficiently, while maintaining all safety and distancing measures to minimize the risk of infections. To avoid interruptions in production and the supply chain and the related impact on the economy, it is essential to ensure that manufacturing facilities can operate also in case of such disruptive situations. Reduce the need for person-to-person contact on the shop floor was one key factor for resilience to continue manufacturing in such periods. The aim of the research is therefore to propose models for contactless shop floor interaction of workers in manufacturing enterprises. The findings in this research propose a combination of collaborative robotics, sensorial/physical/cognitive worker assistance systems, simulation, real-time connectivity and monitoring, vertical data integration as well as digital production planning and control.

Keywords: Covid-19, Corona, Resilience, Manufacturing, Worker Assistance Systems, Industry 4.0

Introduction

As current Covid-19 outbreak proved, pandemics affect not only health, mobility and social life of individuals, but have a strong impact also at systemic level from the healthcare to economics to the manufacturing industry. Many companies were forced to lockdown, many closed facilities voluntarily. The companies that continued or reopened their manufacturing were needed for rapid reorganisation of operational processes to protect their workers. To maintain the shop floor productivity level in a changing production environment was a challenge all over the manufacturing sector. Covid-19 is just a sample case, for what scenarios the manufacturing sector needs to be prepared for. The world has lately faced also other pandemics. Therefore, preparedness is becoming part of strategic objectives of manufacturing companies to be resilient. To avoid a crash of the economy and to maintain availability of consumption goods, it is essential to keep running manufacturing facilities also in the period of increased infection risk. Person-to-person (p2p) contactless interaction on shop floor is a key factor to continue manufacturing in such periods. The aim of the research is to propose different models of adaptation to reduce direct contact on the shop floor. In this way, in case of a new pandemic situation a lockdown in high infection risk periods can be avoided and in the same time productivity can be kept in its conditional level or even increased. Beside the infection risk avoidance, the research contributes to proactive assistance as well as digitalization on shop floor level.

Literature Review

Industry 4.0

The strategic initiative Industry 4.0 originates from Germany (Kagermann et al., 2013), but the concept is widely adopted internationally. Industry 4.0 stands for the fourth industrial revolution which is based on development of cyber physical production systems (CPPS) (Schlick, 2020). The main idea of CPPS is that digital information flow and physical manufacturing flow are parallel fully integrated inseparable phenomena (Aruväli, 2015). Today, there are at least 42 concepts that are related to Industry 4.0 (Rauch et al., 2019). In the era of mass customization, the implementation of these concepts opens up the level of flexibility to strive for the productivity of mass production, while at the same time increasing the physical ergonomics of employees. For example, at the Free University of Bolzano an application of intuitive human–robot interaction was successfully developed and implemented based on features and requirements in context of Industry 4.0 to assemble pneumatic cylinders (Gualtieri et al., 2020). Industry 4.0 forced flexibility, intelligence and connectivity of manufacturing systems and equipment are the key factors to enable easier and faster adaptation to contactless interactions.

Resilience in Manufacturing

As this work deals with the goal to increase resilience in manufacturing we first want to provide a definition of the term. In the current pandemic resilience has become a crucial aspect in manufacturing and supply chain management (Belhadi et al., 2021). However, resilience in manufacturing have been a goal already before Covid-19. According to Gu et al. (2015) unexpected disruptive events in manufacturing always interrupt normal production conditions and cause production loss. Therefore, a resilient system should be designed with the capability to suffer minimum production loss during disruptions, and settle itself to the steady state quickly after each disruption. Resilience is defined as the ability of a system to withstand potentially high-impact disruptions, and it is characterized by the capability of the system to mitigate or absorb the impact of disruptions, and quickly recover to normal conditions (Youn et al., 2011). According to several authors (Chukwuekwe et al., 2016; Emmanouilidis & Bakalis, 2020) Industry 4.0 technologies and concepts play a major role in achieving more resilient manufacturing systems and value chains.

Digitalization

Digital technologies increase productivity of manufacturing processes and provide workers with new skills. In manufacturing digital information is already widely used: analogue information is converted to digital for machine readability; databases in clouds are used to collect and store the digital data; communication between machines, databases and products is digitalized; graphical user interfaces present the digital information to humans. Nevertheless, digitalization is still in the early stage as big potential lies in technologies of 5G and Industrial Internet of Things (Cheng et al., 2018). Today, digital solutions main advantages on shop floor are immediate communication over distances and saving of resources. Digitalization of shop floor enables human-machine interactions to avoid p2p interactions.

Real-time monitoring

Monitoring systems comprise data collection, analysis with prognoses, visualisation and storage (Snatkin et al., 2013). Depending of the measurement method and frequency, the number of measured data sets can be enormous. Crucial is to provide users only with relevant information to increase the efficiency. Various sensors are deployed in the manufacturing to measure vibrations, acoustic, current and other parameters to evaluate machinery condition (Bointon et al., 2020), utilization rate (Astapov, 2014), part quality (Lu et al., 2019) and other manufacturing related parameters. Also social distancing real-time monitoring solutions have been proposed. For instance, Khandelwal et al. (2020) used a computer vision closed-circuit television feed based monitoring to find workers violating the rule of social distancing. However, such violations should be avoided proactively. Further context based assistance systems with real time feedback to constantly monitor the safety equipment and assembling parts presence have been developed (Aruväli et al., 2014). Real-time monitoring of manufacturing processes is the basis for contactless and context based feedback and assistance on the shop floor.

Contactless solutions

After previous pandemics (influenza A H1N1), researchers proved the efficiency of social distancing in workplaces to decrease the case rate (Ahmed et al., 2018). Still, no systematic focusing of that criterion in development of manufacturing systems has been made to prepare for the next pandemic. Today, social distancing and avoidance of p2p contacts has become a new normality in everyday life. New technology has by default also brought social distancing to the manufacturing. Applications as smartwatches, mobile devices and manufacturing related software are the pathfinders to p2p contact free interactions (Schönig et al., 2017). However, the current situation in the context of Covid-19 is challenging manufacturing companies and therefore has created the need for specific research in the field of p2p contactless interactions on the shop floor.

Worker Assistance Systems to Increase Resilience in Manufacturing

The companies that continued or restarted manufacturing needed a rapid reorganisation of operational processes to protect their workers (Rapaccini et al., 2020) and in the same way increasing resilience of manufacturing on the shop floor. The main protective measures introduced were a) wearing of additional personal protective equipment, b) using disinfectants and c) keeping the distance among people. This research is focusing on measure c) keeping the distance of other persons in shop floor environment. The promptly implemented actions on shop floor were often one-purpose and did not investigate the system as a whole.

The research focus is on shop floor and namely on assembly stations due to the following reasons: 1) assembly stations are often less automated than machining stations as the tasks are less standardised, 2) less standardised work needs more human presence and many workers are often working together in one assembly section, 3) less standardised tasks often need additional specific assistance. Further, in assembly production managers or shift leaders need to explain tasks in more detail by means of engineering drawings and are giving instructions for best practice. In addition, in mass customization environment, where batch sizes are small, frequent reconfiguration is needed as product variety is high. Such situations gather crowds (production managers, shift leaders, assembly workers, logistics operators) and also waste production time.

Figure 1 introduces the proposed approach based on worker assistance systems to enable p2p contactless work. The figure describes the options to turn conventional assembly stations into p2p contactless assembly stations. In a first step physical assistance systems like collaborative robots can help to reduce the need for two workers when heavy loads need to be manipulated or when the quantity of assembly tasks requests the presence of more than one worker. In a second step the introduction of a vision system with 3D perception and human tracking allows to increase safety of the human-robot collaborative system and to allow automated quality checks. In a third step the introduction of cognitive assistance systems like the projection of work instructions on the worktable allow to support the operator to perform also complex assembly tasks that usually were needed to be assigned to different workers due to complexity.

