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Acknowledgments

“Success is a collection of the small efforts done day after day.”
Robert Collier.

This Master’s Thesis is a record of accomplishment of my Master’s program of Industrial Asset Management with a specialization in Innovation and Entrepreneurship at the University of Stavanger. The work done to complete this achievement has been a rough path but one that I would gladly walk again as it helped me become a better learner and observer, along with the support from my advisors, which insights aided me to create the work here presented.

Firstly I would like to thank my family for their love and support in this path that I choose to follow, and that is now concluding. Hopefully, I would be able to give back to them the same to them and be an excellent example for my brothers and sisters to chase their dreams no matter how hard or high they seem.

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“It is our light, not our darkness, that most frighten us.”
Marianne Williamson

Abstract

As organizations Implement DT and CPS with the aim to enhance their productivity and maximize the value from the physical assets, some issues come to light with the integration of said technologies, which affect both environments, the cyber one and the physical one, and as happen when new technical or technological trends become part of organizations problems that were part of their processes come to light but also they start creating new issues that industries must recognize to know where they are in their path to having a fully developed digital environment.

The Thesis addresses the main challenges identified in the research paper of applications for DT and CPS from the Huma-Technology-Organization (HTO) and Work Process perspective of different sectors in a general overview. In order to get an understanding of what is a DT and the CPS, the Thesis presents definitions on the AM and digitalization related terms such as IIoT, IoT, BIM, and other associated terms. The work aims to clearly outline the CPS and the DT from what integrates them, the basic building blocks, and how they interact together for the industries and differentiate one from the other.

The work process includes investigating research papers, digital books, and e-books that have application examples on applications from the industry sectors of Construction, Health, and Energy of the DT and CPS. Also, the recommendations from research papers and technical proposals on how the new disruptive technologies are going to shape the next step for the industries.

The author selects the recommendations that could aid in the mitigation or eradication of the issues found from the applications by stating the possible benefits that these technological trends could bring in the same perspective used for the challenges.

From this work, a fair conclusion is that industries have to implement the DT and CPS. However, organizations have to do it, so their processes are not affected or end up costing more in further adaptations. Managers and decision-makers have to include everyone in the business to fully integrate the DT and CPS and evaluate the organization's maturity in the path for digital transformation.

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Abbreviations

- DT Digital Twin
- CPS Cyber-Physical System
- ML Machine Learning
- PE Physical entity
- VE Virtual entity
- HTO Human-Technology-Organization
- AI Artificial Intelligence
- AR Augmented Reality
- VR Virtual Reality
- IT Information Technology
- OT Operational Technology
- IoT Internet of Things
- IIoT Industrial Internet of Things
- CPPS Cyber-physical Production System
- CAD Computer Aid Desing
- O&G Oil and Gas
- BIM Building Information Modelling
- AM Asset Management
- ISO International Standard Organization
- PA Physical Asset
- NTIS National Institute of Standards and Technology
- PaaS Platform as a Service
- IaaS Infrastructure as a Service
- NASA National Aeronautics and Space Administration
- USAF United States Air Forces
- CN Connection Network
- SS Services for PE and VE
- DD Digital Twin Data
- DTP Digital Twin Prototype
- DTI Digital Twin Instance
- DTA Digital Twin Aggregate
- IoB Internet of Behaviors
- IAM Identity Acces Management
- NLP Natural Language Processing
- RPA Robotic Process Automation

- BPMS Business Process Management
- ERP Enterprise Resource Planning

Chapter 1: Academic Framework.

1.1 Background.

Physical Asset owners are always looking for how to improve the value of these in the business. Through its lifecycle, managers and operators feel the pressure to find methodologies and technologies to accomplish the business objectives through Asset Management (AM). In recent times one of the technologies that have gained value to accomplish business goals towards managing physical assets is the Digital Twin (DT). The application of DT is bringing changes on how the operations and management of physical assets are carried out as well as inner changes inside the organization on the human side for consumers, operators, managers, and shareholders.

Despite creating a twin of an asset or more commonly know as prototypes, have been for quite a long time in the industry, it can be traced as back as the 1970s (Wang, 2020). The term DT came to be coined in 2003 by PhD. M. Grieves as *"A digital copy of one or a set of specific devices that can abstractly represent a real device and can be used as a basis for testing under real or simulated conditions"* (Grieves, 2014, pp. 1) (Wang, 2020, pp. 96). More definitions are being brought based on three basic elements of the DT: to have a physical asset, a connection system, and a virtual representation of the asset (Grieves, 2014) (Wang, 2020). In the year 2017, Gartner named DT as the top trend technology (Panetta, 2016) that the application has come to be of common use for many industries that focus on creating a cyber-physical system (Tao et al., 2019).

As of most recently, the world has come across a pandemic situation with the Covid-19. According to Gartner in a survey, they carried out asking 400 companies about the Internet of Things (IoT) investment, found out that *"31% of survey respondents said that they use digital twins to improve their employee or customer safety, such as the use of remote asset monitoring to reduce the frequency of in-person monitoring, like hospital patients and mining operations."* (Goasduff, 2020). The article also mentions, *"Gartner expects that by 2023, one-third of mid-to-large-sized companies that implemented IoT will have implemented at least one digital twin associated with a COVID-19-motivated use case"* (Goasduff, 2020).

1.2 Problem Definition.

Today organizations are increasing the use of digital solutions for managing their assets, and this brings Cyber-Physical Systems (CPS) to close the gap between the physical world and the virtual environment. One leading digital solution which is helping with this integration is the Digital Twin (DT). Industries accelerated the implementation of this technology since 2017 and mainly in the recent year 2020 due to the pandemic of Covid-19.

The companies believe that having access to a full range of data would allow stakeholders and managers to take faster and more accurate decisions, helping to decentralize the decision making leading towards a more lean organization. However, this massive production of information is creating a more complex system where the managers and employees struggle to understand the defined path to manage the asset and cover the objectives of the business. In addition, implementing new technologies bring challenges across the organizations and the human (stakeholders). Industries must recognize these issues in order to avoid unwanted situations such as cyberattacks, employee dissatisfaction, increased Capex and Opex, accidents, and so on. To acknowledge these risks would help look for recommendations on how to approach the implementation of the DT and the final development of CPS.

1.3 Scope and Objectives.

The present work will review three main sectors applying Digital Twin and Cyber-Physical Systems technologies, Construction, Health, and Energy, and this last one would be observed from two main parts: the O&G industry and the Renewable sector. It will look at the current issues these industries face in the HTO and Work Process towards implementing these technologies and provide recommended solutions to solve these problems that are or might arise.

Therefore the objectives are:

- Define what a DT, a CPS, and which technologies help to develop them.
- Present the Current State of Art of DT and CPS for industries sectors: Health, Construction, and Energy from O&G and renewables.
- Observe the challenges being brought about by implementing DT and CPS in the HTO and Work Process parameters of the sectors mentioned above.
- Give recommendations that would help reduce or even eliminate some of the challenges from an HTO and Work Process perspective for DT and CPS applications.

The Thesis begins by addressing a literature review on Asset Management and its basics and the concepts used in the digitalization of industries. Then follows a review on what are Digital Twin(DT) and CPS, which technologies are involved in its developments, operations, also discusses the current state of the art for the application of DT and Cyber-Physical Systems (CPS) in different sectors for the management of its physical assets is. Next, the work presents the challenges of Human-Technology-Organization(HTO) and the Work Process that the industries are having. Afterward, the author presents recommendations based on innovative trends that might mitigate the challenges found in managing physical assets by DT and CPS.

1.4 Methodology.

The Thesis is based on industry papers, academic writing, research papers, electronic academic books, and publications from different experts and industries. The work follows the qualitative methodology for the facility to analyze the current state of the topic discussed in the Thesis. This facilitates the work done in Chapter 2 to introduce Asset Management (AM) discipline and terms related to the digitalization of organization. Then in chapters 3-4, the issues that the author found critical to be addressed for the industries and gave recommendations as to what could be possible innovative solutions for problems from an HTO point of view. Moreover, it finally closes in chapters 5-6 with the insights from the current project, what can be taken from it and which following works can come afterward, and what knowledge has been gained from the current project.

