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HIGH VALUE ADDED, RESILIENT AND SUSTAINABLE INDUSTRY

ABOUT US

INESC TEC SCIENCE & SOCIETY
PUBLISHED BY INESC TEC
INSTITUTE FOR SYSTEMS AND COMPUTER ENGINEERING,
TECHNOLOGY AND SCIENCE
Campus da FEUP
Rua Dr Roberto Frias
4200-465 Porto
Portugal
+351 222094000
info@inesctec.pt
www.inesctec.pt

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science-society.inesctec.pt

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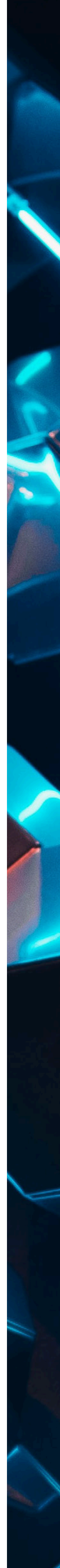
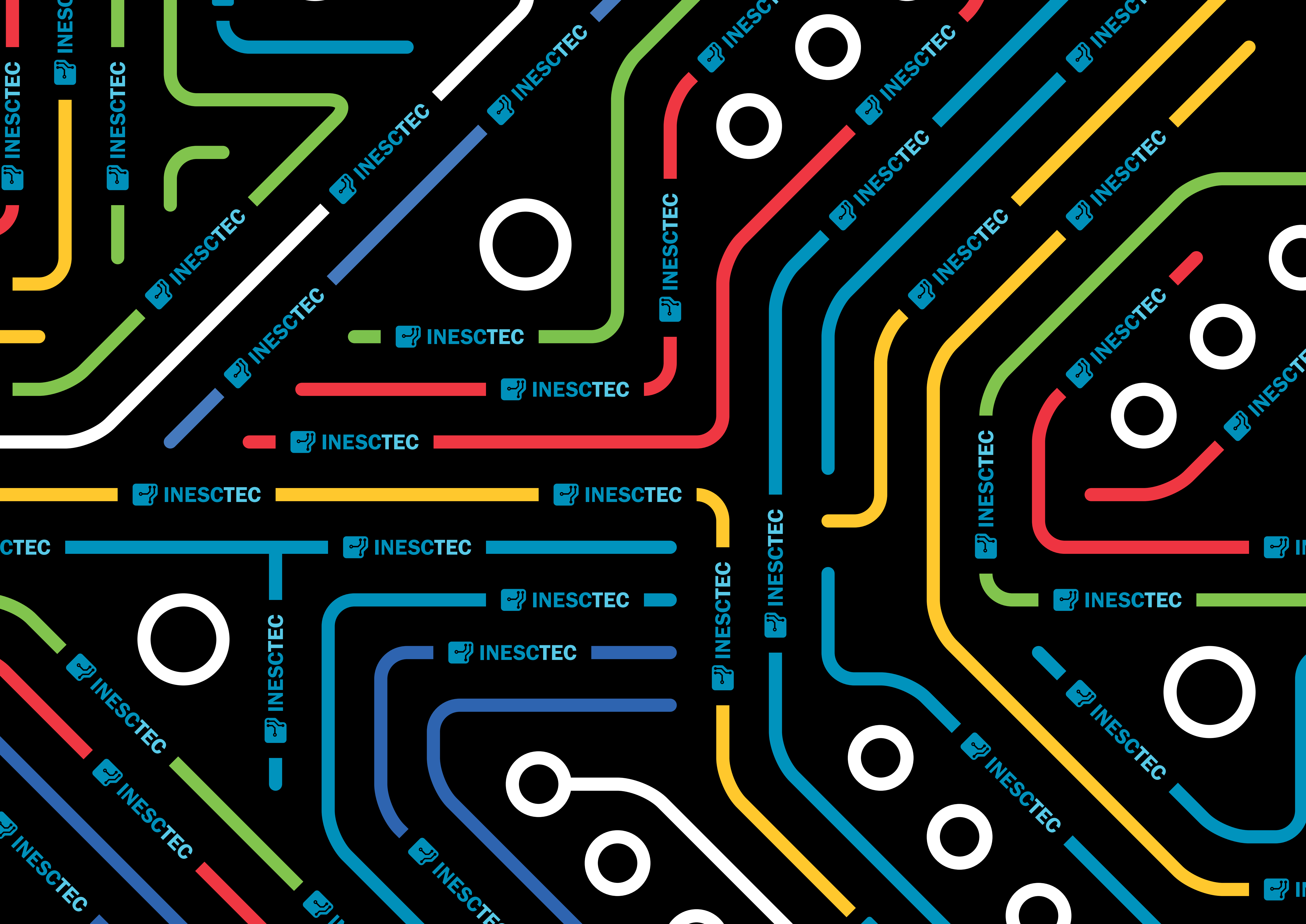
OPENING

This is the 2nd issue of *"INESC TEC Science & Society"* magazine, created with the objective of spreading science to society and contributing to the debate on emerging issues. It is addressed to the general public in the hope that it may be of interest to the managers, politicians and technicians of the systems to which these topics apply.
The magazine is distributed online every six months and addresses a special topic in each issue, although, not excluding other articles of opportunity. The autumn issue will always address the theme of the Autumn Forum that INESC TEC has held since 2015 – with the exception of last year's edition of the event, which unfortunately had to be postponed due to the evolution of the pandemic and created a gap because the magazine was already prepared and distributed on the scheduled date.
It was with great satisfaction that the first issue of this magazine, which was dedicated to technologies in health, was well received.
The 2nd issue addresses the topic of the industry. This time, we decided to extend the invitations for the publication of articles to external personalities, who promote an extended discussion on the theme, giving greater emphasis to public policies.
This is the approach we intend to maintain in the future, hoping to continue to attain the interest of our readers.
In addition to the articles dedicated to the special theme, 2 articles on current themes close this issue. The first, entitled "*Post-normal science*", discusses the role of science in the wake of major crises such as the COVID-19 pandemic; the second presents a set of public policies recommendations to be adopted in the development of future supply chains.
It only remains for me to thank all of those who contributed, highlighting the work carried out by the Editorial Council and the INESC TEC Communication Service, and, in particular, to the team of 3 editors of the Special Theme and to all authors.

We sincerely hope that you like the result.

ARTUR PIMENTA ALVES [1,2,3]
[1] SERIES COORDINATOR
[2] EMERITUS PROFESSOR OF FEUP
[3] ASSOCIATE DIRECTOR AT INESC TEC
artur.p.alves@inesctec.pt

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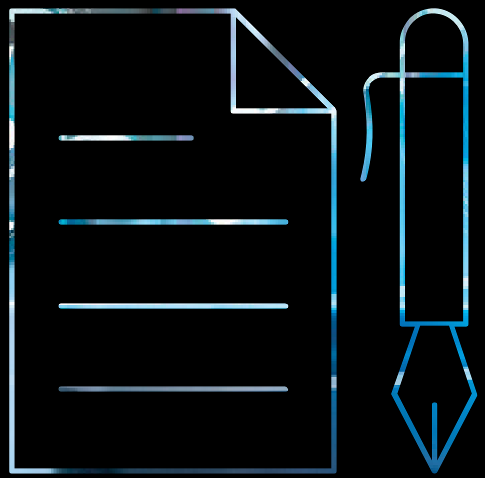

EDITORIAL

Let's Transform the Industry!

It is widely acknowledged that industry, namely the manufacturing industry, is crucial to Europe, as it provides direct and indirect employment to tens of millions of people, while generating, in general, high added value in produced goods, obtaining a large share of investment in research, development and innovation, and originating more than 80% of EU exports[1] .
Since 2000, Europe has experienced a significant de-industrialisation, leading to the reduction of the manufacturing industry's contribution to European GDP - from 18.5% in 2000 to 15% in 2012, as well as the loss of 3.8 million jobs between 2008 and 2012 in this sector[2].
However, in recent years, there has been a reversal of the decline in the EU manufacturing industry, with significant growth rates in terms of the industry's share of total added value (up 6% since 2009); employment (more than 1.5 million new net jobs since 2013) and labour productivity (growth of 2.7% per year on average since 2009)[2] (these statistics refer to the end of 2017).
It is vital to maintain the recovery of the manufacturing industry in Europe. The April 2018 report by the Independent High Level Group on Industrial Technologies, "*Re - Finding Industry Defining Innovation*", clearly states that the European economy will lose competitiveness and will not generate new jobs without a solid and modern industrial base, supported by new knowledge and technologies, and the creation of start-ups and new SMEs,

according to a new approach to public innovation policy. In this sense, the European economy ought to be mission-oriented (public policies must be established around missions that fully embrace the key enabling technologies, or KETs) and cover the entire value creation chain, from fundamental research to applied research, leading to product development and business creation.
The aforementioned report also highlights the need for Europe to pursue technological leadership in industry, mainly due to its net positive impact on the labour market. In this context, the same report states that European industry faces several challenges.
The first challenge relates to the speed of dissemination of already developed and emerging technologies, either seeking to increase the number of new companies entering the market and helping them grow, or contributing to increase productivity in established companies that face obstacles in the implementation of new technologies.
The second challenge is the result of increased global competitiveness, with the EU expected to promote the competitive development of strategic value chains, which are expected to generate most future jobs in manufacturing.
The third challenge is a consequence of the current global race for talent, because of the structural change in the labour market and the nature of labour (largely due to the ongoing digital transformation). This forces the EU to invest heavily in top-level education and skills acquisition among the European workforce, in order to increase employability and competitiveness[3].
In order to address the challenges mentioned above, both the EU and its Member Countries have been defining new public policies, focusing on the promotion of reindustrialisation. As an example of public policies at EU level, it is important to mention that the European Union Framework Program for Research and Innovation 2021 - 2027 (Horizon Europe) prioritises Industry, namely through its Pillar II, "Global Challenges and European Industrial Competitiveness", with a dedicated cluster (Digital, Industry and Space) and three other quite relevant clusters (Climate, Energy and Mobility; Food, Bio-economy, Natural Resources; Agriculture and Environment).
In Portugal, the questions associated with the manufacturing industry take on greater importance than in the rest of the EU, given the profound de-industrialisation experienced in the country as globalisation progressed, and the fact that the country is less prepared to carry out a recovery. This is a result of insufficient qualification of human resources, low added value of the majority of its production and scarce investment made (particularly in the field of research and innovation), all of them negatively affecting the value of productivity.
Therefore, it is crucial to restore the country's level of industrialisation to values similar to, at least, the average of the EU countries, investing in a high added value, resilient and sustainable industry, in line with public policies that have been developed by the EU.
Portugal has been adopting public policies focusing on the transformation of our industrial fabric, towards the targets mentioned previously, such as the following: Portugal 2030 Strategy; Recovery and Resilience Plan; Economic and Social Stabilization Program; Industry 4.0 Initiative; National Strategy for the Digitization of the Economy; Action Plan for Portugal Digital Transition.
Since its establishment, INESC TEC perceives the manufacturing industry as one of the main areas of research, development and innovation activities, carrying out hundreds of R&D and technological transfer projects, the vast majority with key national and international partners, either institutional or corporate. Several of these projects resulted in important contributions to the pursuit of public policies aimed at the industry's progress. This issue of Science & Society Magazine presents a set of articles dedicated to INESC TEC's expertise in this field, in order to demonstrate how it can contribute to the implementation of public policies already defined, or to the design of new ones.
The first is an opinion article stating that the connection between public policies and business strategies in the fields of Research, Innovation and Training will take on a critical importance for the Portuguese and European industry,

which today faces new and disruptive challenges.
The pressing need for Portuguese industry to evolve in the value chain is addressed in an article about the development and industrialisation of products in high added value industries. The article stresses the importance of companies mastering the development of new and innovative products, giving as an example the recognised progress of the Portuguese mould industry.
The following three articles address fundamental concepts associated with the theme of this magazine: a company's Maturity (within the scope of its Digital Transformation); Circular Economy; Servitization.
The first addresses the maturity assessment by a company; that is, knowing and understanding its starting point, in the different dimensions of the organisation: resources, processes, systems and technologies, organisation and strategy, culture and people, products and services. The second article presents the concept of circular economy, the basic principles and implications for manufacturing systems and research, advocating its adoption as a new paradigm. The third article presents servitization as a group of services and products, allowing a manufacturing company to differentiate its offer, reinforcing the relationship with the customers, and creating new sources of revenue, more stable and resistant to economic cycles.
The ensuing five articles present a set of technologies that are worth getting to know, particularly by those owning industrial companies, seeking to keep track of the authentic revolution underway. The first article characterises collaborative robotics, depicted as the key technology to enable the harmonious interaction between humans and machines - considered one of the pillars of Industry 4.0. It is followed by an approach to improve the quality of decision-making, resorting to data analysis and machine learning in the development of more appropriate analytical models. Another article deals with immersive technologies that help people improve their ability to act in industrial environments, in a more effective way and with less cognitive overload, thus foreseeing the emergence of augmented humans, integrating themselves in industrial systems, smarter and more autonomous. Another article characterises and exemplifies the IoT (Internet of Things) platforms, considering the development of solutions around smart manufacturing, predictive maintenance and optimisation of manufacturing systems, among others. This set of articles ends with the reasoning behind the need to develop smart manufacturing systems and, consequently, the evolution until the Intelligent Enterprise, i.e., companies that apply advanced technologies and better practices in agile and integrated business processes, becoming more resilient, profitable and sustainable.
The continuous qualification of human resources is a key prerequisite for implementing and monitoring the deep transformation experienced by industrial companies. The article on the Learning Factory presents the programmes and infrastructures that INESC TEC provides, which allow experiencing and learning in an almost real environment – truly, the principle that facilitates understanding and action in the context of the factories of the future.
Finally, the magazine presents a brief "history" of the evolution of the industry in Portugal, highlighting the main difficulties that led to some setback, in relation to the main partners in Portugal, also ending with a message of hope regarding future developments.
In addition to the relevant contribution in the past, well exemplified above, INESC TEC – through the quality of resources, the vast experience in the sector, the results already achieved and the focus on social responsibility - remains very committed to reinforcing its role in the country. This will be possible through an increasingly more active participation in the ongoing transformation of our industry, either influencing new public policies that support and accelerate this transformation, or contributing to their adoption in the field.

[1] MANUFUTURE Vision 2030, http://www.manufuture.org/strategic-research-agenda/vision-2030/

[2] Report *"Re – Finding Industry Defining Innovation" of the Independent High Level Group on Industrial Technologies*, https://op.europa.eu/pt/publication-detail/-/publication/28e1c485-476a-11e8-be1d-01aa75ed71a1

[3] World Manufacturing Forum 2019 Report – Skills for the Future of Manufacturing, https://worldmanufacturing.org/report/report-2019/

JOSÉ CARLOS MARQUES DOS SANTOS [1,2]
AMÉRICO AZEVEDO [1,2]
ANA CRISTINA BARROS [1]
[1] INESC TEC
[2] FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
jose.marques.santos@inesctec.pt
americo.azevedo@inesctec.pt
ana.c.barros@inesctec.pt

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INESC TEC ACTIVITY IN INDUSTRY

KNOWLEDGE AREAS

CYBER-PHYSICAL SYSTEMS	COMPUTER VISION	INDUSTRIAL CONTROL SYSTEMS & AUTOMATION	INTEROPERABILITY AND DIGITAL PLATFORMS
ARTIFICAL INTELLIGENCE	INDUSTRIAL ROBOTICS	SIMULATION & DIGITAL TWIN	DECISION SUPPORT SYSTEMS
VIRTUAL & AUGMENTED REALITY	INDUSTRIAL INTERNET OF THINGS (IIoT)	CYBER SECURITY	OPERATIONS MANAGEMENT
INNOVATION MANAGEMENT	SUPPLY CHAIN MANAGEMENT		

STATISTICS (2016-2020)

+ 240 PUBLICATIONS

2 PATENTS GRANTED

+ 190 PROJECTS WITH INDUSTRIAL CUSTOMERS

10 SOFTWARE REGISTRATION

+ 75 OF PRIVATE PARTNERS AND PUBLIC FUNDING ENTITIES

30M€ OF INCOME

APPLICATION AREAS

AUTOMOTIVE	FOREST & WOOD	MOULD	RETAIL
TEXTILE	METAL & MACHINE	AEROSPACE	FOOD & BEVERAGE
SHOE	OIL	ADVANCED PRODUCTION SYTEMS	CONSTRUCTION

INFRASTRUCTURES

+ 300 RESEARCHERS

8 RESEARCH CENTERS

IILAB INDUSTRY & INNOVATION LAB

MASSIVE LABORATORY

LET-in TECHNOLOGICAL ENTERPRISE LABORATORY

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SPECIAL THEME

HIGH VALUE ADDED, RESILIENT AND SUSTAINABLE INDUSTRY

PUBLIC POLICIES FOR INDUSTRY

The economic development policy must be understood as consistent action at different layers enabling or influencing the maximisation of the economic and social trajectory of a given community, considering its existing heritage of values, institutions, knowledge and individual initiative.