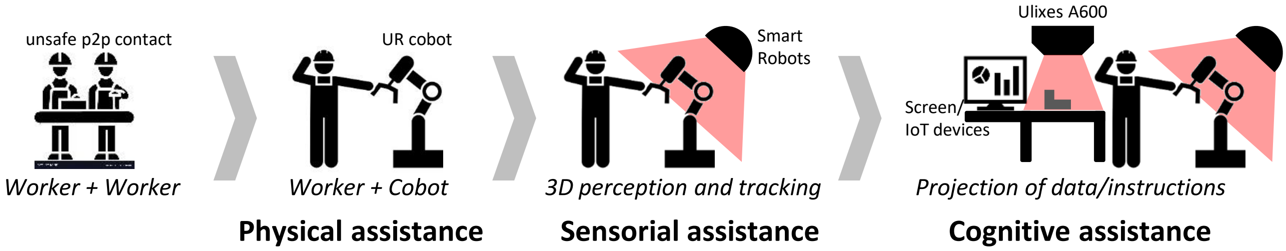

Figure 1: Physical, sensorial and cognitive assistance

Figure 2 and Figure 3 show such worker assistance systems implemented as demonstrators in the Smart Mini Factory Lab of the Free University of Bolzano.

We remind the initially introduced definition of resilience in manufacturing, where a manufacturing system should be designed to withstand potentially high-impact disruptions, and it is characterized by the capability of the system to mitigate or absorb the impact of disruptions, and quickly recover to normal conditions. As illustrated in Figure 1, the worker assistance systems shown in the demonstrators are specifically suitable for situations where usually two or more workers perform together a certain manufacturing or assembly task. The need for more workers could have several reasons. In most of the cases this is necessary due to high weights of parts or complex assembly sequences combined with a high variety of product variants. Thanks to the introduction of Industry 4.0 technologies in form of worker assistance systems the manufacturing system is able to overcome potential disruptions due to social distancing rules.

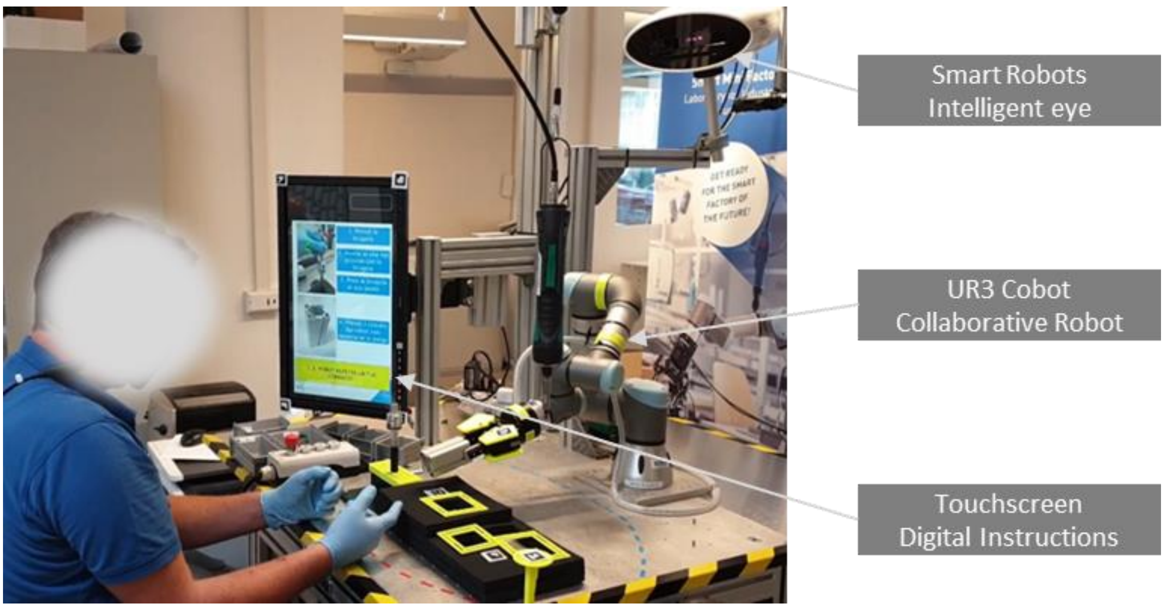

Figure 2: Example of a collaborative robotics workstation with computer vision

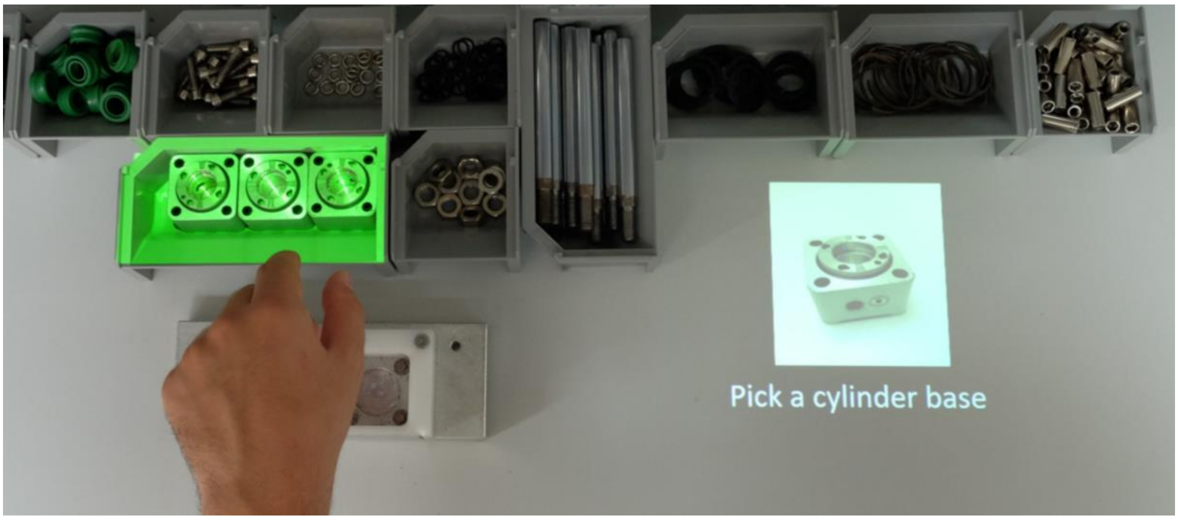

Figure 3: Example of a projection-based cognitive worker assistance system

Outlook and Objectives for a Digital Twin Based Worker Assistance

Based on the already implemented solutions for enabling p2p contactless work, the research team developed also ideas for future research. To increase the efficiency but also resilience in production the before mentioned worker assistance systems need to be integrated in a digital twin of the assembly station. The concept for such a future oriented workstation is shown in Figure 4. In the proposed model the assembly station captures data (related to quantity and quality of the work) through a Manufacturing Execution System (MES) and sends such data to a digital twin of the production system. While the connection of the work station to the ERP/MES allows real-time monitoring, the use of collected data for simulations in the digital twin model allows to find operational bottlenecks and to optimize the productivity.