1.5 Delimitation.

The main focus of the work is on the management process carried out in DT and CPS implementation and usage for the benefit of the asset owner and how it impacts the physical asset value observing from an approach of HTO and Work Process. At the same time, the study will assess DT and CPS core technology choices such as AI type (quantitative vs. qualitative), multi-disciplinarity (single domain vs. cross-sector integration), sensing (selective vs. ubiquitous), HMI (console vs. AR). This work will not provide an exhaustive mapping of the depth of variety in each of these categories but instead, concentrate on highlighting those aspects that have the most significant impact on the management process required to realize value from the DT and CPS.
The focus will be on three main sectors that DT and CPS are currently in use or being developed: the Construction, Health, and Energy sector, divided into O&G and Renewables.

1.6 Thesis Structure.

The Thesis contains six chapters which are:

- Chapter 1: The purpose is to provide the academic framework for the project by setting the main aim, the scope, and objectives, which methodology is the Thesis follows, and delimit the research area of the work.

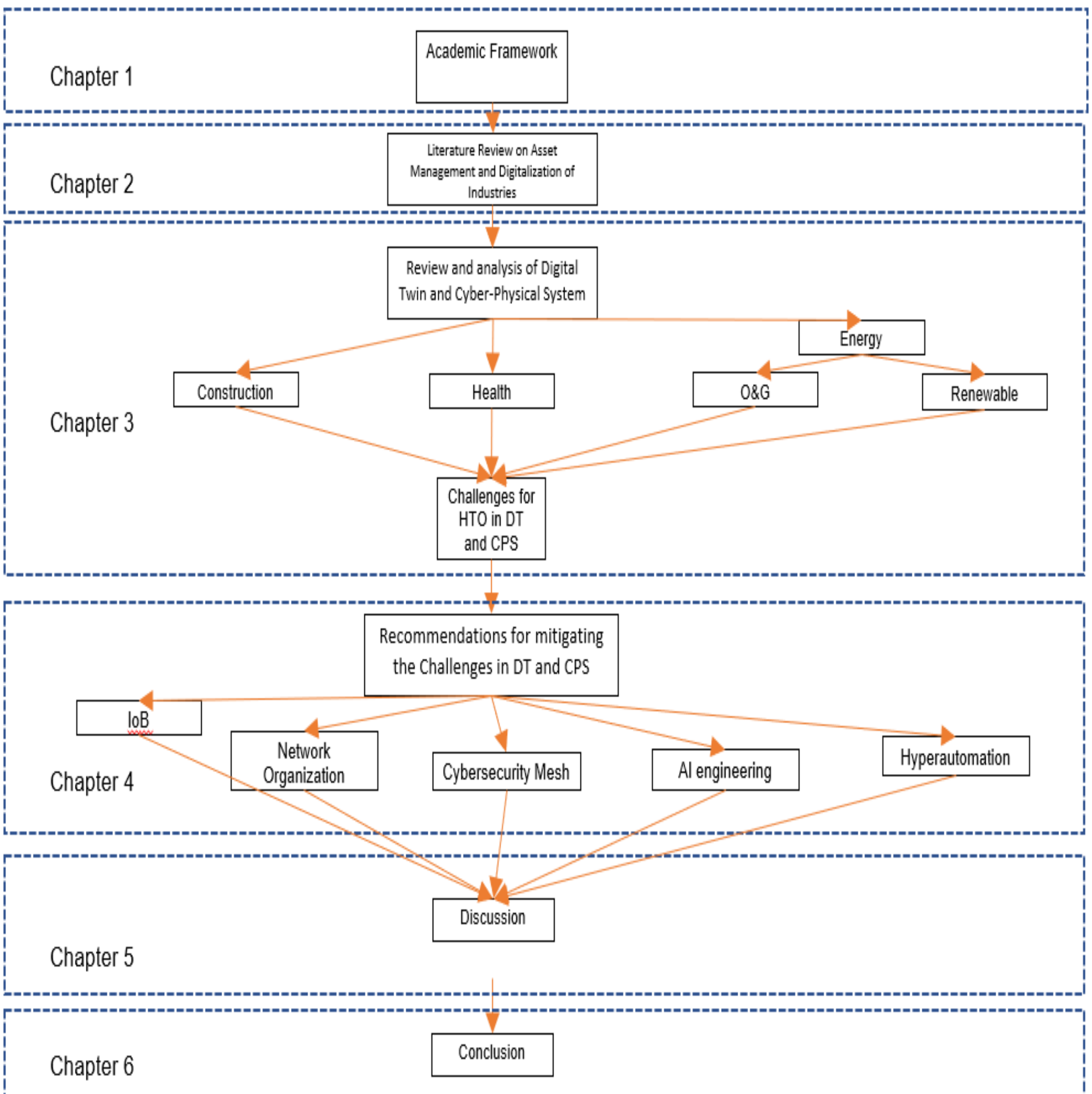
- Chapter 2: Is on literature review for Asset management terminologies and concepts on Digitalization of the Industries. Here terms are introduced briefly for lectors to understand some terminology used in the following chapters.

- Chapter 3: begins by addressing the CPS and DT, the basic building blocks, how they interact and differentiate from one another. Then comes literature review on the State of the Art for three chosen sectors, which are Construction, Health, and energy sector divided into O&G and renewables, here would be seen what the currents developments, applications and notice challenges that are arising in these industries with relation to the HTO and Work Process are.

- Chapter 4: It addresses the challenges found in chapter 3 by proposing recommendations based on innovative solutions to address and what benefits they could bring from the HTO and Work Process perspective.

- Chapter 5: Discuss what challenges were found during the project's development and what future endeavours could be based on the information given.

- Chapter 6: This includes some final remarks regarding the content of this Thesis.



Chapter 2: Literature Review on Asset Management and Digitalization of Industries.

2.1 Asset Management General overview.

2.1.1 Assets.

In the discipline of Asset Management, the center is the asset, which according to the ISO 55000, is defined as *"an item, thing or entity that has potential or actual value to an organization."* (International Standard Organization, 2014, pp. 2). Now, this definition encompasses tangible assets (physical assets) and intangible assets (goodwill and intellectual property) (Anthony, 2015).

- Physical Assets.

In this work, the focus will be on the physical assets, which just to name some could be buildings, oil rigs, machinery, water pipes, wires, communication devices, and other items (Anthony, 2015) (Davis, 2015), the main characteristics of this type are a defined shape, weight, measures, among other physical properties. However, in order to manage the physical asset, it will require the integration of non-physical entities such as skills, data, financial, human, software, and others (Anthony, 2015) (Davis, 2015).

- Financial Assets.

This type of asset is considered an intangible, which is considered a representation of this asset might be bonds or stocks, which on their own do not hold value until a contract bound them. The main difference with a physical asset relies on that this type of asset could be turned into monetary value in a fast way (Market Business News, 2020).

- Virtual Asset.

This term is another type of intangible asset, and these assets refer to the data generated from physical assets and stakeholders from the organization and available for different users at any time. The value here comes from historical data, such as Capex, Opex, which also can help to understand what generates a dangerous situation or how an incident was started, as well it could provide the stakeholders with the vision for future upgrades for the physical asset or the organization changes that would benefit the value generation (SNITKIN, 2018).

- Human Asset.

Within an organization, the human aspect is a critical one as every organization will require employees that would manage the company's physical assets. Most of the time, the physical assets outlive their stakeholders, which might affect the organization and the asset performance as new stakeholders come in place and learn to operate and maintain the equipment (SNITKIN, 2018).

- Production Asset.

These types of assets function in the production is limited or utilized once during the process. It refers to materials that are used in order for the industry to deliver the final product to the customer (The Production Guild, 2020).

2.1.2 Asset Management (AM).

The main objective of the AM discipline is to provide organizations with a set of tools necessary to maximize the value of the business through the optimization of its assets according to how the ISO 55000 defines it (International Standard Organization, 2014).

This discipline looks at the physical asset and an entity that follows a determined lifecycle. The AM has to consider the risk, opportunities, cost, and performance and find the balance in these so that the physical asset could accomplish the primary function and objective in the industry (International Standard Organization, 2014) (Davis, 2015). The AM discipline applies to all types of organizations, from minor to big corporations and from the public to private, run by governments or non-profitable organizations (Institute Of Asset Management, 2015).