CARLOS COSTA [1]
JOSÉ CARLOS CALDEIRA [2,3]
[1] EX- VICE CHAIRMAN DO HIGH LEVEL GROUP MANUFUTURE
[2] INESC TEC
[3] MANUFUTURE
csc1949@me.com
jose.caldeira@inesctec.pt

The economic development is the result of the human initiative towards the production of goods and services, in order to meet the underlying demand, or the outcome of the production initiative itself. Seemingly, it all comes down to a decision by a social agent and the mobilisation of human, financial and physical resources that enable production. In fact, it is a much more complex process, subject to different layers of decision-making or causality, the understanding of which is paramount to grasp the differences in the distribution of economic activity within a country's territory – the so-called regional asymmetries –, as well as the different economic development of countries, their paths and future potential. This process is neither deterministic nor fatalistic, as there are no predetermined tracks; however, it is crucial to analyse its depth and inertia, in order to enable virtuous processes of economic development and improvement of social well-being.

Therefore, and firstly, it is necessary to place the individual initiative towards the production of goods and services within the social and institutional frameworks, which encompass the values and social achievement principles that lead individual action. A value system that rewards merit and initiative, and makes each individual responsible for his or her social position, tends to favour entrepreneurship and risk tolerance. Likewise, an institutional framework that favours interpersonal and intergenerational trust tends to strengthen cooperation mechanisms inherent to the production process, and crucial to optimise the use of resources, namely savings and labour.

Secondly, the individual initiative relies on the mobilisation of specific and general knowledge provided by society, through the individual socialisation process, educational and professional training and the processes of dissemination and acquisition of tacit knowledge available in the different social and professional groups.

This means that economic development policy must be understood as consistent action at different layers enabling or influencing the maximisation of the economic and social trajectory of a given community, considering its existing heritage of values, institutions, knowledge and individual initiative. Thus, a development policy requires:

- **a deep knowledge of anthropological, social, and institutional aspects, an assessment of the levels of education and formal and tacit knowledge, which led a given community to the point where it stands at the moment of political decision;**

- **a plan to change this combination of circumstances, acknowledging the different degrees of inertia - from the deepest, or structural, to the most circumstantial - and different response times. The plan ought to be realistic, i.e., feasible in terms of time and mechanisms necessary to implement the required changes;**

- **a consistent framework of incentives capable of inducing individual behaviours and initiatives, the elements that will ensure the adoption of said changes by the target community.**

Hence, and considering the fact that development trajectories rely on the connection between overlapping levels of key-elements of economic and social dynamics, the social, institutional and economic policy must define, after careful analysis:

- **transformation objectives that consider inertia, hurdles and response times of each of said levels;**

- **the supply of public goods (necessary to the desired transformation). – By nature, public goods must be provided by the community.**

Some of the critical areas of the economic and social dynamics are associated with:

- the nature, intensity and dynamics of the national or regional innovation system, i.e., the coordination between education, production and dissemination of new knowledge and professional training;

- the ability to coordinate the production and innovation systems, with regard to understanding the problems associated with the production of goods and services (like meeting or addressing new market or societal demand), as well as the production system's capability to absorb public goods provided by the innovation system.

The nature, quality and timing of the provision of public goods generated via an innovation system is one of the pillars of the process of economic innovation, and the core of a modern industrial policy. This means not to resist changes, defend incumbent agents or pre-select winners. It is not a matter of preserving what already exists and safeguarding crystallised interests. On the contrary, it means addressing the challenges of technological or market changes, by adjusting existing structures, in a decentralised process of absorbing the public goods available. The success of this process relies on understanding and focusing on the production structures, as well as on the education, technological research and development, and.
The evolution of the national productive sector, particularly of the industrial sectors in the Norte and Centro regions of Portugal, is a good example of the importance of the supply of public goods, adapted to the development stage of the business units::

- the creation, as of the 1980s, of a network of Technological Infrastructures that encompassed the Institutes for New Technologies - INT (with INESC TEC as one of the beneficiaries) and the Technological Centres (sectorial entities). The latter were instrumental in supporting the modernisation and increasing the competitiveness of the respective sectors, particularly the SMEs, in domains ranging from quality or certification, to Research and Innovation. Complementary, the INT helped bring scientific knowledge to companies, by developing, adapting, integrating and disseminating it, directly or in close collaboration with the Technological Centres, through processes of valorisation and transfer of knowledge and highly qualified human resources. The most comprehensive and publicised case is the transformation of the Footwear sector, in which the Portuguese Footwear Technological Centre and INESC TEC played a very relevant role. However, it is also important to highlight the work developed by INEGI, ISQ and IPN, or the Technological Centres for Metalworking (CATIM), Textile and Clothing (CITEVE) and Mould-making (CENTIMFE) industries.

- in 2008, the adoption of the Clusters policy led to several initiatives in sectors considered strategic for the national economy. It became possible to develop and implement comprehensive and integrated strategies and action plans, thus consolidating the cooperation networks, coordinating different investment sources, and expanding value chains, namely through intersectoral cooperation. A good example of the success of such approaches is PRODUTECH – Production Technologies Cluster, which managed to bring together, around a common development agenda, different subsectors of the cluster and the main sectors of the Portuguese manufacturing industry.

- this response of the national industry enabled a greater and more qualified participation in the European programmes and initiatives in the manufacturing area. Some examples: Portugal's key role in the MANUFUTURE Technology Platform, in EFFRA - European Factories of the Future Research Association, and in EIT MANUFACTURING (KIC). , The share of approximately 4% attained by national entities (including companies, many of which SMEs) in the European funding programme associated to the PPP Factories of the Future, thus surpassing the national average of approximately 1.6% (source: ANI, 2020).

This blend of knowledge, technologies and qualified human resources (the result of policies and public and private investment, at national and European level), combined with a diversified and dynamic interface system (covering the innovation cycle), and a system of investment incentives (financial and fiscal), contributed to the notable 2011 reaction of industrial companies. The reaction overcome both the contraction of domestic demand and the effects of the crisis on the markets. , together with a successful approach to global markets and new competitors.
In this sense, one must consider these factors when analysing:

- the increase in exports in terms of GDP, from 30.1% in 2010 to 43.5% in 2019 (15.4 percentage points increase);

- the rise of Portugal in the European Innovation Scoreboard, reaching "Strong Innovator" level.

The need to promote the coordination between public policies and business strategies concerning research, innovation and training will play a key role in the Portuguese and European industry – nowadays facing new and disruptive challenges, namely those highlighted in the MANUFUTURE Vision 2030 document[1]. The response to this new framework will be even more effective and efficient if it:

- considers and benefits from the accumulated experience and successes over the last three decades, and,

- contributes to the definition, by the different stakeholders, of ambitious objectives, targets and commitment levels, consistent with a maximisation of the implicit accomplishment capability.

[1] MANUFUTURE Vision 2030, http://www.manufuture.org/wp-content/uploads/Manufuture-Vision-2030_DIGITAL.pdf

PRODUCT DEVELOPMENT AND INDUSTRIALISATION IN HIGH VALUE ADDED INDUSTRIES

The importance of companies mastering product development, while being capable of securing good connections with clients and, through these, with consumers, integrating both into their own product development and customisation, results from the fact that these enable interesting and positive synergies, providing companies with greater visibility and distinct market positioning.

JOAQUIM MENEZES [1,2]
[1] IBEROMOLDES
[2] EFFRA – EUROPEAN FACTORIES OF THE FUTURE RESEARCH ASSOCIATION
j.menezes@iberomoldes.pt

Certain companies have been able to provide a supply of integrated competences, by leveraging innovative ideas, ranging from design and engineering to product development, including: prototyping, various moulds and tools to support production, as well as the production, assembly and application of sophisticated embellishment techniques for plastic technical components.

Very few products require multiple identical moulds throughout their life cycle. In this sense, high consumption products - namely lab and medical support (hospital treatment and diagnostics) products or electronics - are good examples of high production output with millions of components, in which the use of multiple moulds stems from the need to address global demand requirements and daily use.

Over the past 75 years, both production centres for polymer injection and light alloy moulds, in Marinha Grande and Oliveira de Azeméis, were able to foster the global prestige of this industry, characterised by unit production.

Each mould lasts longer than the product that comes out of it!

Due to its very particular characteristics, of semi-industrial and skilful craftsmanship, this industry relies on a permanent competitive monitoring, update and adoption of emergent technologies. It is an industry that permanently seeks knowledge, competitiveness and productivity. It is an industry in which companies face each other with global assertion and positioning.

In Portugal, mould-making companies' dependence on product exports is higher than 90%. It is a worldwide competition and there is a significant industrial complexity, even greater when considering the use of advanced technologies and processes, required by the polymer-based product innovation – referred to as plastics, taking into account the development of features from these materials over the past three decades. The importance of companies mastering product development, being capable of securing good connections with clients and, through these, with consumers, and integrating both into their own product development and customization, results from the fact that these enable interesting and positive synergies, providing companies with greater visibility and distinct market positioning. This concern, combined with possible strategic opportunities, has allowed many companies to develop new business lines, to achieve greater sustainability and the development and recognition of competences, providing them with greater prestige and distinct market positioning. In many cases, and because companies were able to master product development and to secure good connections with clients, they are allowed to develop strategic partnerships with them, making clients an integral part of that process of multiple opportunities.

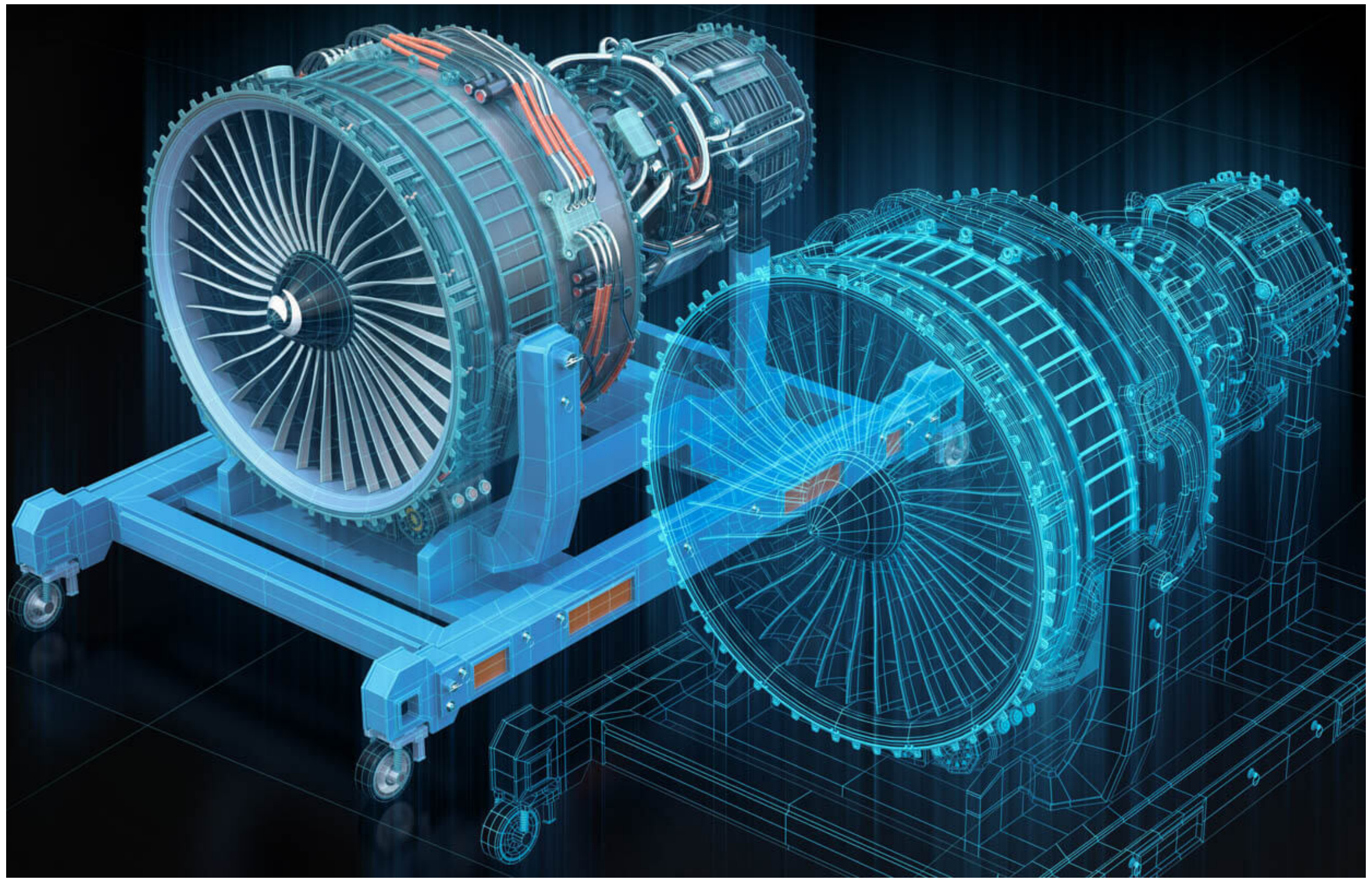
Mastery of product development also helps companies develop new and innovative products, capable of addressing current requirements of the Circular Economy; said products are developed and manufactured with minimal material consumption, integrating recycled materials or environmentally friendly alternatives, while bearing in mind their durability and recycling capability, as well as their own production processes, aligning them with the objective of reducing the respective carbon footprint.

I frequently refer to the mould-making industry as a future industry, with future. It is an industry of constant learning, from the project design and engineering to the assembly and usage, going through precision component machining processes, in which the use of advanced manufacturing technologies, namely metal additive manufacturing, is currently common, particularly in high volume series and high cadence production moulds and other complementary tools.

Portugal has become a reference for clients and peers, currently occupying the third position among the major European manufacturers, presenting itself as a pivotal industrial cluster, in line with the desired increase in Foreign Direct Investment (FDI) - mainly due to its uniqueness, tech requirement levels, modernity and differentiated skills.

The path taken by the Portuguese product development and manufacturing cluster (Engineering & Tooling Cluster) in the digitalisation area dates back to the 1980s. In Europe, Portuguese mould-making companies were the first to understand the importance of digitalisation at shop-floor level (CAD/CAM/CAE), and of the co-development (concurrent engineering) of new projects, with its multinational and market leading customer base. This led to varied and distinguished products, targeting prominent sectors such as the automotive sector, household appliances, packaging, medical and hospital devices, etc.

Resulting from this pioneering vision, the mould-making cluster reinforced its involvement in the product co-development area, together with clients, where the constant investment from companies in the various value chains has caused significant impact.
Considering the need to explore new opportunities and markets for the full use of the competences resulting from the strong investment in advanced manufacturing technologies, the cluster has dedicated great attention to the possibilities of entering in other excellence sectors, such as aeronautics, space and defence.
There are well-known and relevant projects in these areas, many of them winners of awards of international relevance. Regarding these domains, the unit production, a specific element of this industry, becomes even more evident and hinders the interaction of companies with these restricted markets, of highly specialised groups, and normally organised in established supplier clubs.
We may say that there are competences, talents and knowledge in this cluster – considering the Portuguese general context – that can and should be taken into account for the new paths of the country's development in the near future. We suffer from a chronic issue: we do not know ourselves well enough, and we do not

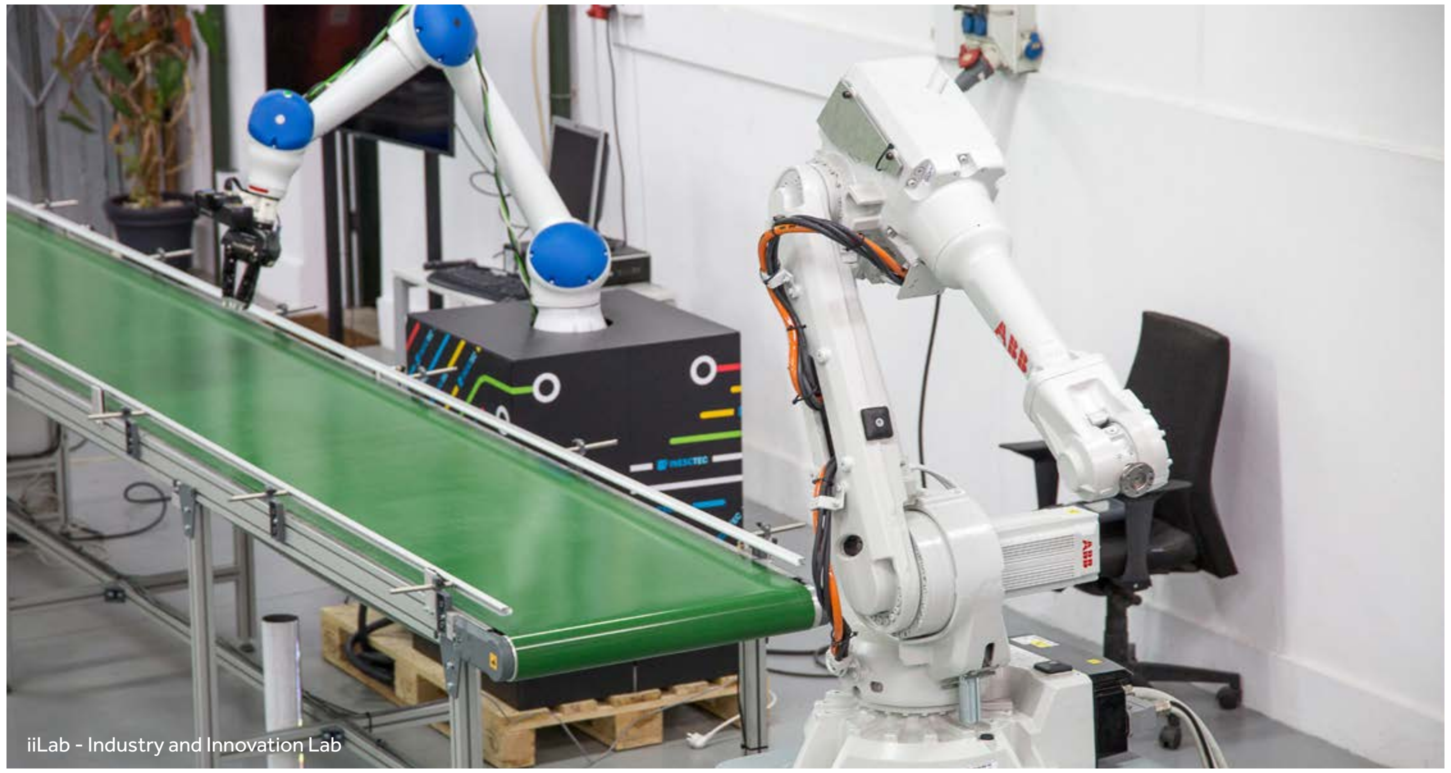


acknowledge our own potential…the market is small, it does not leverage the competences and capabilities of national companies and of the multiple knowledge centres operating today. Much has been done; yet, it is not enough.
Above all else, Portugal is internationally acknowledged for its competences and capabilities at the manufacturing level and the respective processes. In order to keep this competitive advantage and excellence at the manufacturing processes level, it is necessary to develop the product knowledge area and respective supporting services, aiming at a broader control of the value chains, and the creation of greater economic value and social impact. The existence of a mould-making industry in Portugal, strong and dynamic, is a decisive factor on this transformational agenda of our economy, allowing the establishment of strategic partnerships with multiple and wide-ranging sectors of the national industry.
The new opportunities that may be created and developed under the Portuguese Program for Economic Recovery 2020-2030 represent a sign of hope, in a sense that Portuguese companies, competences and know-how will have an effective opportunity, and play a key role in the most needed economic revival.

