Position Paper n° 1

CONTEXT, TECHNOLOGY AND SEMANTICS OF THE DIGITAL TRANSITION IN THE GLOBAL MARKETS.

THE STEEL SECTOR.

The ESTEP Smart Factory Focus Group

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Note

The Chairperson informs that during the preparation of some paragraphs, the ChatGPT 3.5 of OpenAI and its free version was used as an evaluation experiment to test the impact on this kind of work.
The result was very positive in term of decreasing the spent time resulting into an interesting acceleration of the time needed.
However, and according to many publications the hands of Authors are absolutely necessary to refine the concept and even to intervene on the logical redline of the proposed text change such as for example the priorities of the arguments.
Moreover, in Rev 3.5 is also evident the lack of precision when the requirements of technical details progressively increase.

Summary

List of Acronyms

AI	Artificial Intelligence
A.SPIRE	Association SPIRE
BB	Building Block
BF	Blast Furnace
BOF	Basic Oxygen Furnace
CAGR	Compound Annual Growth Rate
CAPEX	CAPital EXpenditures
CE FG	Circular Economy Focus Group
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Usage and Storage
CDA	Carbon Direct Avoidance
CE	Circular Economy
COM	Commission (European)
CPPS	Cyber Physical Production System
CPS	Cyber Physical System
CS	Crude Steel
CSP	Clean Steel Partnership
DB	Database
DCS	Distributed Control Systems
DML	Digital Maturity Level
DR	Direct Reduction
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
ERP	Enterprise Resource Planning
ESTEP	European Steel Technology Platform
EU	European Union
GeSI	Global e-Sustainability Initiative
GMS	Global Market Size (of expenditures)
H2020	Horizon 2020
H2M	Human to Machine
HMI	Human to Machine Interface
HMS	Holonic Manufacturing System
I2M	Integrated Intelligent Manufacturing
I3.0	Industry 3.0, the 3rd stage of the manufacturing evolution based on computers
I4.0	Industry 4.0, the 4th industrial revolution based on the full digitalization of manufacturing
I5.0	Industry 5.0, the 5th stage of manufacturing evolution based on the human centrality
IaaS	Infrastructure as a service
IIoT	Industrial Internet of Things
IoT	Internet of Things
IBRSR	Iron Bath Reactor Smelting Reduction
ICT	Information and Communication Technology

ISA	International Standard for Automation
ISO	International Standardization Organization
IT	Information Technology
HEU	Horizon Europe
MAS	Multi-Agent System
MES	Manufacturing Execution System
MFP	Multi-Factor Productivity
ML	Machine Learning
M2M	Machine to Machine (connection)
OHSAS	Occupational Health and Safety Management System
OPEX	OPErational EXpenditure
OSI	Open System Interconnection
OT	Operational Technology
PaaS	Platform as a service
PI	Process Integration
PPP	Public Private Partnership
PPP	Profit, Planet, People
R&D&I	Research, Development and Innovation
RoI	Return of Investments
RoR	Rate of Return
RFCS	Research Fund for Coal and Steel
SaaS	Software as a Service
SCADA	Supervisory Control And Data Acquisition
SCU	Smart Carbon Usage
SF FG	Smart Factory Focus Group
SOA	Service Oriented Architecture
SoS	System of Systems
SPIRE	Sustainable Process Industry through Resource and Energy
SRA	Strategic Research Agenda
TCP/IP	Transmission Control Protocol/Internet Protocol
TRL	Technology Readiness Level
VTT	Technical Research Centre (in Finnish)

CONTEXT, TECHNOLOGY AND SEMANTIC OF DIGITALISATION
THE SF FG POSITION PAPERS
Introductory Document

1 Introduction.

This document introduces the series of Position Paper (PP)[1] discussing the role the *Digital Transition*[2] and the Digitalisation within the decarbonisation of the European steel industry. It aims at sharing terms, definitions and meanings of the Digital Transition of the European manufacturing industry which represents one of the two legs of the *Twin Transitio*n embraced by the EU.

Thus, definitions and terms will be used in the following Position Papers to be published by the *Smart Factory Focus Group* (SF FG) of the European Steel Technology Platform (ESTEP[3]) dealing with the most important advances of the Information & Communication Technologies in the field of Digitalisation.

The ESTEP represents the target audience and the context of the discussion having the "*mission to engage in collaborative EU actions and R&D&I projects on technology, which are tackling EU challenges (notably on renewable energy, climate change and low-carbon emissions and, circular economy) to create the sustainable EU steel industry*".

Furthermore, this introductory PP is established to collect and share a digital vocabulary and related semantic specific of the digital domain within the steel sector. To do that, definitions and descriptions of meaning are introduced through a short overview of the current challenging steel context in Europe.

To close these preliminary notes, it is important to underline that this document refers to the contents of the Clean Steel Partnership Strategic Research and Innovation Agenda (CSP SRIA[4]) for what concerns the general and specific information regarding the Green Technologies, the European context including the R&D&I Pathways which are the foundation and the general framework of the green transition of steel manufacturing.

2 Ambitions

This Position Paper has the following ambitions:

1. In the first part of the document, the ambition consists in giving the most referenced definitions of the Digital Transition related to the introduced concepts for providing a shared vocabulary and semantics.
2. To establish an approach based on quantitative economic considerations to analyse the forecasted trends of the key digital technologies determining the Digital Transition that, in turn, enables the Twin Transition of the Industry Sector with the assumption that they are indicative also for the Steel Sector. The used database has been built up with the access most referenced free literature sources relevant to the economic and technological trends regarding the digital technologies that are reported in Appendix 2.
3. Based on that, the ambition of the second part consists in determining the technological priorities of investments through the comparison of the intensity of expenditures of the last three years and the referenced forecasts up to the 2030.
4. The above-mentioned technological priorities can be used for designing and implementing the Digital Transition Plan to achieve the Smart Factory status assumed as the most effective and efficient reference model for decarbonising the steel sector in parallel to the implementation and deployment of steel manufacturing novel technologies.

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1 The term Position Paper means a synthetic document designed for 1) stating an organization's policy or position about a subject (in the digital domain, this is understood as a specific digital technology or an ensemble of digital technologies). 2) putting a problem or question and then answering such question with information or a proposed solution also called an Issue Brief (that is meant as Issue Brief is a that includes basic information about an issue and specific or general concerns).

2 Transformation is often used as synonym of Transition.

3 https://www.estep.eu/estep-at-a-glance/

4 https://www.estep.eu/assets/CleanSteelMembersection/CSP-SRIA-Oct2021-clean.pdf

3 The Twin Transition of the Manufacturing Industry. Definitions and description.

The so-labelled Twin Transition considers two legs represented by the Digital Transition and the Green Transition. The conceptual context of the PP considers three topics strictly included in the Twin Transition perimeter:

1. *Sustainable Manufacturing.*
2. *Smart manufacturing*
3. *Smart Steel Factory*.

All are connected into a cascade sequence of relationships as shown in Fig. 1, where Smart Manufacturing enables Sustainable Manufacturing though the deployment of Digitalisation within Smart Factories belonging to both.

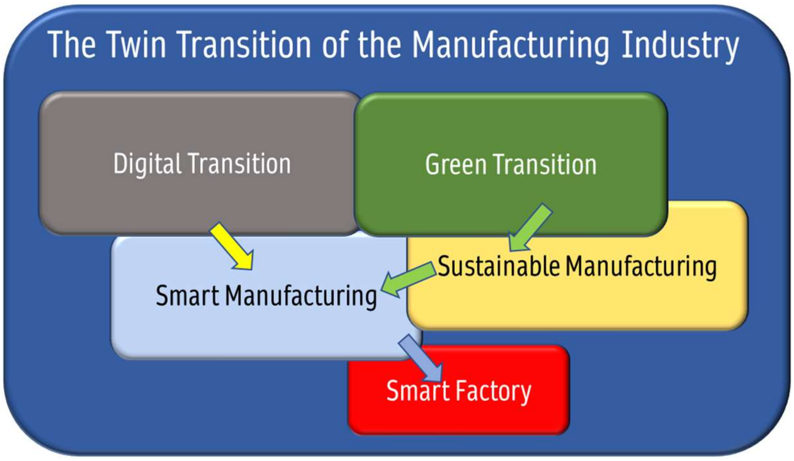

Fig. 1 The cascade pathway toward the Smart Factory: from the most general to the most specific along the Digitalisation pathway.

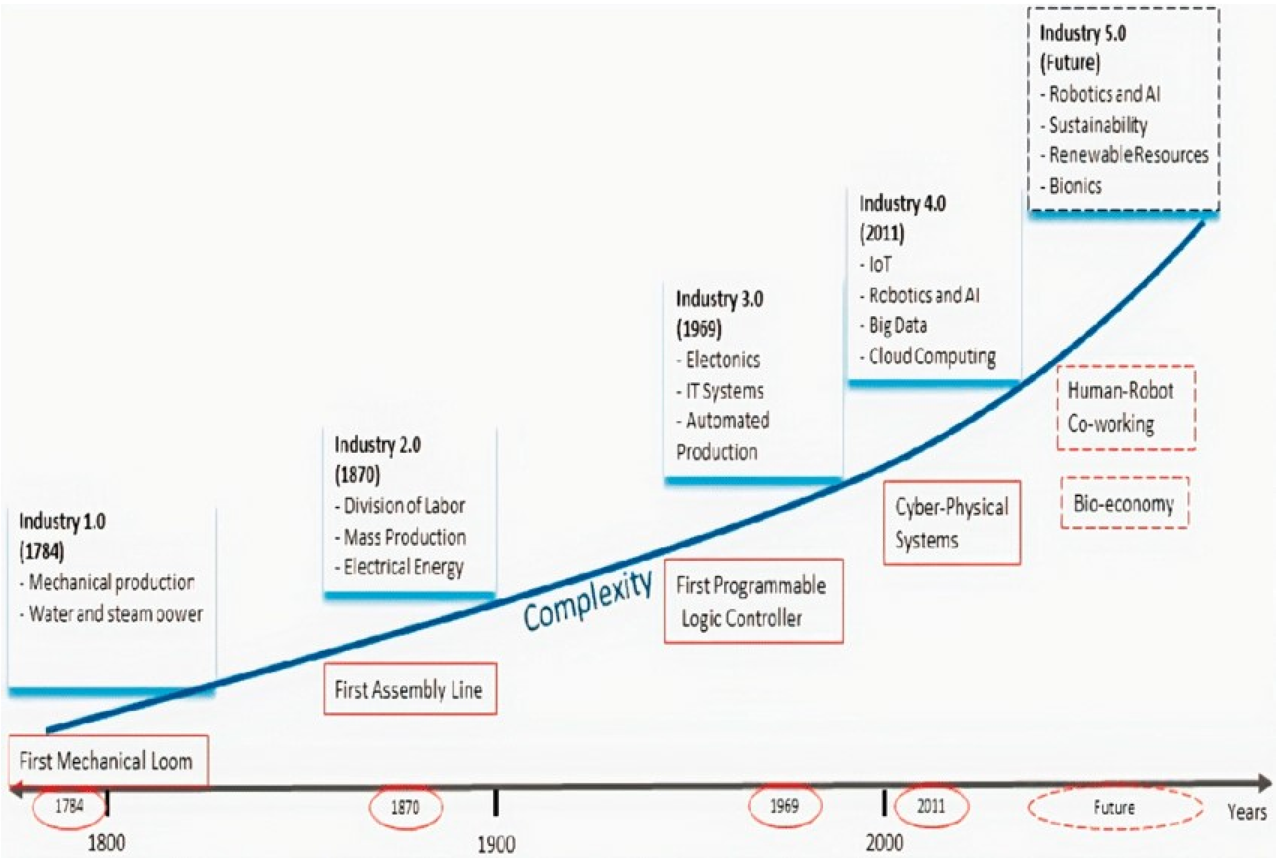

Fig. 2 The historical view of the Industrial Models

In accord to this schema, the pathway toward the decarbonisation and the two cornerstones of 2020 and 2050 will be considered for the steel sector and relevant definitions and concepts will be discussed.

Aimed at introducing a shared semantic, two premises and three definitions are introduced. Starting from two premises:

- ✓ First, *Smart Manufacturing* is part of the *Digital Transition and Sustainable Manufacturing* is part of the *Green Transition*.
- ✓ Second, *Smart Factory* is part *of both the Sustainable Manufacturing and Smart Manufacturing* like the last ring of a chain.

To introduce the definitions of *Digital Transition*, that is a general concept applicable to each industrial sector, it is necessary to consider the sectorial specificities, in particular for the Steel Sector that is of our direct interest. Instead, *Smart Manufacturing* shares most concepts with some more limited distinctions[5].

3.1 Digital Transition, Digitalisation and Digitisation.

Digitalisation[6] can be defined as ***"the socio-technical processes surrounding the use of (a large variety of) digital technologies and their impact on social and institutional contexts that require and increasingly rely on digital technologies"***

Instead, **"*digitisation*[7] *is the technical conversion of analogue information into digital form*"**.

The progression of the Digital Transformation is shown in Fig. 2[8] whose roots lie in the first Industrial Revolution of the beginning of '700 with the advent of steam powered machines. The second relates essentially to the themes of industrial production models (I2.0). Finally, the three further steps refer to the appearance and diffusion of the Informatic.
The first step, named the Industry 3.0 (I3.0) takes almost 50 years form the 40's since the development of the Turing Computational Machine (1943) up to the Arpanet (1969) and then its evolution into the Internet (1991). In this period many events characterised the evolution of digitalisation leading to the concept of Factory Automation, as we know it today also named the Industry 3.0 (I3.0). The combination of networking, the development of computing machines and the connection between sensors and software-controlled actuators through Programmed Logical Controllers (PLC) enabled by the dramatic evolution of micro-electronics lead inevitable to the Industry 4.0 (I4.0) officially born in 2011.

More in deep, the I4.0 condenses the dramatic change of manufacturing and related business processes evidencing additional aspects of growth such as the creation of value[9] from data made possible by the pervasive diffusion of the Internet, the Big Data, the large social platforms, the IoT, the AI and the intelligent and autonomous systems[10].etc.

This leads to consider the time factor and the acceleration of complexity [i.e., the derivative of the function *Complexity(t)*] highlighting the acceleration of the digitalisation process which suggests speaking about *revolution* because the disruptive impact mostly stays on the *acceleration of the Digitalisation process* (which enables the *acceleration of manufacturing processes*).

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5 Smart Manufacturing has two main lines having many commonalities but also substantial differences: the batch industry and the process industry. Furthermore, some concepts belonging to Smart Manufacturing can be applied in terms of services within the trend of privileging use instead of ownership for those not considered strategical such as cloud applications, Platforms (or extensively, Platform Economy) etc.

6 Tilson, Lyytinen, & Sørensen, 2010, mentioned by Kelly Rijswijk, "Digital Transformation: Ongoing digitisation and digitalisation processes", Wageningen University & Research, The Netherlands.

7 Despite Digitisation and Digitalisation are frequently confused each other however, "Digitisation must be understood as the transformation of analogical information into digital formats".

8 Source: F. Aslam, W. Aimin, Mingze Li, K. Ur Rehman, "Innovation in the Era of IoT and Industry 5.0: Absolute Innovation Management (AIM) Framework.", Information (Switzerland), February 2020, DOI: 10.3390/info11020124, https://www.researchgate.net/publication/339481698 .

9 https://www.gartner.com/en/information-technology/glossary/digitalization.

10 This evolution is not pushed by the ethical issue rather than technological factors and business pressure. However, the possibility to satisfy the ethical issue is not secondary because up to now, the human factor is central creating and "consuming" value.

From Fig. 2, the I3.0 seems to be simply a label corresponding to specific characteristics assumed along the time since the 1944[11] and characterised by the slow rate of digital growth corresponding to a longer duration of equipment (and investments) whose shortage represents one of the biggest disruptions (and issues) of the I4.0[12].

3.2 Industry 3.0, 4.0 and 5.0.

Looking more in deep to the three steps I3.0, I4.0 and I5.0, the Industry 3.0 prevalently refers to the automation of factories and the IT-based business models. The best way to understand the passage consists into analysing the key differences in the context of manufacturing. The main differences between I3.0 and I4.0 lies prevalently on the automation of processes based on logic processors and information technology still programmed by humans in a deterministic way such as not to require its presence in the execution phase of the program itself.

Instead, the Industry 4.0 uses large quantity of data taken from the production floor in a way in which systems can self-program themselves. It does not mean that humans disappear, but the trend consists in changing their role toward organisation, design and supervision.

Moreover, whereas systems and assets in the I3.0 way can also run separately and reconciliated by humans, their integration in the Industry 4.0 is obtained through the seamless flow of data from field. Considering the complexity that the integration of actual digital technologies allows the implementation of the integrated data-driven manufacturing model, it is important to include the centrality of the Human Factor as part of this paradigm.

In this line, the advent of the Industry 5.0 follows the need to overcome the impression that people are becoming more and more passive towards digitalization or playing a secondary role with respect to economic issues.

Instead, while the theme of Industry 4.0 revolves around connectivity through cyber-physical systems, Industry 5.0, even though also aligned with platforms made possible by Industry 4.0, also addresses the relationship between "man and machine"[13]. In this view, it also evident that aspects such as ethical issues take and important role due to the assumed human centrality.

3.3 Definitions of Twin Transition and Sustainable Manufacturing.

Once the paradigm of Digitalisation has been clarified to be the industry 5.0, the *Twin Transition* (Paragraph (3.1) is composed by the parallel and interconnected transformations of *Society, Industry and Economy* (labelled as the *Green Transition* or *Sustainability Transition*) enabled by *Digital Technologies* labelled as the *Digital Transition.* In Fig. 3, the enabling impact of Digitalisation and the strict connection between the two Transitions is shown highlighting the particular intensity in the overlapping zone called the *Sweet Spot* which regards particular sectors and technologies. Among them, we can consider the so-called Digital Megatrends (see chapter 4).

However, the resulting complexity and the mutual interactions between needs coming from the Green Transition and the enabling effects of Digitalisation represent two faces of one coin, the concept of *Sustainability*.

Therefore, beginning with the *Twin Transition,* the EU defined the Twin Transitions as ***"the key to decarbonising the economy and adopting a circular development model, transforming linear industrial value chains to minimise waste and pollution and making better use of the waste generated, to optimise resource and guaranteeing environmental standards[14]"***.