The ISO 55000 establish four fundamentals for the AM, which are (International Standard Organization, 2014) (Institute Of Asset Management, 2015):

- Value: Assets exist to provide value to the organization and its stakeholders.
- Alignment: Asset management translates the organizational objectives into technical and financial decisions, plans and activities.
- Leadership: Leadership and workplace culture are determinants of the realization of value.
- Assurance: Asset management gives assurance that assets will fulfill their essential purpose.

By following a good strategy for AM, it could provide benefits such as:

- Improve financial performance.
- Inform asset investment decisions.
- Managed risk.
- Improve services and outputs.
- Demonstrate social responsibility.
- Demonstrate compliance.
- Enhanced reputation.
- Improve organizational sustainability.
- Improve efficiency and effectiveness.

These are just some benefits listed in ISO 55000, but there are other benefits that an organization could have by implementing a good AM policy (International Standard Organization, 2014).

- The lifecycle of a Physical Asset (PA) and the stakeholders.

In the AM, the physical asset is observed from what is named a lifecycle, and these are stages through which every PA goes under the organization's AM strategy, which considers all the activities carried out in the whole life cycle and not in the individual stages. Figure 1 shows how organizations could divide the lifecycle stages of an asset, from this image, four main stages could be named acquired, commission, operation, and disposal (Institute Of Asset Management, 2015) (Davis, 2015).

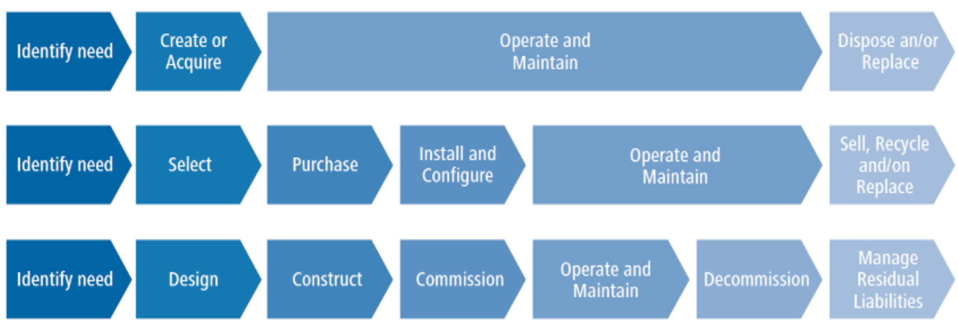


Figure 1 Examples of variations in the description of asset lifecycle stages (Institute Of Asset Management, 2015, pp. 13)

Through these stages, several people inside and outside the business get involved, so the physical asset could carry on its primary function and thus deliver value for the corporation. They are known as stakeholders, which ISO 55000 defines as *"person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity"* (International Standard Organization, 2014, pp.12) (Institute Of Asset Management, 2015). There could be internal stakeholders, including employees, shareholders, owners, and external stakeholders, which to name some are customers, suppliers, authorities, and users (Anthony, 2015) (Asset Management Council, 2014).

- Asset Management System.

The organizations employ AM systems to handle, direct and organize their asset management activities. Here is where the companies are able to measure if the objectives of the asset management could be accomplished, as well helps with enhancing the risk control. The asset management system is defined by the ISO 55000 as a *"set of interrelated and interacting elements of an organization, whose function is to establish the asset management policy and asset management objectives, and the processes needed to achieve those objectives"* (International Standard Organization, 2014, pp. 4-5). The asset management system covers some requirements listed in ISO 55000, which are:

- Context of the organization.
- Leadership.
- Planning.
- Support.
- Operation.
- Performance operation.
- Improvement.

- Asset Management System Model.

Asset management system models are used to show the connection between the elements of the asset management system and the relation among them (Asset Management Council, 2014). Although AM system models used might vary from organization to organization, they have to find the best one that suits their needs. Figure 2 shows an example of a conceptual model proposed by the Institute of Asset Management (Institute Of Asset Management, 2015, pp. 16).

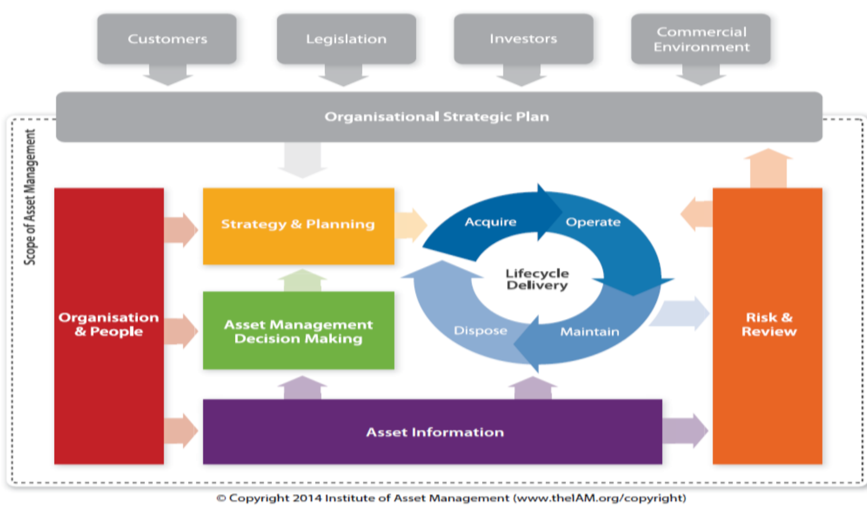


Figure 2 IAM's Conceptual Asset Management Model (Institute Of Asset Management, 2015, pp. 16)

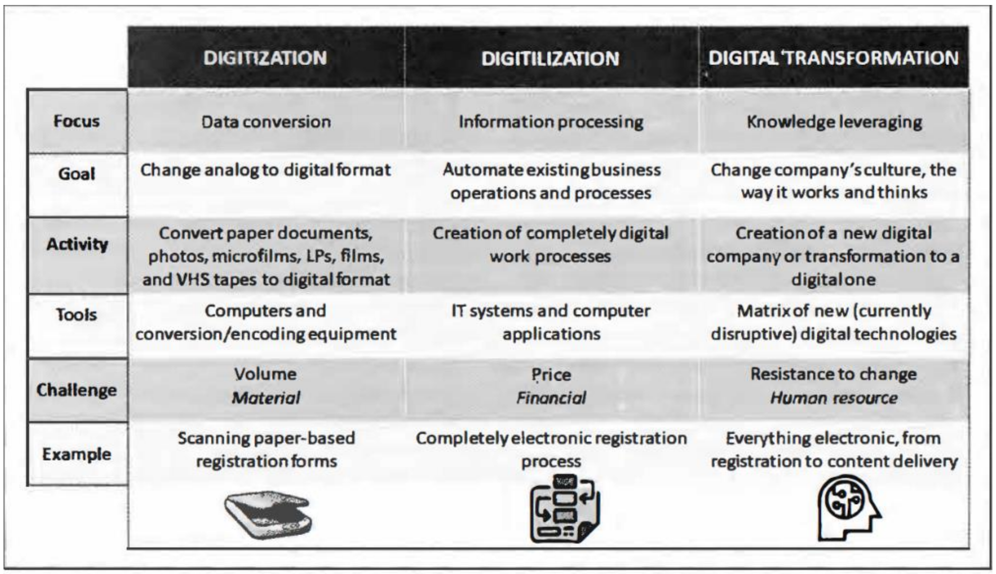
Furthermore, figure 3 is an example from the Asset Management Council in Australia (Asset Management Council, 2014, pp. 19). Even though they look different, the AM's roots maintain the central cores for the AM system to be deployed.

Figure 3 Asset Management System Model (Asset Management Council, 2014, pp. 19)

2.2 Overview of the Digitalization in the Industries.

2.2.1 Digitization, Digitalization, and Digital Transformation.

The first concepts that come into play are digitization and digitalization; these terms are mistakenly taken as synonyms, but they represent two different aspects of the digital environment; the third and most recent concept that industries are applying is the digital transformation that has also come to be used as either of the above term mentioned (Savic, 2019), (Savic, 2020). In figure 4, it can be observed the difference between these terms and examples for each (Savic, 2019).