STARTING POINT: MATURITY!

In the beginning, was the Maturity, and the Maturity was with Industry, and the Maturity was Industry!

AMÉRICO AZEVEDO [1,2]
[1] INESC TEC;
[2] FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
americo.azevedo@inesctec.pt



iiLab - Industry and Innovation Lab

Industry, accounting for over 20% of the EU economy and directly employing some 35 million people and providing over 80% of merchandise exports, is key to future progress and prosperity. Small and medium-sized enterprises represent over 99% of all European businesses - a similar distribution in Portugal. The vast majority are family businesses - and are our economic and social backbone.

While the European Industry still has a competitive edge over many high added-value products and services, it is undergoing a significant transformation towards a greener and more digital Industry to guarantee its future global competitiveness.

Digitalisation and its associated digital technologies transform the face of Industry, and the way value is created, delivered and captured. Digitalisation powers the emergence of new business models, enables Industry to be more efficient, provides workers with new skills and supports the decarbonisation of the economy by providing a source of clean technological solutions and actively contributing to the European Green Pact.

The current general and specific competitive environment that traditional and new industries are subject to, against the backdrop of a period of global economic uncertainty on the horizon, poses significant challenges, in particular, to domestic Industry when it wants to engage in green and digital evolution.

The opportunity exists: to create and deliver differentiating value propositions, to act effectively and more efficiently. In other words, the chance to be more competitive and in a sustainable way - the desideratum that Portuguese companies cannot ignore.

The opportunity exists, and there are also barriers and risks. Barriers and risks of internal and external origin. Ignorance or lack of confidence around the potential and the benefit, or the empirical overestimation of the necessary cost and effort, with the resulting understanding, that it is not worth it or that it is not for us, inevitably places the company in a quadrant characterised by an essentially delayed and then reactive behaviour.

Barriers are recognised. But they will not be insurmountable. However, it seems opportune to recall the recognised axiom that to transform or evolve presupposes change. And change may necessarily cover different dimensions. The organisational structure may evolve, resources may be readapted, the way we transform and generate value may be redesigned and the skills we want to ensure may be enriched. We, therefore, have significant challenges. Starting with the organisational culture and the preparedness of the organisation as a whole.

When the Industry is faced with the challenge of its ecological and digital transformation / evolution, it is also faced with a vision of what it will look like in the future. The benefits arising from operationalising this Vision vary from Industry to Industry and company to company! To exploit the full potential that they may be able to develop, they must adopt a roadmap that guides, in an aligned way, the transformation/evolution process. While it is true that a large part of companies sees digitalisation as an inexorable opportunity, it is also true that most, anchored in uncertainty and a comprehension deficit, still do not have a properly structured plan for the development, implementation and adoption of the digital technologies that will play a relevant role in their Industry.

The transformation/evolution around digitalisation is not just about the adoption of technologies. Due to the comprehensiveness, scope, and multidisciplinarity involved and the multiple challenges of internal and external scope, industry digitalisation initiatives recommend a properly cared, judicious and structured approach. A result of the lack of a structured approach is the proliferation of disconnected initiatives, or, to some extent, the creation of an environment of "digital fragmentation". Since the initiatives to be developed need to be unified so that the organisation can attain the full potential inherent in its digital Vision.

Successfully overcoming the challenges of a 'digital transformation' requires having a global vision for the organisation and a good understanding of the 'current situation', namely regarding the various dimensions inherent to this 'transformation'. Having a global vision that the whole organisation understands means

considering three fundamental pillars, namely those related to:
1. business model - how does the company want to create, deliver and capture value in the future;
2. internal processes - how does the company want to develop its work activity and with which technologies and tools;
3. customer relationship - how does it want to manage the customer's needs and expectations throughout the life cycle of the product or service it delivers to them.
A structured approach to transformation is, therefore, fundamental. Consequently, it is relevant to adopt and follow a methodology that supports the entire journey inherent to Digital Transformation.
Where to start?
To answer this question, and to think about Portuguese companies and capitalising all its experience in this domain, INESC TEC has developed a Digital Transformation methodology that comprises of four main steps.
The first step is to know and understand the starting point. We have referred to this step as assessing the company's Maturity in the context of its Digital Transformation scope.
Assessing Maturity means knowing and understanding the starting point well in the organisation's different dimensions: resources, processes, systems and technologies, organisation and strategy, culture and people, products and services. Each dimension is structured in a set of assessment vectors that consider several requirements oriented to each analysis vector. After assessing the collection of vectors underlying a certain dimension, the respective Maturity level is calculated. The quantification of the organisation's overall level of Maturity is obtained through the weighted average of the maturities of each dimension considered.
A second important step is the definition, communication and adoption of a digitalisation Vision for the company, aligned with its global strategy. This Vision should consider the different dimensions referenced in the previous step.
The next step focuses on planning the implementation of the actions that lead to the desired evolution. Thus, based on the Vision defined above, this step comprises of identifying priorities, defining goals to be achieved, and identifying proofs of concept to be developed, implemented, and validated. From here, several action plans may promote the advancement of the Maturity level in the various dimensions previously considered. This set of action plans can be seen as the detail of a global Roadmap.
Execution is the next step.
Execution is understood as the operationalisation of the outlined transformation plan. Tasks and deliverables are scheduled, key indicators to assess impact are defined, strategies and partnerships to support implementation are identified, risks are identified, budgets are calculated and resources are allocated.
The end of the implementation leads to a new starting point. The company is ready for a new iteration! Ready for a further Maturity evaluation with the assessment of the level of progress achieved. With greater Maturity, the company will also be, for sure, more competitive. This is your new starting point to attain a higher level of Maturity.
In a context of high uncertainty, the rebuild of the economy in the coming years recommends a set of public policies that revitalise the sustainable creation of social capital, and promote productivity, innovation, and, consequently, competitiveness in organisations, especially SMEs. The obligation of a recurrent maturity assessment exercise should be one of the essential elements in the subsequent development and transformation programs of the Portuguese Industry.

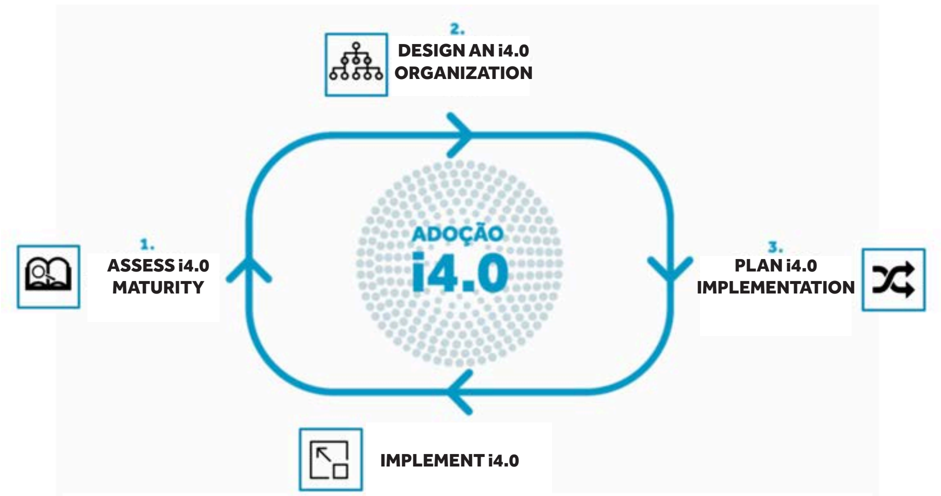
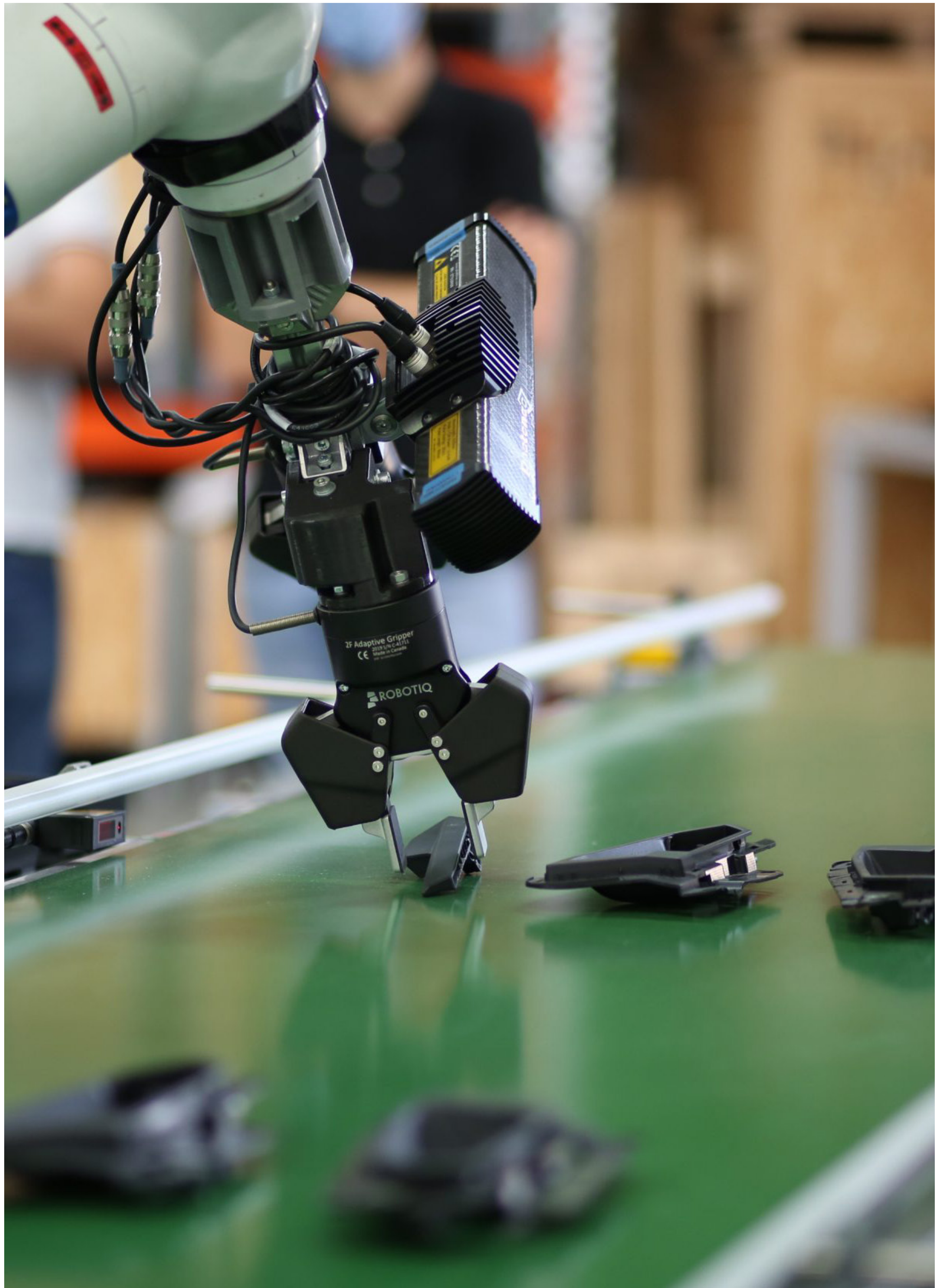


Figure 1 - Steps for i4.0 Maturity Assessment and Technological Roadmapping



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CIRCULAR ECONOMY: RESEARCH AND INNOVATING FOR A SUSTAINABLE FUTURE

The expression "circular economy" has entered our ears and has become indelible in our professional, family and lives as a citizen. However, the concept and its implications may not have been fully internalized yet. In addition to the basic principles, we need to better understand the implications of this concept in production systems and research, where it should be embraced as a new paradigm.

ANTÓNIO LUCAS SOARES [1,2]
ANTÓNIO BAPTISTA [3,4]
[1] INESC TEC
[2] FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
[3] INEGI - INSTITUTE OF SCIENCE AND INNOVATION IN MECHANICAL AND INDUSTRIAL ENGINEERING
[4] LAETA – ASSOCIATE LABORATORY OF ENERGY, TRANSPORTS AND AERONAUTICS.
antonio.l.soares@inesctec.pt
abaptista@inegi.up.pt

Imagine that it is time to replace your washing machine. After a first selection made online, you go to a store where the machines you pre-selected are on exposition. It is in the final stage of your decision. You open the "Sustainability" application on your smartphone and point the camera at one of them. The application recognizes the model and presents you with information previously customized by you as important when purchasing an appliance. This includes, amongst others: information on energy efficiency (average electricity and water consumption costs), expected life span for the main components and respective probability of replacement at the end of that period, comparison of the collection services of the old machine in terms of the incentives received or the reduction of packaging and transport materials. The application also shows a ranking of the brand and respective models, related to the Product's Environmental Footprint (through LCA models - "Life cycle analysis") and its social assessment of the life cycle (social-LCA). Based on this information, you will decide what your next washing machine will be, with the satisfaction of being able to decide not only based on individual economic criteria, but also taking into account environmental and social sustainability aspects.

What is the circular economy?

In this context of increasingly digitalised products, we are led to imagine, just as in the scenario described above, a world where, as consumers, we have the power to participate actively and positively in the management of the life cycle of products we buy, resulting in less of an environmental impact on the planet and promoting greater sustainability. It is thus possible to create a virtuous cycle in which organizations (companies, public entities, non-governmental organizations, associations, etc.) can collaborate and then assist consumers, who, as a result of their awareness, start to model their behaviours and decisions in a properly informed manner. But what does "Circular Economy" mean? One of the international non-governmental organizations that has been working actively and with high visibility to foster a world based on Circular Economy principles is the Ellen MacArthur Foundation[1], which defines Circular Economy as "A new way of designing, developing and using goods and services, respecting the boundaries of the planet. It involves decoupling economic activity from the consumption of finite resources and eliminating waste from the system by principle. It must be based on a transition to renewable energy sources, in an economic, natural and social way". Three fundamental principles are defined: design out waste and pollution, keep products and materials in use, regenerate natural systems. The adherence of products and the respective activities carried out in production with these principles, came about in the observance of norms, techniques and good practices, define their "circularity", that is, the way they contribute to managing the cradle-to-cradle life cycle. Due to the recent international policies, agreed by dozens of nations, together with a greater awareness of the citizens, the Circular Economy paradigm is gaining more and more attention, with multiple initiatives embraced by organizations, accelerating its implementation. New terms and words are gradually entering the vocabulary of consumers, such as the "circularity" of products and materials, or the promotion of renewable energy sources (such as in photovoltaic electricity for self-consumption). We are heading, hopefully at a faster pace, to a near future in which a consumer has easy access to the "circularity" information of a given product through a simple QR code, which he/she accesses via smartphone, to have information in quantities, degrees of recyclability or reuse of raw materials, relevant data on the manufacturing of the product, expected lifetime, and possibilities for retrofitting or upgrading. These will be fundamental to the future phases-of-use of the product, or to the best way to manage its end-of-life e.g., where to discard it properly.