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[11] Historians of science and technology have different opinions regarding the date in which Digitalisation was born. Some assume the 1944, corresponding to the installation of the first Touring Machine. Others prefer the 1948 on which Claude E. Shannon described digitalisation as we know it today in its seminal paper "A Mathematical Theory of Communication" (The Bell System Technical Journal, Vol. 27, pp. 379–423, 623–656, July, Oct, 1948). Furthermore, others assume 1969 with the installation of the ARPANet (label for the Advanced Research Projects Agency Network), with which the first network based on communication packet switching was installed by DARPA (Defence Advanced Research Project Agency) to connect computing centres of Universities, R&D Labs and military entities. https://people.math.harvard.edu/~ctm/home/text/others/shannon/entropy/entropy.pdf.

[12] For example, in the era of mainframes, the IBM 360 took 20 years from 1970 and its successor IBM 390 roughly 12 years.

[13] International Society of Automation, https://blog.isa.org/whats-the-difference-between-industry-40-industry-50.

[14] https://www.insight-erasmus.eu/what-is-twin-transition/

In this definition, the three pillars of *Sustainability* synthetically labelled ***Prosperity, Planet, People*** are explicitly mentioned leading to the conclusion that the Twin Transition is a combined process having the goal to implement the *Sustainable Society and Industry*.

Thus, based on the definition of Sustainability [15] and its further revision by financial players[16], ***Sustainability represents the way to fulfil the needs of current generations without compromising the needs of future generations, while ensuring a balance between economic growth, environmental care and social well-being".***

Accordingly, the *Sustainable Manufacturing* represent the aim focusing the manufacturing industry This definition underlines the centrality of *Digitalisation* of the triangle shaped from the three pillars.

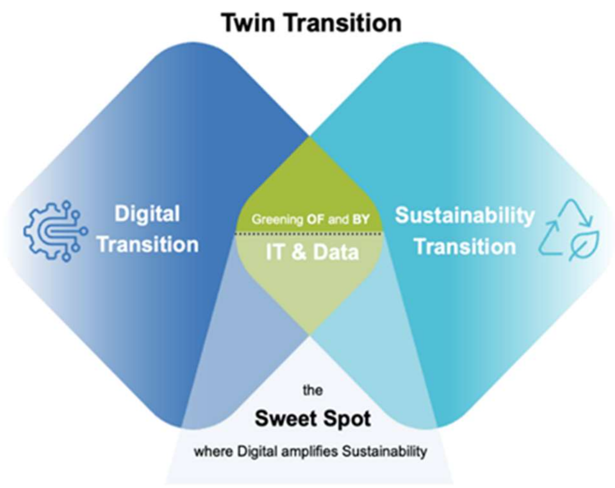

Fig. 3 The Twin Transition.
Source: World Economic Forum, Oct 2022. https://www.weforum.org/agenda/2022/10/twin-transition-playbook-3-phases-to-accelerate-sustainable-digitization/.

Regarding the Manufacturing Industry and steel in particular, the definition implicitly anticipates the concept of ***Sustainable Manufacturing*** is introduced and defined as "***the creation of manufactured products through economically-sound processes that minimize negative environmental impacts while conserving energy and natural resources. Sustainable Manufacturing also enhances employee, <u>their culture</u>, community, <u>product and workplace safety</u> and, organisation and <u>data security</u>[17]***".

From these considerations, a *physical representation* of the Sustainable Manufacturing must be introduced with the aim to give concreteness to what has to be deployed and in which combination as well.
Such *physical representation* is in general understood as the *Smart Factory* whose declination in the steel context is named *Smart Steel Factory*.

3.4 Definition of the Smart Steel Factory.

The ***Smart Factory*** is a status assumed by complex manufacturing systems when the Twin Transition is achieved. It is based on *manufacturing and digital technologies deployed for managing the complexity of manufacturing systems through novel organizational models aimed to ignite the transformation of the key processes"* of the steel sector.
In the ***Smart Steel Factory***, the cooperative environment between *humans and machines* aims to condense the most significant aspects of the I4.0 and I5.0 (introduced in 3.2) represented by:

1. *Centrality of humans* in processes.
2. *Empowerment of human's capabilities.*
3. *Deployment of Intelligent Machines*.[18]
4. Making feasible *Sustainable Manufacturing* into a Sustainable society.

Based on these considerations, the Smart Steel Factory is also defined as follows:

"***The Smart Steel Factory is a safe and secure plant based on the integration of factory automation into a network of connected intelligent and autonomous systems, humans and digital services. The Smart Steel***

[15] The United States Brundtland Commission, 1987, https://www.un.org › academic-impact › sustainability
[16] https://www.becas-santander.com/en/blog/what-is-sustainability.html, April 6, 2022
17 Such definition is taken largely from: EPA, United States Agency for environment protection, https://www.epa.gov/sustainability/sustainable-manufacturing [9]. The underlined terms have been further implemented by the Authors.
18 The Intelligent Machines are able to learn and automatically adapting/reconfiguring themselves to the circumstances.

Factory is respectful of the environment by enabling full carbon neutral steel manufacturing and integrating production and humans toward efficiency while dynamically exploiting human expertise"[19].

As said in paragraph 3.2, regarding the Digitalisation process, the Smart Steel Factory is modelled upon the I4.0/I5.0 paradigm. So, the process for achieving such status requires monitoring the evolutive process and the assessment of some selected states, typically represented by the achievement of key milestones described by the capability level reached through the deployment of digital technologies.

3.5 Toward the Smart Steel Factory: relationships with Digital Technologies.

Once more, with reference to the steps introduced in 2.2 and the definition of the *Smart Steel Factory* status based on the steel sector's needs, the evolution of steel manufacturing companies and plants involves many factors related to the Twin Transition and the Sustainable Manufacturing upon which the importance of engineering and technological issues are emerged. First of all, the ***Digitalisation Strategy*** is a fundamental step requiring general implementation and a *unified reference model* compliant to the Industry5.0 paradigm.

Indeed, Industry 5.0 is in the middle of the standardisation process because the necessary set of standards is not yet fully available at industrial level. Conceptually, some key hints can be extracted by Sustainability looking to ISO 45001 (Health & Safety and ISO 18000 for environmental aspects).

Some general principles of the ISO95 can be considered as a reference regarding the general approach to Digitalisation. This is only a very small portion of the existing standards paving the way to the new ones.

The above-mentioned strategy is in practice a specific activity aimed at customising ICT landscape and organisation supporting the Green Transition of plants. Therefore, the strategy is not limited to spending action, but a sustainable, realistic and effective **Smart Factory Transition Plan** should be built**.**

According to CSP SRIA, the implementation of novel green technologies to directly improve the environmental performances and the systemic deployment of ICTs must be jointly considered.

Accordingly, the premise of the plan consists in focusing the objectives such as increasing competitiveness in environmentally gentle ways while enhancing collaboration between machines and humans which summarise in a few words the Industry 5.0 paradigm.

Despite the long-term view, it can be summarised into five steps:

- ✓ Appointing a cross-functional team with multi-cultural competencies.
- ✓ Defining the objectives to be achieved and relevant priorities, timeline and efforts.
- ✓ Progressively Implementing the new technologies.
- ✓ Changing the company culture through upskilling, training and organisational improvements.
- ✓ Monitoring the transition and measuring progress and compliancy with expectations.

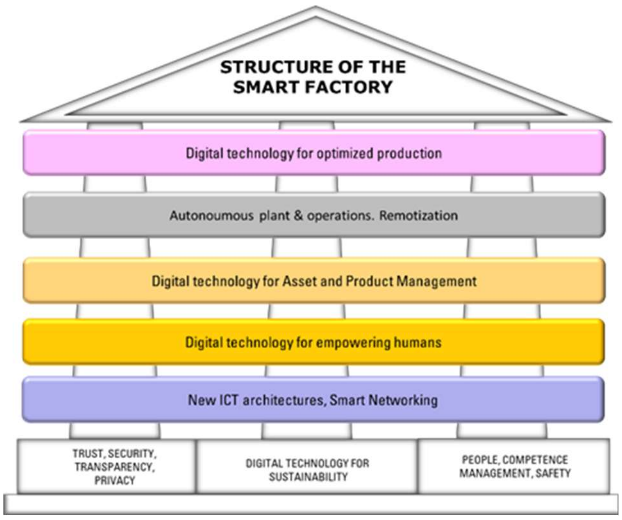

Fig. 4 The Smart Factory reference model.

The Smart Factory pathway is based on a flexible model which structure is characterised by three ***Top-Level Needs*** (the three pillar's basis of Fig. 4, in the bottom part of the Greek temple), and five ***Technology Classes*** in which each Class include Technologies having qualifying characteristics in common such as for example, the group of modelling, Virtual and Augmented Reality, converging into the Digital Twin concept. Another example can be the group of AI and ML, Advanced Statistics and Big Data.

19 Such definition has been developed in the Smart Factory Focus Group in 2021.

According to Fig. 4, the Smart Factory reference model can be represented by a matrix where horizontal *Technology Classes* are cross-referenced with *Top Level Needs*. This concept of Classes will be later discussed in 7 in terms of Clusterisation of the reference Digital technologies.

4 Megatrends in the Digital Transition of the steel industry.

4.1 Megatrends of the year 2023.

By definition, megatrends indicate a general direction of development or change over time that innovation is occurring at global scale. So, to understand megatrends such as Digitalisation is very useful to embrace the Digital Transition having a clear idea of the direction technology is following.
This is fundamental in particular for steel manufacturing because related markets and relevant issues of the supply chain have a worldwide scale. However, it is quite difficult to have precise indications on the digital megatrend in general because constituent technologies change very fast and year by year updates are needed.
As a consequence, a prudent approach consists in analysing what can be statistically measured and/or collecting global data such expenditures, market penetration etc. With this filter but not in order of importance, the digital megatrend relevant to 2023 and based on at least data of three years before can significantly describe the impact on the industrial sector as a whole in terms of market prices, contribution to decarbonisation and novel manufacturing and business models. A look to magazines leads to define the four major impacting factors for 2023:

a. Climate change and Resource scarcity.
b. Energy and shift of energy sources.
c. Rise of Technology.
d. Instability of the geopolitical scenarios.

Among them, factors *a, b* and *c* need active actions of technological updates and investments to decarbonise manufacturing of companies that embraced the Digital Transition pathway by deploying and optimising green technologies and digital systems. In general, companies are pushed by the needs of increasing *Flexibility* and *Resilience* to adapt to dynamical conditions through the dramatic re-design of the manufacturing and supply chains.
Regarding digitalisation, besides allowing the dynamical optimisation of processes and resources, megatrends highlight the strong influence of digitalisation also on the ways of doing business by pushing new business models.
Therefore, complexity of interacting effects and factors suggests to establish a *Digitalisation Plan* for avoiding the temptation to look like an "innovative company" at any cost by investing into the “*technology of the day*”.
On the one hand considering point *d*, private companies (nowadays, oil companies as well, at the current times) have very limited chances of influencing markets in normal conditions, with limited exceptions to very large ones, mainly in the sector of finance. Market instability, on the other, has great influence on private companies, as was recently observed looking to geopolitical issues affecting the supply chain in many industrial sectors. Therefore, updates and changes to both business attitude, technological assets and processes toward the above-mentioned characteristics of *Flexibility* and *Resilience* looking to their own perimeters, are strongly recommended.
This means to empower capabilities connected with event and macro-event management (from early detection to optimal management of recovery actions or by establishing proper predictive strategies) within both domains focusing on stability of processes, product quality and attractiveness of companies.
As a consequence, change from *Reactivity* to *Predictivity* is strongly needed.

4.2 Trends of Digital Technologies.

Digitalisation domain is so huge to be considered by some primary authors and consultancy companies as a *per se* megatrend[20]. However, it is very difficult to envisage the ICT' evolution also in the short term. Instead, considering possible scenarios could be easier.
In this line and in spite of the large spread of opinions, the following three key technologies as the emerging leaders in the field of Digital Technologies define the global Digitalisation Megatrend relevant to all industrial, social, financial and economic considered together.

1. ***Artificial Intelligence and Machine Learning***[21]***.***
2. ***Cloud Technology***[22]***.***
3. ***Internet of Things (IoT)***[23]***.***

It is important to highlight that the three technologies and their ranking come from the heuristic approach founded on personal experience, literature sources (the most important source of information) and contacts with decision makers of steel industry. In the second part of this document, the attention will focus the Digitalisation Megatrend in the industrial sector as a whole in a worldwide perspective.

To do that a Business Analysis has been carried out considering investments and expectations of investors (see Chapter 5 and following paragraphs) for methodology and results).

Results will be commented in depth in the following with the objectives of determining the ranking of Digital Technologies and the R&D&I directions for orienting the innovation efforts.

[20] Digitalisation and Digital technologies have radically changed the foundation of all activities in our society and will continue to do so in a way that we cannot be reliably predict.
[21] Grand View Research, Artificial Intelligence Market Size Report, 2022
[22] Straight Research, Cloud Computing Report till 2031.
[23] Precedence Research, Industrial IoT Market

5 Preliminary business analysis for supporting the selection of Key Trends. Data and KPIs

5.1 Rationale and technological scenario of Digital Key Trends.

The three key trends defined in 4.2 are preliminarily based on the heuristic approach of round tables among ICT and steel processing experts on the one side and specialised literature sources on the other. However, the outcome of this preliminary step should be reinforced by a parallel approach based on the business analysis of economic factors to also increase the validity and the robustness of results. With this aim, an additional dedicated literature survey has been done looking to economic and financial indicators made available from very recent sources (not older than 2022). However, results are aggregated by technology but relevant to the whole manufacturing industry for aggregated batch and process industry of the Western Countries.

5.2 KPIs and Business Analysis

The announced Business Analysis is based on two economic and financial indicators:

- The ***Global Market Size of Expenditures on each technology (GMS)***[24].
  The calculation formula of this factor shown just below is relevant to the yearly GMS value:

$$GMS_j = \left(\sum_{1}^{NI}{}_i InvP_i \times EXP_{i,j}\right) \qquad [F1]$$

NI = Total Number of Players (they can be year by year fixed or variable)

$InvP_i$ = i^{th} Player (with i = 1, NI).

$EXP_{i,j}$ = Total Expenditures of i^{th} Player on j^{th} Digital Technology.

Despite meaning is self-consistent and scopes are very simple and clear, some considerations must be mentioned after the introduction of the second indicator.

Here, we highlight that expenditures are relevant to the investments and paid fares in case of services delivered by Service Providers and business companies in terms of both external expenses spent for their business. So, it is important to say that such expenditures are done by industrial companies and do not include consumer's, financial and economic expenditures and social media in favour of the significance of data for the scopes of the analysis to restrict the perimeter to the industrial sector in which Metal plays a large role.

- The second indicator is represented by the ***Compound Annual Growth Rate*** **(CAGR)**[25] defined as ***"the rate of return (RoR) that would be required for an investment to grow from its beginning balance to its ending balance, assuming the generated profits were reinvested at the end of each period of the investment's life span"***.

The calculation formula of CAGR is:

$$CAGR = (V_{final}/V_{beginning})^{1/t} - 1 \qquad [F2]$$

Where:

V_{final} = the ending balance of investments at the end of the timespan.

$V_{beginning}$ = the final balance of investments at the first year of the timespan.

t = number of years of investment.

[24] Being this Business Analysis a preliminary one referred to the global market of each digital technology excluding the consumer markets, the GMS is the best indicator. However, it must be pointed out that values might differ so much from the values referred to the industrial sector and the manufacturing sector as well.

[25] https://www.investopedia.com/terms/c/cagr.asp.

Aimed at explaining the significance of GMS and CAGR, GMS is a static value used year by year to define the basic curve of the forecasted technological growth starting from *a posteriori* data from 2018 to 2023.

Instead, GAGR allows to capture the dynamic of the economic growth because of its inherent proportionality to the derivative of GMS curve. Regarding the significant ICTs among a wider group of digital technologies, fifteen of them were selected preliminarily based on the highest GMS values. Thus, in the following paragraphs, it is explained how the business analysis is carried to determine the technological ranking of the selected set of Digital Technologies (indicated also as ICTs).

5.2.1 Combining GMS and CAGR into the novel parameter $KPI_{TT\%}$.

To complete the analysis, the two factors CAGR and GMS must be combined into a unique KPI according to the further step to be discussed just below. This indicator is based on the combination of GMS and CAGR into a single KPI named $KPI_{TT\%}$ (TT means Technological Trend) or Compound Economic Factor of Digitalisation (CEFD).

The basic idea behind CEFD is based on two considerations:

1. the diffusion of each digital technology measured by GMS can be correlated to the year-by-year static impact on decarbonisation.
2. In parallel, CAGR can be correlated to the total expected economic benefits due to the deployment of the digital technology in the manufacturing aggregated sector.

These two aspects can be merged together by combining CAGR and GSM for each technology to define the final technological ranking. Accordingly, a first step consists in the introduction of the KPI_{TT} factor calculated by the following simple formula:

$$KPI_{TT,i} = GMSi * \; CAGRi \qquad [F3]$$

However, $KPI_{TT,i}$ is a dimensional number measured in Billion US$. To obviate this representation, a dimensionless formula $KPI_{TT,i}$ (i.e., the i^th^ Digital Technology among the fifteen selected) can be introduced by modifying [F3] according to the following form:

$$KPI_{TT\%,i} = \frac{(GMSi * CAGRi) * 100}{\sum_1^{15}(GMSi * CAGRi)} \qquad [F4]$$

Based on $KPI_{TT\%}$, a more significant determination of the economic ranking can be carried out. As it will be seen in the discussion of the results at the accomplishment of the business analysis, it will be possible to mirror economic factors mirrors and the technical considerations though the interpretation of experts.

5.3 Analysis of economic data

5.3.1 Context of the analysis

Coming to the analysis, fifteen digital technologies have been selected and relevant data have been gathered from literature sources (see Appendix 2) looking to the homogeneity of sectors, indicators and, timespan.

Being very difficult and even impossible at this preliminary stage focused on the metal sector and, in view of the lack of homogeneity in the available data, it was decided to carry out first the analysis looking to aggregated industrial market of each technology. This passage is unfortunately obliged by the inhomogeneity of data focusing digitalisation in the Metal sector that are rarely available

Despite this limit, authors guess that results looking to the aggregate industrial sector in terms of investments and R&D&I directions may give important information for orienting decisions of industrial players.