	DIGITIZATION	DIGITILIZATION	DIGITAL TRANSFORMATION
Focus	Data conversion	Information processing	Knowledge leveraging
Goal	Change analog to digital format	Automate existing business operations and processes	Change company's culture, the way it works and thinks
Activity	Convert paper documents, photos, microfilms, LPs, films, and VHS tapes to digital format	Creation of completely digital work processes	Creation of a new digital company or transformation to a digital one
Tools	Computers and conversion/encoding equipment	IT systems and computer applications	Matrix of new (currently disruptive) digital technologies
Challenge	Volume *Material*	Price *Financial*	Resistance to change *Human resource*
Example	Scanning paper-based registration forms	Completely electronic registration process	Everything electronic, from registration to content delivery

Digitization, digitalization, and digital transformation reviewed through five facets: focus, goal, activity, tools, and challenges, with examples of each.

Figure 4 Difference between Digitization, Digitalization, and Digital Transformation (Savic, 2019, pp. 37)

- Digitization.

The increase of conversion from analog to digital format came with the optimization of scanners, the use of more simple devices to carry information, and more storage capacity. Here the main characteristic is that once the digital form is created, the physical one would not carry any effect on the virtual one; there is no need for connection devices between physical and virtual objects (Savic, 2019).

- Digitalization.

The use of data is one of the central cores for this term, and the base is on the automation of processes and operations in the industry. To fulfill this goal is a need for implementing IT solutions, digitization data, and a defined business process that could be represented and optimized using digitalization technologies

(Savic, 2019). Unlike digitization, digitalization is able to be connected to the physical object and with that has the capability to create new data related to the physical entity or the surrounding processes (i-SCOOP, 2020), and let the users be able to monitor the operations, and as mention find ways to optimize the management of the assets, so the business goals could be achieved (Savic, 2019).

- Digital Transformation.

This term represents a dynamic change inside the business that decides to apply it, as it means to create new regulations, set new management rules, the industry operations (Savic, 2019). Digitalization uses technological solutions, but it does not represent the current business of a company. It has the capability to create new business models or products that would add value to the company (i-SCOOP, 2020). The effect of digital transformation as well includes the stakeholders in the business as they are the main impacted when the business goes into changing the current set of culture, technology applications, and evolve on management. The central core for the digital transformation of industries is to have a customer-centric approach, decisions, and how to proceed in the companies based on customer needs (Savic, 2019) (i-SCOOP, 2020).

2.2.2 Industry 4.0.

The German government acquainted this term to describe the interaction between the physical world and the digital one (Smit et al., 2016b). In order to accomplish this, there is a need to implement technologies such as the Internet of Things (IoT), Industrial Internet of Things (IIoT), sensors, 3D printing, Artificial Intelligence (AI), cloud computing, Digital Twins (DT), CPS, and others. The combination of these technological advances had lead to the development of smart factories. Where decisions are managed in real-time connectivity and communication of the devices, sensors, and operators (stakeholders) and other entities physical or virtual that belong to the production and supply chain, with the objective that the data created would optimize the decision making in the industry (Renjen and Deloitte Insights, 2018), (Parrot and Warshaw, 2017), (Negri, Fumagalli and Macchi, 2017) (Zhong et al., 2017). For example, in figure 5, Deloitte proposed a loop for Physical-Digital-Physical interaction, where the physical environment produces data for the digital, this data is analyzed and allows the stakeholders to make decisions towards the processes and thus affect the real-world environment of the business by trying to enhance the production and value of the business (Tidhar, Siegman and Paikowsky, 2018).

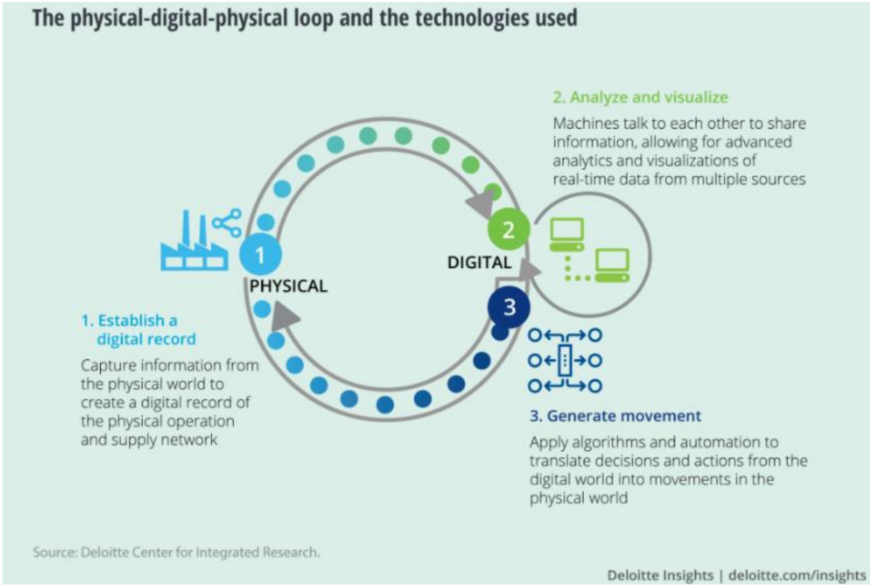


Figure 5 Physical-Digital loop Deloitte (Tidhar, Siegman and Paikowsky, 2018)

Industry 4.0 has some characteristics among which the following correspond to the main ones (Smit et al., 2016b):

- Interoperability.- Is accomplished through the adaptation of CPS that permits stakeholders to connect with the factories and have interactive communication.
- Virtualization.- Is creating a DT of the factories using sensor technologies that would allow forecasting future states inside the factories production and maintenance.
- Decentralization.- The CPS is capable of working on its own, having the capability to deliver products integrating different technologies.
- Real-Time Capability.- The sensor technology captures data in real-time that is analyzed through modeling systems and DT capabilities to predict future states for the factory.
- Service Orientation
- Modularity.- The systems are seen as modules that could be replaced or modified to increased efficiency for the business.

2.2.3 Internet of Things (IoT) and the Industrial Internet of Things (IIoT).

These terms are linked as the IIoT is a sub-element of the IoT, the difference lies in the application for the IIoT that has come to mind with Industry 4.0 (Khan et al., 2020), (Smit et al., 2016b), below definitions are giving for each.

- Internet of Things (IoT): The European council defines IoT as *“refers to IT systems connected to all sub-systems, processes, internal and external objects, supplier and customer networks; that communicate and cooperate with each other and with humans”* (Smit et al., 2016b, pp. 20), using technologies such as Radio Frequency Identification (RFID), Wireless Sensors Networks (WSNs) and more technological advances and devices are helping the IoT to be applied in the industries and day to day life, figure 6 shows some of these high techs (Mehta, Sahni and Khanna, 2018).

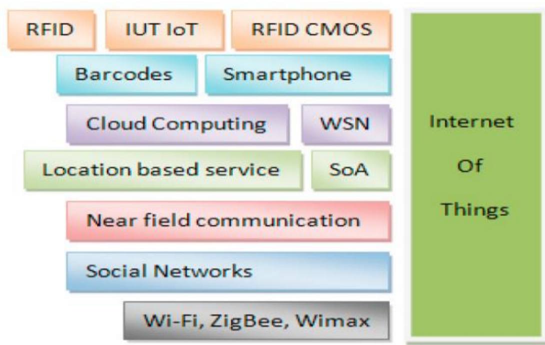


Figure 6 Technologies empowering IoT (Mehta, Sahni and Khanna, 2018, pp. 1264)

- Industrial Internet of Things (IIoT): (Khan et al., 2020, pp. 2) define the IIoT as *“Industrial IoT (IIoT) is the network of intelligent and highly connected industrial components that are deployed to achieve high production rate with reduced operational costs through real-time monitoring, efficient management and controlling of industrial processes, assets and operational time.”* The technologies used for the IIoT are the same as the IoT, but the application is centered on the industry's use, as could be noticed in the definition. In figure 7, are shown the operational differences proposed by (Khan et al., 2020).