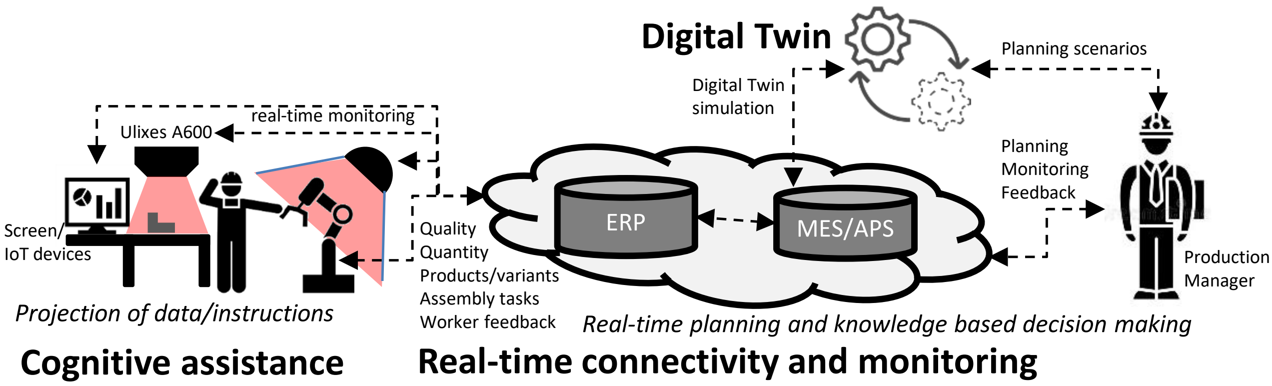

Figure 4: Real-time connected and digital twin based worker assistance system

Using such kind of an enhanced and digital twin based worker assistance system p2p interactions can again be reduced by minimizing the need to directly communicate with the production manager or supervisor. In the future the research team plans to start a project working together on the planning, design, realization and validation of such a real-time connected monitoring system and a digital twin based optimization of the workstation and work processes.

Discussion

The introduction of such worker assistance systems helps to increase resilience in manufacturing. Compared to classic manufacturing and assembly concepts, worker assistance systems offer the possibility to make workers more independent of disruptive influences and to support them in their work both physically and cognitively. At the same time, such systems also increase ergonomics at the workplace by reducing biomechanical stress as well as mental strain. These systems not only help to increase the capabilities of "normal" workers, but also enable the inclusion of target groups with reduced performance, such as older people or people with physical or mental impairments and thus enable social sustainability in manufacturing companies.

Despite all this, there are limitations to using these systems to increase resilience. These systems have only limited added value for increasing resilience in the case of pandemic-related social distancing, since the advantage here only arises for situations in which several workers are involved. On the other hand, the introduction of such technologies also entails not inconsiderable investment costs, which represent a barrier for SMEs in particular. The integration into a digital twin, mentioned in the outlook, also still requires some effort in research as well as qualification of existing employees in the companies in order to develop application-oriented solutions.

Conclusion

The Covid-19 pandemic is still challenging for many manufacturing companies. Social distancing has been a crucial aspect over the last period to enable resilience in manufacturing. In this research we propose sensorial, physical as well as cognitive worker assistance systems as valuable solutions for reducing p2p interaction on the shop floor. Further future research directions regarding digital twin based worker assistance systems have been announced. In all these proposed solutions, the social and emotional aspect from the perspective of the employee himself must not be forgotten. Such a reduction of the p2p interaction between workers and workers with supervisors naturally also entails an alienation as well as a reduction of the social contacts of the employee during working hours. Further studies will also be needed in the future to investigate the negative effects of such reductions in p2p interactions.

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Assessment of Industry 4.0 Maturity Level

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Abstract
Industry 4.0 (I4.0) is a concept that was coined in Germany in 2011 and has been rapidly evolving around the world. It is imperative to develop a framework for measuring the companies' level of maturity and develop a roadmap tool which will then move them towards complete digitization. Although there are several studies and models to evaluate the companies' readiness and maturity models in different countries around the world, Argentina was still lacking an in-depth study of this type, mainly for the small and medium-sized enterprises (SMEs). The aim of this research work has been to study those models, improving and adapting them to the Argentinian reality. The project has been carried out in two phases: (i) literature review and identification of different assessment models for I4.0, and (ii) a field study for testing the assessment model. This assessment includes 32 factors grouped into 5 dimensions. To improve the questionnaire design, 10 in-depth interviews were conducted, and the assessment model has been applied to a survey in 146 companies. Results indicated that the average rate in Argentinean large enterprises was 2.9, while in small ones was 2.2, in a range from 0, minimum, to 5, maximum.

Keywords: Industry 4.0, SME, Maturity assessment, Digital transformation, Smart manufacturing, Readiness

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Introduction

Digitization essentially refers to taking analogue information and encoding it into zeroes and ones so that computers can store, process, and transmit such information; while digitization is encoding, digitalization is the process of change (Romero, Vazquez Serrano and Castro Lozano, 2007).

Digital technologies have been becoming key factors for those companies seeking to achieve their goals. The application of these technologies to business and entered life is called Digital Transformation (DT).

At the 2011 Hannover fair this phenomenon is mentioned as I4.0 (Matt, Modrák and Zsifkovits, 2020; Qin, Liu and Grosvenor, 2016; Sanders, Elangeswaran and Wulfsberg, 2016). The term I4.0 describes the revolution in the manufacturing industry around the world (Matt et al., 2020); I4.0 is the integration and interaction of technologies, both in the digital and physical domains, which differentiate it from other industrial revolutions (Demartini and Tonelli, 2018). The physical and the virtual world are integrated into cyber-physical systems (CPS) (Sommer, 2015).

New technologies make up the I4.0, such as Cloud Computing (CC), Mobile Technologies, Communications between Machines, Additive Manufacturing, Advanced Robotics, Big Data, Analytics, Artificial Intelligence (AI), Industrial Internet of Things (IIoT), Cybersecurity and CPS. (Javaid, Haleem, Singh and Suman, 2021; Lydon, 2019).

Enterprises must have a roadmap to reach a complete digitalization, then, they must know at what level of organizational and technological maturity they are.

The aim of this work is to assess the Maturity Level of I4.0 in Argentina, using 32 factors clustered into 5 dimensions.

Literature review

DT is the change associated with the application of digital technologies in all aspects of human society. The term Digital comes from digit, and refers to the binary system, and the action of the conversion to said system is called Digitization (Romero, 2007).

Gottfried Wilhelm von Leibniz developed in 1703 the concept that would become known as "digitization". The first electronic analogue computer was introduced by Bulgarian-born John Atanasoff in 1939. With the introduction of the World Wide Web, the size, speed, and effects of digitization changed, speeding the transformation process of societies (Ford & Baum, 1997).

Regarding standardization, there are two basic requirements to build an I4.0 platform: the definition of a communication structure and the development of a common language. Similarly, it is essential to achieve connectivity and interoperability between devices; it is one of the most outstanding characteristics of the DT applied to the industry. For that reason, an I4.0 platform architecture was created in 2013 by the “Deutsche Kommission Elektrotechnik Elektronik Informationstechnik”, which was called Reference Architectural Model Industrie 4.0 or RAMI4.0.

Digitalization is needed, but many companies are not well-prepared for that challenge. In the United States, 63% of manufacturing companies identified I4.0 as necessary for their further development; 65.7% of companies of the Czech Republic started implementing I4.0 because it is important for their future, and German enterprises plan to increase digitization between 24% and 86% in the next five years (Vrchota, 2019). In Turkey, 83.5% of SMEs is aware of the term I4.0, but only 8.7% of them have been implementing it for more than 1 year (Sari, 2019).

According to researchers, the size of the company matters when it comes to implementing I4.0 (Grufman, 2020). A cross-sectional survey in Brazilian manufacturing enterprises also says that the level of I4.0 implementation depends on the size of the enterprise (Vrchota, 2019). Various phases need to be taken to make an enterprise smarter. In the way of digitalization and achievement of a fully implemented I4.0, a well-structured roadmap and planning are needed, especially with SMEs with limited financial and technological resources (Hamzeh, 2018).