5.3.2 Set of considered indicators

The two chosen economic indicators are the well-known *CAGR* and *GMS*, already introduced and defined in paragraph 5.2. They are considered scientifically robust in the Economic Science and valid for comparing the most diffused as well as the emerging niche technologies considering also their infant phase of deployment.

However, because some concerns could be made on the metrics, the third indicator named $KPI_{TT\%}$ (or CEFD) has been introduced in paragraph 5.2.1 and Formula [4].

Furthermore, the literature analysis refers almost to the same Observation Period (the time span) comprised between 2022 or 2023 in case of missing initial data, and 2030. This can be acceptable because farer data after 2030 are not significant because of the fast evolution of the digital technology landscape.

5.3.3 Working Database.

The Database gathered from literature is reported in Table 1; looking to the Global Market Size (of Expenditures, GMS) indicator. It is worthy to anticipate that the first three technologies (evidenced in orange) confirm the heuristic approach of the first assessment introduced in Paragraph 4.2.

Table 1 DB of the economic performances of the selected digital technological set.

n°	Set of Digital Technologies	Observation Period2	CAGR1 Compound Annual Growth Rate	Global Market Size Expenditures billion US$	CEFD KPITT%
1	IoT	2022-2030	20,47%	1.742,80	30,85%
2	Cloud Computing	2022 -2030	17,20%	1.470,11	21,86%
3	Big Data & Business Analytics	2020-2030	26,70%	731,13	16,88%
4	AI and ML	2022-2030	39,16%	333,40	11,29%
5	Digital Twin	2023-2030	41,90%	139,93	5,07%
6	Industrial Automation	2022-2030	10,50%	377,25	3,43%
7	Industrial Logistics	2022-2030	13,15%	162,50	1,85%
8	Edge Computing	2021-2030	36,30%	139,58	4,38%
9	VR & AR	2022-2030	29,30%	62,71	1,59%
10	Industrial Business Intelligence	2022-2030	13,10%	73,57	0,83%
11	Cybersecurity	2021-2030	14,80%	49,53	0,63%
12	Industrial Robotics	2022-2030	10,50%	60,56	0,55%
13	Modelling and Simulation in Industry	2022-2030	11,83%	40,50	0,41%
14	Data Centres	2021-2030	15,50%	20,00	0,27%
15	Platform Economy	2022-2030	18,00%	6,73	0,10%
TOT.			318,41%	**5.410,30**	**100,00%**

1 Base Year of the CAGR estimation is the first year of the Time span
2 Forecast is updated each year with fixed end year in 2030

Furthermore, the ranking list has been derived using the $KPI_{TT\%}$, an original indicator introduced for considering both the static value at the end of the time span and the technological dynamics.

As described in paragraph 5.2.1, this was obtained by merging GMS and CAGR into the new KPI named the Compound Economic Factor or $KPI_{TT\%}$. Therefore, $KPI_{TT\%}$ (or CEFD) highlights in a unique view GMS and CAGR values of each digital technology among the fifteen. Moreover, the necessity of combining GMS and CAGR becomes clear due to difficulty of privileging one of the two factors for the ranking determination (see the rigorous definitions of GMS and CAGR in paragraph 5.25.2).

5.4 Determination of the ICT's ranking

Based on the previous considerations and data shown in Table 1 that includes also the column of CEFD/$KPI_{TT\%}$, values calculated by formula [4], the determination of needed rankings of digital technologies can be carried out to better discuss the Digital Megatrend[26].

In Table 2 and Fig. 5, the three rankings are obtained by ordering technologies from the highest to the lowest values of $KPI_{TT\%}$, GMS and CAGR.

[26] Digitalisation, in its extensive meaning in the society and business contexts, is per se a Megatrend so finding the three more attractive ICTs is better addressed by using the term of Key Trend because this analysis is relevant to the manufacturing sector including it services and auxiliaries.

Table 2 The three Rankings of Digital technologies based on CEFD, GMS and CAGR.

n°	Digital Technology Ranking 1	CEFD $KPI_{TT\%}$	n°	Digital Technology Ranking 2	Global Market Size Expenditures billion US$	n°	Digital Technology Ranking 3	CAGR Compound Annual Growth Rate
1	IoT	30,85%	1	IoT	1.742,80	1	Digital Twin	41,90%
2	Cloud Computing	21,86%	2	Cloud Computing	1.470,11	2	AI and ML	39,16%
3	Big Data & Business Analytics	16,88%	3	Big Data & Business Analytics	731,13	3	Edge Computing	36,30%
4	AI and ML	11,29%	4	Industrial Automation	377,25	4	VR & AR	29,30%
5	Digital Twin	5,07%	5	AI and ML	333,4	5	Big Data & Business Analytics	26,70%
6	Edge Computing	4,38%	6	Industrial Logistics	162,50	6	IoT	20,47%
7	Industrial Automation	3,43%	7	Digital Twin	139,93	7	Platform Economy	18,00%
8	Industrial Logistics	1,85%	8	Edge Computing	139,58	8	Cloud Computing	17,20%
9	VR & AR	1,59%	9	Industrial Business Intelligence	73,57	9	Data Centres	15,50%
10	Industrial Business Intelligence	0,83%	10	VR & AR	62,71	10	Cybersecurity	14,80%
11	Cybersecurity	0,63%	11	Industrial Robotics	60,56	11	Industrial Logistics	13,15%
12	Industrial Robotics	0,55%	12	Cybersecurity	49,53	12	Industrial Business Intelligence	13,10%
13	Modelling and Simulation in Industry	0,41%	13	Modelling and Simulation in Industry	40,50	13	Modelling and Simulation in Industry	11,83%
14	Data Centres	0,27%	14	Data Centres	20,00	14	Industrial Automation	10,50%
15	Platform Economy	0,10%	15	Platform Economy	6,73	15	Industrial Robotics	10,50%
TOT.		**100,00%**	TOT.		**5.410,30**	TOT.		**318,41%**

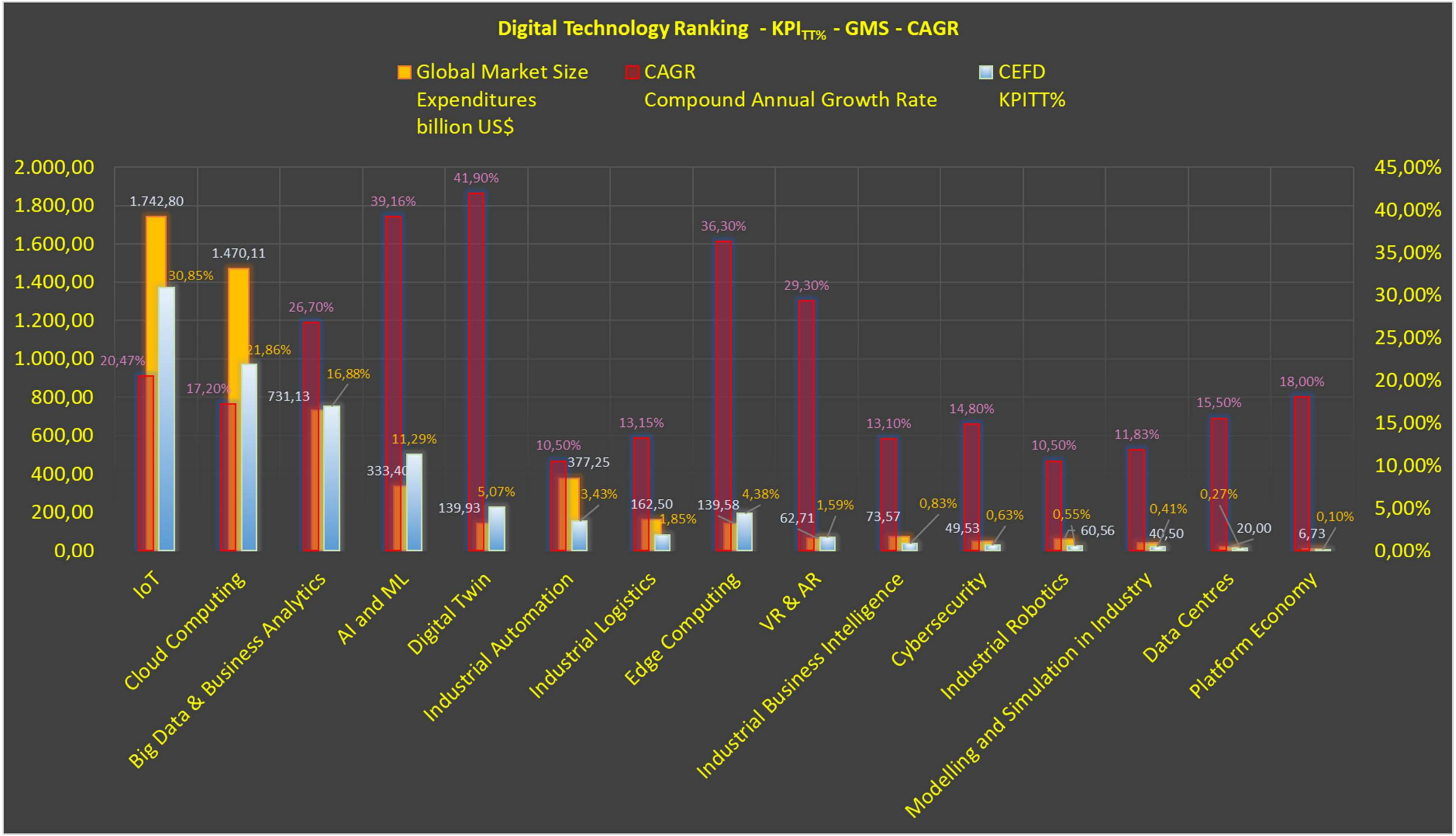

Fig. 5 Database of the GMS, CAGR and CEFD indicators.

The resulting rankings[27] are also reported in Table 3 with reference to the first five positions where the ordinal number of each digital technology has been restarted from 1. Regarding to GMS and CEFD ($KPI_{TT\%}$), the first position is occupied by IoT.

This is a strong signal towards the interest to provide an ICT landscape characterised by an effective and efficient infrastructure as confirmed by the other positions looking to In addition to Table 1 and to better catch these results, the view of radar diagrams of data in Table 1 is shown in Fig. 6 and Fig. 7 but an introduction to the diverse ranking derived by ordering values for each indicator are presented.

6 Preliminary analysis of rankings.

6.1 Analysis of the positions of the technology set.

As a premise of the preliminary analysis of results, CEFD is chosen as the master indicator to find the most opportune directions of investment and R&D&I actions to maximise efficiency, effectiveness and convenience considering the way in which CEFD is calculated (see formula F4).

Furthermore, the scope of introducing the CEFD becomes more evident for its role of conciliation factor between the economic impact represented by GMS and the dynamic factor of the financial aspects highlighted by CAGR.

Accordingly, the results shown in Table 3 highlight the Rankings based on three indicators $KPI_{TT\%}$ (or CEFD), GMS and CAGR:

Table 3 Rankings based on CAGR, GMS and $KPI_{TT\%}$ (CEFD).

n°	Ranking 1	CEFD $KPI_{TT\%}$	n°	Ranking 2	Global Market Size Expenditures billion US$	n°	Ranking 3	CAGR Compound Annual Growth Rate
1	IoT	30,85%	1	IoT	1.742,80	1	Digital Twin	41,90%
2	Cloud Computing	21,86%	2	Cloud Computing	1.470,11	2	AI and ML	39,16%
3	Big Data & Business Analytics	16,88%	3	Big Data & Business Analytics	731,13	3	Edge Computing	36,30%
4	AI and ML	11,29%	4	Industrial Automation	377,25	4	VR & AR	29,30%
5	Digital Twin	5,07%	5	AI and ML	333,40	5	Big Data & Business Analytics	26,70%
TOT.		85,95%	TOT.		4.654,69	TOT.		173,36%

A preliminary analysis of results allows to grasp some important specific aspects. To do that, the CEFD indicator and its two components CAGR and GMS are shown using radar diagrams of Fig. 6, Fig. 7 and Fig. 8 in addition to Table 2.

They are used to evidence by turning from the vertical axis in clockwise direction the ranking progression and so, the prevailing topics. To provide the scale of intervention priorities for implementing the Effective, Efficient and Just Digital Transition the results must be commented to estimate the intensity of "*sentiment*" of markets and analysists up to 2030.

[27] Values are very high but it must be remembered that the Global Market Size is considered.

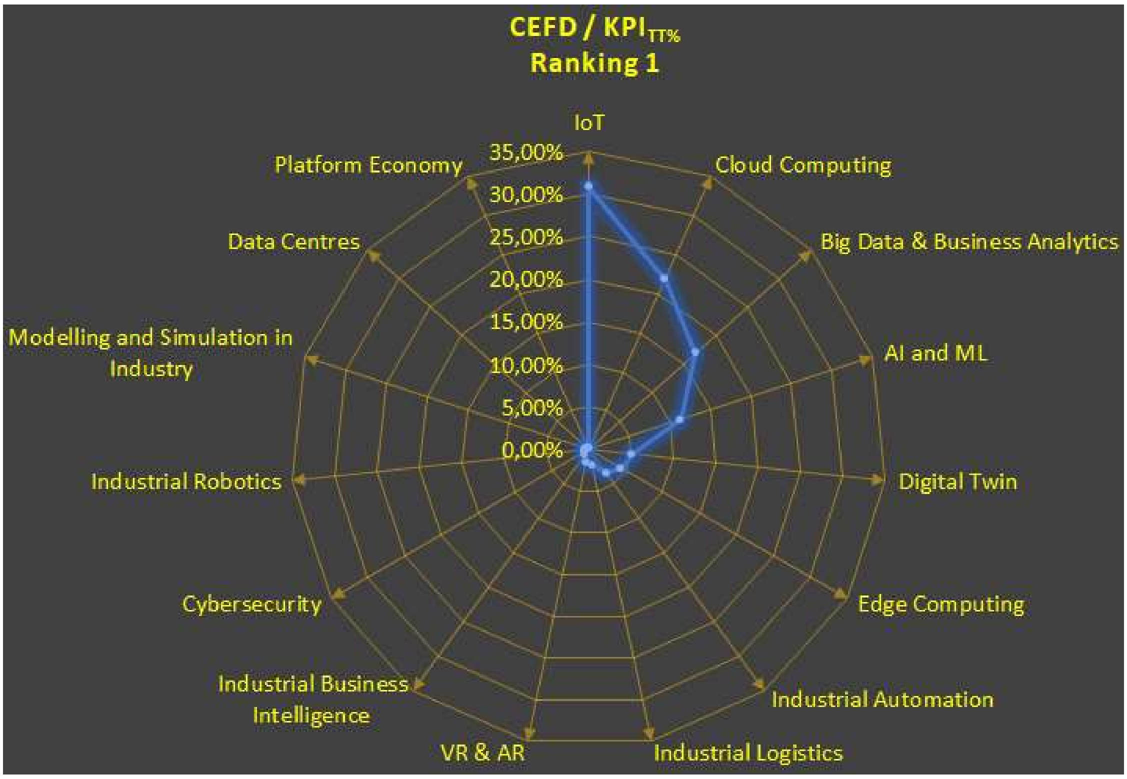

Fig. 6 Distribution of the 15 Digital technologies in terms of CEFD / $KPI_{TT\%}$

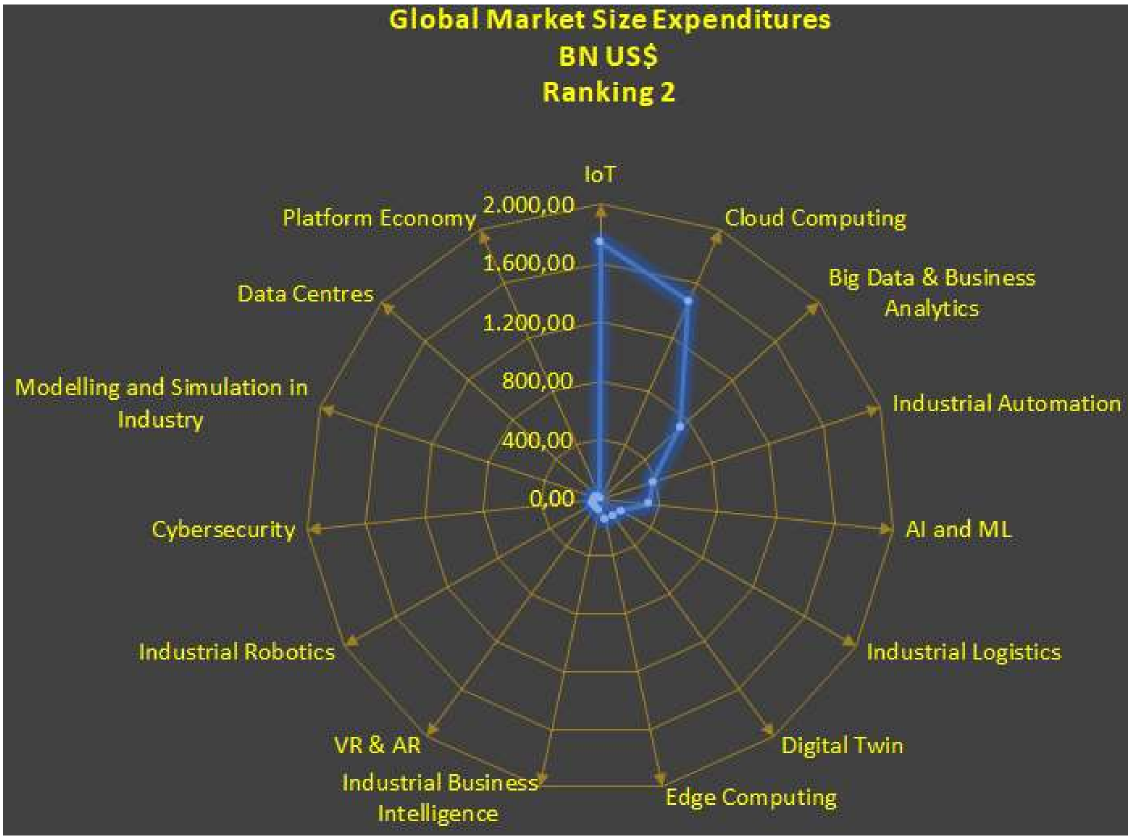

Fig. 7 Forecast of Global Market Size in terms Expenditures at 20230 for each digital technology.