Concentration	IIoT	IoT
Area of Focus	Industrial Applications	General Applications
Focus Development	Industrial Systems	Smart Devices
Security and Risk Measures	Advanced and Robust	Utility-centric
Interoperability	CPS-Integrated	Autonomous
Scalability	Large-scale Networks	Low-scale Network
Precision and Accuracy	Synchronized with milliseconds	Critically Monitored
Programmablity	Remote on-site programming	Easy Off-site programming
Output	Operational Efficiency	Convenience and Utilization
Resilience	High Fault Tolerance Required	Not Required
Maintenance	Scheduled and Planned	Consumer Preferred

Figure 7 Operational Difference Between IoT and IIoT Systems (Khan et al., 2020, pp. 2)

2.2.4 Sensor Technologies.

Sensors are of primary importance for the development of DT as these devices will provide information on a daily basis on how the PE is operating, as loads, speeds, temperature, and other physical parameters that could be measured with these devices. Hence, it is essential to know the types of sensor devices in the market and what they are capable of transmitting (Cai et al., 2017).

There are different definitions for what a sensor is. The one selected for this project is by YOKOGAWA Electronic Corporation *"sensors are devices that detect the feature quantity of a measurement object and convert this quantity into a readable signal, which is displayed on an instrument."* (YOKOGAWA Electronic Corporation, 2020). As for sensing technology, it is defined as *"Sensing technology, simply put, is a technology that uses sensors to acquire information by detecting the physical, chemical, or biological property quantities and convert them into a readable signal."* (YOKOGAWA Electronic Corporation, 2020). As mentioned before, the objective of sensors is to detect physical parameters and display reading signals to the operators, so this could know the current state of the physical asset. Figure 8 is showing in general view how a sensor works typically(Macgrath and Cliodhna Ní Scanaill, 2014, pp.15–32).

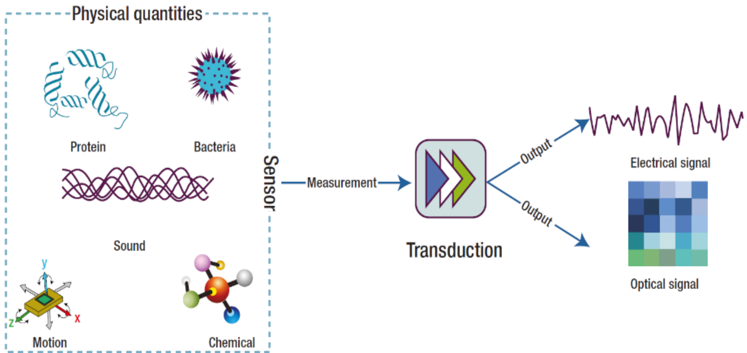


Figure 8 The Sensing Process (Macgrath and Cliodhna Ní Scanaill, 2014, pp.17)

Now figure 9 shows how the new intelligent sensors work in which is noticeable the transition into digital signals that are used for the DT to record and later use for its simulation and prediction processes (EROR et al., 1995, pp.9–18)

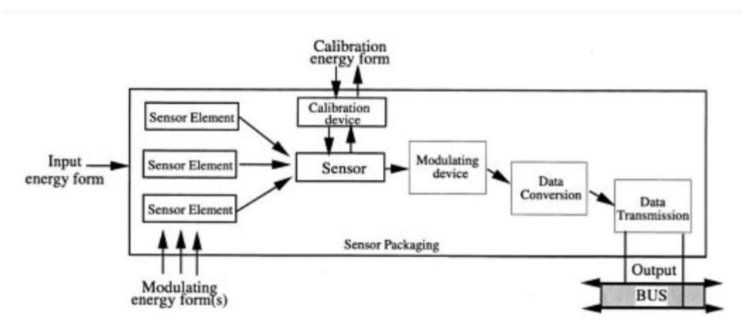


Figure 9 Schematic Representation of a Smart Sensor (EROR et al., 1995, pp. 16)

The sensors, accordingly to what type of measure they are providing, could be divided as follows:

- Mechanical/Electromechanical Sensors: Those who can take inputs measures such as motion, velocity, acceleration, and displacement, afterward convert into electrical signals; thus, they are named electromechanical. Figure 10 shows a table from IEEE Sensor Council on the most common sensors for mechanical/electromechanical types (Macgrath and Cliodhna Ní Scanaill, 2014, pp.15–32).

Sensor	Type	Sensor	Type
Strain Gauge	Metallic Thin film Thick film Foil Bulk Resistance	Displacement	Resistive Capacitive Inductive
Pressure	Piezoelectric Strain gauge Potentiometric Inductive Capacitive	Force	Hydraulic load cell Pneumatic load cell Magneto-elastic Piezoelectric Plastic deformation
Accelerometer	Piezoelectric Piezoresistive Capacitive MEMS Quantum tunneling Hall effect	Acoustic Wave	Bulk Surface
Gyroscope	Vibrating structure Dynamically tuned MEMS London moment	Ultrasonic	Piezoelectric Magnetostrictive
Potentiometer	String Linear taper Linear slider Logarithmic Membrane	Flow	Gas Fluid Controller

Figure 10 Common Mechanical and Electromechanical Sensors (Macgrath and Cliodhna Ní Scanaill, 2014, pp.19)

- Optical Sensors: This type work by detecting light waves or light photons, it could be that it detects the presence of these parameters or the absence of the same ones to provide readings. These are some examples of sensors are (Macgrath and Cliodhna Ní Scanaill, 2014, pp.15–32):

  a. Photodetectors.
  b. Infrared.
  c. Fiberoptic.
  d. Interferometers.

- Semiconductor Sensors: The leading utility for these is the detection of gases during operations. They have the advantage of being low cost, reliable, long-life operation, and small form factor (Macgrath and Cliodhna Ní Scanaill, 2014, pp.15–32).
- Biosensors: The primary function is to detect and analyze chemicals, environment compositions, and biological elements. Figure 11 shows a general view of the process for this type of sensing (Macgrath and Cliodhna Ní Scanaill, 2014, pp.15–32).

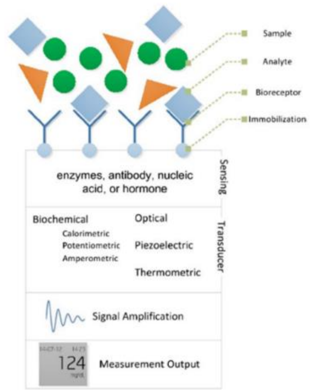


Figure 11 The biosensing process (Macgrath and Cliodhna Ní Scanaill, 2014, pp.29)

2.2.5 Cloud Computing.

The use of this technology is incrementing as data transmission is growing. The term was coined in 2007 by Google, and cloud computing brings IT infrastructure, quality of services for computing environments, and software services (Wang et al., 2010).

Despite the different definitions for cloud computing, one of the most accepted is provided by the National Institute of Standards and Technology (NTIS) (Birje et al., 2017) (Rad, Diaby and Bashari, 2017) (Haris and Khan, 2018). Which define cloud computing as *"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models."* (Mell and Grance, 2011, pp. 2).

Figure 12 shows the essential characteristics, the three service models, which are Sofware as a Service(SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS), and the deployment models (Mell and Grance, 2011).

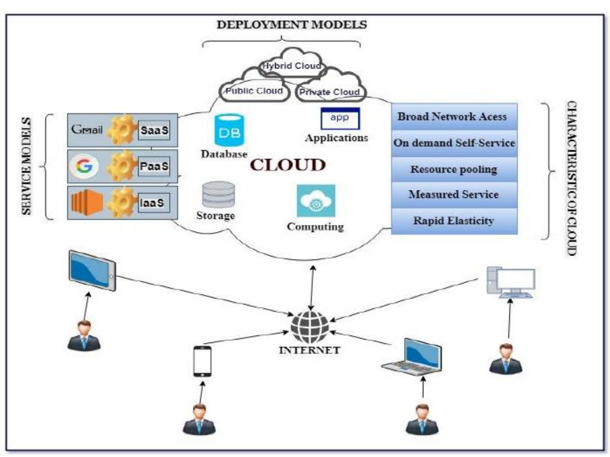


Figure 12 Overview of Cloud Computing (Haris and Khan, 2018, pp. 634)

2.2.6 Cyber-Physical Systems (CPS).

The term refers to the interaction that is created between the physical environments and the cyber (virtual) environments, for physical environments, it is referred to assets, sensors, human (stakeholders) (Zhong et al., 2017), processes, while the cyber environment is meant for the computational base knowledge such as IoT, IIoT, ITC, BIMs, and others (Bolilla, 2019), both environments interacting is what creates a CPS as could be observed in figure 13 the network feeds through sensing technologies and has the capability to use controllers to affect the physical system (Liberatore, 2007). Thus this has misled to use CPS as if it was the same as Digital Twin (DT) when in reality, the DT is a facilitator to adapt the CPS (Tao et al., 2019).