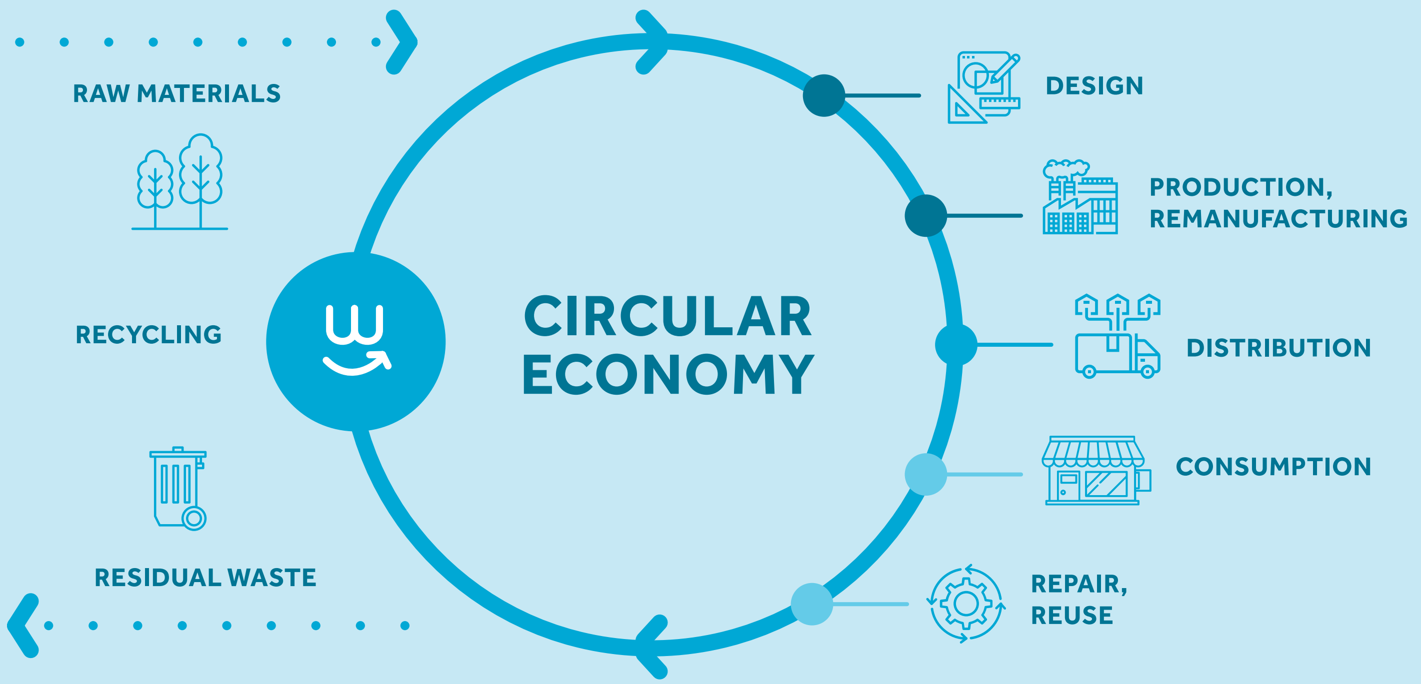
Circular production: the link between value chains

Production systems, technological companies and waste treatment and recovery companies play a key role in the transition and should act in the direction of wide decarbonisation of their activities and the carbon footprint of new products throughout their use. A key aspect of this process is to base the design of new products on principles of Sustainable Design (also known as EcoDesign) and integrating new design approaches for Circularity, providing multiple product use cycles, via facilitated upgrades, reconfigurations, simplified reconditioning and repairs, or even components reuse. The design for circularity implies not only production systems designed with the objective of minimizing the consumption of materials and energy, but also putting in place enriching and socially fair work practices. Emerging information and production technologies are a key factor in the evolution towards a full circular model. For example, the need to establish interconnected value chains, consolidated in an "industrial symbiosis" is complex, requiring advanced coordination and information systems, using technologies such as the Industrial Internet of Things, Blockchain, Digital Platforms, techniques for handling large amounts of data and securely, reliable and distributed information systems.

The circular economy as a paradigm for R&D in the industrial area

To accelerate and widen the implementation of the Circular Economy paradigm, building capabilities for Research and Development (R&D) in industrial companies is fundamental, not only for the design of new products and services based on circularity, but also for reformulating and redesigning their production systems and, more broadly, the entire industrial ecosystem. From research on new synthetic materials, substitutes for non-renewable resources or materials whose production is harmful in environmental terms, to research about new business models, R&D in the industrial area should be governed by the circularity paradigm, aiming at much more than just contributing to economic sustainability.
In fact, there are many products, such as mechatronics, textiles, footwear, where the production phase represents high environmental impacts, whether through the materials and processes used, or the energy intensity involved. It is therefore essential to research strategies for life cycle assessment in production systems, measuring in particular their impact on carbon footprint and water footprint depending on their products. It is also important to coordinate the design of new products oriented to material circularity and carbon neutrality, with more sustainable production systems (economically, environmentally and socially).
INESC TEC's multidisciplinary approach to research, intersecting industrial engineering and management, robotics, artificial intelligence, information systems and energy systems management has contributed decisively to innovate and adopt the circular economy paradigm. An example is the innovative platform for product life cycle management (PLM) developed in collaboration with INEGI as part of the Produtech_SIF mobilizer project[2].

[1] http://www.ellenmacarthurfoundation.org
[2] http://mobilizadores.produtech.org/pt/sif



SERVITIZATION: A SERVICE-BASED RESILIENCE STRATEGY FOR MANUFACTURING FIRMS

Any manufacturer, big or small, can servitize. Although servitization does not represent a panacea for manufacturers, it is a concept of significant potential value, providing routes for manufacturers to move up the value chain and exploit higher value business activities, therefore contributing to the resilience of manufacturing companies.

MIGUEL LEICHSENRING FRANCO [1]
BERNARDO ALMADA-LOBO [2,3]
RUI SOUCASAUX SOUSA [4,5]
[1] SCHMITT-ELEVADORES, LDA
[2] INESC TEC
[3] FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
[4] CATÓLICA PORTO BUSINESS SCHOOL
[5] CATHOLIC UNIVERSITY OF PORTUGAL
m.franco@schmitt-elevadores.com
almada.lobo@fe.up.pt
rsousa@porto.ucp.pt

Manufacturing companies in developed economies face strong competition from companies based in countries where labor costs are lower. The former companies tend to focus on two strategies: product innovation and cost reduction. These are often associated with the use of new materials or technologies, automation and more precise machinery, as well as lean programs. There is, however, a complementary way that is often overlooked: creating value by adding services to products.
Through the bundling of services and products, the manufacturing company can differentiate its offering by reinforcing the relationship with the customer, and therefore creating new sources of revenues that are more stable and resilient to the economic cycles. By including additional services into their total offering, manufacturers can create new growth opportunities in mature markets. Manufacturing firms can sell multi-year service contracts that, although generating smaller revenues than product sales, yield regular revenue streams that can smooth the effect of lumpy product sales revenues. Furthermore, the product-service combinations also seem to be less sensitive to price-based competition, thus providing higher profitability levels in comparison to the physical product offerings alone.
In simple terms, servitization refers to manufacturing companies starting to sell services bundled with their products, creating value for the customer. In a service-led competitive strategy, the manufacturer can follow different paths. One option is to provide a portfolio of relatively conventional services (the so-called basic services), like the inclusion of an additional warranty period, the sale of spare parts, preventive maintenance, repair or overhaul of installed equipment, or even their remote monitoring. The other option, on top of basic services, is to sell advanced services, where the manufacturing company takes control of all activities that are integrated into the customers internal processes, by means of long-term pay-for-use contracts.
There are many successful examples of servitized manufacturers. Xerox, which manufactures printers and copier machines, was one of the pioneers in servitization. Instead of solely selling equipment, it started offering a complete printing solution to its business customers. These customers pay only for each copy made, without having to acquire the equipment (i.e. they will not own the printer). According to this business model, the manufacturer provides remote monitoring of the printer and replaces the toner whenever needed, without any intervention from the customer. In case of a malfunction, the printer itself sends an alarm to the central system and a technician is sent onsite, without further costs to the customer. Throughout the contract, and with no investment in hardware, the customer pays a monthly fee according to the copies made (pay-per-use). The end game for the manufacturer is being able to lock in the customer with a predictable cash flow. This strong

customer relationship also fosters cross-selling from the manufacturing company. In this case, the manufacturer provides a document management solution, selling advanced services.
Fricon manufactures and sells refrigerator cabinets and freezing and frosting solutions for supermarkets. If Fricon were to sell only the equipment, it would be dependent on the investment cycle of the supermarket sector. Imagine now that this producer installs a machine-to-machine (m2m) communication system in the equipment that it sells, allowing for remote monitoring. Whenever the temperature of the refrigerator cabinet exceeds a certain threshold, an alarm signal is sent to the manufacturer's centralized monitoring system. A technician immediately goes onsite to fix the problem. According to this business model, the manufacturer sells an additional service to the supermarkets – such as remote monitoring and corrective maintenance, locking in the customer with a long-term service contract. All in all, new and more stable sources of revenues are generated through advanced services.
Hilti is a world-leading manufacturer of power tools for the construction, building maintenance, energy and manufacturing industries, mainly for the professional end-user. Following its customers' needs, Hilti moved from selling power tools to its customers, to leasing them as a service. Its Fleet Management (FM) offering allows customers to use a defined set of tools for a multi-year fixed period. The fixed monthly rate paid by the customer covers all the costs with tools, including their use, service and repair costs, and minimizes downtime. Moreover, the tools in the fleet are regularly replaced with novel models that comply with the latest safety standards. Not only is FM benefiting Hilti's customers, but it also allows Hilti to cooperate even more closely with its customers, thus creating entry barriers for the competition, while providing advanced services.
Caterpillar is an equipment and power systems manufacturer that provides life support systems for all of its equipment and power systems (condition monitoring). Caterpillar has shifted its strategy from solely manufacturing and selling construction equipment to adopting leasing and remanufacturing strategy. Caterpillar guarantees revenues per operating hour of equipment, which includes all maintenance and repair activities; it also guarantees the availability of equipment. Remote monitoring technologies are used to track the state of the assets and make predictions about service and support requirements. Real time data is used to help optimize the performance of the client's business, by minimizing equipment downtime and operating costs. Caterpillar clients are requesting long-term partnerships (through advanced services), where the manufacturing company takes on and manages risk that the client used to carry.
In conclusion, manufacturing companies from different sectors are beginning to understand the strategic importance of service to gain a competitive advantage. The integrated product-service offerings can be distinctive, long lived, and easier to defend againstcompetition from lower-cost economies, being a conscious and explicit strategy for market differentiation. Ultimately, it brings a stronger competitive advantage.
From a manufacturing company perspective, servitization can lead to increased sales revenues. By responding to the demands of customers, manufacturers can prevent competitors from gaining a foothold in their markets. Servitization can also deliver increased customer numbers and growth with existing customers through closer and stronger relationships, as improved customer intimacy can lead to opportunities for new services.
From a customer perspective, it may help reduce risk and lower maintenance and support costs, or at least make them more predictable. Clearly, customers of servitized manufacturers benefit from improved asset management. Another key advantage for customers is that servitized contracts allow them to focus on their core business, improving their competitiveness through better service quality to their own customers.
Any manufacturer, small or big, can servitize. Although servitization does not represent a panacea for manufacturers, it is a concept of significant potential value, providing routes for manufacturers to move up the value chain and exploit higher value business activities, therefore contributing to the resilience of manufacturing companies.

Franco, Miguel L. (2020), "Servitization of manufacturing firms over time: An empirical investigation in the elevator industry". PhD thesis,184 p., https://repositorio-aberto.up.pt/bitstream/10216/128473/2/412036.pdf

Sousa, R., da Silveira, G. (2020), "Advanced services and differentiation advantage: An empirical investigation". International Journal of Operations & Production Management, 40(9), 1561-1587.

Baines, T., Bigdeli, A., Sousa, R., Schroeder, A. (2020), "Framing the servitization transformation process: A model to understand and facilitate the servitization journey". International Journal of Production Economics, 221, 107463.

HUMAN MACHINE COOPERATION FOR A RESILIENT INDUSTRY

The future of Human-robot cooperation requires deeper cognitive interaction, where Humans and machines adjust themselves and help each other to compose an efficient and resilient production system.

GERMANO VEIGA [1]
[1] INESC TEC
germano.veiga@inesctec.pt

The human ability to cooperate flexibly and on a large scale to reach inaccessible goals is commonly pointed out as the single most important factor in Human dominance over other species. As magnificently described by Harari (2014)[1], other animals can cooperate on a large scale, such as ants, or with great flexibility, such as dolphins or chimpanzees in their intimate circles, but none can do it with flexibility and on a scale such as humans.

Different levels of cooperation complexity have been defined, that evolve from sharing a common goal to include the coordination of time and space. In his seminal work, Boesch (1985)[2] defined cooperation hunting as the highest level of cooperation complexity in chimpanzee hunting, in which chimpanzees share a goal (the prey), synchronize the time and define a spatial approach to the attack. To achieve this future-oriented cooperative behaviour, there is the need to share models and representations, that allow each agent of the cooperation to anticipate future states of themselves, the other agents and from the environment.

The context of vacuum cleaning can be used to explain different levels of interaction tightly correlated with the autonomy of the machines: from the handheld vacuum cleaner, which presents no autonomy and therefore is a tool; to the simple robotic vacuum cleaner, that performs dumb autonomous cleaning without any intervention from the user described as an adaptive tool; to the advanced robot vacuum cleaner, that allows the coordination of the task with the human in terms of space and time through the shared representation of the house with the human (map) and an advanced human-machine interface, described as a cooperative assistant (Krüger, 2017)[3].

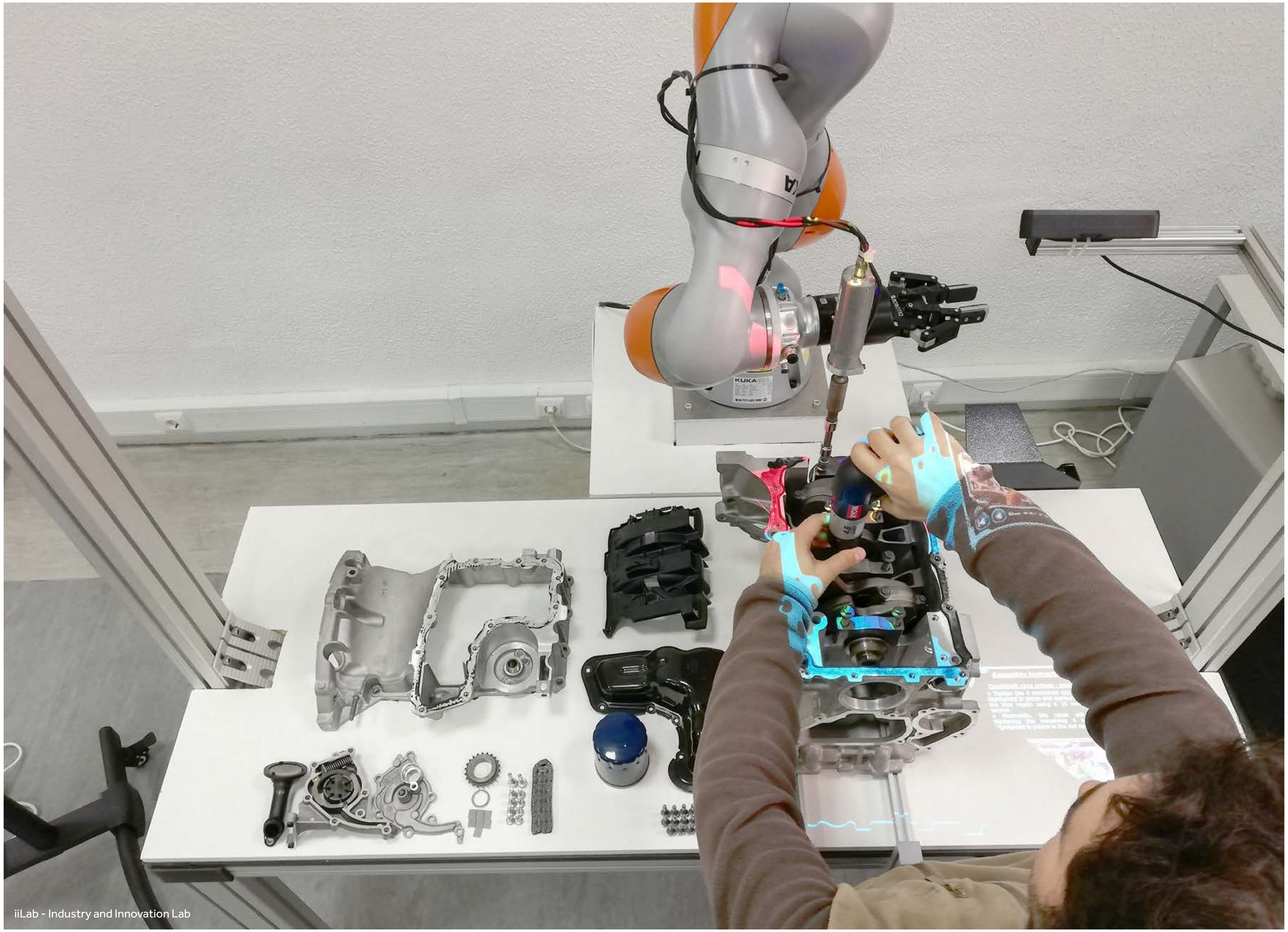
In industry, most of the cooperation is nowadays at the adaptive tool level. Consider for example an industrial robotic cell: the robot performs a pre-programmed task autonomously in parallel with a task performed by the human operator, but minimal or no adjustments are allowed in the cooperation strategy and there is no shared representation of the task in hand.