Comparing Table 3 with the help of Fig. 6 and Fig. 87[28], the two rankings based on CEFD and GMS leads to similar results in terms of prevailing topics, justified by the following considerations.

1. The first two positions of Rankings 1 and 2 (see Table 3) are occupied by *IoT* and *Cloud Computing* (more in general *Cloud-based Technologies*), directly highlight the importance of ICT infrastructures as enablers of others technologies. Big Data & Analytics occupies the third position in Ranking 1 and the fourth in Ranking 2. But it is questionable to include Big Data & Analytics into to the Infrastructure group even though Big Data is *per se* an ensemble of technologies dealing with data and, only a proper set of analytics is deployed, the expected value can be extracted. For this reason, it could also be included in the infrastructure of the Data-Driven Factory
   Therefore, being Big Data a basic technology in the Industry 4.0 paradigm, the large contribution to turning current plants into Data-Driven Factories is evident and indispensable for example to run complex systems for managing operations such as MESs (Manufacturing Execution System).
2. The fourth and fifth positions of Ranking 1 (CEFD) are occupied by AI & ML and Digital Twins. In principle, both are not infrastructures such as the Industrial Automation however, this mostly refers to technologies and solutions related to the Level 1 of the Automation Pyramid that can be assimilated to an infrastructure even though devoted to command execution and control. For this reason, the attractiveness and the size of expenditures are very high in terms of CAGR occupying with 39,16% the second absolute position of attractiveness (see Table 3b) and GMS with US$ 333,40 BN in the fifth position of Ranking2 (see Table 3b). However, the contrast between such high CAGR value and the relatively low value of the AI & ML Industrial Market Size raises some doubts about the reliability of the GMS forecast in particular due to the high value of GMS relevant to the global market that makes Artificial Intelligence the primary set of technologies. We will come back later on this point
3. According to GMS viewpoint (Ranking 2), the third position occupied by *Data and Business Analytics* (GMS forecast equal to US$ 733,13 BN) is roughly one half of the second position occupied by Cloud Computing. This could make evident the presence of a bias towards the *Data-driven Factory* approach.
4. The fourth position of *VR & AR*, with a GMS value of US$ 451,5 billion, a CAGR value of 38,5% and CEFD/$KPI_{TT\%}$ of 10,83%, focuses the importance of *Human Centrality* and the substantial adherence to the Industry 5.0 model that is still confirmed for the attractiveness of investment, due to the large expectations in this direction.
5. Considering Cybersecurity, let us take the opportunity to introduce this topic by giving the definition. ***Cybersecurity is the ensemble of policy, practices and tools to protect organisations, people, data and assets against Cyber-attacks.*** It is ruled by ISO 27001 regarding the information security management and by ISO 27002 that is the supporting standard to implement security controls. In the context of the Digital Transformation, Cybersecurity represents an infrastructure to support the other systems and players guaranteeing the process continuity, the system resilience, the product quality threatened by malicious external attacks. For these reasons, it is based on organisational measures such as access protection, monitoring and control, the mindset of people through education, training and cooperation, and AI-based software applications.

   The qualifying numbers of Cybersecurity in industry within the perspective of 2030 consist in a GMS of US$ 49,53 BN (twelfth position in Ranking 2), CAGR of 14,8%[29] (tenth position in Ranking 1) and a CEFD/$KPI_{TT\%}$ of 0,63% (eleventh position in Ranking 1).

   Such scores could be interpreted as the underestimation of Cyberthreats but in light of other available data[30] this point can be further developed looking more in depth to CAGR. However, before spending some words on that, out must be pointed out that data differ for a certain extent: the GMS forecast

[28] Rankings are visible by looking to each radar diagram in the clockwise direction.
[29] Industrial Cybersecurity Market to be Worth $49.53 Billion by 2030 - Exclusive Report by Meticulous Research® https://www.globenewswire.com/news-release/2023/06/28/2696341/0/en/Industrial-Cybersecurity-Market-to-be-Worth-49-53-Billion-by-2030-Exclusive-Report-by-Meticulous-Research
[30] Straits Research: Industrial Cybersecurity Market Size is projected to reach USD 51.28 billion by 2031, growing at a CAGR of 10.5%. https://www.globenewswire.com/en/news-release/2023/06/14/2688218/0/en/Industrial-Cybersecurity-Market-Size-is-projected-to-reach-USD-51-28-billion-by-2031-growing-at-a-CAGR-of-10-5-Straits-Research

spread of the two sources is comprised between US$ 49,53 and 51,28 B that, statically speaking, is nothing. Instead, CAGR is comprised between 14,8% and 10,5%.

Table 4 The Frame of Cybersecurity focusing CAGR.

FRAME OF CYBERSECURITY	TOPICS	CAGR
Types of Components	Product	10,40%
	Software	
	Services	
Types of Industrial Cybersecurity	Network Security	10,60%
	Cloud Security	
	Wireless Security	
Types of end-use	Energy & Power	10,30%
	Manufacturing	
	Transportation Systems	
	Chemicals	
	Others	

The most recent source of data relevant to 2022 are summarised in the form of the "Frame of Cybersecurity" shown in Table 4 where the three categories are considered:

- Components of the Cybersecurity System.
- Potential Industrial breaches.
- Possible end-use.

Unfortunately, in this case it is not possible to sum the three CAGR values because many factors are disseminated among the three categories. This discussion will be resumed in the conclusive part of the analysis to highlight the key aspects of the enablers of Cybersecurity systems to make them in condition to effectively protect companies.

To close these first comments about Cybersecurity, it is worthy to say that Cybersecurity is not only a question of implementing software but, the involvement of all levels of workers is very high and, in consequence, also the impact on the organisation. This is not easy to be accepted by companies together with the evidence that a reliable Risk Analysis asks for the support of specialised Companies because data are scarce and sometimes unclear. Foer example, the attribution of the probability of occurrence of events and the list of threats to be considered lies on generally crude approaches with little scientific basis where the use of the simple Risk Matrix based on the cross reference of probability and consequences. Apart the impression that Cybersecurity can be understood as a superstructure within the ICT landscape, the possibility of slowing down the operational applications can be a credible fear. This part will be resumed in the second part of the comments.

6. From now on, the attention is focused on the ensemble of digital technologies and their holistic impact on decarbonisation. Thus, regarding the combination of the five positions in Ranking 3 of Table 3 (reminding once again that CAGR is an indicator measuring the expectations in terms of RoR) exhibits a partial CAGR equal to 173,6 % (see Table 3 and Fig. 8 in the clockwise direction starting from the vertical axis) with respect to the global CAGR of 318,41 % (see Table 2) representing the 54,4 % of the total CAGR given by the fifteen technologies that is a quite good performance but not so good as the 86% of Ranking 2 and 1.

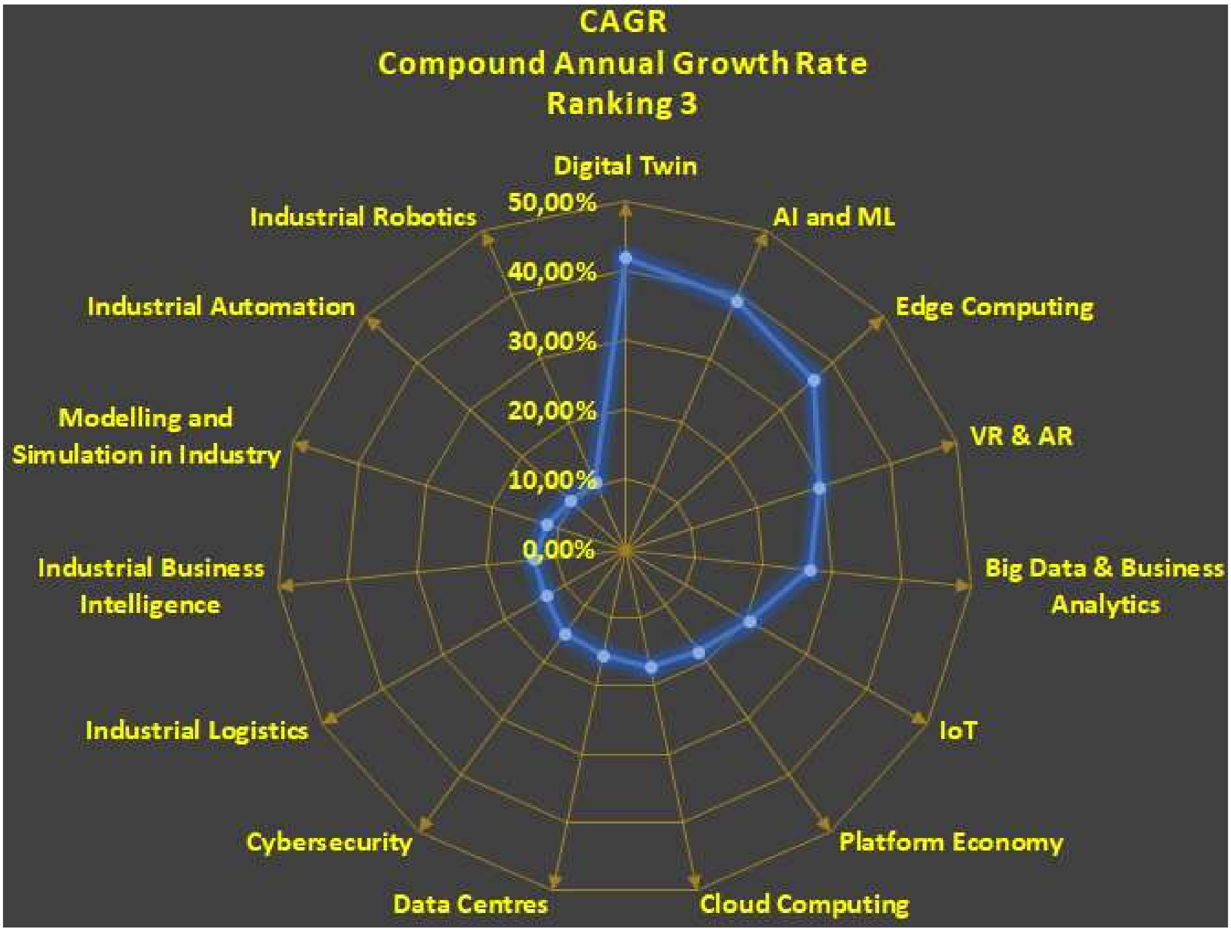

Fig. 8 Compound Annual Growth Rate (CAGR) of each ICTs looking to 2030

Furthermore, this is another conformation that the Smart Factory achievement is a priority of the Digital Transformation and also that the Industry 5.0 reference model is largely shared by the industrial companies.

7. The first five technologies and the comments at a glance suggest to add further considerations to the analysis of AI & ML considering the combination of technologies rather than each single technology.
   AI & ML performs quite well in terms of CEFD/$KPI_{TT\%}$ (fourth position of Ranking 1 with CEFD equal to 11,3%,) an excellent value of CAGR of 39,16 % with the second position of Ranking 3.
   In terms of GMS, the value is US$ 333,40 BN that is not so bad (fifth position of Ranking 2) but not good as expected looking to the global prevalence of AI in the global market of Digital technologies.
   However, this can be considered the sign of a prudent approach of industry on the one side and the confirmation of the large expectations generated by AI on the other.
   Furthermore, a diffuse lacks of infrastructure's quality could be perceived as a barrier for a proficient diffusion of automatic systems in general.

6.2 Main findings of the Business Analysis - Summary.

At this stage, the main findings can be summarised by the following considerations:

- There is a large attention to the implementation of a robust, flexible and resilient infrastructure to overcome potential barriers to Digital Transformation. Industrial Companies are aware of its importance to provide attention and investments to this topic.
- The Smart Factory i.e., the massive deployment of automatic systems is seriously considered however, prudence suggests to create in advance the right conditions to exploit the whole potential of AI in the plants.

- The Digital Transition is in general well accepted as one of the primary objectives of investments for the industrial evolution that is evolving by embracing the Industry 5.0 Reference Model. This confirms that the Digital Transition has been fully embraced in the industry since the ‘80s.
- Should it mean that Sustainability is fully accepted as well by companies?
  This question might hide some doubts related to the imposition of the Sustainable Transition.
  If this is true or not is difficult to say but a serious reflection is necessary.

7 ICTs and ICT’s Clusters in the Smart Factory perspective.

7.1 The concept of Technological Cluster.

Coming back for a while to the above points, it is worthy to say that the *technology-by-technology approach* has been substituted by considering sets of technologies instead of singularly analysing the fifteen technologies despite the exception of AI, Cybersecurity and VR & AR.

Moreover, operations to be performed within a Production System to supply goods or services, can be described by the set of correlated or independent Tasks in relation to the specific objectives. With the premise that tasks can be extraordinary or repetitive and are part of the conceptual specification of the design and implementation of the Production System, once a task (or mission) has been defined, the specific models and software applications contributing to accomplish the Task itself are individuated. The absence of some of them is an outcome of the gap analysis regarding the ICT landscape and specific aspects of the manufacturing control and management systems.

In other words, how to optimally design and organise such digital applications defines the higher layer based on the ICT landscape of the Production System. However, just one digital technology can be in general not sufficient to carry out tasks but usually a set of applications depending on several digital technologies are needed.

So, after the gap analysis, how to analyse and solve the issue of designing a Robust, Reliable, Flexible, Resilient, Reconfigurable (etc.) Production Systems is the scope of this part of the document.

7.2 Criteria of Digital Technology Clustering

The idea of *clustering* Digital Technologies descends from the analysis of specific tasks and so, it is carried out task by task. Using heuristic methods. For example, the most frequently used technologies, the most critical tasks for a given plant, the most attractive technologies for capability empowerment, the prevailing technologies object of large expenditures etc. have been considered to define the fifteen technologies considered in the Business Analysis (see paragraph 5.3.3).

Based on these considerations, ***clustering* the *Digital Technologies may be defined as the action of defining sets of ICTs using specific criteria based on mutual relationships aimed at exploiting the holistic potential of the ensemble to accomplish tasks involving assets, processes and services.***

In the definition of ICT clusters, two main criteria for grouping Digital technologies have been mentioned. In this document, we consider two criteria among the number of possibilities having the characteristic of covering a large spectrum of cases because of their adaptability to many circumstances:

1. *Technological Criterion*: Clusters of ICTs groups are based on digital technology having common knowledge domains (for this reason the use of this criterion is called Technological Approach).
2. *Functional Criterion*: Clusters of ICTs are based on the so-called Functional Criterion consisting in the enabling effect of some of them on the most important technologies necessary for accomplishing specific tasks. Due to that, this kind of relationships are named enabled-enabler or driving-driven relationships.

Two exemplar cases in which clustering is opportune are given below in paragraph 7.3 respectively based on the “Technological Criterion” and the “Functional Criterion”. Furthermore, it must be underlined that both criteria are applied to comment the results of the Business Analysis.

7.3 Examples of Clusters

Whether the "Technological Criterion" leads to relatively fixed Clusters in the sense that component technologies are more or less defined, the "Functional Criterion" depends on the task under considerations and so, digital technologies may vary. To clarify these aspects, four examples are briefly described, two relevant to "Technological Criterion" and two relevant to the "Functional Criterion" or the *enabled-enabler* approach).

Technological Criterion – Example 1: the cluster is composed by AI & ML and by Big Data & Business Analytics on the other.

Technological Criterion – Example 2: The second example is represented by the Infrastructures in Ranking 1 and 2 of paragraph 6.1, already discussed in the final part of paragraph 5.4.

Functional Criterion - Example 1: the Cluster is based on AI & ML as the driver and by Digital Architectures and, in consequence, IoT and Cloud Technology as enablers because AI & ML properly works in presence of a robust data management infrastructure.

Functional Criterion - Example 2: in case the issue consists in transferring solutions from offline to real-time mode, the *driver* could be the Industrial Automation and the enablers the Edge Computing and again a proper data management infrastructure.

7.4 Clustering Exercise: ICT list and clustering ICTs to drive the transition.

Table 1 has been re-arranged in terms of Digital Technology Clusters to carry out the clustering exercise to obtain four Clusters by applying the "Technological Criterion" (see **Errore. L'origine riferimento non è stata trovata.**Table 5). Moreover, the value of sum of the Compound Economic Factor CEFD/$KPI_{TT\%}$ evidences the combined effect (and RoR) of the composing technologies relevant to each Cluster.

Table 5 Examples of Clusters with the sum of CEFD/$KPI_{TT\%}$.

CLUSTERS	Digital Technologies	GMS (B US$)	CAGR (%)	CEFD / $KPI_{TT\%}$ (%)
Data-Driven Factory and AI & ML	AI & ML	333,4	39,16%	11,29%
	Big Data & Business Analytics	731,13	26,70%	16,88%
	Industrial Business Intelligence	73,57	13,10%	0,83%
SUM		1138,1	78,96%	29,00%
Infrastructures (internal - External)	Cloud Computing	1.470,11	17,20%	21,86%
	IoT	1.742,80	20,47%	30,85%
	Data Centres	20,00	15,50%	0,27%
	Industrial Logistics	162,5	13,15%	1,85%
	Cybersecurity	49,53	14,80%	0,64%
SUM		3444,94	81,12%	55,47%
Modelling, Simulation, Integration with Automation and HMI	Modelling and Simulation in Industry	40,5	11,83%	0,41%
	VR & AR	62,71	29,30%	1,59%
	Platform Economy	6,73	18,00%	0,10%
	Digital Twin	139,93	41,90%	5,07%
SUM		249,87	101,03%	7,17%
Process Automation	Industrial Automation (PLC, Sensors, Connectivity etc.)	377,25	10,50%	3,43%
	Industrial Robotics	60,56	10,50%	0,55%
	Edge computing	139,58	36,30%	4,38%
		577,39	57,30%	8,36%
		5.410,30	318,41%	100,00%

Of course, the reliability of the indicator's value depends on the quality and significance of data. In this case the combination of the Global Market Size GMS and the CAGR into CEFD can result into very different orders of magnitude that might be a problem when expected very diffused and attractive digital technology are compared with niche technologies. However, an analysis limited to defined thresholds can help.