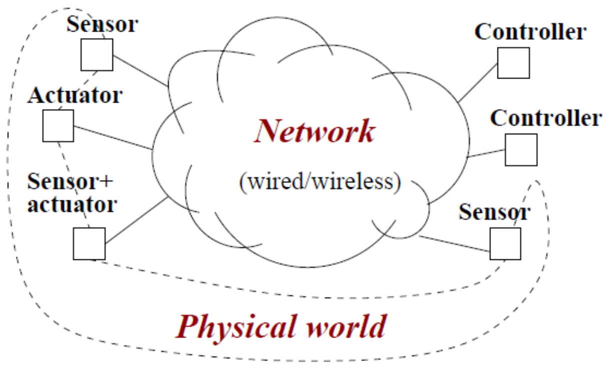


Figure 13 The Network control Vision (Liberatore, 2007, pp. 1)

2.2.7 Building Information Modelling (BIM).

The BIM could be considered a type of DT, as it is defined by the National Building Information Modeling Standards (NBIMS) committee of the USA as *"Digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition."* (Smith et al., 2007) (Azhar, Khalfan, and Maqsood, 2015, pp. 1).

Now the difference between a DT and a BIM radicates mainly in the way that each one is updated on information from the PE. At the same time, the DT can do it directly, mostly from sensors and related technologies without almost any human interaction. The BIM requires humans to update the data on the phase that the physical building is set (Scotland et al., 2021), design, construction, operation, and maintenance or demolition (Azhar, Khalfan, and Maqsood, 2015). However, with the integration of accurate live monitoring, sensor technologies, and communication advance a BIM model could turn into a DT, which is the aim for smart cities to monitor, track and manage their operations in real-time and also due to the allowance of DT to manage assets as systems in dynamic ways despite its complexity (Scotland et al., 2021). Figure 14 represents the BIM from a life-cycle perspective, which shows the integration of Building, Information, and Modelling (Willem Kymmell, 2008) (Azhar, Khalfan, and Maqsood, 2015).

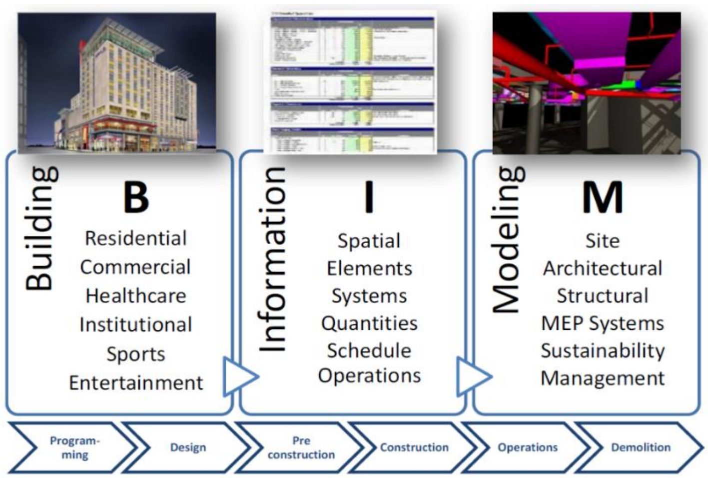


Figure 14 Visual Representation of the BIM concept (Azhar, Khalfan, and Maqsood, 2015, pp. 16)

2.2.8 Digital Twin.

Table 1 shows the different definitions across industries and some authors for Digital Twin (DT). These terminologies have their base on what Ph.D. M. Grieves defined as DT back in 2003 and also elements from the definition that NASA and USAF (United States Air Forces) provide in 2011 (Wang, 2020); what could be noticed is that three main elements are named physical entity, connection system, and virtual entity.

Table 1 Definitions of Digital Twins.

Companies or Authors	Definition
KAIROS Technology.	*"A digital twin is a digital representation of a physical asset and/or its processes, which is able to interact with available field data."* (Myllerup, Lind and Eldor, 2020, pp. 4).
DNV GL.	*"A digital twin is a digital representation of a physical object, asset or system: a ship, a car, a wind turbine, a power grid, a pipeline, or a piece of equipment such as a thruster or an engine.* *It can contain various digital models and collections of information and processes related to this object. Data can be in the form of graphical 3D models, dynamic and discrete simulation models, virtualized control systems and communication networks, analytical models, data models, sensor data, relationship data, process data, as well as digital*

Companies or Authors	Definition
	information such as documentation and reports." (Smogeli, 2017, pp. 2).
SAP.	*"A digital twin is a virtual representation of a physical object or system – but it is much more than a high-tech lookalike. Digital twins use data, machine learning, and the Internet of Things (IoT) to help companies optimise, innovate, and deliver new services."* (SAP, 2021).
Deloitte.	*"A digital twin can be defined, fundamentally, as an evolving digital profile of the historical and current behaviour of a physical object or process that helps optimize business performance."* (Parrot and Warshaw, 2017, pp. 3).
BERHTECH.	*"A digital twin is a virtual model that mirrors a physical object or process throughout its lifecycle. Providing a near real-time bridge between the physical and digital worlds, this technology enables you to remotely monitor and control equipment and systems."* (BehrTech, 2019).
ARC Advisory Group.	*"A digital twin, by definition, replicates attributes of a physical asset. Digital twins enable oil and gas companies to respond with fact-based decision support for the industry's challenges."* (Rio, 2020).
SIEMENS.	*"A digital twin is a digital copy of a physical building, which includes a 3D model of a facility combined with dynamic data to allow easy-to-understand visualization and analysis."* (SIEMENS and Malkwitz, 2018, pp. 6).
ABAB.	*"A digital twin is a digital representation of a physical asset, process or system, as well as the provider of information that allows its users to understand and model its performance. A digital twin can be continuously synchronised from multiple sources, including sensors and continuous surveying, to represent its near real-time status, working condition or position."* (Scotland et al., 2021, pp. 3).
Endress+Hauser and Fabricio Andrade	*"The idea is to create a digital version of a real thing in the cloud of a product, process, or service. Then, with an online connection between the digital version and the real one, it's possible to run analyses to find out health conditions and prevent potential*

Companies or Authors	Definition
	problems from happening." (Andrade and Endress+Hauser, 2019).
Zongyan Wang	*"Digital twin refers to the processes and methods for describing and modelling the characteristics, behaviour, formation process, and performance of physical objects using digital technology, and can also be referred to as digital twin technology."* (Wang, 2020, pp. 100).
Ph.D. Michael Grieves and John Vickers	*"The Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physically manufactured product can be obtained from its Digital Twin."* (Grieves and Vickers, 2016, pp. 3).
ADIL RASHEED, OMER SAN, AND TROND KVAMSDAL	*"Digital twin can be defined as a virtual representation of a physical asset enabled through data and simulators for real-time prediction, optimization, monitoring, controlling, and improved decision making."* (Rasheed, San, and Kvamsdal, 2020, pp. 21980).

Three main dimensions are observed in the definitions in Table 1, the physical object (entity) (PE), the virtual twin (virtual entity)(VE), and the flow of data (the connection between physical and virtual environments)(CN). These are considered the elemental cores for establishing a Digital Twin (DT), as shown in figure 15 (Grieves, 2014). For a further understanding of the DT, two more dimensions are proposed services for both physical and virtual environments (SS), and Digital Twin data (DD) (Tao and Zhang, 2017), (Tao et al., 2018), (Tao et al., 2019b).