There are different models, each one dedicated to different niches or vertical markets. Rauch et al. (2020) have developed a model which contains 4 dimensions: (i) information technology, (ii) production and operations, (iii) automation and (iv) human resource. Grufman (2020) instead, proposed 5 dimensions: (i) smart factory (ii) smart operations (iii) Data-Driven services (iv) strategy and organization and (v) cost. Schumacher (2019) proposed 8 dimensions using 65 maturity items, while Hofmann and Rusch (2017) proposed only two dimensions. Chonsawat (2021) says that processes driven by technology, human skills, and digital support, are also important dimensions.

It could be said that the other models analysed are based on those mentioned above.

Research methodology

This project used a pragmatic approach to address Argentine enterprises needs by means of multiple interviews and questionnaires. The techniques used were: (i) in-depth interviews and (ii) online surveys. Questionnaires’ results were used to calculate a maturity level index. During a first phase, 328 documents were read, 48 of which were selected for a deeply analysis. Said work was carried out as follows: (1) in academic databases (Scopus and ResearchGate) with a search string through the combination of the operator “or” between the keywords, references were collected meeting the following criteria: (a) they were published in conference, articles, magazines, and books between 2015 and 2021; (b) contained at least one of the search terms in the title and / or keywords. (2) duplicates were removed; (3) those which did not have full texts available were discarded; (4) documents that defined I4.0 outside the scope of this research work were excluded; (5) they were classified according to the research questions and (6) the documents collected were analysed and the data of interest were collected to answer the questions of our research work. In the second phase, an I4.0 online questionnaire was prepared. Data collected from 146 respondents was transferred to electronic spreadsheets for its analysis, both in MS Excel™ and Minitab™. After a data cleaning, 100 suitable samples were classified according to: (1) role of the respondent, (2) size of the company, (3) region, (4) type of industry, (5) national or multinational, (6), (7) and (8) were characterization questions of the respondent.

This research project was performed in Argentina since July 2018 to December 2020. It included micro, small, medium, and large companies, both from manufacturing and service industries. The 32 variables were grouped into 5 dimensions. An Alpha Cronbach test was performed for each set of questions. Questionnaire results were compared according to the size of the company and the vertical market. To ensure whether the similarities or differences between said means were statistically acceptable, two sample T-tests and CI were performed. Before applying the T-test, normality tests were done. It was also done a Mann-Whitney to test medians.

Results

Based on the works analysed, also incorporating suggestions from RAMI4.0, and considering that our model had to be applicable to all vertical markets, the assessment of the I4.0 maturity level model proposed in this work was organized in 32 factors grouped in 5 dimensions, as shown in Table 1.

Smart Working & Organization	Information System	Smart Manufacturing
Roadmap Industry 4.0	CRM	Sensoring
Training multi skills	ERP	MES
Innovation iniciatives	PPM	Smart energy
Process Management	PLM	Predictive Maintenance
Agile Management	EQM	Flexible Manufacturing
Collaboration Networks models	EHSM	

Base Technologies	Smart Value Chain
IoT	Materials and parts trazability
CC	Digital Integrations with suppliers
Big Data and Analytics	Digital integration with clients
CPS / Cobots	Product trazability (on clients)
Information Security	Remote monitoring of Products
3D	Machines controlled by Products
VR / AR	Intelligent Products
Simulation / Digital twin	

Table 1: Dimensions and factors

According to this model, the overall average maturity level in Argentinean enterprises is 2.5 (scale from 0, minimum, to 5, maximum). In large enterprises is 2.9 and in small ones 2.2. It is interesting to note the similarity of the results obtained by Blanc (2020) in the northeast region of Argentina., in which he got an average score of 2 over 5. Values obtained from large companies are bigger than the small ones, not only in the 5 dimensions, but in each of the 32 factors (Figure1).

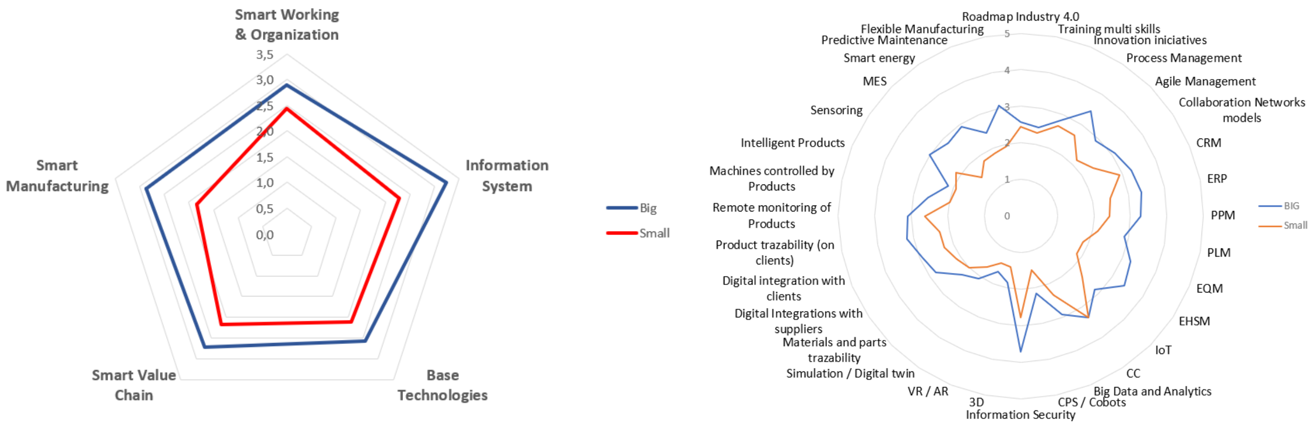
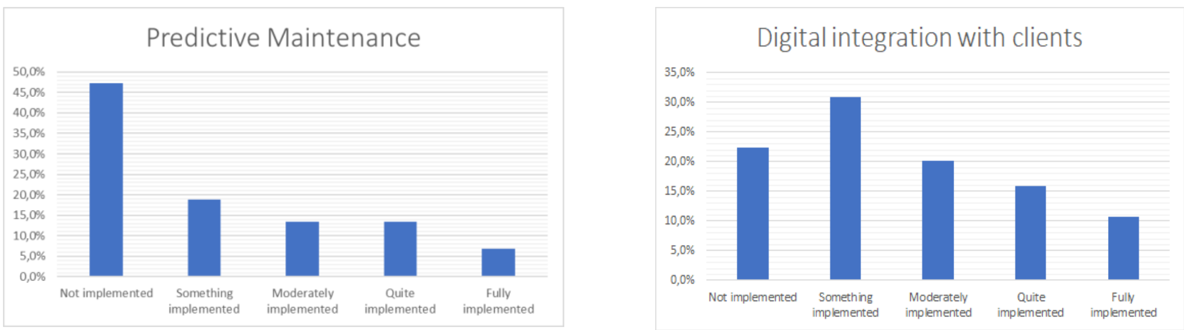


Figure 1: Maturity levels.

Each of the 32 factors has been analysed, e. g. their frequency distribution, means, medians and deviations. a right skew has been found, which means a rather immature level in each of the variables analysed. Two examples are shown in Figure 2.



Predictive maintenance factor

Digital integration with clients factor

Figure 2: Predictive maintenance and digital integration with clients

Results, in the maturity level assessment of I4.0 in Argentina, also says that there is not enough development in transversal competencies nor adequate training, obtaining an average value of 2.4 / 5.0. During in-depth interviews, 8 out of 10 were found to agree that ongoing training is the way to go.

Process management is currently the best developed factor, although it barely reaches a value of 3.1 / 5.0. Agile methodologies are better positioned than expressed in our hypotheses, with a 2.6 / 5.0.