Regarding the quality of data, the dataset of the fifteen technologies and the relevant values of GMS, CAGR and CEFD / $KPI_{TT\%}$, is characterised by their good homogeneity and reliability due to same timespan (see Table

3) declared in the literature sources and the definition of the same target sectors (industry verticals, such as automotive, healthcare, retail, finance, manufacturing, energy, other transports, and Oils & Gas).

Considering the basis of the Clustering exercise developed in this paragraph, four clusters have been determined[31]:

1) *Data-Driven Factory and AI & ML.*
2) *Infrastructures (Internal and External).*
3) *Modelling, Simulation, Integration with Automation and HMI.*
4) *Process Automation*.

However, considering Cluster 1 (Data-Driven Factory and AI & ML), it focuses the capability of dealing with data from managing manufacturing processes, assets and event to supply chains for obtaining added value from their holistic integration (for this reason, AI & ML have been evidenced in the cluster's name).

Furthermore, regarding the general enabling role of infrastructural technologies, the relevant digital technologies include AI & ML as well as IoT and Cybersecurity that are two powerful enabler of data management, quality and security though the implementation of the seamless dataflow and the impact on data reliability.

From Table 5, the lesson learned consists in primarily considering the objectives to be reached.

This is particularly true for the following aspects:

1. Determination of the investment's directions by looking to payback, Rate of Return, impact on sustainability, efficiency etc.
2. On the macro-scale, the support to policy makers for injecting R&D&I resources for the implementation of Sustainable Manufacturing in the right directions.
3. The optimal ways to design the digital transformation plan to avoid risks of investing in bad direction such as the "*technology of the day*" as often happens.

8 Finalisation of the Business Analysis based on the "Functional Criterion".

In the business analysis, the application of the "Functional Criterion" was step-by-step introduced because of the difficulties to discuss each digital technology in a meaningful way. Instead, the combined assembly of technologies into clusters leaded to general conclusions valid for both economic and technical aspects, in particular for determining the R&D&I directions starting from the factual evidence of expenditures. All these considerations leaded to introduce the "Functional Criterion" as the privileged approach for the discussion. In view of that, some further details in addition to the already introduced points of paragraph 6.1, are developed in the following.

8.1 AI/ML impact on manufacturing.

Artificial Intelligence and Machine Learning (AI & ML) applications are the most fashionable and attractive technologies in the Digital Transition also for industry applications. However, large expectations (CAGR of 39,16%) in the medium terms seem to be not supported by large investments (GMS of US$ 333,4 BN).

As said in point 7 of paragraph 6.1, this result is not in line with the first position occupied in the last five-four years in the context of the Digitalisation Megatrend relevant to the global market. How can this apparent contradiction be explained?

In our opinion, the methodology to consider the expenditures in the industrial context could be not correct because AI & ML are part of embedded systems, training tools, automation systems in the form of autonomous Cyber-Physical Systems, support to operators, soft sensors, network management and many others.

[31] The "Functional Criterion" can lead to include a specific digital technology in more than one cluster because the definition of the relationships is prevalently arbitrary (see paragraph 7.2). This issue becomes less important when the target of clusterisation is accurately defined in relationship with the expected finding of the analysis. In this exercise, the best has been done by the analysist for defining the outcomes and accordingly identifying clusters.

This leads to the possible explanation that the entire industrial market of AI (and ML) is very dispersed because AI is impacting on so many contexts of applications that real expenses cannot be correctly traced. This could be confirmed by the high attention to the Autonomous Intelligent Systems shaped as anthropomorphic robots, functional robots or task-oriented complex systems empowered and powered by AI and the capacity to self-learn from experience.

In these multi-morphic shapes, autonomous intelligent systems will indubitably cover the role of basic stones of the Smart Factory. So, recollecting the redline of the preliminary chapters, a definition of ***Intelligent System*** is useful.

Autonomous Intelligent Systems are AI-based software or cyber-physical systems able to act independently of human supervision (e.g., self-driving cars, UAVs, smart robots such as care robots for the elderly people or virtual agents for training or support)**.** Furthermore, ***such systems need to be able to make safe, rational and human values-compatible decisions in unforeseen circumstances. Their decision making should be understandable by human users and collaborators, to ensure the necessary trust on behalf of the human users[32].***

In addition, the already mentioned ability to learn from experience and accordingly provide flexible responses, makes them adaptable to a huge spread of circumstances including the self-reconfiguration driven by the context as perceived thanks to the extensive sensing and reasoning capabilities.

However, why does this document consider AI and ML together?

The term "machine learning" was initially defined in the 1950s by AI pioneer Arthur Samuel as **the field of study that gives computers the ability to learn without explicitly being programmed**. To this aim, an interesting definition of the relationship between AI and ML stands on the consideration that ***an "intelligent" computer uses AI to think like a human and perform tasks on its own. Machine learning is how a computer system develops its intelligence[33]***. This addition leads to the consideration that *ML is an application of AI* being in favour of considering ML as a sub-set of AI.

8.1.1 The market growth of AI

Looking to the economic figures, the global[34] AI & ML Market Size of Expenditures was US$ 136,5 B in 2022[35] (see Fig. 9) in which the part relevant to ML was US$ 19,2 B for ML. The total market size GMS relevant to all the sectors of potential application such as the Public Administration, Healthcare and Finance forecast by 2030 is expected to grow until US$ 1.597,10 BN by 2030. Limiting the horizon to the industrial context, the reported figures of the Business Analysis have been estimated to achieve US$ 333,4 B in 2030 and the combined value of US$ 1.138,1 B summing AI, Big Data & Business Analytics and Industrial Business Intelligence.

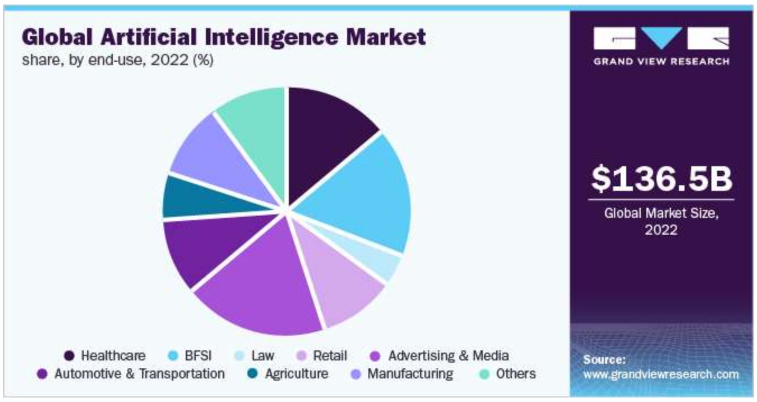

Fig. 9 Global market Size of AI & ML in 2022.

It is important to highlight that Cloud Computing and IoT with respectively US$ 1.555 B and US$ 1.058 B are significantly higher than AI & ML considered alone.

[32] Source: Utrecht University, Autonomous Intelligent Systems, https://www.uu.nl/en/research/human-centered-artificial-intelligence/special-interest-groups/autonomous-intelligent-systems .
[33] Artificial Intelligence (AI) vs. Machine Learning (ML) – Microsoft Azure, https://azure.microsoft.com/en-in/solutions/ai/artificial-intelligence-vs-machine-learning/#introduction .
[34] The Global Market Size includes the total expenditures done in all economic sectors so, not limited to industry.
[35] Artificial Intelligence Market Size, Share & Trends Analysis Report By Solution, By Technology (Deep Learning, Machine Learning), By End-use, By Region, And Segment Forecasts, 2023 – 2030. Source: Grand View Research, 2022.

In case of aggregation as above highlighted (that is an arbitrary assumption), the value of US$ 333,4 B, is quite far from Cloud Computing and also from IoT.

In any case, according to the extensive perspective of summing AI & ML as it is (US$ 333,4 B), Cloud Computing and IoT have a total size that is the double of sum of the remaining twelve technologies.

These values might introduce the explanation that AI & ML is for sure a disruptive ensemble of digital technologies however, it is software, complex but still software. Therefore, to deploy its potential, other expenditures are needed changing the order of magnitude of GMS thanks to the implementation of specific enablers as already discussed in the clustering exercise of paragraph 7.4 substantiated by Table 5

So, the high GMS forecasted value seems to confirm the gamechanger role of AI in the Digital Megatrend instead, despite the general perception confirms this role in the Industrial context some doubts raised (see paragraph 6.1 point 2. Maybe, the discussion on the impact of AI on workplaces, process and asset management and in particular the appearance of the Generative AI[36], attracted and still is attracting the attention on the big difference with the Industrial Market Size of Expenditures and the GMS of the global Megatrend. It might be explained with the way in which the base for the forecast has been considered For example, The embedded AI or autonomous system enabling applications may have been considered within the value of host systems such as complex vision systems, intelligent robots, decision making support systems etc. It is a fact that a specific analysis on this issue would be appropriate but, at the moment, it would seem that this step has not yet been taken.

Remaining within AI & ML, we touched on the theme of Generative AI. A few more words can be useful in this document. Even though Generative AI is perceived by many as a branch of Machine Learning, this assumption is not generally correct because the learning phase is very long but it is the premise to develop the algorithms and, in the end, the application such as the ChatGPT[37]. However, also in this extended context, AI & ML alone including Generative AI, takes the risk to be a *lame duck* because others digital enablers are needed to support intelligent applications such as Data analytics and the proper infrastructure (see paragraph 6.1 Point 1).

Despite that, AI-based applications within the Manufacturing and Supply Chain have been widely demonstrated to provide faster payback of investments confirming the high value of expected worldwide CAGR of the total AI market at 2030 of 37,90 %. For example, remaining on our days, Algoma Steel extensively uses Artificial Intelligence applications for processing data declared to have achieved the reduction of 5% of unplanned downtime and production increase of 140.000 ton per year in the Cold Mill of Sault Ste. Marie, Ontario, Canada[38]. Furthermore, McKinsey forecasted in 2018 that the integration of AI platforms and advanced data analytics with CMMS under a DCS and IoT infrastructure has the potential to increase EBITDA in the order of 3% and to decrease operational costs by 5%. For these reasons, AI & ML together are believed to be the current key enablers of the social disruption extended to industry considering the Industry 4.0/5.0 model, as evidenced by the estimated growth.

In general, AI & ML and the other *enablers*[39] produce other needs such as:

1. Transformation of Workplaces and upskilling of workforce to be trained for operating into extended digital environment.
2. The implementation of a unique and efficient infrastructure along the Supply and Manufacturing Chains ensuring data gathering and seamless flow.

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[36] Generative AI refers to deep-learning models that can generate high-quality text, images, and other content based on the data. IBM Research, https://research.ibm.com/blog/what-is-generative-AI

[37] ChatGPT (Chat Generative Pre-Trained Transformer) is a large language model-based chatbot developed by OpenAI and launched on November 30, 2022, notable for enabling users to refine and steer a conversation towards a desired length, format, style, level of detail, and language used.

[38] OSISoft Petuum, "Beyond Digital Transformation: What AI Means to the Steel Industry", Webinar May 20, 2019. https://www.youtube.com/watch?v=8DczJIzlyDw

[39] M.W. Vegter, R. Vesserling, Responsible Innovation for the Acceptance of AI in the Process Industry, University of Wegeningen, 2021.

3. The extensive interconnection of "*things*" such as sensors, equipment, cyber-physical-systems and software tools is the key for transforming factories into data-driven systems through IoT/IIoT networks that occupy the first place in Ranking 1 (CEFD) and Ranking 2 (GMS) and the sixth place among the most reputed ICTs in Ranking 3 of Table 3.
4. Implementation of Data Science applications and, in particular, Advanced Data Analytics for real time applications and Business Intelligence in the wider sense (fifth place in Table 1).

8.1.2 AI & ML and Workplaces: acceptance of digitalisation through centrality of Human Beings.

The Workplace Transformation (see just above point 1), highlights the general issue of the consequences of an uncontrolled shift from the I3.0 to the I4.0/5.0 Factory (or Smart Factory) due to in particular to AI & ML. In fact, although the Smart Factory is still technology-driven, Human Centrality generates additional needs and constraints coming from employees' involvement and active participation.

This depends on AI that represents the larger disruption of the last decade in every aspect of Society including ethical, industrial, economic activities etc.

These considerations introduce the issue of the *acceptance* that is a general factor not limited to AI but extended to the whole Digitalisation Transition in factories. The solution cannot consist into the mere *acceptance* of working within deeply digitalised ecosystems but a cooperative approach between humans and digital technologies is needed. In other words, humans are in primary positions in the factory's ecosystem.

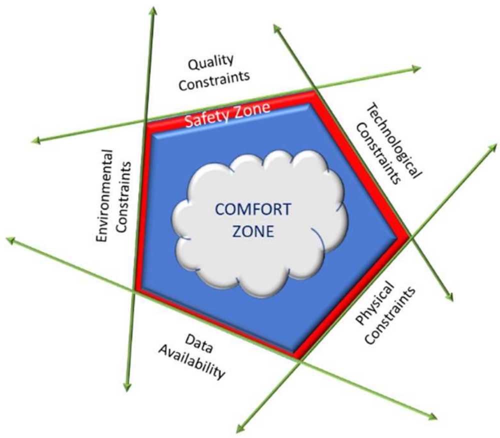

Fig. 10 Comfort, Safety and Limit Zones. Source: Petuum, Next Generation AI. https://www.youtube.com/watch?v=8DczJIzlyDw

To achieve the full cooperation, some hurdles must be faced such as the generational digital divide leading young generations to embrace digitalisation in their social life apparently with no fear that instead seems to characterise older people. Regarding the industrial AI, it is the aspect mostly at the basis of such contrast so, the influence of skills and upskilling considering the natural rate of retirements, makes evident the key role of the advanced training[40] which is part of the solution. However, the ethical problems still remain suggesting to carefully hear the voice of employees.

Going in deep to this issue, positive benefits such as the empowerment of employees can be mentioned. In particular, AI-based tools push employees going beyond their comfort zone (see Fig. 10 where comfort zone is depicted in grey) by managing constraints to widen their working zone beyond the limits (blue zone) through the reliable optimisation of process operations. In this zone, threats still exist but digitalisation allows to deal with them with reasonable probability of success.

This is part of the transition push the transformation of the ensemble of humans and machine from reactive to predictive factories enabled by higher and higher volume of data, the effective possibility to pursue reliable multi-objective optimisation supported by ever-cheaper computing power.

However, unsuccessful uptake of AI within the job routine is observed in terms of '*resistance*' towards diffused digitalisation and AI in particular. Thus, AI is today at the basis of controversial positions in the relationship between Digital Technologies in general and employees. For the time being the discussion and political positions contrasting the AI are raising because of, for instance, the *Generative AI.* This will grow in the future if these aspects are not taken into account with due urgency and with specific upskilling plans through the deep change in the teaching approach involving the educational systems as well.

[40] The way of saying "*Advanced Technical Training*" means the combination of frontal relationships with teachers and coaches, digital systems specifically designed for training (remote or assisted in classrooms) on the basis of psychological principle, ergonomics and in line comparison with the shop floor. The extended use of simulators up to Digital Twins powered by data taken from the field but unable to send commands except in a simulated way having available simulators capable of analyzing the nature and quality of the command itself.

Unfortunately, individual and mass psychology play a key role. In fact, studies on the matter seem to link the contrast to AI with the unclear position of operators of the process industry with respect to the tasks they have to deal with. To explain such negative relationships, the loss of operator's autonomy with respect to rigid procedures and prescriptions inherent to AI approach are often invoked.

However, despite explanations are important, the key question still lies on the way of recovering the *contrast* because in many cases, instead of productivity growth, its decrease is observed.

To close the AI topic, a dramatic but interesting and ethically correct conclusion is reported in the source specified in the footnote[41]:

"If Process Industry wants to become "smart", its innovators should be keen to develop skills and to safeguard meaningful work … through development of skills and inclusion of worker in co-creation of value".

8.1.3 Robust, Reliable, Resilient and Flexible Infrastructure; Architectures and Frameworks.

As said before, the ecosystems of driving technologies, their enablers and data availability are summarised by saying *What, Where, When.* Tough it was introduced in the healthcare context but it is generally extendable to all the other sectors and in particular to discuss about *Digital Infrastructure* for delivering the *right data where* and *when* it is required.

Table 6 Set of digital technologies prevalently defining the ICT landscape.

n°	Digital Technology Ranking 1 Basic Infrastructures	CEFD $KPI_{TT\%}$	n°	Digital Technology Ranking 2 Basic Infrastructures	Global Market Size Expenditures billion US$	n°	Digital Technology Ranking 3 Basic Infrastructures	CAGR Compound Annual Growth Rate
1	IoT	30,85%	1	IoT	1.742,80	2	IoT	20,47%
2	Cloud Computing	21,86%	2	Cloud Computing	1.470,11	3	Cloud Computing	17,20%
4	Industrial Logistics	1,85%	3	Industrial Logistics	162,50	4	Data Centres	15,50%
5	Cybersecurity	0,63%	5	Cybersecurity	49,53	5	Cybersecurity	14,80%
6	Data Centres	0,27%	6	Data Centres	20,00	6	Industrial Logistics	13,15%
TOT.		55,46%	TOT.		3.444,94	TOT.		81,12%

A very basic sub-set of technologies roughly defining the concept of Digital Infrastructure (often said *the ICT landscape*) is reported in Table 6 with the relevant sub-rankings 1, 2 1nd 3 however, the concept is much complex to be reduced to a list of technologies.

First of all, the complexity of a suitable representation asks for the adoption of a functional layering schema. Such model, has been developed along the way of defining a standardised (unified) reference model of the Industry 4.0 or the Smart Factory, depending on the side of the Atlantic Ocean we are. So, because the visible part of the ICT infrastructure is represented by Architectures[42] we like to establish a link between the different logical elements of such Unified Reference Model evidenced by the different layers.

The first visible (superior) layer of the ICT infrastructure is the Architecture upon which systems are built up with the aim of extracting the full holistic potential of the different technologies or clusters of technologies such as AI & ML and its enablers for ruling the flow of data allowing data gathering and processing for feeding the application throughout the whole ecosystems.