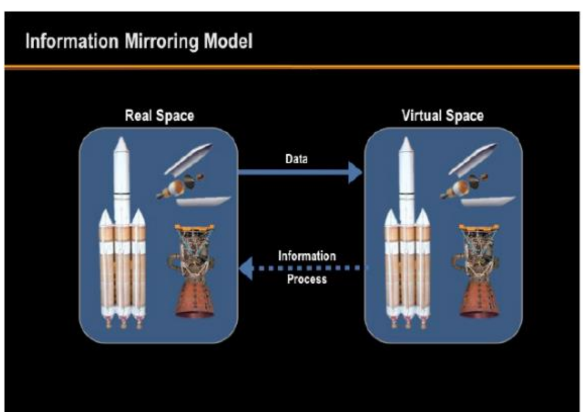


Figure 15 The Digital Twin concept model (Grieves, 2014)

Chapter 3: Review and analysis of Digital Twin and Cyber-Physical System.

3.1 Cyber-Physical Systems (CPS).

As mention before, the Cyber-Physical system is an integration of physical entities that are recreated in a virtual environment and have the capability to interact with each other in order to have an integrated cyber system to monitor and control the physical environment, leading to automated processes, which is one of the goals of Industry 4.0, to have a merged environment between virtual and physical where the cyber environment has the capability of decision and control over the production on the physical world. As could be observed in figure 16, the CPS has its essential cores on communication, computational, and control technologies (Boulila, 2019). Therefore, from figure 16 can be identified that there are two central functions that a CPS has to carry out one is on the communication and control, which is sensor technologies and intelligent devices which affect the physical environment, and then the computational, which has carried out to collect historical data, analyze with the data through modeling and analytics in order to embed the cyber environment(Boulila, 2019) (Boulila, 2017).

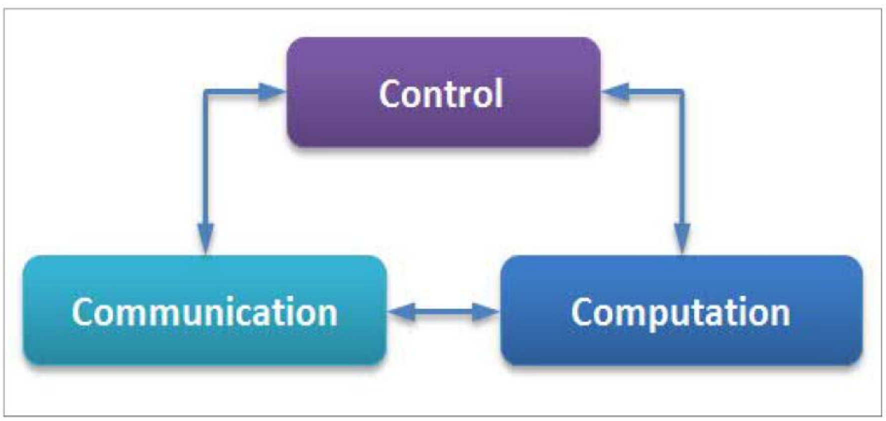


Figure 16 The 3C minimal requirements a system must fulfill to be considered cyber-physical (Boulila, 2019, pp. 6)

3.1.1 Main Building blocks of a CPS.

Considering the 3C shown in figure 16, the CPS can be seen as a system of systems that embeds different components from physical and cyber environments, and figure 17 shows the core components for the 3C's perspective (Boulila, 2017).

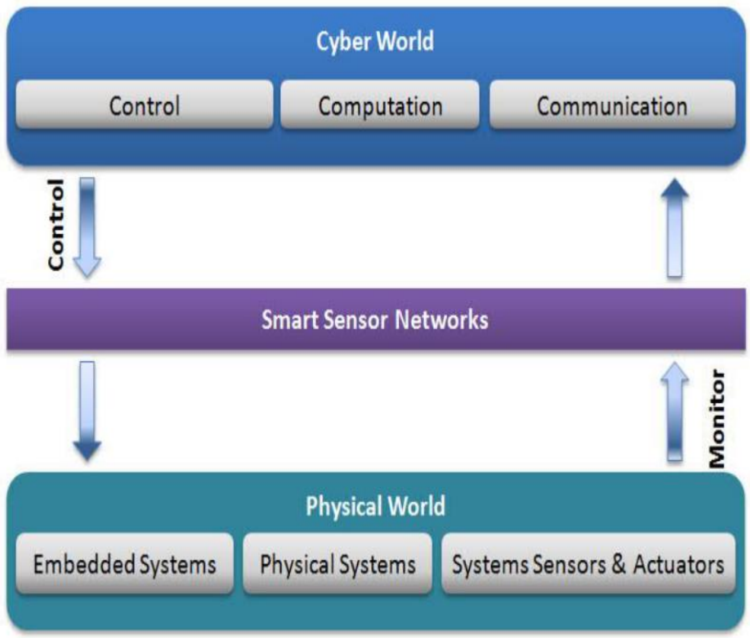


Figure 17 Main building blocks of a cyber-physical system (Boulila, 2017, pp. 3)

3.1.2 Physical environment.

This unit refers to the hardware systems that allow the CPS to collect data, such as sensors and actuators, as well as the physical structures, such as equipment and flow processes, end every system involved in creating the network to carry data (Pascual, Daponte, and Kumar, 2019) (Boulila, 2019b).

3.1.3 Cyber environment.

Here, the system focuses on software solutions, which analyze and merge the data collected from the physical environment. Also, the use of cloud servers to store the information recollected and created through digital solutions, and with the use of communication technologies, the control of remote physical entities is facilitated (Pascual, Daponte, and Kumar, 2019) (Boulila, 2019b).

3.1.4 Smart Sensors Network.

This unit comprehends sensors that send their measures through wireless connections, here actuators are included as part of the network; they receive the signals from remote locations to make operational changes to the physical asset; both sensor and actuator rely on communication technology to carry on their functions. In figure 18, The structure shows nodes where data is created; this could be a sensor or collection of sensors in the physical entity. On the other hand, there are sinks, which are the entities that solicit information but can act as a node to, form here can be inferred that the purpose of the sensor network is to collect data and transmit (Boulila, 2019b).

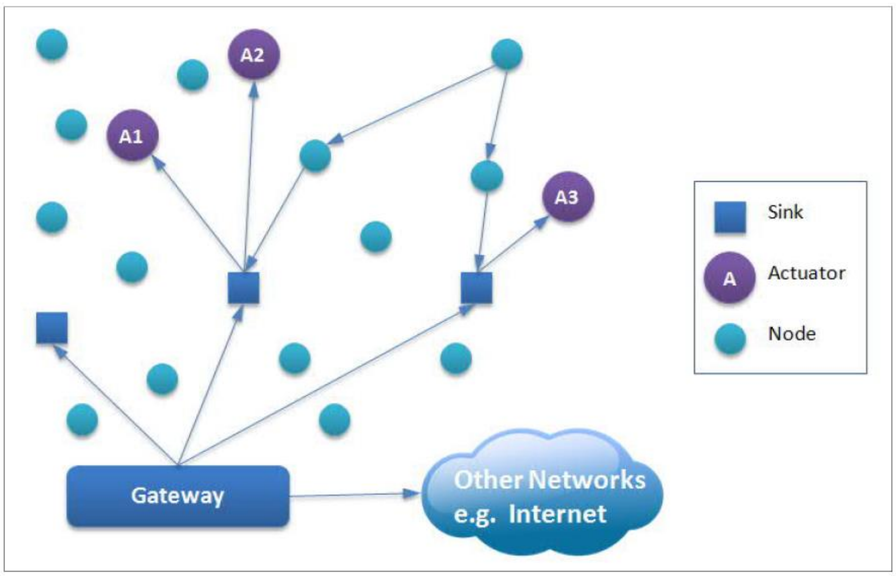


Figure 18 Common Sensor and actuator network (Boulila, 2019b, pp. 17)

3.1.5 The architecture of CPS.

In order to integrate a fully CPS, a 5 level structure is proposed, as could be observed in figure 19. These five levels show a configuration on how to implement a total CPS that goes from how to obtain data to the final value delivery (Lee, Bagheri, and Kao, 2015).