In the context of the Industry 4.0 paradigm, collaborative robotics is described as the key technology for seamless interaction between humans and machines. This assumption is one of the major pitfalls of most of the industry 4.0 approaches, as shown by the contrast between the hype around collaborative robots and the actual sales numbers (less than 5% of total robot sales in 2019 according to the International Federation of Robotics). A key element in this analysis is the definition of a collaborative robot like the one that allows safe operation in shared spaces with humans.

In perspective and considering the levels of cooperation defined above collaborative robots, per se, are close to a chimpanzee that does not harm the other chimpanzee, but there is still a long way to go to achieve productive cooperation.

Human-robot cooperation, sometimes referred to as cognitive cooperation, will require not only collaborative robots (safe) but also significant developments in the three main pillars of the human-machine interaction: the robot, the interaction, and the human. The robot must evolve to become more autonomous, namely through the deeper integration of perception and artificial intelligence. The interaction must evolve from human to machine interaction via graphical interfaces, to bidirectional and intuitive processes, using, amongst others, augmented reality, speech recognition, that allow humans and the machine to share world and task representations. Finally, the human, whose role must be central in the development of cooperative systems, requires relevant technical education to develop deeper

cooperation with complex machines, in the context of learning factories for example.
An interesting example that shows the work needed on the pillars mentioned above came up during the development of the ScalABLE4.0 project, led by INESC TEC[4]. In one of the demonstrators of the project, the team started with two collaborative robots (in the safe perspective) and evolved to a highly flexible manufacturing system, with the introduction of advanced sensing and vertically integrated artificial intelligence (robot pillar) and friendly human-machine interfaces (interaction pillar). At the end of the project, one operator and two robots were able to deal with the output of four plastic injection machines in a flexible way: complex tasks were performed by the operator and the rest performed by the robot and the system can be re-arranged very quickly. However, the flexibility of the system still relied on a support team with some technical knowledge, required to properly allocate the robots and to adjust or reprogram the robots and injection machines for different scenarios. During the final discussions with the Simoldes Plásticos team (the end-user), a glimpse of the future came up: one operator orchestrating his own cooperative production system, by allocating and reprogramming robots and machines to maximize production in high mix scenarios. To fulfil this vision, significant work must (also) be carried on the human pillar, with the empowerment of the operator the proper tools to achieve an effective cooperative production system.
Resilience in the industry has always been based upon human flexibility to overcome major challenges namely the limitations of traditional industrial automation. Nowadays the challenges have changed, with smarter and more autonomous machines in the need for deeper and more cognitive interactions with their human partner.



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[1] HARARI, Yuval Noah (2014). Sapiens: A brief history of humankind. Random House, ISBN-10 : 9780062316097

[2] Boesch, Christophe & Boesch, Hedwige. 1989. Hunting behavior of wild chimpanzees in the Tai National Park. American journal of physical anthropology 78, 4 (1989), 547–573.

[3] Krüger, Matti & Wiebel, Christiane & Wersing, Heiko. (2017). From Tools Towards Cooperative Assistants. HAI '17: Proceedings of the 5th International Conference on Human Agent Interaction.

[4] https://www.scalable40.eu/

DATA AND MACHINE LEARNING IN DECISION-MAKING

All models are incomplete and approximate. Modelling is extracting from a reality that is always chaotic and complex, the essential characteristics for the decision-making process in question, organizing, simplifying, and creating meaning and purpose. This is only possible at the cost of a high dose of abstraction and simplification.

PEDRO AMORIM [1,2]
JOSÉ FERNANDO OLIVEIRA [1,2]
[1] INESC TEC
[2] FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
pedro.amorim@inesctec.pt
jose.f.oliveira@inesctec.pt

In the summer of 2019 in Seattle, we attended a talk by Jeff Wilke, global CEO of Amazon's Consumer Business. The first slide of that presentation was split into two. On the left, the slide was subtitled Decision Support and showed an analyst analysing the output of a mathematical model, and on the right side, the subtitle was Hands-Off Wheel and showed an analyst programming a model that made decisions autonomously. With the following click, Jeff Wilke put a cross on the left side and simultaneously commented that at Amazon the way to make decisions should be like the one described on the right side of the slide - investing the time necessary for the model to best portray the decision to be made, but without interfering with the result.

Decision-making supported by analytical models is usually described on a scale of three main categories (Figure 1). The first category - descriptive analytics - concerns models that support the understanding of past events. For example, when analysing a retailer's promotional campaign, these models can identify how effective and efficient that activity is. In the second category - predictive analytics - the goal becomes to anticipate the impact of a certain business activity. Using the same example, with these models, the retailer could predict the sales of a particular promotional campaign. Finally, in the prescriptive analytics category, mathematical models have the responsibility of suggesting actions that are then analysed and refined by decision makers. Going back to the retailer's case, these models would suggest the best parameterization of the promotional campaign given a business objective and constraints.

This last category of analytical models - prescriptive analytics - currently brings many challenges in terms of adoption by organizations. These challenges are rooted in the fact that decision-makers in these organizations do not believe it is possible to codify and improve the current decision-making process. This baseline position causes the requirements for modelling not to be fully mapped out and the mathematical description of the problem to fall too short of reality. Even beyond these initial challenges, changing the decision-making process is always challenging and transformational in nature. This reality makes it necessary to accompany the technical rigor of model development with a practical sense of changing minds and habits.

Going back to Jeff Wilke's presentation, it is clear that Amazon has extended the scale of analytic models and brought autonomous analytics to the forefront. This category has at its foundation a distinct stance on the development and application of decision-making models. Being a natively digital company, Amazon's employees have never made decisions in any other way and this makes it easier to overcome the challenges elicited for prescriptive analytics. With the intensive use of this category of analytical models, Amazon puts substantial effort into the development stage, using successive iterations. Thus, considering, again, the case of defining promotional campaigns, Amazon will attempt to determine, after multiple experiments, the price elasticity profiles of different customer segments and model comprehensively the corresponding business dynamics. In use, these models, as they have no human intervention downstream, will produce systematic deviations that can be continuously analysed and refined.

All models are incomplete and approximate. Modelling is extracting from a reality that is always chaotic and complex, the essential characteristics for the decision-making process in question, organizing, simplifying, and creating meaning and purpose. This is only possible at the cost of a high dose of abstraction and simplification.
In a simple way, and quoting George Box[1], all models are

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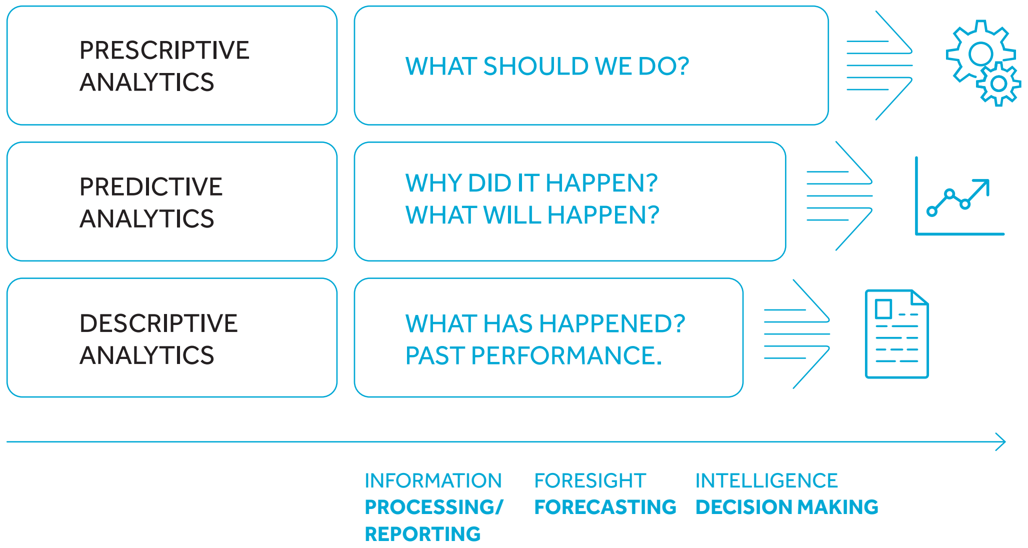
Figure 1 - Scale of the of the three key analytics models



[1] Box, G. E. P. (1976), "Science and statistics", Journal of the American Statistical Association, 71 (356): 791–799, doi:10.1080/01621459.1976.10480949

wrong, some are useful. George Box derives from this assumption two important conclusions. The first is that as all models are wrong, it is not possible to obtain the "correct" model by overelaboration. The second, which follows from the first, is that if we must live with the error, we have to be particularly attentive to those aspects where error is important and relevant.
What distinguishes the models of prescriptive analytics from the models of autonomous analytics is the focus on human intervention and, consequently, the sources of subjectivity and error. Thus, prescriptive analytic models carry within themselves the subjectivity of the analyst who decided what was relevant or not to the quality of the decisions to be obtained, incorporating in greater or lesser detail such features into the model. If the model automatically generates decision proposals, it does so based on the rules and objectives mathematically modelled by the analyst. The validation of these models is done by the controlled feeding of data, which allows the verification and validation of the results. There is thus a huge ethical responsibility on the part of the analyst in the construction of the prescriptive analytics model.
Autonomous analytic models seek to be immune to the analyst's subjectivity themselves, building the decision rules based on huge volumes of historical data, which allow correlations between actions and consequences to be established. But the "Achilles heel" of autonomous analytics is exactly that correlations are not cause-and-effect relationships. On the other hand, these models also simplify the data used by selecting the features that have the most impact on the correlations, they are also wrong and can produce significant systematic biases, as we stated earlier. Thus, these models require human intervention in search of these deviations, which will also be fraught with subjectivity.
If the error is inherent to the use of analytical models, autonomous or otherwise, then human subjectivity will also always be present, and, consequently, ethical considerations. The discussion around which analytical methodology is more permeable to human (lack of) ethics has advocates on both sides of the barricade, but it will only be serious if we keep in mind that decisions will always have to be made by concrete women and men, who, informed by science and technology, cannot alienate the ultimate responsibility of the decision. By doing so, we will dehumanize our society.

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FROM VIRTUAL WORLDS TO THE AUGMENTED HUMAN

Immersive technologies enable humans to enhance their ability to intervene in the industrial environment more effectively and with less cognitive overload.
The future industry will most likely be the stage for the emergence of an augmented human, immersed in industrial systems that will be more intelligent and autonomous.

ANTÓNIO COELHO [1,2]
AUGUSTO SOUSA [1,2]
RUI RODRIGUES [1,2]
FILIPA RAMALHO [1,2]
[1] FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
[2] INESC TEC
antonio.coelho@inesctec.pt
augusto.sousa@inesctec.pt
rui.p.rodrigues@inesctec.pt
filipa.ramalho@inesctec.pt

The industry of the future is expected to undergo a revolution in the way humans interact with increasingly more intelligent machines. In the coming years, the industry faces the challenge of adjusting to and taking advantage of significant change drivers that are already very noticeable. Based on various digital technologies, the world we live in today is already highly interconnected, with humans, intelligent systems, machines, and devices acting together, trying to evolve into new forms of collective intelligence. With the development of cyber-physical systems, the Internet of Things (IoT), and sensor networks, we now see a greater interpenetration between the physical (real world) and the virtual world.
Today's human being finds increasingly autonomous and intelligent environments and productive systems that involve a considerable diversity of technologies.
This trend brings new challenges, mainly concerning the relationship between human beings and these industrial environments, with an increasing amount of data and information available that has to be understood, increasing the complexity of management and decision making. The revolution in the way humans interact with machines translates into solving several challenges, of which we can highlight the following:

- **Transformation of the workforce, promoting the development of new skills in humans that enable them to manage work digitally with the support of cyber-physical systems;**

- **Development of human-centred industrial systems, enabling greater action in all industrial processes and providing them with more adequate resources to extend their decision-making and action capabilities;**

- **Promotion of more significant, more efficient, and more effective collaboration of the human being with intelligent machines, systems, and robots, also enabling the increase of the added value of final products and services.**

Given these challenges, immersive systems technology has been developing to increase the human beings' ability to intervene in this new work environment through technologies such as Virtual Reality (VR) or Augmented Reality (AR).
Paul Milgram's seminal article, published in 1994[1] but still prevailing today, defines a continuum between Reality and Virtuality, where solutions like VR and AR are mapped (figure 1). Therefore, this continuum represents different combinations of real and virtual elements within what Milgram refers to as Mixed Reality (MR) and is currently encompassed in the broader concept of Extended Reality (XR). .

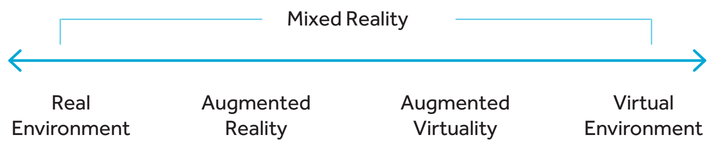


Figure 1 - The "Reality–Virtuality continuum" (Milgram et al. 1994)[1]

On the right side of the reality-virtuality continuum come the virtual environments, where the user is fully immersed in a world that is not interconnected with the real context in which the user is - immersive systems. In the virtual environment of Fig. 2, developed within the scope of an industrial project of INESC TEC, we observe a training situation in which a maintenance technician practices a procedure. The user is completely isolated from the real world by the equipment s/he uses, feeling "transported" to a virtual environment, where s/he can operate a set of tools to repair electrical equipment.
Immersion and the sense of presence that can result from it are two very relevant characteristics of a VR system.

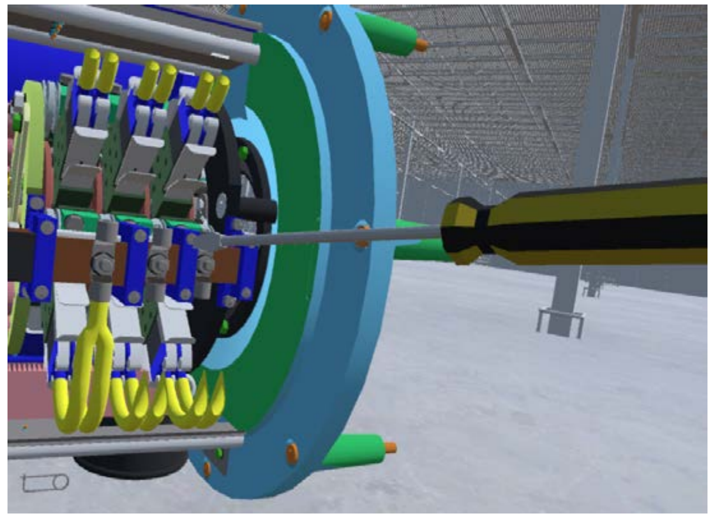


Figure 2 - Virtual environment for training in the industry (collaboration with Vestas) [4]

On the left side of the continuum comes augmented reality, in which virtual three-dimensional objects are positioned in an integrated way with real objects. Here arises a strong connection of the user with the context in which s/he is inserted or operates. As an example, Fig. 3 shows a paper map being augmented with virtual information such as routes and green areas. The tablet is, in this case, used as a "magnifying glass"...