However, whether AI is a key enabler of the Industry 4.0/5.0 paradigms, the architecture in turn enables AI through the implementation of the Reference Models to be necessarily accompanied by the development of specific standards.

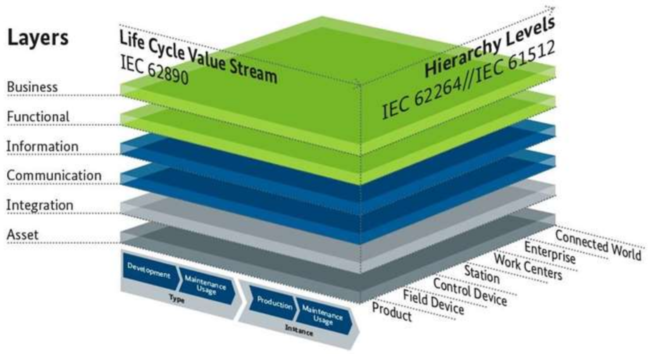

Fig. 11 The Reference Architecture Model Industrie 4.0 (RAMI 4.0)

[41] Inclusion and co-creation: Essential ingredients for the large-scale acceptance of digital solutions, Institute for Sustainable Process Technology, The Netherlands, https://ispt.eu/news/inclusion-co-creation-industry-4-0/ , June 20, 2021.

[42] Infrastructure describes the actual set of components that make up a system, while architecture describes the design of the components and their relationships. In a nutshell, a system is built upon an infrastructure that has a particular architecture. https://stackoverflow.com/questions/22648450/what-is-the-difference-between-architecture-and-infrastructure-in-software#:~:text=Infrastructure%20describes%20the%20actual%20set,that%20has%20a%20particular%20architecture.

An example of this standardised approach is the Industry I4.0 compliant architecture relying on the *RAMI 4.0 model* (Fig. 11). RAMI 4.0 is a 3D Service Oriented Architecture able to link Legacy by maintaining the hierarchical dimension according to IEC 62264//IEC 61512 standards.

Another example of architecture is the OPA-S (Fig. 12), a DCS[43]-based architecture considering the Legacy issue as well as the RAMI 4.0. The integration of Legacy represents in any case a limit to the top efficiency of communication and control but saving the RoR lifespan.

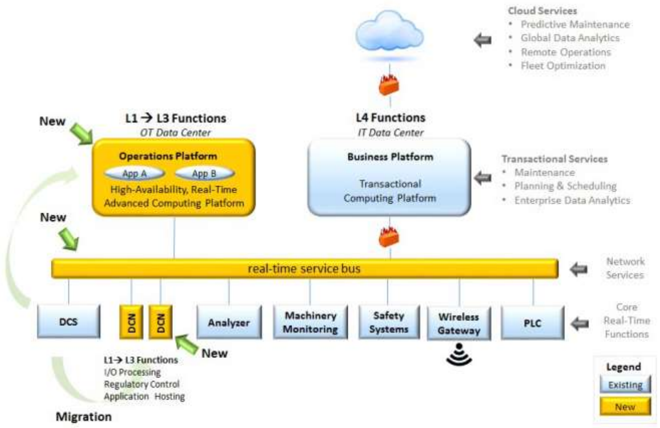

Fig. 12 The OPA-S Architecture

Architectures in general, must be reliable regarding data delivery certifying provenience and quality on the one side and the capability to grow in terms of data throughput, by managing capabilities and processing facilities on the other.

So, an effective and efficient architecture must be:

1. *Robust* to face threats and unpredictable events infringing dataflow continuity (see Cybersecurity that is a key aspect of the infrastructure).
2. *Reliable* for data cleaning and validation (see Tech. 7,8 and 9).
3. *Flexible* regarding the possibility to plug new or updated equipment by adding them to the constituent backbone and the connection grid (see IoT and Logistic in the wider sense for product and relevant data tracing).
4. *Resilient* regarding the capabilities to carry out operations and processes in the respect of quality, effectiveness and environment and human respect, eventually by optimally reconfiguring routes and scheduling.

Such kinds of architecture ready to grow by extending functionalities and able to host new devices, equipment and systems is named Framework[44] that is typically allocated within the third layer of the model.

A graphical, example of framework connecting systems and devices is shown in Fig. 13 below, where the IIoT platform[45] plays a key role in realising very complex evolutive and interoperable digital ecosystems linking predictive maintenance to assets for increasing efficiency, robustness and reliability decreasing OPEX (and CAPEX as well, due to the decrease of spare parts and programmed interruptions typical of the reactive maintenance model.

8.1.4 Growth and impact of the IoT market.

According to IEEE, ***the Internet of Things (IoT) can be defined as a world of interconnected things that are capable of sensing, actuating, and communicating among themselves and with the environment (i.e., smart things or smart objects)***[46].

For the time being, the diffusion of IoT technology and worldwide applications is representing one of the disruptions that are changing the ICT landscape within the social life, economy and industry (where it is labelled as *Industrial Internet of Things, IIoT*).

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[43] Distributed Control Systems

[44] A framework is a pre-built general or special purpose architecture that's designed to be extended.
Source: https://softwareengineering.stackexchange.com/questions/229415/difference-between-an-architecture-and-a-framework

[45] Both framework and platform include toolkits for mobile development, but frameworks operate as software-only skeletons for building applications, and platforms operate as hardware and software systems that help run applications.
Source: https://www.brainspire.com/blog/mobile-development-platform-vs-framework-how-they-differ

[46] "Introduction to the Internet of Things," in Internet of Things A to Z: Technologies and Applications , IEEE, 2018, pp.1-50, doi: 10.1002/9781119456735.ch1.

McKinsey have forecasted in 2019[47], the number of IoT-connected devices reaching 43 billion by 2023, three times the number of 2018. Considering the industrial context (where IoT is called IIoT), the primary factor was attributed to decreasing of sensor's costs pushed by the needs of enhancing shop floor visibility and field operations. However, IIoT 2022 market held up somewhat steadily, with the number of connected IoT devices growing to approximately 14.4 billion with roughly $202 billion in IIoT spending[48]. At the level of Global Market Size, IoT (including IIoT) was estimated in 2015 to have a total economic impact of $3.9 trillion to $11.1 trillion per year in 2025[49]. Instead, recent research drastically resized the growth of global IoT market to about $1,1 trillion in 2027 at a CAGR of 21.4%[50].

So, in spite of the unfavourable global macroeconomic scenario, expenditures in the IoT market were and are still huge as reported in communications by the majority of industrial companies and end-users highlighting faster project roll-out and investment payback time for their IoT projects.

Technically speaking, an IoT-based network is aimed to connect both wireless and wired more complex devices than sensors such as computing machines, robots, software systems. In addition, it can be connected to cloud solutions and to the edge in favour of Flexibility and Interoperability.

Therefore, despite the economic situation and the forecast to the next two years, IoT remains a key trend inside the Digitalisation panorama.

However, we cannot overlook the necessary costs to ensure Robust, Reliable and Flexible dataflow and data processing. In fact, CAPEX is not a secondary aspect of the consequences in this investment direction.

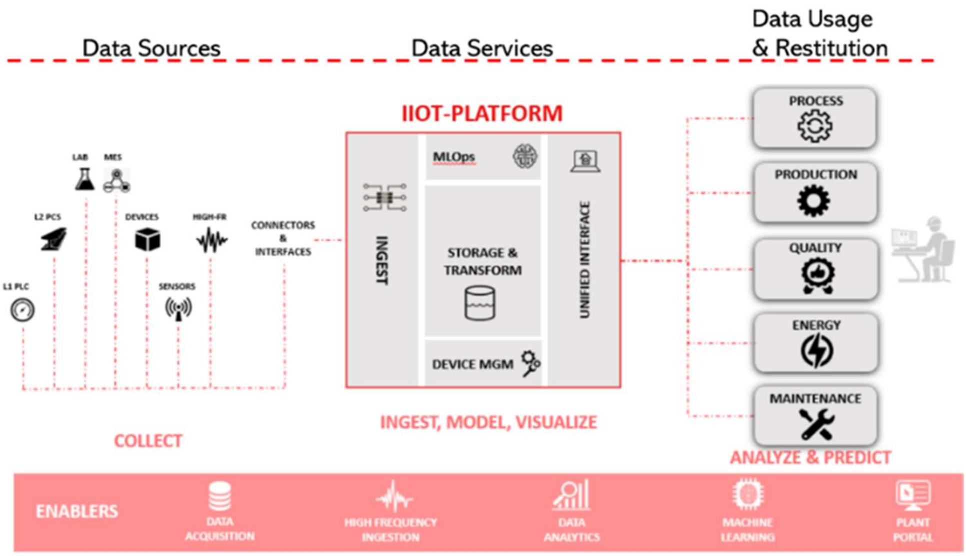

Fig. 13 The complex ecosystem integrating maintenance, assets and operations thanks to the IIoT Platform. Courtesy of Danieli Automation SpA.

This is made visible through the forecast of GMS in 2030 (the biggest amount in our Dataset with US$ 1.742 BN) and the first in the CEFD/KPI$_{TT\%}$ ranking representing 38% of the total. Furthermore, because the Smart Factory is also a data-intensive system requiring extensive monitoring of processes, product quality and business large facilities for storage and computing are necessary.

As a consequence, the implementation of the data-driven factory model requires high direct and indirect CAPEX to provide large *Data Siloes* and huge *computing power*. Considering AI and ML, both CAPEX and OPEX are important; CAPEX is related to investments in data centres, edge computing, internal cloud solutions and the already discussed digital infrastructures on the one side. On the other, OPEX increases in case of access

[47] McKinsey Company, "Growing opportunities in the Internet of Things", July 22, 2019, https://www.mckinsey.com/industries/private-equity-and-principal-investors/our-insights/growing-opportunities-in-the-internet-of-things .

[48] A. Taparia, "IoT 2022 in review: The 10 Most Relevant IoT Developments of the Year", IoT-Analytics, January 9th, 2023. https://iot-analytics.com/iot-2022-in-review/

[49] J. Manyika, M. Chui, By 2025, Internet of things applications could have $11 trillion impact., Fortune, article July 22, 2015.

[50] Source: the Business Research Company, IoT Global Market Report 2023, https://www.thebusinessresearchcompany.com/report/iot-global-market-report#
https://www.thebusinessresearchcompany.com/report/iot-global-market-report#

to external services (cloud computing and storage services) to feed ML applications in the learning phase and energy connected to the robust data infrastructure.

In Fig. 13[51], the practical application of an industrial IIoT network is shown: a core IIoT Platform is in the central portion of. It is realised upon a specific generalised framework. The extensive data flow supported by the infrastructure is in the left side and the application architecture on the right side. The list of possible enabling application is in the bottom of the picture. Based on Fig. 13, the complexity and the involved data volume must be considered for the possible consequences on the operativity of such *System of Systems*[52].

8.2 Data bottlenecks in the context of Sustainability[53].

Data and Data Technologies are not limited to the AI topic but they are the pervasive presence of all the key technological drivers in the Digital Transition context. Therefore, data management must consider for all aspects including enabling of seamless dataflow, the relevant bottlenecks.

More in depth, the production industry faces a number of technology, organisational and cultural bottlenecks on the path to become efficient and flexible in collecting, protecting, sharing and using data for production, business and society communication.

Since the data and cyber part of production is moving from a support functionality to a critical core part of any production, most companies need to upgrade their view on data and cyber capabilities. Looking at currently very successful production companies like Tesla and other green field producers started as *IT companies* first forming an IT architecture to which they have merged existing knowledge, assets and production. Most other companies have added the automation and IT knowledge to their existing product and production competence.

The main consequence consists in considering company cultural and organisational position in addition to technology as a part of the potential bottlenecks needed to address in a production world with increasing society and customer interest to environmental impact of produced goods. Given the societal urgency and market trends related to environmental impacts, its rather likely that upgrade and new policies in combination with rapid changes in market demand should be expected.

Thus, pushing industry to continuous updates of their related capabilities. Based on this flexible and efficient such capabilities will become a large and larger part the company competitiveness portfolio.

8.3 Cloud Technology: on-premises vs as-a-service and associated threats.

Cloud Technology, named also Cloud Computing, ***is the technology developed, applied and made available for delivering computing services (including servers, storage, databases, networking, software, analytics, and intelligence) over the Internet ("the cloud")*** to offer faster innovation, flexible resources, and economies of scale[54]. However, the in-field situation is more complex than it might be understood from this definition. Indeed, such services can be internal or externally provided. In this last case, ***cloud services based on infrastructure, platforms, or software that are hosted and provided by third-party and made available to users through the Internet***[55] ***or local facilities***.

[51] The picture in Fig. 13 is reproduced in the document under the authorization of Danieli Automation owning the relevant IP rights.

[52] A System of Systems is a collection of task-oriented or dedicated systems that pool their resources and capabilities together to create a new, more complex system which offers more functionality and performance than simply the sum of the constituent systems. Wikipedia, Popper, S., Bankes, S., Callaway, R., and DeLaurentis, D., System-of-Systems Symposium: Report on a Summer Conversation, July 21–22, 2004, Potomac Institute for Policy Studies, Arlington, VA.

[53] This Paragraph has been taken from the Position Paper of the Smart Factory FG entitled: Steel industry and environmental footprint data collection and aggregation (to be published).

[54] "What is cloud computing?", https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-cloud-computing/

[55] https://www.bmc.com/blogs/cloud-computing-roles/

The differences between *As-a-Service* and *On-premise* are summarised in Fig. 14 according to the five indicators listed on the left side of the picture. The selection of one of the two options can be made based on costs, security, trust on relationships with Service Providers etc. Such success factors towards the *On-premise* option are summarised in the right-side column but, some of them such as the use of third parties' servers, can be convenient or source of barriers at the same time.

Furthermore, despite the uncertainties of the time beings, the view to the impact of economic indicators on the digital market, the Cloud Computing Industrial Market Size is estimated to grow up from the initial value of US$ 545,8 billion in 2022 to US$ 1.470,11 BN in 2030[56] (GMS relevant to the second position after the IoT of Ranking 2 shown in Table 2). Furthermore, the growth rate measured in terms of CAGR should be about

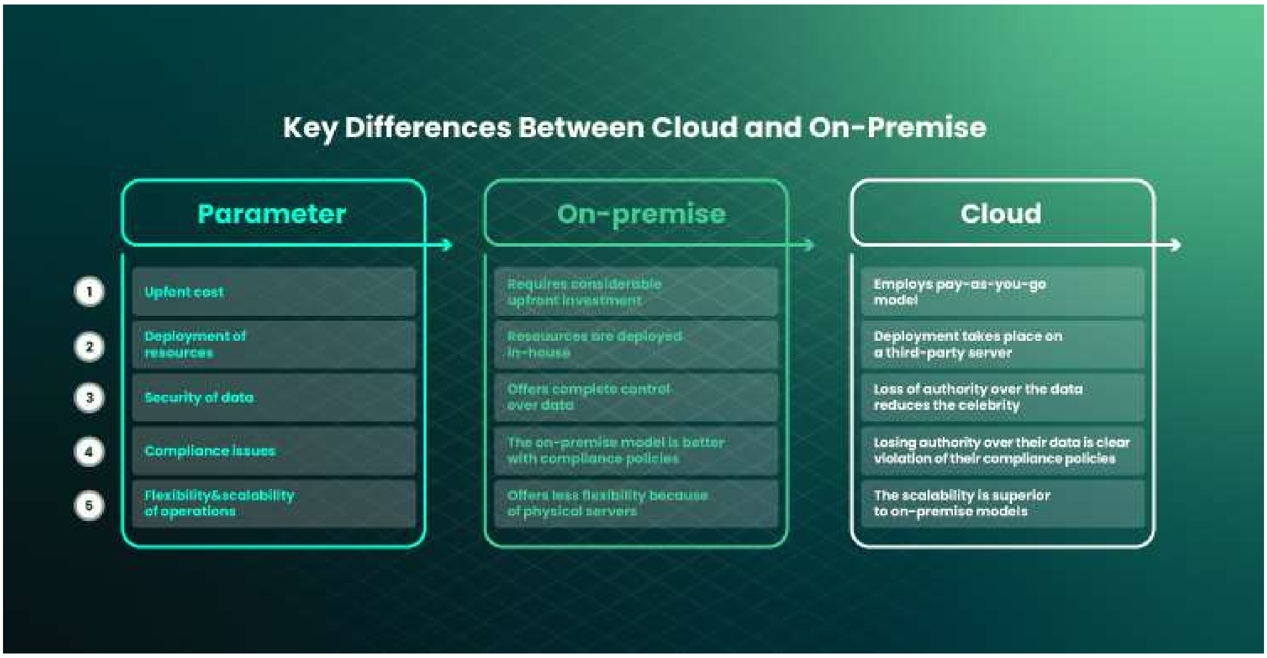

Fig. 14 On-premises vs as-a-service Cloud solutions. Differences. Source: Forbytes, January 2023. https://forbytes.com/blog/on-premise-vs-cloud-comparison/

18% that remains an important payback for investors even though lower than the 21,4% of the IoT.

Furthermore, the CAGR value of such trend measure also the *propension towards services* (by companies and government agencies that together determine the largest volume of business related to this technology). Despite the forecasted values to 2030, some important concerns regarding Security and Privacy of data and information must be mentioned. Such concerns are not peculiar to Cloud only, but common to other Internet-based technologies as well with the result of restraining the diffusion of Cloud services not only due to the presumed vulnerability of the Internet but also for the protection of data from third parties and the associated threats to data integrity for example.

Clearly, the more services vendors and users populated markets, the more threats become real risks and then likelihood events. This is amplified by the analysis of needed skills that are in common with privacy, revealing a big lack in particular regarding not only skills but also the mindset towards Cybersecurity (see next paragraph 7.3.2).

[56] Source: *MARKETSandMARKETS*, https://www.marketsandmarkets.com/Market-Reports/cloud-computing-market-234 .

8.4 Implementation of Cybersecurity Systems.

8.4.1 Targets, Functional Missions and Impact of Cybersecurity Systems on the company organisation

Cybersecurity has been already introduced and commented regarding the economic indicators in Paragraph 6.1 leaving suspended the discussion about its apparently limited GMS. In this part, the importance and the approach toward the contrast to digital threats are discussed however, some more comments are required in relationship with the results of the Economic Analysis.