In case of manufacturing SMEs, the five dimensions, ranked by performance, were as follows: (i) Smart Working & Organization, (ii) Information System, (iii) Smart Value Chain, (iv) Base Technologies and (v) Smart Manufacturing. A complete report is available at “Current status and key factors for the evolution of the national industry towards industry 4.0” (Salimbeni, 2021)

Conclusions, limitations and future research

The maturity level assessment of Industry 4.0 in Argentina shows that large enterprises was rated 2.9, while small ones 2.2, in a range from 0 to 5.

In regards to the 5 proposed dimensions, the best performer were Smart Working & Organization and Information Systems, with an average value of 2.6. The worst performer was Smart Manufacturing, with a score of 2.0 over 5.

Contrary to what was hypothesized at the beginning of this study, there is not enough statistical evidence to confirm a verifiable difference between the average rate between manufacturing and service enterprises, such as logistic, retail, energy. On the other hand, it was confirmed our hypothesis about a marked difference in the development of micro and small companies, index 2.2, in comparation to medium and large companies, index 2.9. It can be added that the better performance of large enterprises over small ones, is confirmed in all the five dimensions. The most developed among the 32 factors, were: Cloud, CRM, and management by process.

This work has had two major limitations. First, even though the study was statistically rigorous, results generalization is not recommended. The sample, consisting of 146 companies, have not been statistically proportional according to the different regions in Argentina. In future research projects, it is proposed to improve the segmentation by vertical markets and regions, as well as to increase the size of the sample to carry out a more detailed and precise study.

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Relationship between Maintenance, Lean Philosophy, and Industry 4.0: Systematic Literature Review

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Abstract
The challenge of the survival of companies, combined with competitiveness and technological agility, has emerged new management techniques, in which vision to keep companies in a constantly changing scenario, developing administrative systems efficiently agile and strong enough for the standards established by the new economic formation of society. The present study was carried out through a systematic literature review (SRL) using scientific databases: Google Scholar, B-on and Science Direct, in the period from 2015 to 2021. Based on the result of the research, a a total of 68 articles were analyzed. The analysis shows that the theme of this study is of interest to the scientific community and has increased in recent years as seen. It was also possible to verify that the studies on this theme are the design of a model and its application in a case study. The type of industry that is most involved is the automotive and agricultural industry. Regarding the most used tools among the combination of topics, the following stand out: intentional maintenance, Sensors, Big data, 5S, Total Productive Maintenance (TPM), Value Stream Mapping (VSM), Lean tools / Principles and Industry 4.0 principles / techniques.

Keywords: Maintenance, Maintenance 4.0, Lean, Industry 4.0, Lean Smart Maintenance

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Introduction

Globalization marked the transition from artisanal production methods to mechanized production processes, making the market increasingly competitive, leading to a drastic change in companies, as they seek solutions that increase productivity and reduce costs to face the market. highly competitive today. Thus, efficient maintenance must be achieved to constitute a competitive advantage in relation to competing companies. The demands of the current market oblige those responsible for maintenance to look for new approaches to achieve high levels of effectiveness and efficiency (Mehmeti, Mehmeti and Sejdiu, 2018; Poor, Basl and Ženíšek, 2019).

In this context, the concept of Lean production emerges as an answer, which aims to reduce waste, improve the production process, and decrease production time and cost. Lean, in turn, can be applied in several areas, this being the area of maintenance, where it is intended that the equipment operate without interruption and with a quality production. Some of the tools of the Lean philosophy applied in maintenance management can contribute to improving maintenance activities causing positive impacts on the overall functioning of companies (Mouzani and Bouami, 2019; Cordeiro, 2019).

In turn, the industry is constantly changing consequently, the production processes are increasingly complex and more variable, requiring an evolution in this sector. The new approach is linked to evolving technological advances, oriented towards the digitization of production processes. The fourth industrial revolution or Industry 4.0 began and brought with it enormous social and economic challenges. This concept is an approximation between the physical production processes and the information and communication processes that are provided by technologies that work through integrated systems, sensors, and mobile devices capable of communicating with each other over the internet (Santos, Alberto, Lima and Charrua-Santos, 2018; Zheng, Ardolino, Bacchetti and Perona, 2021). These changes bring with it a new paradigm to force companies to create an operational model to become faster and more agile and adapted to the constantly changing world where competition is increasingly complex and competitive that is why the analysis of these topics it is important to note (Passath and Mertens, 2019).

Methodology

The research method chosen to carry out this study was the systematic literature review (SLR), as it is an explicit, understandable, systematic, and reproducible method, aimed at the identification, evaluation, and synthesis of scientific works (Tranfield, Denyer and Smart, 2003). In previous researches it was verified that the interest for the combination of the themes: Maintenance, Lean and Industry 4.0 has increased in the last years, however the literature shows to be emergent with regard to the interaction of the respective themes, whether in the combination of the three topics, Maintenance, Lean and Industry 4.0 (MLI4.0), as combined between peers: Lean and Industry 4.0 (LI4.0), Lean Maintenance (ML), Maintenance Industry 4.0 (MI4.0). Thus, as a basis for the research, the main research questions of this study are: a) How has interest in these themes evolved? b) What are the industries most involved in this area? c) What are the most used tools when the themes are combined: ML, MI4.0, LI4.0 and MLI4.0? d) What type of study is carried out? In this way, three electronic databases for research were defined: Google Scholar, B-On and Science Direct. The relevant studies were searched in the referred databases using the keywords as shown in Table 1.

Interaction	Keywords
MI 4.0	Maintenance 4.0, Smart Maintenance
ML	Lean Maintenance, Maintenance Lean Techniques
LI4.0	Lean Industry 4.0, Lean 4.0
MLI4.0	Lean Smart Maintenance, Lean Maintenance 4.0

Table 1: Keywords used in the SLR

The inclusion criterion includes works published in journals, conferences with open access, between 2015 and 2021, in the following languages: English, Portuguese and Spanish that are related to the themes in question. Bibliographic reviews, duplicates, studies published outside the scope and determined electronic databases are excluded.

In the initial research, step 0, 1696 articles were identified. Next in step 1, the titles of the articles previously selected are read to verify their importance. In step 2, the titles, abstracts, and keywords were read. Finally, step 3, of the remaining 438 articles, 68 were accepted and included as the main studies for our research (Figure 1). The remaining works were excluded because they did not comply with the inclusion criteria or due to the scope of the research.

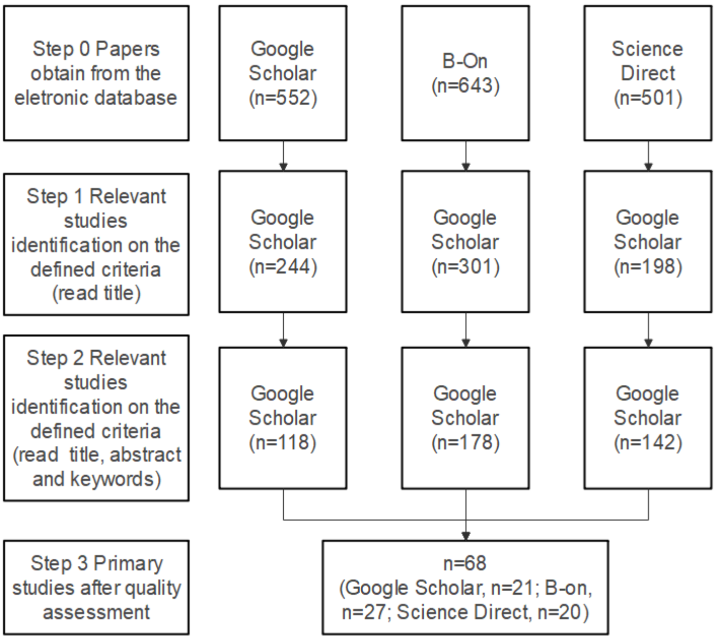

Figure 1: Search strategy diagram (Adapted from Tranfield et al., 2003)

Analysis and discussion of results

In this phase, we present the analysis and results of the SLR. The intention is to elaborate on the extracted data and answer the questions previously formulated. Thus, after selecting the articles, a table was created for each of the combinations referred to with the following information: Author, year, industry, interaction, lean tools, industry 4.0 techniques, model case study and benefits. Table 2 shows as an example an excerpt from one of the tables and refers to the study of the interaction between LI4.0.