Figure 3 - AR application for paper maps

Considering these examples, what solutions could we consider as something intermediate in the reality-virtuality continuum? The intermediate solutions of Mixed Reality combine virtual environments augmented by real objects present in the actual environment in which the user is inserted. The real room walls and the furniture can be integrated into the virtual environment, allowing the user to touch the wall or lean against a table to perform a specific task. Fig. 4 illustrates stepping on a step of a virtual walkway. Although the user is only a few millimetres off the ground, on a wooden board, his brain feels present in a virtual environment hundreds of metres high, providing a physiological sensation of vertigo.
Research in the area of immersive systems is several decades old, from Morton Heilig's "Sensorama" in the 50s to Ivan Sutherland's "Sword of Damocles" in the 60s. However, only in the last decade has the technology and its production reached levels of maturity that allow, on the one hand, the generation of real-time content, with quality and response times feasible to create a good sense of presence and immersion, and, on the other hand, produce the devices at prices that facilitate wider adoption.
We can find several systems on the market today with different device configurations. One of the most appealing is the "Head-Mounted Display" (HMD). It includes a viewing and listening device to be placed on the user's head and a pair of controls to be used in the hands - called "wands" (among other auxiliary devices). (Figure 5)

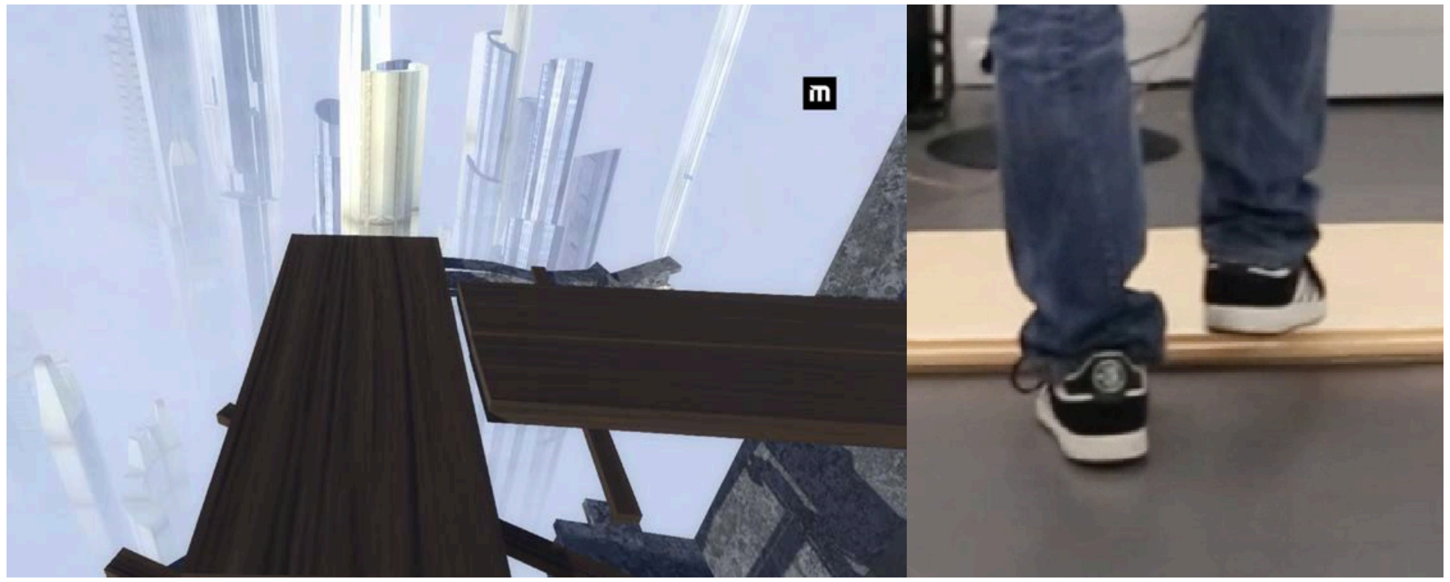


Figure 4 - Mixed reality experiment in the MASSIVE laboratory of INESC TEC [2]

These configurations accommodate:

a. Stereoscopic vision - the user has a sense of depth, as each eye receives the image from a slightly different viewpoint, as happens in a real situation;

b. Synchronization between head movements and the virtual viewpoint/audience - the view received follows the head movement, and sounds are reproduced according to the orientation relative to the sound sources;

c. Control of hand position and orientation, access to buttons for symbolic interaction, and vibration feedback;

d. Position of the user in space (in some configurations) - the user has the sensation of moving in virtual space when doing so in the real space where s/he is located.

In some cases, users may report a feeling of nausea when using these types of devices, which mainly occurs when the synchronization between actual movements and what is visualized is not well achieved. Motion synchronization is one of the challenges shared with augmented reality systems. Additionally, the integration - also referred to as registration - of virtual elements into the real elements of the scene being augmented is another challenge of AR. For example, a virtual box seems to be correctly placed on a real table, maintaining visual coherence even when the user or the device moves.
INESC TEC has been developing training scenarios in the scope of Industry 4.0. One of the applications that have been gaining interest is the use of "digital twins": real machines and systems in operation are virtually replicated and augmented with real-time information about their status and task planning. Additionally, the institute has been working on interactive 360° videos[3], which are an alternative to virtual replicas when it comes to capturing and visualizing reality in an immersive way. Also, it has been possible to test future industrial layouts in virtual environments at the planning and management level and evaluate their effectiveness and cognitive load, focusing the new industrial systems on the human being. And in maintenance tasks or even in jobs on an assembly line, augmented reality allows more efficient performance, through augmented information on the machine itself, or remote collaboration with experts, in a mixed reality environment to solve more complex problems.
Through immersive technologies, humans can increase their ability to intervene in the industrial environment more effectively and with less cognitive overload.
The future industry will most likely be the stage for the emergence of an augmented human being, integrating immersively into industrial systems that are more intelligent and autonomous.

Figure 5 - Using a HMD and the wands for interaction.

[1] Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, 77(12), 1321-1329.

[2] https://massive.inesctec.pt/

[3] https://av360.inesctec.pt

[4] Cassola, F., Pinto, M., Mendes, D., Morgado, L., Coelho, A., & Paredes, H. (2021, March). A Novel Tool for Immersive Authoring of Experiential Learning in Virtual Reality. In 2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW) (pp. 44-49). IEEE.

ARCHITECTURES AND DIGITAL PLATFORMS

IoT (Internet-of-Things) platforms have been enhancers of a close connection between the elements present on the shop floor and production management systems. This article presents INESC TEC's framework in the development of solutions for the operational management of flexible production systems.

CÉSAR TOSCANO [1]
RAFAEL ARRAIS [1]
[1] INESC TEC
cesar.toscano@inesctec.pt
rafael.l.arrais@inesctec.pt

IoT (Internet-of-Things) platforms have been enhancers of a close connection between the elements present on the shop floor and production management systems. This article presents INESC TEC's framework in the development of solutions for the operational management of flexible production systems.
The creation of the movement Industrie 4.0 (i4.0) in Germany had as its main element a reference model, called RAMI 4.0[1], where the fundamental principles of the movement were identified. The concepts of Cyber-Physical System and Component i4.0 gave form to the model, and the notion adopted of a close interconnection between the real world (elements existing on the shop floor), and the virtual world, the digital representation of those real elements, had been worked on for some years. So, it is not surprising that at that time there were already solutions (e.g. OPC-UA) for connecting equipment on the shop floor with production management applications (e.g. Manufacturing Execution System - MES). However, the various initiatives that were subsequently created around the world, gave strength to what started to be called IoT (Internet of Things) platforms, in the context of the development of solutions around intelligent/smart production, predictive maintenance and optimization of production systems, amongst others. Both in the commercial world and the open source community, solutions have been established that aim to capture data in real time from different elements on the shop floor, through different communication protocols (e.g. MQTT, ROS, AMQP, REST) and the development of concepts such as intelligent/smart objects. The term IIOT (Industrial IoT) started to be in fashion. Data processing functions, for filtering, annotation and format conversion started to be made available on these platforms. Lately, the concept of Digital Twin has been heavily emphasized. The trend in the coming years is to extend these integration features to the communication of information between organisations.
In this context and following a collaboration between the INESC TEC Centre for Enterprise Systems Engineering (CESE) and the INESC TEC Centre for Enterprise Systems Engineering (CRIIS) on the European project STAMINA "Sustainable and Reliable Robotics for Part Handling in Manufacturing Automation"[2], these two centres began to define a generic application framework, OSPS - Open Scalable Production System, for the operational management of flexible production systems, and supported on an IIoT Platform. This system (Figure 1) defines a set of production resources, comprising of robotic manipulators, 3D printers, automatic conveyors of material in progress, and automatic storage units.
For the first two cases, a control system (TaskManager) was defined that allows logistical operations (e.g. transportation of logistic units, construction of parts kits), assembly and additive production to be carried out. This element has as its fundamental pillar the APM Advanced Plant Model system (centre of Figure 1), defined as a data model responsible for maintaining a virtual representation, in three dimensions, of all the physical elements available in a specific physical area of

production or logistics. (e.g. logistical shelves and pallets, workstations, assembly lines). This model contextualizes the production plan defined by a typical production management system (MES), linking the temporal definition of operations, their allocation to production resources and the definition of product routes with the physical and geometric representations of the elements that comprise the physical area of production.
Production management features are also defined in the APM, in order to control and monitor the execution of the operations defined in the production plan in the supported production resources, namely robotic manipulators and 3D printers.
At a more tacit level, the OSPS architecture identifies a set of tools to support human decision-making (Figure 1) regarding the best organisation of a manufacturing system. The simulation of discrete events is the main instrument, used to analyse various production scenarios and estimate the value for several performance indicators[3]. This analysis results in importance levels to be assigned to several criteria such as minimising setup times, minimising delays, waiting times, or increasing the level of use of production resources, criteria that aim to change the way the plan of production is generated by the MES system.

The interaction between the elements of the OSPS architecture is performed by a set of messages that, through communication protocols specific to each element, allow the system to function as a whole.
This architecture was implemented and demonstrated in different cases, with different IIoT platforms, in two international projects, FASTEN (www.fastenmanufacturing.eu) and ScalABLE 4.0 (www.scalable40.eu)[4]. In FASTEN, a demonstrator of IIoT technologies between Europe and Brazil (involving INESC P&D Brasil), an IIoT platform was defined around the open source ecosystem Apache Kafka. Kafka acts as the main decoupling element between physical production resources and production management systems.
This system was demonstrated in two industrial scenarios: in Portugal, in a logistics warehouse where parts of various types are stored. The challenge was to develop a mobile robotic manipulator, capable of moving autonomously in the space occupied by the warehouse, moving to the place where the parts are stored, and collecting a set of parts for building a kit, then transporting that kit to the workstation on the assembly line where the kit is needed at any given time. In Brazil, the challenge consisted of the development of an additive production unit of components produced for solving part faults in elevators with some antiquity, for which there is no longer the production of parts.
A second implementation of the OSPS architecture took place in the European project ScalABLE 4.0. The prototype of the system was demonstrated on an engine assembly line in the automotive industry, where diesel and gasoline engines were subjected to robotic operations, carried out by fixed robotic manipulators, installed in some workstations along the line, and by mobile robotic manipulators, able to move to certain workstations on the line.
These two examples demonstrate the major objective of an IIoT Platform, the integration of a wide range of systems, from the equipment with activity in a certain manufacturing area to the management of the operations, providing adapters and converters to deal with the different possibilities of interaction.

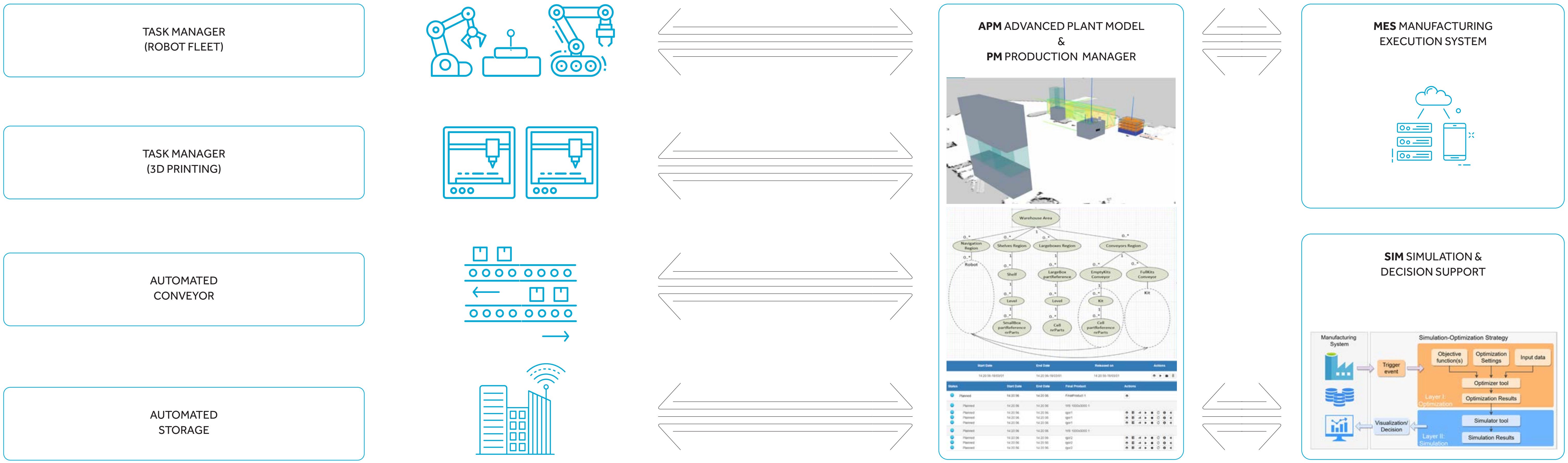
[1]. VID, VDE, ZVEI (2015). "Reference Architecture Model Industrie 4.0 (RAMI4.0)", Status Report, July 2015.

[2]. Krueger et al (2016). "A Vertical and Cyber-Physical Integration of Cognitive Robots in Manufacturing". Proceedings of the IEEE, https://www.authenticus.pt/P-00K-A3T.

[3]. Santos, Romão; Basto, João; Alcalá, Symone; Frazzon, Enzo; Azevedo, Américo (2019). "Industrial IoT integrated with Simulation – A Digital Twin approach to support real-time decision making" Management", in Proceedings of the International Conference on Industrial Engineering and Operations Management, Pilsen, Czech Republic, July 23-26, 2019.

[4]. Arrais, Rafael; Veiga, Germano; et al (2019). "Application of the Open Scalable Production System to Machine Tending of Additive Manufacturing Operations by a Mobile Manipulator", In: Moura Oliveira P., Novais P., Reis L. (eds) Progress in Artificial Intelligence. EPIA 2019. Lecture Notes in Computer Science, vol 11805. Springer, Cham, 2019, https://doi.org/10.1007/978-3-030-30244-3_29.

Figure 1- OSPS architecture



THE RISE OF THE INTELLIGENT ENTERPRISE

Intelligent Enterprises (IE) streamline and integrate their processes by implementing advanced technologies and acknowledged best practices, becoming more resilient, sustainable and profitable. Two fundamental technologies in IE are Advanced Planning and Scheduling Systems (APS) and Advanced Internal Logistics Systems.

RUI REBELO [1]
LUÍS GUARDÃO [1]
LUÍS LIMA [1]
[1] INESC TEC
rui.d.rebelo@inesctec.pt
luis.guardao@inesctec.pt
luis.lima@inesctec.pt

More and more companies face changes to their business, with a growing demand for customised products, the introduction of new ones, and an increased product mix. This reality leads to increased shop-floor complexity, with more processes to manage, tools to share between concurrent operations and a demand for limited specialised resources, required by multiple work stations during the setup/changeover operations, or to monitor the execution of operations.

If, at a given moment, the production flow is stable, with sufficient resources, and one is able to comply with delivery dates, at another moment, the changes in product demand mix could lead to delays and a lack of information to understand what has changed and how one should act in order to re-establish balance.

This context justifies the need to develop intelligent production systems and, consequently, to evolve towards the Intelligent Enterprise!

Intelligent Enterprises (IE) streamline and integrate their processes by implementing advanced technologies and acknowledged best practices, becoming more resilient, sustainable and profitable. The IE implements a strategy that enables rapid transformation of knowledgeable data – maximising process innovation, automation and optimisation. The IE resort to emerging technologies like artificial intelligence (AI), machine learning (ML), Internet of Things (IoT) and analytics to connect people, equipment and systems. These technologies will further allow the workforce to perform higher value-added tasks and the enterprise to be more agile and benefit from sustainable growth.

An IE must invest in process automation, optimisation and a set of so-called intelligent and integrated applications, supported by a digital platform that enables acquisition, the establishment of relations and orchestration of data originating from the entire enterprise, its clients and suppliers. The use of intelligent technologies will enable data processing, resulting in pattern detection, forecasting the impact on results and suggesting improvement actions.[1]

Two fundamental technologies in IE are Advanced Planning and Scheduling Systems (APS), namely for determining when and under which circumstances the industrial processes will take place, and Advanced Internal Logistics Systems, given their ability to apply the APS decisions at the shop-floor level. In the following section, we present these two technologies, perceived as structural for IE.

Advanced tools for Planning and Scheduling (APS)

The planning and scheduling of production orders are widely known as critical production management activities, which enables companies within a variety of sectors to differentiate themselves at operational performance level.

However, mapping complex production systems and their restriction, while simultaneously providing optimised scheduling solutions in due time, is not an easy task. Many industrial companies with sophisticated ERP and MES systems still use planning and scheduling systems based on spreadsheets, supporting their execution in outdated information normally gathered through daily-run batch processes or at multiple-hour intervals. These limitations usually require manual adjustments to the initial plans before they can be deployed to the shop-floor.

As technology advanced, planning and scheduling systems evolved, modelling reality more precisely. At the same time, manufacturing production systems have also become increasingly complex and dynamic, enforcing planning and scheduling systems to keep up with this evolution.

If an APS is not able to model the manufacturing production system faithfully, including its constraints and behaviour, then it will be incapable of producing optimised plans. In order to achieve this, APS must become increasingly more sophisticated and intelligent, i.e.:

- Stay connected and constantly updated with available information by all systems that form the IE, as a mandatory condition to generate optimised plans.

- Have a flexible internal information model that enables changes to the manufacturing system (e.g., through the implementation of new constraints).

- Continuously monitor the execution of plans and make adjustments when necessary, based on operational information acquired and processed with the shortest possible latency. Most recent technological advances in areas like Big Data, IoT or Analytics, which are associated with technological development both at software and hardware levels, favour the acquisition and processing of massive volumes of data in (almost) real-time, facilitating the fast detection of deviations between the approved plan and what is actually happening at shop-floor level. Examples of situations that can cause deviations are: equipment malfunction, production hot lots, raw materials shortage, larger operations' execution and preparation times, tool failure, amongst others. These deviations may have a significant impact, and require adjustments to the approved plan, in order to reflect the new reality. This is possible through real-time scheduling methods that, using (near) real-time event acquisition from the manufacturing system, are able to detect deviations and quickly adjust the plan, optimising it once more to deal with recent changes.

- Adopt a distributed operation logic, where the planning and scheduling systems of distinct supply chain players are able to communicate amongst themselves, allowing for real-time definition of delivery dates and material availability from suppliers, as well as their selection during the planning stage. Real-time scheduling may also take advantage of this network enabling, for instance, the shifting of raw material orders from one supplier to another in the event of different delivery dates or stock shortage, favouring a faster decision-making.