Table 7 Main targets of Cybersecurity Systems in the security policy of companies.

TARGETS OF CYBERSECURITY APPLICATIONS	CONTEXTS OF THREATS AND IMPACT OF CYBERSECURITY ON ORGANISATION
Data Protection and Privacy	Companies handle vast amounts of sensitive data, including customer information, intellectual property, financial records, and trade secrets. Effective cybersecurity measures ensure that this data is safeguarded against unauthorized access, theft, or manipulation, helping to maintain customer trust and comply with data protection regulations like GDPR, HIPAA, and CCPA.
Business Continuity	Cyberattacks or security breaches can disrupt business operations, leading to downtime, financial losses, and damage to the company's reputation. By implementing robust cybersecurity measures, organizations can minimize the risk of such disruptions and ensure smooth business continuity, even in the face of cyber threats.
Reputation and Trust	A company's reputation is closely tied to its ability to protect customer data and maintain online services without disruptions. A single data breach can erode customer trust and tarnish the company's image. Strong cybersecurity practices demonstrate a commitment to protecting sensitive information and maintaining a secure environment, fostering trust among customers, partners, and stakeholders.
Legal and Regulatory Compliance	Many industries are subject to cybersecurity regulations and compliance requirements. Failing to meet these standards can result in legal consequences, fines, and other penalties. Implementing effective cybersecurity measures helps companies avoid legal issues and ensures adherence to industry-specific regulations.
Financial Impact	Cyberattacks can lead to financial losses in various ways, including theft of funds, loss of intellectual property, lawsuits, and costs associated with recovery and remediation. Investing in cybersecurity can mitigate these financial risks by preventing attacks or minimizing their impact.
Innovation and Competitive Advantage	Companies that prioritize cybersecurity create a more secure environment for research, development, and innovation. When customers and partners trust a company's security practices, they are more likely to collaborate and share sensitive information, fostering a culture of innovation. Moreover, a strong cybersecurity posture can become a competitive advantage, as security-conscious customers may prefer to do business with companies that prioritize data protection.
Supply Chain Security	In an interconnected business landscape, the security of a company's supply chain partners and vendors can impact the organization's overall security posture. Weaknesses in one part of the supply chain can be exploited to target other linked organizations. Therefore, organizations need to ensure that their partners also adhere to robust cybersecurity practices.
Employee Productivity and Awareness	Cybersecurity training and awareness programs educate employees about safe online practices, such as recognizing phishing attempts and using secure passwords. When employees understand their role in maintaining security, they contribute to the overall cybersecurity strategy and reduce the risk of inadvertent breaches caused by human error.
R&D Protection	Companies investing in research and development heavily rely on the protection of their intellectual property. Cybersecurity measures prevent industrial espionage and intellectual property theft, safeguarding a company's innovative ideas and proprietary technologies.

To close the suspended point about the GMS, we claimed the similarity with the AI & ML case. In fact, as AI & ML, despite its disruptive role in the Digital landscape of companies, seems to be lower than expected, the necessity to also consider the enablers and particularly the infrastructures and the additional expenses to build up the communication network among assets such as the use of IoT platforms, systems and workplaces (Humans). The case of Cybersecurity may mirror AI &n ML.

As a consequence, part of the infrastructure and additional costs are not related only to software but also to external special services and further empowerment of assets for their protection and the workforce training. So as for AI, it seems very difficult to distinguish the total expenditures for Cybersecurity but the possibility that the forecast is underestimated could be real.

To do a step ahead, I two factors are extremely important in the design of the customised effective Cybersecurity system: identification of threats and the list of critical information. Individuation of potential threats is part of the Risk Analysis so, it will not be discussed in depth considering also the possibility to cooperate with vendors and with consultancy companies.

Regarding the critical information, in Table 7 on the left column, key kinds of them information to be protected in the industrial context are listed. On the right, some consideration on data and usual actions to deploy a real protection are given.

However, this is not enough to provide a complete shielding unless smart solution based on AI and a proper organisation upon which the Cybersecurity model is founded. For example, data of the same kind are not stored or exchanged through the same devices or channels.

Moreover, lack of standardisation even in the same company and its plants exists. This issue is particularly detectable in brownfield. AI & ML can be a real support to abate these problems however, in case of complex industrial organisation, the implementation of an effective and efficient Cybersecurity System cannot be casual but needs a careful analysis and System Design considering not only assets and manufacturing systems as a whole but also the organisation of operation and workforce. For this reason, the following paragraph provides a possible implementation model scheme on which to design and implement the Cybersecurity System. Such model considers the informatic part and also the menaces to be faced and the countermeasures in terms of application specific of such system.

8.4.2 A functional schema for implementing Cybersecurity Systems

The following synthetic schema outlines the software solutions and applications that can be integrated to create a comprehensive cybersecurity architecture for an industrial company. It's important to highlight that customizing the solutions based must be based on the analysis of the company's specific needs to be turned into industrial requirements considering also the status and the possible update of the existing company technology landscape. Regular updates, testing, and collaboration with cybersecurity experts are crucial for maintaining the effectiveness of the architecture over time.

To this aim, a detailed schema for the software implementation of a cybersecurity architecture for an industrial company, including specific software solutions and applications is presented drawing attention to the fact that, while cybersecurity is a part of the digital infrastructure, it is based on the overall first-level design of what we called the digital landscape of the company.

1. ***Network Segmentation and Perimeter Security:***
   - ✓ Firewall Solution: Implement a robust firewall solution to enforce traffic filtering and rules between different network zones.
   - ✓ Intrusion Detection/Prevention System (IDS/IPS): Deploy IDS/IPS software to monitor network traffic for suspicious patterns and block known attack signatures.
2. ***Access Control and Identity Management:***
   - ✓ Identity and Access Management (IAM): Utilize IAM software to manage user identities, enforce access policies, and enable single sign-on (SSO) capabilities.
   - ✓ Multi-Factor Authentication (MFA): Implement MFA software to add an extra layer of authentication for accessing critical systems.
3. ***Endpoint Protection and Device Management:***

- ✓ Endpoint Security Suite: Deploy an endpoint security suite that includes antivirus, anti-malware, and behaviour-based threat detection.
- ✓ Mobile Device Management (MDM): Use MDM software to manage and secure mobile devices accessing the corporate network.

4. ***Encryption and Data Protection:***
   - ✓ Encryption Software: Employ encryption solutions for data in transit (using protocols like TLS/SSL) and data at rest (full disk encryption, database encryption).
   - ✓ Data Loss Prevention (DLP): Implement DLP software to monitor and prevent sensitive data from leaving the organization.
5. ***Security Information and Event Management (SIEM):***
   - ✓ SIEM Platform: Deploy a SIEM platform to collect, correlate, and analyse security events across the network, providing real-time threat detection and incident response capabilities.
6. ***Industrial Control System (ICS) Security:***
   - ✓ SCADA and Distributed Control Systems (DCS) Security: Utilize SCADA-specific security solutions to protect industrial control systems, including anomaly detection, protocol analysis, and control system firewalls.
   - ✓ Network Monitoring: Implement network monitoring tools tailored for ICS environments to detect unusual behaviour and potential threats.
7. ***Vulnerability Management and Patching:***
   - ✓ Vulnerability Assessment Tools: Use vulnerability scanning tools to identify and prioritize vulnerabilities in systems and software.
   - ✓ Patch Management Software: Implement patch management solutions to automate the process of applying security patches and updates.
8. ***Incident Response and Forensics:***
   - ✓ Incident Response Platform: Deploy an incident response platform to streamline incident handling, coordination, and communication.
   - ✓ Forensics Tools: Utilize digital forensics tools to investigate and analyse security incidents after they occur.
9. ***Backup and Disaster Recovery:***
   - ✓ Backup Software: Implement backup software for regular data backups, ensuring data availability in case of data loss or ransomware attacks.
   - ✓ Disaster Recovery Solution: Set up a disaster recovery solution to quickly restore systems and services in case of major disruptions.
10. ***Employee Training and Awareness:***
    - ✓ Security Awareness Training Platform: Utilize software platforms to deliver cybersecurity training modules and assess employee knowledge.
    - ✓ Phishing Simulation Tools: Conduct phishing simulations to train employees to recognize and report phishing attempts.
11. ***Vendor and Supply Chain Security:***
    - ✓ Third-Party Risk Management Software: Employ software to assess and manage the cybersecurity risks associated with third-party vendors and partners.
12. ***Continuous Monitoring and Compliance:***
    - ✓ Continuous Monitoring Tools: Implement tools for ongoing security monitoring, including log analysis, threat intelligence feeds, and behaviour analytics.
    - ✓ Compliance Management Solutions: Utilize software to track and demonstrate compliance with industry regulations and standards.

13. ***Security Policy Enforcement:***
    - ✓ Policy Management Software: Deploy software to define, enforce, and monitor security policies across the organization.
14. ***Threat Intelligence and Analysis:***
    - ✓ Threat Intelligence Platforms: Utilize threat intelligence platforms to gather and analyse information about emerging threats and vulnerabilities.
15. ***Secure Development Practices:***
    - ✓ Application Security Tools: Integrate application security tools into the software development lifecycle to identify and mitigate vulnerabilities in code.
16. ***Remote Access and VPN Solutions:***
    - ✓ Remote Access Software: Use secure remote access solutions and Virtual Private Networks (VPNs) to enable remote work while maintaining security.

8.5 Digital Twins, VR & AR and Industry 5.0

The evolution of the I4.0 to the I5.0 paradigm is not only the increase of the sequential "revolution number" but an important change based on the centrality of the Human Factor whose importance was not sufficiently highlighted by the I4.0. As already introduced in paragraph 8.1.2, the acceptance of digital systems takes benefit from the company culture, the improvement of workplace conditions and a dedicated training policy founded on continuous upskilling of employees implemented by taking care of the psychological aspects to fit with expectations and dignity.

Regarding the technical aspects, there is not only one driver but a holistic combination of the technologies listed in Table 2 whose outcomes consists in linking psychological and technical aspects.

This set of technologies has in first position according to CEFD/$KPI_{TT\%}$) the way to interface humans and machines with the virtual world through digital tools (VR) empowered by specific AI applications to augment the content of information coming from data of the real world (AR).

Table 8 Aggregation of ICTs for Human Centrality.

n°	Digital Technology Ranking 1 Human Centrality	CEFD $KPI_{TT\%}$	n°	Digital Technology Ranking 2 Human Centrality	Global Market Size Expenditures billion US$	n°	Digital Technology Ranking 3 Human Centrality	CAGR Compound Annual Growth Rate
1	Digital Twin	5,07%	1	Digital Twin	139,93	1	Digital Twin	29,30%
2	Industrial Automation	3,43%	2	Industrial Automation	377,25	2	Industrial Automation	10,50%
3	VR & AR	1,59%	3	VR & AR	62,71	3	VR & AR	41,90%
	Total	10,08%		Total	579,89		Total	81,70%

So, the aggregation/integration of VR & AR (4th position in Table 1) and Digital Twins (10th position) is joint with the Industrial Automation (and Control) as reported in Table 2.

However, Industrial Automation (IA) as reported in Table 8 represents the set of digital technologies enabling the Industry 5.0 Unified Reference Model in the wider sense so, extended to Banks, Financial services etc. The common background of such technologies is characterised by the unique objective of connecting digital and/or cyber-physical objects with humans to execute operations that can led to not separately consider the connecting expenses but within the total expenses of such systems as in the case of the AI. In fact, based on the experience of Systems Integration companies, the 2,5% of the AI's GMS at 2030 (i.e., around US$ 40 Billion) can be a reasonable estimation for complementing the economic resources to be spent for deploying the Human Centrality that leads to the global value of US$ 620 Billion.

Par. 8.1, 8.3, and the current 8.5 can give the idea of the interactions between the ethical, psychological and technical aspect of the impact on workplaces very well underlined by the results of the ESSA project[57].

[57] https://www.estep.eu/essa/essa-project/

9 General Conclusions.

To conclude, the present analysis joins economic and technological considerations demonstrating that, despite the hybrid approach based on two very different factors, it can provide indications for the Sustainable Transition and how Digitalisation enables this process.

As a consequence, economic data are was used to provide information to steelmakers on investing topics promoting the consideration of Clusters of Digital Technologies to highlight the holistic impact of the ensemble instead of the sum of impacts coming from specific technologies.

Therefore, such analysis does not consider each digital technology by its own as the best approach rather is oriented to highlight the *holistic* impact of sets of them according to the criteria of *enabler-enabled* relationships.

It has been also demonstrated that this approach makes sense when a clear vision of the future of the steel factories is defined. This vision has been declared and the role of Digitalisation has been analysed and directions of development discussed.

So, based on these considerations, the key factors of the "*digital landscape of the future*" are:

- ✓ The achievement the Smart Factory charcterised by pairing humans and machines in presence of autonomous and Intelligent Cyber-Physical Systems. In this context, AI has been considered as the most attractive investments to realise in presence of the necessary enablers allowing AI to deploy its full potential.
- ✓ The integration of the Manufacturing and Supply Chains into a seamless data-driven *System of Systems* was confirmed by the huge efforts forecasted for infrastructures, architectures and frameworks. For this aim, robust, reliable and resilient infrastructure realised to host integrated architecture models and frameworks.
- ✓ The increasing propension towards external "*as a service*" access vs ownership or internal services is evidenced by the high GMS, CAGR and $KPI_{TT\%}$ values (Cloud Technology is exemplar in this case).
- ✓ The attention to Cybersecurity, that is a part of the ICT infrastructure, will become more and more evident in the future according to the third position of the seven digital technologies qualifying the infrastructures and the forecasted value of $KPI_{TT\%}$ (see paragraph 9.3.1).
- ✓ Last but not least, Industry 3.0, the automation and manufacturing model of the 90's, is still alive despite the hard assault of AI&ML.

Table 9 Digital Technologies belonging to the Industry 3.0 model of the 90's

n°	Set of Digital Technologies	CAGR Compound Annual Growth Rate	Global Market Size Expenditures US$ BN	CEFD $KPI_{TT\%}$
4	Industrial Automation	10,50%	377,25	3,43%
6	Industrial Logistics	13,15%	162,50	1,85%
9	VR & AR	29,30%	62,71	1,59%
13	Modelling and Simulation in Industry	11,83%	40,50	0,41%
14	Data Centres	15,50%	20,00	0,27%

Therefore, Table 9 shows the five key technologies appeared during the consolidation of the Industry3.0 model of the 90's. They are listed yet because their evolution was disruptive at that dates and still today cover a fundamental role in the digital transition. So, they are part of the Industry 4.0/5.0 reference model. In particular VR&AR topics that are fundamental pillars of the Human Centrality (see Par. 8.5).

✓ the Functional Approach, (see paragraph 7.2), demonstrated to be the most appropriate for clustering technologies accordingly to given tasks and objectives. Moreover, the impact assessment is very significant to define a wise implementation plan for the transition of plants. Instead, Companies have to deal with differently because the approach is not focused on details but on the general approach to manage the manufacturing and supply chains.

9.1 Some hints relevant to the quality of data in relationship with the reliability of results.

The goal of defining primary investment directions and R&D&I priorities is a very complex step because to uncertainties, reliability of information, data and outcome dispersions and inhomogeneities related to the reference sample affecting the rapid, effective and reliable activation of ML algorithms.

As a consequence, during the data gathering phase of this analysis in terms of outcomes, the dispersion of farecasting values was verified. Unfortunately, a scientific approach to determine the reliability and the characteristics of the response is very costly (the average cost of one report for one digital technology has an average cost of US$ 3.500) and the description of the applied methodology is often somewhat lacking.

An exemplar demonstration of this premise is represented by the economic performances of AI & ML. The large difference between the Global Market Size and the Industrial Market Size contributed to raise the doubts already anticipated in paragraph 5.1 and further discussed in paragraph 7.1.1. Despite the difficulties to do that, an answer in this sense has been attempted by revising Fig. 5 as shown in Fig. 15 just below. Infrastructure Cluster (red box including the Cybersecurity box) and AI Cluster (light blue boxes).

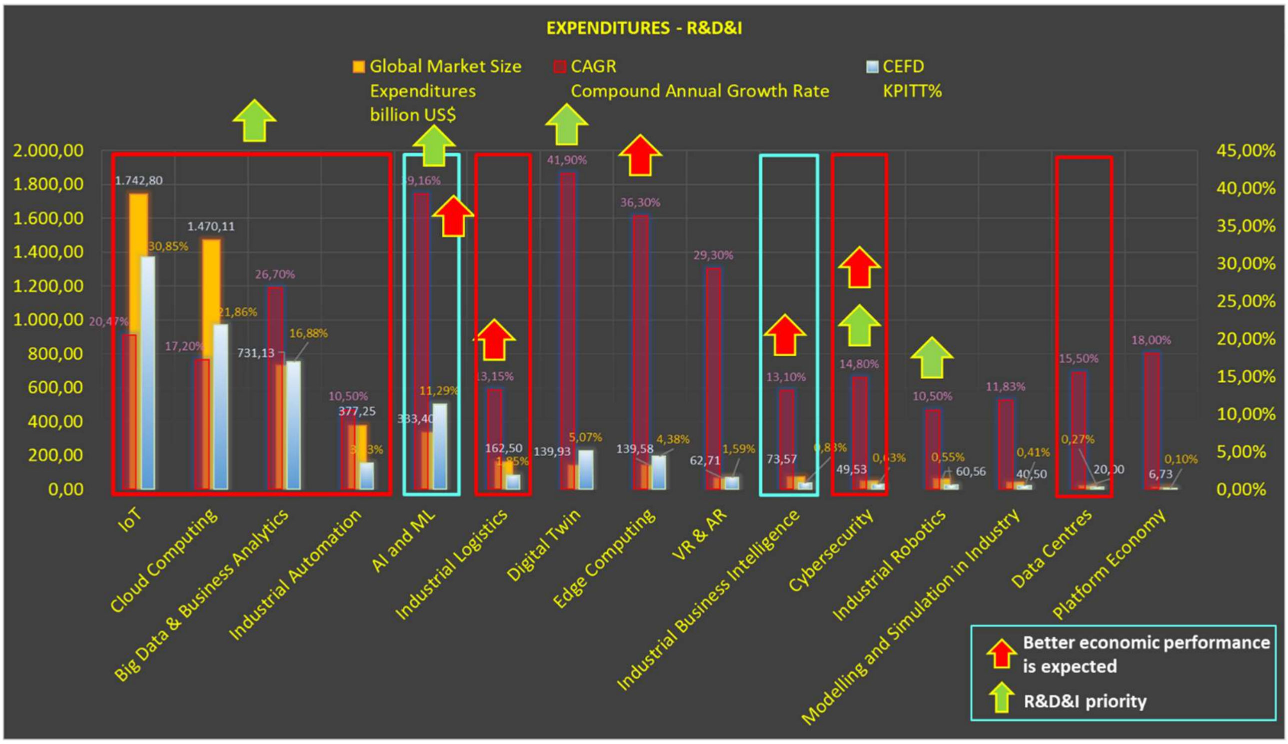

Fig. 15 Key investment directions and R&D&I priorities.