Autor	Year	Industry	Interaction	Lean tools	Industry 4.0 techniques	Model	Case study	Benefits
Shahin, M., et. al.	2020	-	LI4.0	Kanban	Cloud Computing Dashboard	X	X	Real-time visualization of the production process, actual quantity produced, hours of work used, number of items with poor quality, number of line stops. Improvement of decision making.
Gaziero, C., Cecconello, I.	2019	Furniture industry	LI4.0	VSM	Simulation		X	Improvement of productive performance and decision making. Increased availability of equipment. Reduction of optimal lead. Elimination of tasks that do not add value.
Phuong, N., Guidat, T.	2018	Textile industry	LI4.0	VSM	RFID		X	Visualization of potential problems in real time, quantity produced, number of stops on the line, among others.
Senkayas, H., Gürsoy, Ö.	2018	Factory industrial rims	LI4.0	OEE	Digitalization MES		X	Improvement of the production process and OEE. Obtaining useful production information

Table 2: Example of the table created for data processing

a) How has interest in these themes evolved? - In general, the results indicate that the interaction between ML, MI4.0, LI4.0 and MLI4.0 has been of interest and attention on the part of the research community, and it can be noted that that 26,7% of the articles are from the year 2020, 19,3% of 2019, 14,8% of 2018 as shown in Figure 2.

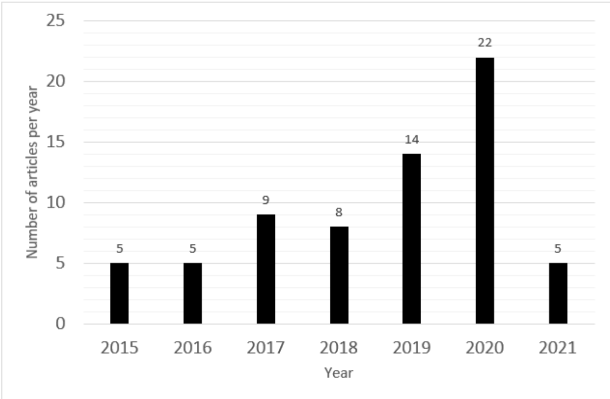

Figure 2: The distribution of publication years

b) Which industries are most involved in this area? - In general, there are a wide variety of industries to implement, either partially or in full, some of these themes simultaneously. After analysis, it was identified that the automotive industry represents 14,7%, aeronautical industry 7,4%, Plastic industry 5,9% and Energy sector 5,9%, with the remainder divided into several other industrial areas.

c) What are the most used tools when the themes are combined: ML, MI4.0, LI4.0 and MLI4.0? - The most used tools are shown in Table 3:

Interaction	Tools used
ML	5S 12,5%, Total Productive Maintenance (TPM) 10,7%, Single minute Exchange of Die (SMED) 8,9%, Value Stream Mapping (VSM) 7,1%, Kaizen 5,4%, Kanban 5,4%.
MI4.0	Predictive Maintenance (PdM) 11,6%, Sensors 10,1%, Big Data 8,7%, Internet of Things (IoT) 8,7%, Cloud Computing 4,3%, Augmented Reality (AR) 4,3%.
LI4.0	Lean tool / principles 10,3%, I4.0 principles / techniques 7,4%, Internet of Things (IoT) 5,9, Cyber Physical System (CPS) 5,9%, Cloud Computing 4,4%
MLI4.0	Lean Smart Maintenance (LSM) 40,0 %. Lean tools 20,0%, Artificial Intelligence (AI) 20,0%, Lean Smart Maintenance Maturity Model (LSM MM) 20,0%.

Table 3: Summary table of the most used tools in the interaction between the concepts

d) What kind of study is carried out?

The type of publications over the years has varied, however in this research, it was found that 55,9% of the articles are in the design of a model with the application of a case study, 30,9% case study and 13,2 % focuses on building models.

Conclusion

This study aimed to identify the relationships between the concepts: Maintenance, Lean Philosophy, and Industry 4.0 through a systematic review of the literature. From the results achieved and the discussions established, the following conclusions can be drawn: When analyzing the documents described between the years 2015 and 2021, a growing interest in the scientific literature focusing on the three topics was evidenced, which demonstrates the importance of these in the scientific context. The most published works are studies related to the design of a model and its application in a case study (45,8%). Regarding the type of industry that is most involved in the application, a study of these concepts is the automotive industry (11,5%), agricultural industry (6,3%) and the food industry (4,2%). The most used tools between Maintenance and industry 4.0 are: Predictive Maintenance (11,6%), Sensors (10,1%), Big Data (8,7%). On the other hand, when applied to the pair, Maintenance and Lean are: 5S (12,5%), TPM (10,7%), SMED (8,9%). When the combination is between Lean and Industry 4.0, they are: Lean Tools / Principles (10,3%), Industry 4.0 Techniques / Principles (7,4%), IoT (5,9%). When the three concepts are applied simultaneously, most of them apply Lean Smart Maintenance (LSM) 40,0%. Lean tools 20,0%, Artificial Intelligence (AI) 20,0%, although the number of articles for analyzing the interaction of the three concepts has been relatively small. Although the review was carried out rigorously, the research has some limitations, such as few keywords, short study interval. For future research, a more comprehensive search is suggested, with a greater number of keywords that can highlight and provide a better analysis in relation to the interaction between the three topics covered in this article.

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Synergies between Sustainability, Lean Philosophy, and Industry 4.0: Systematic Review of the Literature

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Abstract
To preserve competitiveness in their markets, companies are constantly looking for tools to help them manage their activities. This study addresses the scenario of the literature on Sustainability, Lean and Industry 4.0 through a systematic review of the literature (SLR) extracted from three different scientific databases: B-on, Google Scholar and Science Direct, in the period from 2015 to 2021. The tendency of the literature is in constant evolution off time. The contribution of this work is the opportunity to suggest a knowledge repository. The results of this SRL are intended to help researchers and professionals to obtain a better perception of the current state of application of the concepts simultaneously or in pairs.

Keywords: Lean, Green, Industry 4.0, Lean Green, Sustainability, Lean 4.0

Introduction
The strong increase in the competitiveness of markets at a global level has brought with it the need in organizations to improve their production processes to satisfy the needs of customers (Varela, Araújo, Ávila, Castro and Putnik, 2019). In this scenario, Lean Philosophy has led to the improvement of processes in search of achieving greater productivity in industrial companies. With the new productive paradigms, the creation of a large amount of pollution by some companies arises, so there is a need to include the principles and objectives of sustainability. Environmental management consists of the adoption of organizational practices that encourage the reduction of the environmental impact caused by industrial operations, these two Green and Lean approaches both have the same objective since they seek the elimination of waste contributing to the reduction of the environmental impact of the production systems (Sartal, Bellas, Mejías, and García-Collado, 2020; Mouzani and Bouami, 2019; Antosz and Stadnicka, 2017).

The industry is undergoing a transformation driven by the development and use of enabling technologies, more and more there is talk of a new industrial revolution, the fourth or Industry 4.0. This new paradigm is characterized by the incorporation of new resources, which combines technological transformations, mainly enabling the connectivity and interaction of equipment and people, thus allowing the industry to remain competitive in the market based on intelligent and high-tech production with less costs and offering more innovative products and services (Oláh, Aburumman, Popp, Khan, Haddad and Kitukutha, 2020).