- Incorporate, in the production plans, not only the manufacturing operations, but also the automation of internal and external logistics processes. For instance, the use of AGVs for transportation of work-in-progress, and tools necessary to the operations and the management of outsourcing operations logistics - with their lead times and scheduled visiting time windows. Concerning intelligent and integrated information systems, it is important to highlight the ability to implement a controlled visibility over outsourcing partners, in order to monitor the execution of operations and to evaluate their response capability correctly.

- Incorporate process optimisation, that is, optimisation of distribution routes, truckloads, material cutting (sheet, leather, foam, etc.) and energy consumption, together with the reduction of production costs.

- Optimise the use of human resources, their skills and preferences, at the planning level, enabling the correct assessment of their demand and preventing them, for instance, from performing excessively repetitive tasks.

[1] https://www.digitalistmag.com/finance/2019/10/24/what-is-the-intelligent-enterprise-why-does-it-matter-2-06201136/

Advanced Internal Logistics Systems

A reference IE model is Kyaia, a company from Paredes de Coura, where INESC TEC played a decisive role. The SmartSL 4.0 logistics system is one of the most advanced in terms of job-shop manufacturing systems management, i.e., in processes where a large number of different items are manufactured, normally in small quantities and following concrete client specifications. This technology led Kyaia to productivity gains and decreased response times, enabling the manufacturing of the models in 24 hours. The SmartSL 4.0 solution embodies advanced production balancing and sequencing algorithms, as well as graph operating sequences for efficient management of sewing and pre-sewing production lines. It allows for dynamic assignment of workstations, leading to an unlimited number of simultaneous models, distinct operation sequences, and the possibility to assign priorities to manufacturing orders, thus, enabling the manufacturing of small series, with shorter lead times. This management and decision-support system provides detailed information on all executed operations and calculates performance KPIs at the shop-floor level, in order to evaluate if targeted objectives are being fulfilled.

In conclusion

Concerning IEs, advanced technologies such as APS systems and flexible internal logistics systems (data-driven), when combined with best practices of agile and integrated business processes, result in more resilient, sustainable and profitable enterprises.

LEARNING FACTORY

Learning by experimenting in a quasi-real environment — the enabling principle for understanding and acting in the context of the factories of the future.

ANA CORREIA SIMÕES [1]
ANTÓNIO HENRIQUE ALMEIDA [1]
AMÉRICO AZEVEDO [1,2]
[1] INESC TEC
[2] FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO
ana.c.simoes@inesctec.pt
antonio.h.almeida@inesctec.pt
americo.azevedo@inesctec.pt

The digitalisation of industry is a trend of no return. Addressing the different dimensions underlying digitalisation is a challenge for both academia/researchers and industry, with associated elements one ought to consider:

1. Ensure the adequate availability of a qualified workforce.

2. Achieve a practical awareness and understanding of cost-benefit related to the adoption of digital solutions.

3. Ensure effectiveness in the development of suitable initiatives to transform organisations.

Regarding industry, we found two distinct poles. On the one hand, the large companies, with their prevailing power and availability of resources, launching wide initiatives of testing, evaluation and adoption of technologies, as well as operating and organisational practices, in order to increase their competitive position in the market. On the other hand, many small and medium size enterprises (SME), generally with limited resources, acting fundamentally on a regional niche basis and without a strategic orientation in terms of business evolution. They end up having a reactive attitude, very much supported by the need for survival in the markets where they operate.

SMEs are the backbone of the Portuguese and European economies. These companies represent an important subset of the entire manufacturing industry, compared with larger enterprises, accounting for over two-thirds (68.4%) of overall value-added and over three quarters (78.0%) of employment [2]. Therefore, research and adequate knowledge transfer mechanisms are mandatory for the successful implementation of Industry 4.0 technologies and concepts in SMEs[3].
Consequently, and despite the exceptional competitive opportunities that digitalisation strategies open to companies, the implementation of this digital transformation in SMEs is not risk-free or straightforward. A key obstacle in the digitalisation process is the decision makers' lack of awareness of the digital technologies' potential and impact/implications. Some decision-makers reject digital transformation simply because they do not understand how it can be incorporated into their businesses[1]. Therefore, research centres, clusters, and Digital Innovation Hubs (DIH) are responsible for building the infrastructures and providing the support and the services that will progressively change this mind-set. Within a secure/protected environment and, following an iterative methodology, the risk is mitigated by trust and collaboration.
Considering this reality and ambition, especially among Portuguese SMEs, innovative training programmes and specialised innovation laboratories for technology experimentation and demonstration in almost real scenarios are crucial[4]. These tools and infrastructures must be flexible and adapt to all levels of the companies' hierarchy and organisation structures, from management to technical staff. This vision drives the design and

development of the Industry and Innovation Lab (iiLab) at INESC TEC - an industry 4.0 learning factory. This i4.0 compliant infrastructure allows the installation of digital technologies in a plug & play way to foster the demonstration of technologies with low effort and cost. In this way, it is possible to provide new services, thus helping SMEs interested in evaluating/considering the adoption of new technology and attesting their return on investment, with the support of a multidisciplinary team of researchers and a network of technology providers carefully selected.

In addition, this Learning Factory also provides programmes targeting decision-makers, according to an active training methodology, firmly supported by state-of-the-art knowledge and reference cases, hands-on experience and real applications. During these training sessions, the trainees/participants are expected to become familiar with a comprehensive set of concepts, principles, methodologies and tools capable of significantly improving decision-making capability at both strategic and tactical levels.

The scope of said programmes is multidisciplinary, in order to explore different thematic areas (self-contained) and cross-cutting thematic subjects, focusing on Industry 4.0 and the Digital Transformation paradigm.

The questions addressed relate to the digital maturity assessment, smart factories and flexible production systems, big data and artificial intelligence for smarter decision-making in Industry, and new production processes for new business models. In the same line of thinking, technology-oriented training programmes have been developed to meet the need for the upskilling of employees and to leverage the introduction of new technologies in the manufacturing industry. For example, areas such as cognitive automation, augmented and virtual reality, collaborative and industrial robotics, artificial vision, Industrial Internet of Things (IoT), and interoperability, among other technologies, are explored.

In order to materialise this vision, INESC TEC has defined a strategy of participation in a series of educational projects within the scope of EIT Manufacturing and other European projects, which serve as a foundation for the development and continuous improvement of the training programmes to be provided by the iiLab.

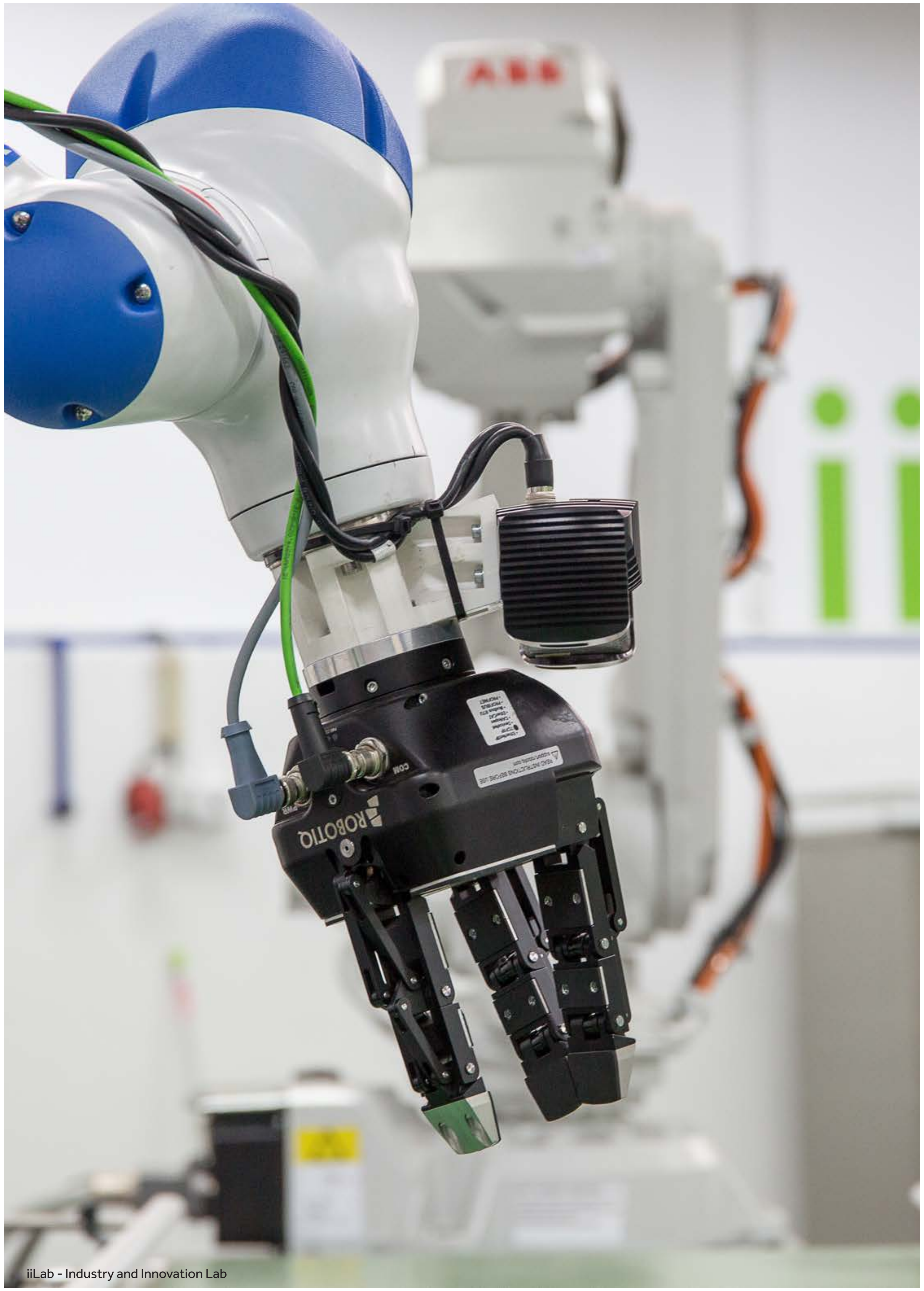
The idea behind these projects is to design a wide range of teaching and learning activities, focused on the most advanced processes and ICT-enabled production technologies, to support academic education, advanced training, R&D and technology transfer activities to different audiences.

[1] European Commission (2019), "SBA Fact Sheet: Portugal", Brussels

[2] Horváth, D. and Szabó, R. Z. (2019) Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?, Technological Forecasting and Social Change, 146, 119-132, https://doi.org/10.1016/j.techfore.2019.05.021.

[3] Reis, J., Amorim, M., Melão, N., and Matos, P. (2018) Digital transformation: A literature review and guidelines for future research, In: Rocha Á., Adeli H., Reis L.P., Costanzo S. (eds) Trends and Advances in Information Systems and Technologies. WorldCIST'18 2018. Advances in Intelligent Systems and Computing, vol 745. Springer, Cham. https://doi.org/10.1007/978-3-319-77703-0_41.

[4] Abele, E., Metternich, J. and Tisch, M. (2019) Learning Factories: Concepts, Guidelines, Best-practice Examples. Basel: Springer International Publishing.



iiLab - Industry and Innovation Lab

4

LOOKING INTO THE PAST

PORTUGUESE INDUSTRIALISATION: OVERCOMING A TROUBLESOME LEGACY

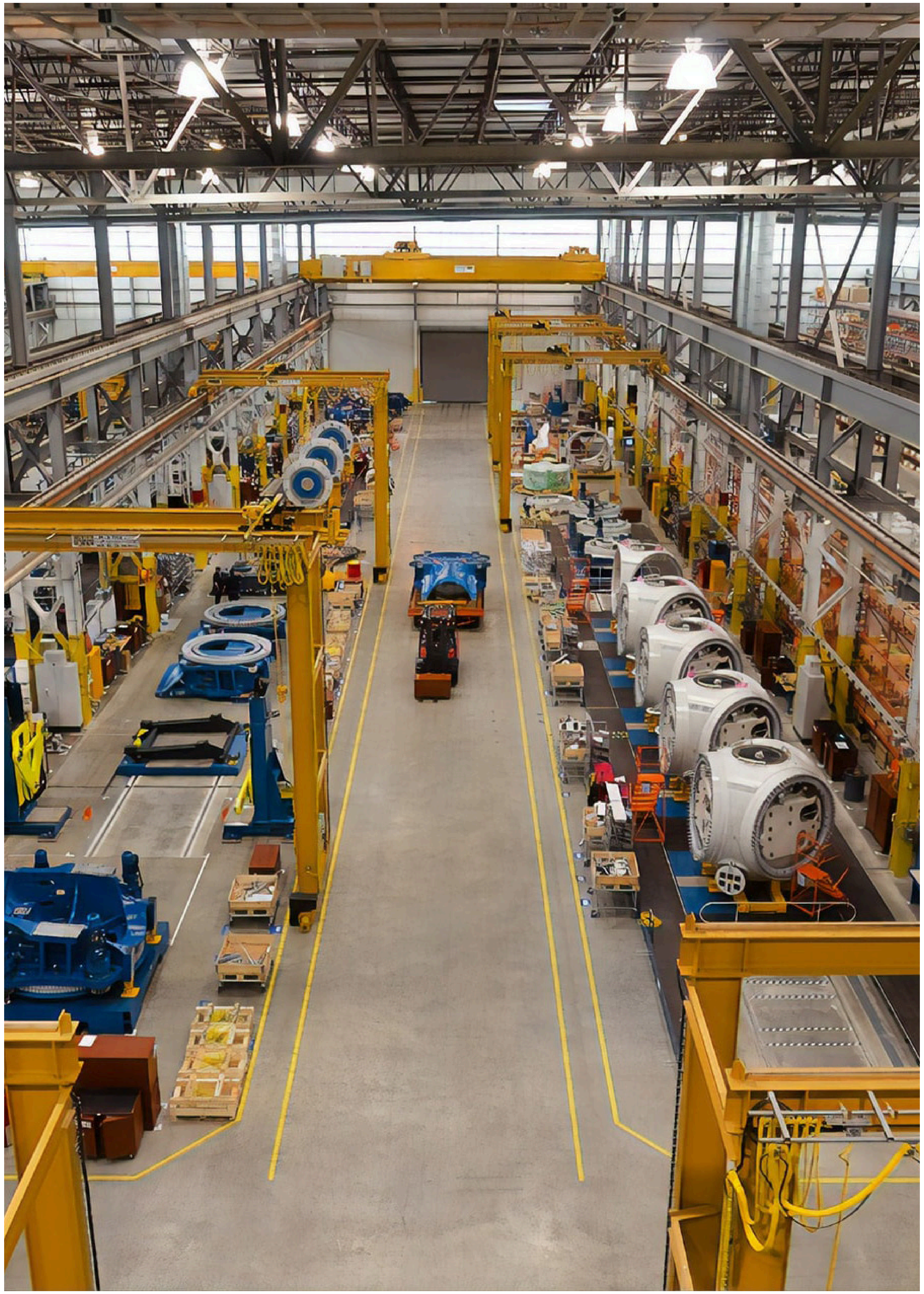
MARIA FERNANDA ROLLO [1]
ANA CRISTINA BARROS [2]
LUÍS CARNEIRO [2]
JOSÉ CARLOS CALDEIRA [2,3]
[1] NOVA UNIVERSITY LISBON
[2] INESC TEC
[3] MANUFUTURE
mffr@fcsh.unl.pt
ana.c.barros@inesctec.pt
luis.carneiro@inesctec.pt
jose.caldeira@inesctec.pt

With a past full of delays and constraints, with periods of widespread rejection to industrialization, as well as periods of accelerated economic development, Portugal reaches the fourth industrial revolution with a troubled legacy. However, Portugal is now ready to face the main challenges and contest a position among the more advanced countries, namely in terms of overcoming some of the more complex processes of the ongoing 4.0 revolution.

The recent landscape of the Portuguese industry, based on the fourth Industrial Revolution, points out promising perspectives, supported by the outcomes and international prominence achieved in different sectors. However, the innovative and relevant position of many Portuguese industrial companies falls in with the lack of industrial fabric and activities, preventing us from positioning the country at the level of the most industrialised nations. These circumstances call for a reflection that takes us to the past on two levels. On the one hand, it leaves us optimistic, yet hanging over the consolidation of an effectively winning position - or even a top position, considering a few of these sectors. On the other hand, it allows us to recognise the success in overcoming a repeated historical position as subordinate, which achievement ought to be emphasised, mainly due to the intensity and permanence of many factors that form the heavy burden of our industrial past.

A past characterised by delays, divergent strategies, hesitation or even disregard for the economic and social modernisation of the countries, which has conditioned the path of the Portuguese industry, keeping it, until very recently, in a much too modest position compared to the overwhelming majority of our European peers. We must address this aspect properly.