The previous considerations and their evidence leaded to carry out this Business Analysis by processing data according to the three indicators GMS, CAGR and CEFD/KPITT% and showing the outcomes relevant to the most significant indicator, if any, among the three defined in paragraph 5.2, or two or three according to the quality of the outcomes.

To prove this concept, the idea of following the GMS trends of each technology while it may seem the most intuitive, it does not, for example, manage to discriminate between widespread technologies and niche technologies created for limited classes of tasks and contexts. Furthermore, as we have learned during thus journey, the RoR expectations described by CAGR indicator can be very significant to select among diffusion and attractiveness. For these reasons, we collected and processed data according to the three indicators analysing, discussing and summarising the most significative results according to the evidence of the outcomes.

9.2 Outcomes, investment directions and R&D&I priorities.

As introduced at the earliest stage of this document, it can be divided into two logical parts:

1. To provide and share the common language and the semantic relevant to the enabling impact of the Digital Transition on the other leg of the Twin Transition. To this aim, the key definitions have been given in the first chapters and along the text of the document.
2. To provide and analyse the set of digital technology and data allowing the definition of investment directions and R&D&I priorities for the achievement of the status of Smart Factory, inherently considered the key enabler of the Sustainable Transition model and so, the premise of manufacturing the Green Steel.

The first point is more or less achieved considering the reported mess of definition and information. The second one has to the finalised in the following based on the information given by Fig. 15.

9.2.1 Investments Directions.

Here, two Clusters are highlighted to define the primary investment directions:

1. Infrastructures grouped into a in red rectangle composed by IoT, Cloud Computing, Big Data & Analytics, Industrial Logistics, Industrial Automation, Cybersecurity and Data Centres.
   As reported in paragraph 6.2, some concerns were raised for the presence of Industrial Automation and Analytics however, it must be reminded that the structure and components of Clusters depends on the analysis' scopes so, we can accept it as it is in Fig. 15. Furthermore, Data Centres con be substituted by Cloud Services.
2. AI & ML composed by AI & ML and Industrial Business Intelligence. As presented below in the detailed discussion of clusters, this one may include Big Data & Analytics for which the previous consideration about the dependence on the analysis' scope is still valid.

Moreover, big red and green arrows respectively represent technologies expected to perform better from the economic point of view and R&D&I priorities. In this part, it is not distinguished the technological maturity status but, at this stage, all are present on the market and still object of further evolutions even though breakthroughs are not considered.

In synthesis, the implementation effort toward the achievement of the Smart Factory privileges the infrastructure for its enabling impact on all the other digital technologies and the AI & ML that is the main disruption whose impact is forecasted to exponentially grow in this decade.

9.2.2 R&D&I priorities.

Regarding the R&D&I priorities, the following digital technologies are considered:

1. Infrastructures, in particular for the standardisation of data exchange and architectures (see
2. AI & ML regarding all the aspects such as Generative AI, Deep and Reinforcement Learning. The application fields of AI are huge and regards also the development of Autonomous Systems and Robots. Particular attention must be put on the ethical and social aspects of the industrial life as far as the paradigmatic change of the manufacturing ecosystem that includes humans.
3. Digital Twins integrated into the industrial Automation landscape that can largely contribute to product tracking and quality, safety of humans and assets.
4. Robots both in the forms of autonomous and remotised equipment pursuing the total safety approach of processes and the dramatic reduction of downtime due to predictive maintenance of assets.

Expressions such as Investment Directions and R&D&I are not expression of a hierarchical relationships between digital technologies but must be understood in terms of logical concatenation of actions such as for instance the deployment of enablers to ensure efficient use of enabled technologies.

Regarding R&D&I, priorities are looking to Sustainability and Decarbonisation of steel processes including the considerations on ethical issues. Indeed, to should be more correct to speak about the distinction between general digital technologies and niche technologies. This concept recalls also the impact of public funds that must consider also costs and complexity of industrial-scale demonstrators and pilots possible for large companies but not to SMEs. From that, the private role on developing niche technologies and solution is asked to increase. In this context, we have not yet discussed the sensor's topics. Despite some particular sensors are very complex and costly, the majorities of solutions are a good representation of the concept of niche technologies. This does not mean that the sensor issue has been underestimated but it must be considered as activities embedded into larger projects regarding for example the sustainability of processes made possible by data provided also by sensors.

9.3 Detailed analysis of Clusters.

The clustering approach is discussed with some more details in this part to provide a sort of guideline for designing the digital transformation of plant that may largely differ.

We consider three clusters: Infrastructures, AI & ML and the Human Centrality. We have already in depth discussed such themes however, a synthesis looking to the indicators is meaningful for better understand how to deal with clusters, how to carry out the analysis considering basic data and the three indicators by time by time selecting the most representative. In the following, the CEFD indicator is not used because we are looking to specific details.

9.3.1 Infrastructures.

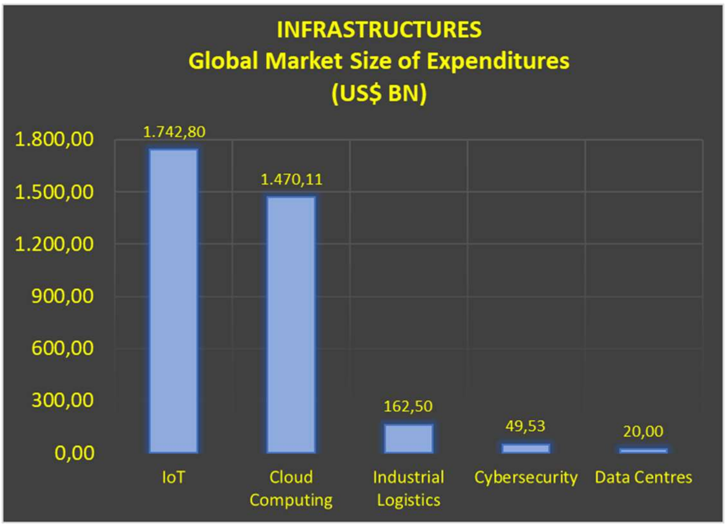

Fig. 16 A possible Infrastructure Cluster.

In Fig. 16 a possible selection of digital technologies to define the Infrastructure Cluster is shown. In this case the GMS indicator has been selected to give the idea of the expenditure size we are speaking of.

This selection of technologies among the set of the fifteen leads to a GMS to US$ 3444,9 BN, representing the 63,7 % of the global forecasted expenditures by 2030 (US$ 5.410,3 BN).

Moreover, the total CAGR of the cluster is 81,1 % representing the 25,5 % of the total CAGR.

It is interesting to see that despite the high GMS, CAGR is not so high. It could mean that decision makers are aware of the importance of the infrastructures and their enabling effect but the propension to invest there is not so high. In other terms, the relevant investments must be carefully analysed and implemented without any consideration out of the necessary "*must have*". This explanation makes sense but can lead to increase the life of legacy systems underestimating the loss of efficiency of their presence represented by the contrast between systems belonging to the Industry3.0 with respect to the Industry4.0/5.0. Indeed, large companies are in general mature enough to carefully analyse all the aspects of the investments but SMEs can be different.

9.3.2 AI & ML Cluster.

The AI & ML Cluster is shown in Fig. 17. It must be once again reminded the doubt raised in paragraphs 6.2 and 8.1.2 about the incongruency between the Global Market Size of Expenditures and the Global Industrial Size. The possible explanation relying of the possible embedding of expenditures into complex systems empowered by AI but not limited to these techniques may make sense but it remains a problem for the reliability of the analysis.

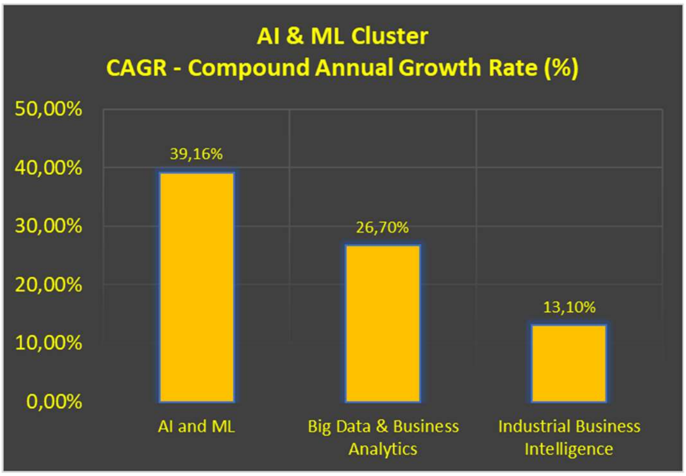

Fig. 17 The AI & ML Cluster.

In case of Fig. 17, Big Data & Business Analytics AI & ML has a CAGR of 39,2 % that is very high compared with the CAGR of Big Data & Business Analytics equal to 26,7%. Moreover, the addition of the Industrial Business Intelligence gives an important contribution of 13,1% resulting in a Cluster CAGR of 79% that is the 24,8% of the total CAGR.

Looking to GMS, AI & ML Cluster has a total GMS value of US$ 1.138,1 BN in which Big Data & Business Analytics is almost the double of the AI & ML (US$ 733,1 BN vs US$ 333,4 BN). The AI & ML Cluster represents the 21% of the total GMS. Also in this case, it seems that the expectations of RoR (CAGR) are quite good and expenditures are qualitatively and quantitatively lower. For these reasons, two hypotheses can be made. The first one lies on the enthusiasm toward the AI joined with a prudent approach to its implementation due to the complexity of the infrastructural parts and/or the CAPEX and OPEX issues as discussed in paragraph 8.1.3 regarding the indirect costs of the enablers.

9.3.3 Empowering Humans.

Another very important cluster is represented by the sub-set of digital technologies to maintain and reinforce the central positions of humans, whatever they do in the operations, from execution to supervision and control.

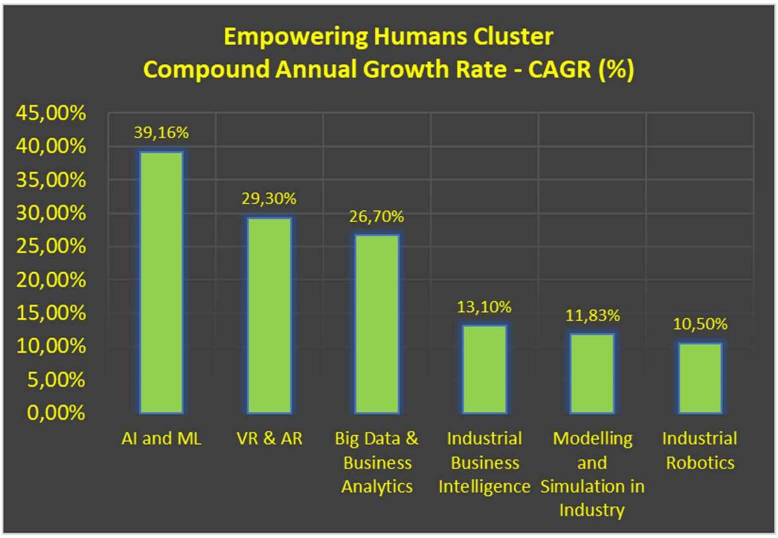

Fig. 18 A possible selection for the Empowering Human Cluster.

In Fig. 18, a possible configuration of the digital cluster is shown. This is obtained by merging the AI & ML Cluster with technologies devoted to empower and integrate humans "*in-the-loop*" of the manufacturing and supply chains. Among them, VR & AR, Modelling & Simulations and Industrial Robotics have been considered. The quantitative aspect is described by a cluster' CGAR of 130,6 % corresponding to the 41% of the total CAGR.

In terms of GMS, this cluster has a value of US$ 1.301,9 BN representing the 24,1% of the total GMS. On the one hand, this could mean that the contribution of the other considered digital technologies is relatively low. On the other, the massive presence of the AI direct and related technologies could overwhelm the true scope of repositions humans in the centre. However, the transition from the reactive to the predictive Smart Factory is prevalently based on AI reinforcing the reliability of data and the derived Clustering Approach.

9.4 Summary

Some key definitions among the many available have been given in this document aimed at defining a common language to discuss the further steps of the steel sector's Digital Transition. Despite the attention given to provide examples related to the steel manufacturing domain, this part must be reinforced in future documents where the connection between steel evolution and key manufacturing issues will be part of the work based on the definition of goals and related ICT Clusters.

How this will be possible in the perspective of decarbonisation depends on the evolutive dynamics of digital technology. Considering these aspects and sharing relevant information, Digitalisation will continue to be the "*must have*" of the steel community aimed at the implementation of the Sustainable Manufacturing in general with the three qualifying pillars of Prosperity, Planet and People and for decarbonisation in particular as required by the EU.

To conclude, we like to underline that R&D&I in general remains the Key Factor to preserve Future Generations because "*the human right to a healthful environment should be viewed in the context of a duty to future generations. The duty to preserve and protect the environment is a duty that is owed not merely to all other human beings, non-human beings, and inanimate objects in present time but extends also to future generations*"[58]. This is necessary because Green Technologies and Digital enablers are mutually interconnected.

To close, it must be underlined that we did not speak about the Dark Factory[59]. Maybe in some years but not now. even though someone spent time to coin a definition.

[58] https://archive.unu.edu/unupress/unupbooks/uu25ee/uu25ee0mm .

[59] A lights-out factory, also called a dark factory, is one where requirements for human activity are so minimal that the facility can operate in the dark with zero human intervention onsite. - Siemens Software. https://www.plm.automation.siemens.com/global/en/our-story/glossary/what-is-a-lights-out-factory/99912

APPENDIX 1

Table 6 Barriers, enablers, challenges and impact of key technologies.

Cluster	Key Technologies within Clusters	Barriers	Enablers	Challenges	Goals
ICT Infrastructures	• Flexible and Data-driven ICT Architectures, Cloud, Edge Computing • IIoT, Standards for Communications • Cybersecurity • Edge computing • Cloud Computing	• Expertise and Skills • Lack of software tools • Training • CAPEX • Legacy • Lack of Company Culture	• IIoT • Big Data & Analytics • AI, ML • Virtual Twin • Cloud (enabling Service Oriented and Microservice Architectures)	• Large scale Integration • Horizontal data integration and reconfigurable manufacturing capabilities in ISA-95 • Shift of focus from macro to micro services in manufacturing SOA • Real Time data processing and use • Integration of micro-services	• Overall Equipment Efficiency • Event Management • Extended Integrated Monitoring of processes (maintenance, emissions, etc.) • Increasing value extracted from data (+ + +)
Digital technologies for optimal manufacturing	• Modelling, Simulation & Virtual Reality. Predictivity & Optimization • Big Data & Big Data Analytics, ML & DL • AI, Edge Computing, Advanced Process Monitoring & Control • Product Tracking & Tracing	• Lack of Extended & Continuous Monitoring of processes, assets and products. •	• New ICT Infrastructures • Advanced Process Control •	• Large scale Integration and time-varying process adaptation • Use of both structured and unstructured big data • From focused to through-process applications	• Increased Efficiency • Fast decision support • Real time applications (+ +)
Digital Technologies for Asset Management; Platform Economy	• Asset Management & Smart Product Inventory. Smart & Continuous (Preventative & Predictive) Maintenance • Intelligent Internal and External Logistics • Digital Platforms for Circular Economy • Energy & Resource Management, Monitoring and Control	• Lack of Integration • CAPEX	• AI • Extended MES functionalities such as environmental control such emissions and related execution capabilities. • Early warning •	• Large scale Integration of assets for seamless dataflow	• Environmental Footprint (+ + +)
Autonomous & Embedded Systems; Robotics	• Autonomous local and remote Systems, Robot, Drones • Cyber Physical Systems, Systems of Systems. • Digital Twins	• Multi-vendor context • Lack of interoperability	• IIoT • AI & ML	• Legacy • Standardization of data • Standardized datasets for environmental footprint monitoring •	• Flexibility of the ICT Landscape (+ +)
Digital technologies for Human Centrality	• Augmented and Mixed Reality. Portable systems • Advanced HMI, H2M • New Skills, Supported Training, Continuous Learning	• Legacy • Digital Skills	• IoT • Improved training approach	• Security • Training and Upskilling of workforce	• Increased operational • (+ + +)

APPENDIX 2
DATABASE –Sources of Data

[A1.1] AI & ML

Vantage Market Research https://www.vantagemarketresearch.com/industry-report/ai-in-manufacturing-market-1404

[A1.2] AI

GlobeNewswire https://www.globenewswire.com/en/news-release/2023/05/05/2662532/0/en/Artificial-Intelligence-AI-in-Manufacturing-Market-is-expected-to-accumulate-a-value-of-US-22-6-Billion-by-2030-registering-a-CAGR-of-48-20-MRFR-Study.html

[A2] Cloud Computing

Spherical Insights https://www.sphericalinsights.com/reports/cloud-computing-market#:~

[A3] IoT

Precedence Research https://www.precedenceresearch.com/industrial-iot-market

[A4] VR & AR

Grand View Research https://www.grandviewresearch.com/industry-analysis/augmented-reality-virtual-reality-manufacturing-market-report

[A5] Big Data & Data Analytics

SKYQUEST https://www.skyquestt.com/report/big-data-in-manufacturing-industry-market#:~:text=What%20is%20the%20global%20market,period%20(2023%2D2030)

[A6] Edge Computing

Global Newswire https://www.globenewswire.com/en/news-release/2023/03/31/2638443/0/en/With-36-3-CAGR-Edge-Computing-Market-Size-Worth-USD-139-58-billion-by-2030.html

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