The radical change that the industry needs cannot be achieved with traditional processes, so the Lean, Green philosophy, and emerging technologies, I4.0 can be responses to this change (Lima, Miranda, Dusek and Avelar, 2019; Rafique, Qureshi, Malkana, Haider and Atif, 2020).

Methodology

The article proposes a systematic literature review (SLR) to analyze the relationship between Sustainability, Lean Philosophy, and Industry 4.0, as it is an explicit, understandable, systematic, and reproducible method, aimed at the identification, evaluation, and synthesis of scientific works (Tranfield, D., Denyer and D., Smart, P., 2003). In previous research, it has been found that interest in the combination of themes has increased: Sustainability, Lean Philosophy and Industry 4.0 in recent years, despite this increase, the literature is emerging with regard to the interaction of the respective themes, whether in combination of the three topics, Sustainability, Lean and Industry 4.0 (SLI4.0), as combined between peers: Sustainability and Lean (SL), Sustainability and Industry 4.0 (SI4.0), Lean and Industry 4.0 (LI4.0).

In support of research, the main research questions of this study are: RQ1: How has interest in these themes evolved? RQ2: What are the industries most involved in this area? RQ3: What are the most used tools when the themes are combined: Sustainability and Industry 4.0 (SI4.0), Sustainability and Lean (SL), Lean and Industry 4.0 (LI4.0) and Sustainability, Lean and Industry 4.0 (SLI4. 0)? RQ4: What type of study is carried out?

The electronic database platforms identified to obtain the information are: Google Scholar, Science Direct and B-on. The relevant studies were searched in the databases using the following keywords as shown in Table 1.

Interaction	Keywords
SI4.0	Green 4.0, Sustainable Industry 4.0
SL	Lean Green, Lean Sustainable
LI4.0	Lean Industry 4.0, Lean 4.0
SLI4.0	Lean Green 4.0, Smart Lean Green

Table 1: Keywords used in the SLR

Thus, the inclusion criteria were works published in journals, conferences with open access, between 2015 and 2021, in the following languages: English, Portuguese and Spanish, which are related to the review theme. Duplicates, bibliographic reviews, studies published outside the identified electronic database, blocked access and publications that are outside the research topic are excluded.

In the initial research, step 0, 1811 articles were identified. In step 1, the titles of the articles selected in the previous step are read to verify their importance. Then, in step 2, the titles, abstracts, and keywords were read. Finally, in step 3, of the remaining 318 evaluated articles, 96 were accepted and included as the main studies for our research (Figure 1). The remaining works were excluded because they did not comply with the inclusion criteria or the scope of the research.

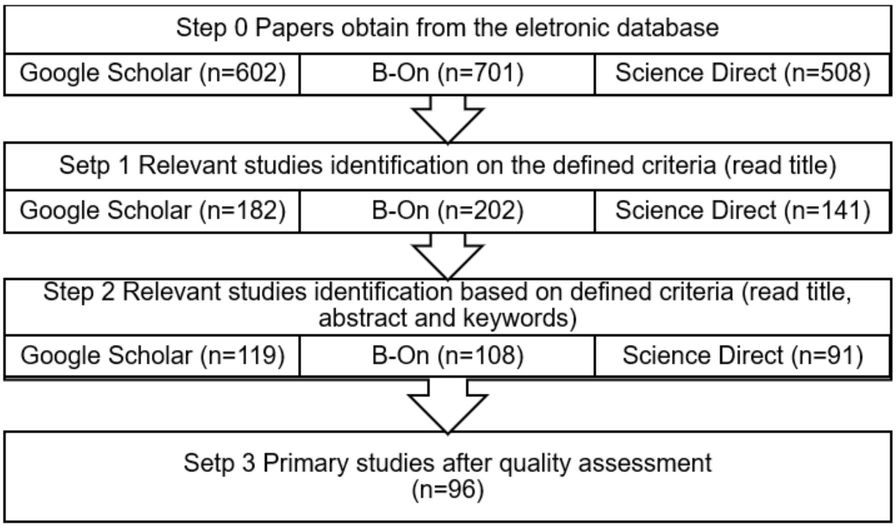

Figure 1: Search strategy diagram (adapted from Tranfield et al., 2003)

Analysis and discussion of results

In this phase, the analysis, and the results of the SLR are presented, with the main objective being to answer the questions previously formulated based on the study of the selected and properly treated articles. After selecting the articles that best fit the study, a table was created to assist in the treatment of the data. The table shows the following information: Author, year, industry, interaction, lean tools, industry 4.0 techniques, model case study and benefits. Table 2 shows as an example an excerpt from one of the tables and refers to the study of the interaction between LI4.0.

Autor	Year	Industry	Interaction	Lean tools	Industry 4.0 techniques	Model	Case study	Benefits
Spenhoff, P., et. al.	2021	Transportation and logistics industry	LI4.0	Heijuka Every Product Every Cycle 4.0	Cyber Physical Systems	X	X	Operate the production system as efficiently and flexibly as possible.
Mayr, A., et. al.	2018	Electrical / electronics industry	LI4.0	TPM	Cloud computing, Condition monitoring, Sensors, Graphical usar interface	X	X	It aims at perfection in all daily activities. Integration of employees. Equipment monitoring.
Wagner, T., et. al.	2017	Automotive industry	LI4.0	Just-in-Time	Cyber Physical Systems	X	X	Improvement in the choice of Lean methodologies and I4.0 technologies.
Ma, J., et. al.	2017	Automotive industry	LI4.0	Jidoka	Cyber Physical Systems, Internet, Internet of Things, Cloud Computing, Function Block	X	X	Considerable improvement of the productive performance at a global level. More decentralized controllers. Cost reduction.

Table 2: Example of the table created for data processing

RQ1: How has interest in these themes evolved?

In view of the data collected between 2015 and 2021, and as shown in Figure 2, it can be observed that there is great interest in realizing the benefits that the interaction of Lean Philosophy, Sustainability, and Industry 4.0. Thus, it should be noted that 26,7% of articles are from 2020, 19,3% from 2019, 14,8% from 2018.

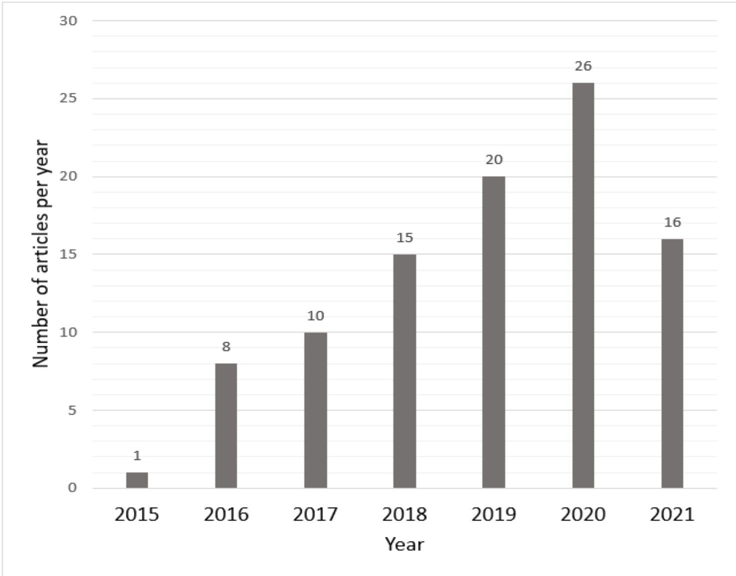

Figure 2: The distribution of publication years

RQ2: Which industries are most involved in this area?