Having lost its way slightly from the first periods of the Industrial Revolution, Portugal could, just as many others have done, at a second glance, caught up with the industrialisation train, even benefiting from some advantages, and settling into the club of industrialised countries. We would only come to achieve this much later, more so due to necessity rather than sheer willpower - and in a context clearly conditioned by the political environment in which we found ourselves. In fact, and comparing to other countries, it took Portugal a century and half more (at the beginning of the 1950s) to reach a stage where the industrial sector surpassed agriculture, in terms of contribution to the GDP and working population. Moreover, only by the end of said decade - and after a first attempt, albeit frustrating, which took place after the end of the Second World War (spearheaded by Ferreira Dias, and the country's 1944-45 laws for electrification and industrial development and restructuring) - did the option for the industrialisation become genuinely accepted, notwithstanding the persisting hurdles. Finally, it was possible to settle the disagreement that opposed more progressive individuals, committed to a fast and generalised industrialisation of the country, to those that rejected this path, advocating the relevance of the agricultural activities and the modus vivendi associated with the rural world to the economic model framework, favoured by the Estado Novo



INDUSTRIAL REVOLUTION	INDUSTRIAL DEVELOPMENTS	START	PIONEER COUNTRY	RELEVANT FACTS IN PORTUGAL
First	Steam-powered machines	1780s	England	1820s: Establishment of the first steam-powered machines in factories [3]
Second	Mass production	1870s	United States of America	1944 – 1945: Approval of the electrification and industrial restructuring laws [4]
Third	Electronics, telecommunications and computers	1970s	United States of America	1975-7: Establishment of the first computers in factories [5]
Fourth / Industry 4.0	Cyber-physical Systems, Human-Machine Systems, Artificial Intelligence	2011	Germany	2017: Launching of the programme Indústria 4.0. (i4.0) [6]

Table 1 - Industrial Revolutions [1][2]

Following the trends and the international environment, a new stage of sustained and accelerated economic growth began, until 1973. During this period, Portugal reached unprecedented growth rates in national history, more so at the manufacturing sector level, while converging and coming close to more developed European countries, partially recovering from the delays. This growth and modernisation cycle incorporated structural changes, notwithstanding the resilient social and political resistance forces that, by persisting, had negatively conditioned the rhythm and reach of the modernising transformations, including at the industrial level.

Among other factors, it is important to recall the prevailing corporate context during the Estado Novo, and point out one of the most determining factors in the nature and dynamics of the Portuguese industrial fabric, which would lead to deep and long lasting repercussions: the industrial conditioning. The first experience of industrial conditioning came to light in Portugal in July 1926, during the Military Dictatorship, through a decree that altered the cereal products regime, encompassing the flour sector, promoting the restructuring and leading to its concentration. Despite emerging as an exceptional measure, the industrial conditioning expanded and became the general regime, lasting until the end of Estado Novo. According to this regime, it was not possible to create any industrial organisation, nor to modify the production capacity of existing businesses, without authorisation by the Government; in addition, companies should, under all circumstances, guarantee at least 75% of their capital originated in Portugal.

Are there a few people who remember this? One should not dismiss its relevance or forget about its impact, particularly during the post-war period: among other aspects, and very briefly, this decree meant that more than half of the new business requirements, including proposals for new industrial activities, were rejected immediately. In other words, all applications considered inconsistent with the prevailing reasoning behind any economic policy of Salazar's dictatorship, or even those against the established interests. The end of the industrial conditioning took place only a few decades ago, following the revolution of April 25, 1974.

Much more could be said regarding the 40-year industrial conditioning legacy, namely about all the actions that it limited and effectively prevented, in terms of dynamics and innovation - with long lasting repercussions to our industrial fabric composition, nature and behaviour. That is why it is important to recall historical revival, of a not so distant past, showing how proud we are of recent achievements of the Portuguese industry, while focusing on more comprehensive limits and opportunities regarding the paths to ongoing or future industrialisation.

Another aspect worth mentioning as we recall our troubled legacy is the relevance of training and the contribution of a scientific and technical-based knowledge for the establishment of the manufacturing fabric, particularly the industrial. Within this scope, it is important to highlight the delays regarding the fundamental education of the population in general and the specialised training of the Portuguese workforce, as well as the overdue nature and decisions made in terms of education planning and definition of different fields of engineering - together with the resistance to innovation, the adoption of science-based knowledge, and technological development; all of these are elements that characterise the majority of the industrial fabric, stemming from the low level of training of most entrepreneurs.

Simply put, the number of engineers with degrees in Portugal only improved significantly over the past few years, (from 356 in 1950/51, to 622 in 1974/75, and to 3500 in 2001/02). Moreover, the generalised implementation of engineering in factories, and in the manufacturing sector, together with the engineers'

entry in these markets, is also very recent. In addition, and still within this context, the changes observed in Portugal in the not so distant past bear relative and absolute prestige and dimension. Moreover, there are many reasons why it is important to point out the successful dynamics of the so-called traditional industrial activities, which currently take up a relevant position in our manufacturing sectors, and even an internationally competitive position, with emphasis on the footwear, textile and mould-making sectors.
Also noteworthy is the impact and transformation stemming from the Portuguese economy and society's internationalisation processes during the last decades. Once more, we recall the legacy of a long period of authoritarianism and autarky brought down by the April 25 revolution, in 1974. The democracy has established itself as the European choice par excellence, presenting opportunities for Portugal's integration in the current European Union, while opening the country to the world. After less than half a century of democracy, during which time the transformation process of the Portuguese society was both quick and profound, the Portuguese industry has now the capacity to face the main challenges and contest a position among the more advanced countries, namely in terms of overcoming some of the more complex processes of the ongoing 4.0 revolution.

[1] Monostori, L., B. Kádár, T. Bauernhansl, S. Kondoh, S. Kumara, G. Reinhart, O. Sauer, G. Schuh, W. Sihn, and K. Ueda. 2016. "Cyber-physical systems in manufacturing." CIRP Annals, 65(2): 621-641.

[2] Mowery, D.C. 2009. "Plus ca change: Industrial R&D in the "third industrial revolution"." Industrial and corporate change, 18(1): 1-50.

[3] Rosas, F. 2014. "História a história - A máquina a vapor, RTP/ Garden Films https://ensina.rtp.pt/artigo/maquina-a-vapor/

[4] Rollo, M.F. 2011, "Em prol da electrificação do País - I", Revista Ingenium N.º 122 - Março/Abril de 2011, https://www.ordemengenheiros.pt/pt/centro-de-informacao/dossiers/historias-da-engenharia/em-prol-da-electrificacao-do-pais-i/

[5] Almeida, J.M.F. 2003. "História da Informática em Portugal: o subsistema de informação da CUF / Quimigal", Memórias das tecnologias e dos sistemas de informação, http://www3.dsi.uminho.pt/memtsi/livros/mesa8.pdf

[6] https://www.iapmei.pt/Paginas/Industria-4-0.aspx

5

CURRENT THEMES

POST-NORMAL SCIENCE

SUSANA BARBOSA [1]
[1] INESC TEC;
susana.a.barbosa@inesctec.pt

In the current times of a pandemic and of new lexicons as the "new normal", the expression "post-normal science" can evoke the effects of the epidemic situation in science.

However, the concept of post-normal science was developed in the previous century (FUNTOWICZ AND RAVETZ, 1990), motivated by disasters such as the explosion of Chernobyl or of the Challenger space shuttle, both paradigmatic of catastrophic risk management. According to this concept, a scientific domain can be considered to be in a post-normal state when uncertainty is very large, cultural values are at stake, societal risks are high, and decisions are urgent. Considering this definition, climate science is an obvious example of a post-normal science (BRAY and VON STORCH, 1999), and the COVID pandemic in 2020 highlighted post-normality in many other areas.

Modern science follows principles summarised by the sociologist Robert Merton (MERTON, 1973) in the acronym CUDOS of Communalism (common property of scientific discoveries, promoting collective collaboration), Universalism (using universal and impersonal criteria, regardless of gender, race, religion), Disinterestedness (actions motivated by the common scientific good and not by personal gain) and Organized skepticism (impartial critical scrutiny, peer review). As a human cultural activity, science cannot be entirely objective but still strives diligently for objectivity and nurtures self-correcting mechanisms. A scientific fact is not understood as an absolute truth, but rather as the most plausible explanation, taking into account the observations and scientific theories considered valid. As such, it can be replaced by an alternative explanation in face of new data or new knowledge. A fact is not scientific, even if expressed by a scientifically educated individual or a professional scientist, if the scientific method is not followed, for example when alternative explanations are not considered, or when an explanation is chosen just because it agrees with a specific school of thought. Although these are well established and widely accepted principles of scientific practice, their application is put to the test in post-normal conditions.

The social pressure to which scientific practice is subject under post-normal situations affects the scientific process itself and its results. In post-normal conditions, the predisposition to choose topics considered socially relevant is inevitable, and explanations consistent with the dominant social view preferred. For example, considering climate, the usefulness of science to either achieve the objectives of the Paris Agreement or to postpone profound economic changes becomes the main focus, rather than the soundness of the science that informs those decisions. The usefulness of science, and its consistency with cultural and political preferences, becomes more important than its solidity in terms of methodological rigor (for example, consistency with Merton norms). Paradoxically, the usefulness of science to inform decision-making processes becomes then significantly reduced, since it no longer has the distance, focus and impartiality that are precisely its strength.

In order to maintain the undeniable usefulness of science to society, particularly in understanding complex phenomena, even in emergency and high-risk situations, as in the case of climate change, science should insist on the methodological rigor that is its strength. Education of younger generations of scientists on the fundamental principles of rigorous scientific inquiry is crucial (RAVETZ, 2019), and more emphasis should be given to science education than to apparently less useful subjects, such as philosophy or the history of science. For those who do not deal directly with scientific issues, it is even more difficult to comprehend the distinctive character of the scientific method, resulting sometimes in the overestimation of the power of science and in what it can effectively contribute to society, and at other times to the underestimation and discredit of scientific results. This polarization is exacerbated in post-normal situations, when science is seen as either meeting or failing societal expectations, irrespective of science's validity.

Science should remain within its domain of competence, which is inevitably very limited in terms of the scope of the reality it describes. In post-normal conditions, science tends to lean towards politics, as the political utility of scientific conclusions becomes more important than its scientific soundness, and politics tends to lean towards science, as political decisions are presented as being based on univocal and non-uncertain scientific knowledge. This bending should be corrected. Science should focus on its hard core of competence, recognising that scientists have very deep knowledge but a narrow focus, and politics on promoting open and inclusive decision-making processes, based on science, but taking into account its uncertainties and unavoidable restricted domain. When leaving the territory of science to enter public or policy-making spheres, it is important to humbly recognize that scientific knowledge is very focused and therefore limited, providing only one component of all the knowledge that is necessary to deal with complex problems such as climate change. The definition of public policies and the response to complex societal challenges must therefore involve not only scientists in the field of natural sciences, but also specialists from other areas, including social sciences, as well as stakeholders from different domains and sectors of society, all respecting limitations and forces of each other for a more constructive and democratic decision-making process.

[1] FUNTOWICZ, Silvio; RAVETZ, Jerry (1990) - Post-normal science: A new science for new times. Scientific European, 20-22.

[2] BRAY, Dennis; VON STORCH, Hans (1999) - Climate Science: An Empirical Example of Postnormal Science. Bulletin of the American Meteorological Society 80, 439–455.

[3] MERTON, Robert (1973) - The Normative Structure of Science, in Merton, Robert K. (ed.), The Sociology of Science: Theoretical and Empirical Investigations, Chicago: University of Chicago Press, 267-273

[4] RAVETZ, Jerry (2019) - Stop the science training that demands' don't ask' , Nature 575(7783), Nature Publishing Group, 417–418.

POLICY RECOMMENDATIONS FOR NEXT GENERATION SUPPLY CHAINS

RICARDO ZIMMERMANN [1]
PEDRO PINHO SENNA [1]
ANA CRISTINA BARROS [1]
[1] INESC TEC;
ricardo.a.zimmermann@inesctec.pt
pedro.senna@inesctec.pt
ana.c.barros@inesctec.pt

The COVID-19 pandemic has highlighted the importance of supply chains and has taught us much about their management. This article presents strategies that companies may use to prepare for future challenges, and recommendations for decision-makers towards the competitiveness and resilience of upcoming European supply chains.

For the past year, the COVID-19 pandemic has taught us much about supply chain management. On the one hand, it taught us how to design a supply chain, from product development (in this case, the vaccine) to distribution to the final customer. On the other hand, it showed us how to re-design and manage companies' supply chains, in order to deal with the frequent disruption of the flow of materials. This is the latest example of a global phenomenon that led society to rethink our way of life, with a significant impact on economy and, in particular, on supply chains. At the same time, global warming is becoming an increasingly urgent issue, and we must face it to ensure future generations' quality of life. Critical issues related to social, sanitary, humanitarian and economic aspects have arisen with increasing frequency and scope, challenging us to find effective and innovative solutions. Furthermore, globalisation and new consumption habits have drastically increased the complexity of supply chains, requiring new ways to address a constantly changing market supply. The fast evolution of digital technologies also influences the way companies do business.

These and other present-day challenges have had a significant impact on companies, regarding business management approaches and, in particular, their supply chains.

The rate of change has been so intense that the task of predicting what happens in the future becomes quite difficult. Obviously, a common method to deal with all obstacles and trends does not exist; therefore, it is necessary to keep thinking about the future, in order to be prepared to act and face the challenges that may arise. In this sense, INESC TEC has worked closely with many European entities during the last three years, in a project financed by the European Commission, focusing on reflecting upon the future of European supply chains (results are available in the book "Next Generation Supply Chains: A Roadmap for Research and Innovation" [1]).

Considering the main political, economic, social, technological, legal and environmental trends, we have developed six different scenarios for the supply chains of the next decade, mapped and analysed the technologies that will be a part of future solutions, and proposed a set of strategies applicable to different contexts.

Results show that the consideration of which strategy to adopt dictated the companies' own characterisation of supply chains, according to eight dimensions: Products and Services, Supply Chain Paradigm, Sourcing and Distribution, Technology Level, Supply Chain Configuration, Manufacturing Systems, Sales Channel and Sustainability. By analysing their specific context regarding these dimensions, companies may adopt several strategies for supply chains, like establishing global chains, urban chains, resource-efficient chains, closed loop chains, disaster-relief chains, customer-driven chains, service-driven chains, human-centred chains, hyper-connected chains or biointelligent chains.

Finally, we ask ourselves the following question: what are the main actions that public/private actors should develop in order to help European supply chains prepare for future challenges? With the support of a significant number of experts – academics and professionals in the

area of supply chain management – we identified a set of transversal topics that affect all supply chain dimensions and strategies, applicable to all industrial sectors (Key Horizontal Issues). These topics include issues related to: standardisation, regulatory framework, training and education, international agreements, funding and incentives, reference bodies and infrastructure.
Supported by these topics, and considering the European Commission's guidelines for technological innovation, research and development (Horizon Europe), we developed a set of recommendations. The main target-audience is the European Commission, including institutions that regularly support this body in the decision-making process, such as research centres, technological centres, public-private partnerships and industrial associations.
The recommendations are presented in three different forms: (1) a policy, understood as a set of ideas or plans to be used as a basis for decision-making, and representing a long-term commitment; (2) a project, which is a temporary effort to create a specific solution; or (3) a programme, which can be defined as a set of related projects, managed in a coordinated way in order to obtain broader benefits. The twelve recommendations are:

- Fostering the harmonisation of legislation and standards on European supply chains;
- Disseminating standards among European supply chain stakeholders;
- Facilitating and boosting multimodal transportation;
- Developing the workforce for the supply chains of the future;
- Promoting bi-lateral and multi-lateral agreements that consider a holistic supply chain perspective;
- Supporting the establishment of R&D networks for the advancement and dissemination of supply chain-related topics;
- Enhancing collaboration based on the results of European Projects: creation of a platform to serve as a data repository;
- Establishing a prize to support and spread best practices in European supply chains;
- Creating synergies between public and private sectors in funding actions;
- Creating a European supply chain knowledge hub for sustainable, resilient and inclusive supply chains;
- Upgrading infrastructures towards low-emission supply chains;
- Promoting the usage of 5G networks and autonomous vehicles (AVs) to improve urban supply chains.

Each recommendation resulted in a policy brief [2], presented and delivered to potential decision-makers related to the domain. This set of recommendations will potentially contribute to the competitiveness of forthcoming European supply chains, but also to the development of a fairer, more collaborative and sustainable society for future generations.

[1] Fornasiero, R., Sardesai, S., Barros, A. C., & Matopoulos, A. (2021). Next Generation Supply Chains: A Roadmap for Research and Innovation, https://www.springer.com/gp/book/9783030635046

[2] Next Horizons for European Supply Chains - Strategic Research and Innovation Agenda (2019), https://nextnetproject.eu/wp-content/uploads/2019/12/DosierParaImprenta_mailing.pdf

SUPPLY CHAIN STRATEGIC DIMENSIONS

Product & Service
Mainstream Products, Customized Products, Frugal Products, Servitization

Supply Chain Configuration
Hyperconnected Factories, Modular Systems, Urban Manufacturing, Simple Systems

Supply Chain Paradigm
Efficient, Agile, Leagile, Risk-hedging

Manufacturing Systems
Digital Lean Manufacturing, Digital Mass Customization, Agile Manufacturing, Flexible Manufacturing, Efficient and Reconfigurable Manufacturing

Sourcing & Distribution
Global, Local, Glocal

Sales Channel
Omnichannel, Consumer to Consumer (C2C), Traditional Sales Channels

Technology Level
Digital Masters, Tech Fashionistas, Tech Beginners, Tech Conservatives

Sustainability
Closed-loop, Green, Resource Efficient, Social Responsible, Humanitarian SC

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