It appears that a wide variety of industrial sectors and other types of companies have implemented all or part of some of these concepts simultaneously. After analysis, it was identified that the automotive industry represents 11,5%, agricultural industry 6,3%, Food industry 4,2% and Infrastructure / Construction 4,2%, with the remainder divided into several other industrial areas.

RQ3: What are the most used tools when the themes are combined: SL, SI4.0, LI4.0 and SLI4.0?

The most used tools are shown in Table 3:

Interaction	Tools
SL	Value Stream Mapping (VSM) 13,5%, Mathematical Model 7,7%, Life Cycle Assessment (LCA), Gemba 3,8%, Kaizen 3,8%.
SI4.0	Robot and / or Mechanical arms 7,5%, Internet of Things (IoT) 6,5%, Sensors 4,3%, Fuzzy Analytical Hierarchy Process (Fuzzy AHP) 4,3%, Activity-Based Costing Method (ABC Method) 3,2%.
LI4.0	Lean tool / principles 10,3%, I4.0 principles 7 techniques 7,4%, Internet of Things (IoT) 5,9, Cyber Physical System (CPS) 5,9%, Cloud Computing 4,4%
SLI4.0	Cyber Physical System (CPS) 5,0%, Big Data 5,0%, Smart Product Control 3,3%, Simulation 3,3%, Kaizen 3,3%.

Table 3: Summary table of the most used tools in the interaction between the concepts

RQ4: What kind of study is carried out?

The type of study most performed is the design of a model with the respective application in a case study with 45,8%. The second most performed type of study is the design of a model (28,1%) and lastly a case study (26,0%). Although it appears that over the years there is a wide variety of types of published studies.

Conclusion

This study aimed to identify the relationships and synergies between the concepts: Lean Philosophy, Sustainability, and Industry 4.0 through a systematic review of the literature. From the results achieved and the discussions established, the following conclusions can be drawn: By analyzing the articles described between the years 2015 and 2021, there is a growing interest in targeted kinetic literature, whether in the combination of the three topics, demonstrating the importance they have in the context scientific. The publications are mostly studies with the design of a model and its application in an industry (45,8%). The type of industry that has applied the most, either partially or in full, these concepts is the automotive industry (11,5%) and Agricultural industry (6,3%). The most used tools both when combined SI4.0 are: Robot, Mechanical arms (7,5%), IoT (6,5%). Among the SL are: VSM (13,5%), Mathematical Model (7,7%). When combined LI4.0 are: Lean Tools / Principles (10,3%,) I4.0 Technologies / Principles (7,4%) and lastly the most used tools among SLI4.0 are CPS (5,0%), Big Date (5,0%).

In general, companies have been concerned with taking measures both to improve their production processes and to improve their environmental performance. However, there is still much to explore in this new environment that still needs better monitoring to obtain the maximum benefits from the interaction of these concepts.

Although the study was carried out rigorously, it has some limitations, such as the few keywords used for each of the possible combinations studied and the time interval stipulated for analysis is small.

For future research, it is necessary to expand this research with a greater number of keywords as well as to cover a longer time interval to allow a better analysis and perception of the advantages and limitations of the integration of these three concepts simultaneously.

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28th of May 2021	
8:30 am to 9:00 am	Conference Start – Official Welcome

Session 1	
9:00 am to 9:15 am	*"Trends and Proposals for European Industrial Engineering"* Jabier Retegi *(presenter)*, Mondragon University, Spain Juan Ignacio Igartua, Mondragon University, Spain
9:15 am to 9:30 am	*"Edge computing in IEM education"* Stevan Stankovski *(presenter)*, University of Novi Sad, Serbia Gordana Ostojić, University of Novi Sad, Serbia Milovan Lazarević, University of Novi Sad, Serbia
9:30 am to 9:45 am	*"Teaching and learning transversal competences in management engineering"* Raffaella Manzini, University Carlo Cattaneo, Italy
9:45 am to 10:00 am	*"Customer Success Management: Success Factors"* Sven Seidenstricker *(presenter)*, Baden-Wuerttemberg Cooperative State University Mosbach, Germany Sebastian Melzig, Accenture, Germany Heiko Fischer, Baden-Wuerttemberg Cooperative State University Mosbach, Germany Vinzenz Krause, Catholic University of Eichstätt-Ingolstadt, Germany
10:00 am to 10:15 am	*"Developing an Industry 4.0 mobile training unit for industrial engineering education"* Emmanuel Francalanza, University of Malta, Malta
10:15 am to 10:45 am	**Break**

Session 2	
10:45 am to 11:00 am	*"Digitalization of Practical Laboratory Teaching in Learning Factories in the Age of Covid-19"* Erwin Rauch *(presenter)*, Free University of Bolzano, Italy Luca Gualtieri, Free University of Bolzano, Italy Benedikt G. Mark, Free University of Bolzano, Italy Matteo De Marchi, Free University of Bolzano, Italy Dominik T. Matt, Free University of Bolzano, Italy
11:00 am to 11:15 am	*"Resilience in Manufacturing During COVID-19 Through Digital Worker Assistance Systems"* Erwin Rauch *(presenter)*, Free University of Bolzano, Italy Tanel Aruväli, Tallinn University of Technology, Estonia
11:15 am to 11:30 am	*"Assessment of Industry 4.0 maturity level"* Sergio Salimbeni, Universidad del Salvador, Argentina
11:30 am to 11:45 am	*"Relationship between Maintenance, Lean Philosophy, and Industry 4.0: Systematic literature review"* David S. F. T. Mendes *(presenter)*, University of Beira Interior, Portugal Helena V. G. Navas, Universidade NOVA de Lisboa, Portugal Fernando M. B. Charrua-Santos, University of Beira Interior, Portugal
11:45 am to 12:00 pm	*"Synergies between Sustainability, Lean Philosophy, and Industry 4.0: Systematic review of the literature"* Elena E. D. Terradillos *(presenter)*, University of Beira Interior, Portugal Helena V. G. Navas, Universidade NOVA de Lisboa, Portugal Fernando M. B. Charrua-Santos, University of Beira Interior, Portugal

12:00 pm to 12:30 pm	**Closing**

Austrian Association of Industrial Engineering and Management (WING)

*„**Industrial engineers** are **engineers educated and trained in economic sciences** with an **academic degree** who **integrate their technical and economic expertise** in their professional activities."*

► WING Facts

1964 Establishment of the **WING**

1984 WINGnet - the WING student group was founded

2018 WING has approx. 1.400 members

► WING Purpose

WING is a **non-political** association with the purpose of **perceiving** and **promoting** the **scientific**, **social** and **cultural** interests of its members.

► Implementation WING Purpose and Activities

WING actively supports its members in **scientific** and **professional** matters e. g. by providing insights on **professional issues** as well as on **questions** about **educational matters**. **WING** promotes the **exchange of ideas** and the **social integration** of the members through **various activities**. There are **many activities** including, but not limited to

- maintaining network and/or contact among the members in e.g. **WING** regional districts,
- transfer of knowledge,
- supporting universities in design of the **WING** curriculum,
- targeted career development measures,
- representation of interests of the members and nourishing association´s image
- strengthening the link between economy and science.

► WING Cooperations

In 2010, the **Austrian Association of Industrial Engineering and Management**, the **German Association of Industrial Engineers** and the **Swiss Association of Business and Industrial Engineers** signed the following **"three-country declaration"**:

"We want to ensure high quality and the distinctive profile of the industrial engineers and managers in order to promote their high labor market value by creating a common and unique educational and training brand."

► WING International

WING and **WINGnet** are members of the **international community** of European Professors of Industrial Engineering and Management (www.**EPIEM**.org) and European Students of Industrial Engineering and Management (www.**ESTIEM**.org).

► WING Contact

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