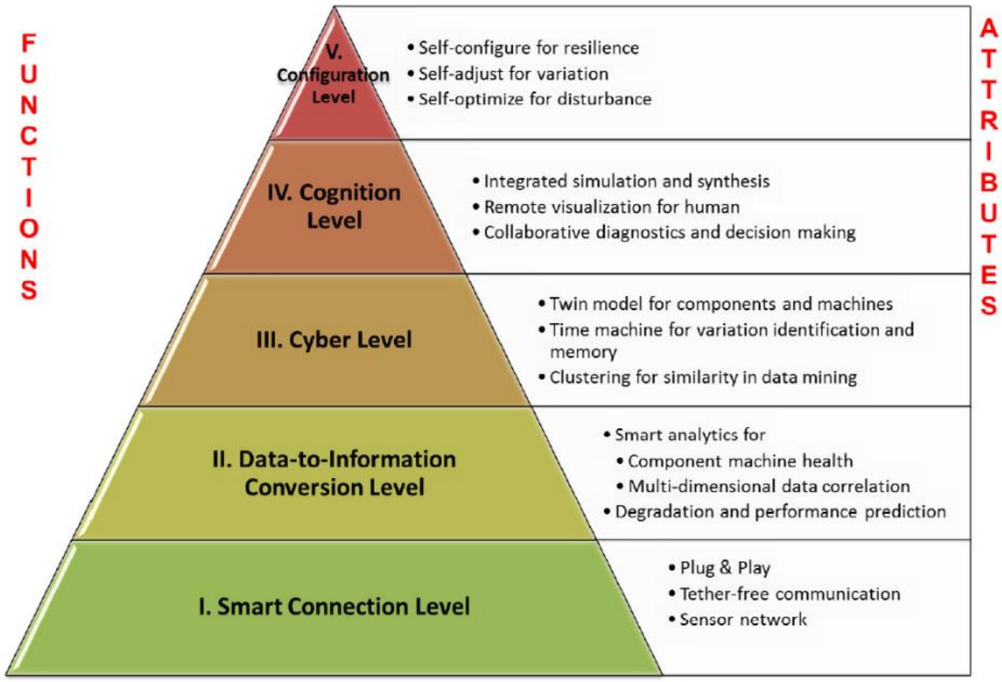


Figure 19 5C architecture for the implementation of Cyber-Physical System (Lee, Bagheri and Kao, 2015, pp. 19).

3.1.6 Smart Connection Level.

The first level to begin with the CPS is based on how to collect the data. Thus the main impact comes from how to implement a helpful network sensor system, using the correct sensor devices for the physical process or physical entity that is going to be represented. The main issues in selecting the sensor are about which type of data is going to be collected and how it is going to be transmitted, as well know the operating conditions in which the sensors are going to place in order to install those which are capable of supporting the environmental challenges in which the physical entity or process is located (Lee, Bagheri and Kao, 2015).

3.1.7 Conversion Level Data to Information.

In this process, the data collected is used to feed probabilistic models, which help in the prognosis and health management of equipment, the main objective at this level is that the physical entity becomes aware of itself (Pascual, Daponte, and Kumar, 2019).

3.1.8 Cyber Level.

This level is on how HUBs collect all information and data for different machinery to create historical records of the machines and analyze their performance accordingly to past behaviors and real-time operation. For example, in the production to observe which equipment could represent a possible risk to the surrounding physical entities, these comparisons and measures could help the operators predict future states of the physical entity (Lee, Bagheri and Kao, 2015).

3.1.9 Cognition Level.

Here, the combination of the information gathered and process through different models goes to the operators and managers to make decisions that will affect the machines and business. The information has to be presented in a clear way, such as graphics, to facilitate the understanding of the current operations stage and the state in which equipment are currently and how operational changes will affect the remaining life of the machines, as to know how to optimize the production and establish times for maintenance and ways to dispose of the equipment when they reach the last stage of the lifecycle utility (Lee, Bagheri and Kao, 2015).

3.1.10 Configuration Level.

This level aims to have a cyber environment that fully interacts with its counterpart in the physical world to optimize the process and machinery lifecycle. Here the decisions made in the cognition level are implemented. The primary purpose is that the equipment can configure itself and self adapt (Pascual, Daponte, and Kumar, 2019).

3.2 Digital Twin(DT).

In chapter 2, definitions of DT are presented, from which, as mentioned, there are three main characteristics observed in order to integrate a DT, a physical object, a connection network (data transmission), and the virtual entity. This interaction is created among the physical entity and the virtual representation, which puts the DT technology as a facilitator to implement CPS solutions in the industries.

Five dimensions are proposed as a model for the DT, which are Physical entity (PE), Virtual entity (VE), Services for PE and VE (SS), Digital Twin Data (DD), and Connection (CN) among the previous dimensions (Tao et al., 2018), how these five elements interact is shown in figure 20 and below short definitions for each one is given.

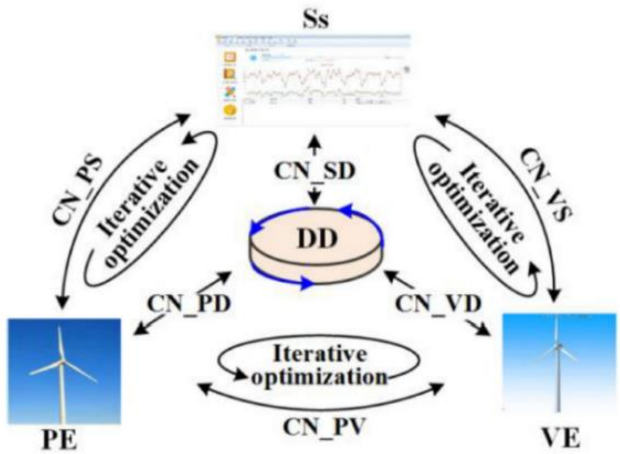


Figure 20 Five-dimension model for DT (Tao et al., 2019b, pp. 2406)

3.2.1 Physical Entity (PE).

The PE refers to the objects, processes, humans, sensors, and everything that exists in the real world and has defined characteristics that follow the physics properties (Fei Tao, Meng Zhang, and Nee, 2019b, pp.15–16) (Tao et al., 2018) (Jones et al., 2020). According to the function that has to be carried out by the PE, it can be divided into unit level, system-level, and system of systems (SoS) level. Knowing what level the DT is going to be implemented delimits the functions that it could have embedded in order to feed the Virtual Entity (VE) (Qi et al., 2019) (Tao et al., 2019a). A Wind Turbine is shown in figure 21, an example of the SoS, System-Level, and Unit Level.

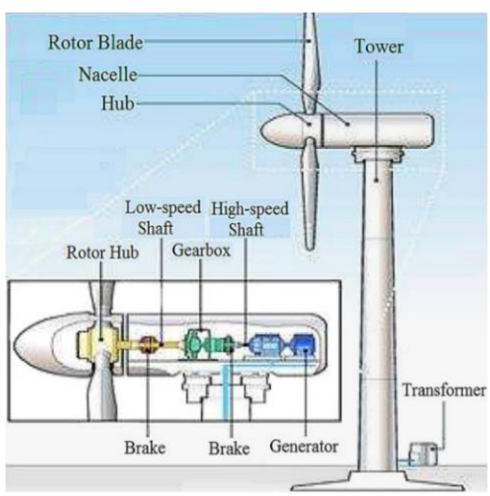


Figure 21 The main components of the Horizontal Axis Wind Turbine (Mahmoud and Xia, 2012, pp.16)

System of systems: Energy Grid, composed of different energy sources, such as fossil fuels, solar, hydroelectric and wind. **System Level:** Wind Farm, compose of several Wind Turbines and the elements necessary for this to function and provide energy to the SoS. **Until level:** Wind Turbine is an element composed of sub-elements which aim is to produce energy from the wind (mechanical force transform into electrical force) (Tao et al., 2018) (Tao et al., 2019a).

3.2.2 Virtual Entity (VE).

The VE is developed from the PE, and it mirrors the geometry (G_v), physical properties (P_v), behaviors (B_v), and rules (R_v) of the PE as reliable as possible in a digitalized world (virtual environment). Figure 22 shows an example of a virtual Wind Turbine (Tao et al., 2018) (Jones et al., 2020). The VE is fed by data provided for sensors, human experience, and expert domains. To accomplish this, it uses different technologies such as 3D-CAD designs, Virtual Reality (VR), Augmented Reality (AR), Industrial Internet of Things (IIoT), and other related technologies that are presented in the following topics (Fei Tao, Meng Zhang, and Nee, 2019b, pp.15–16).

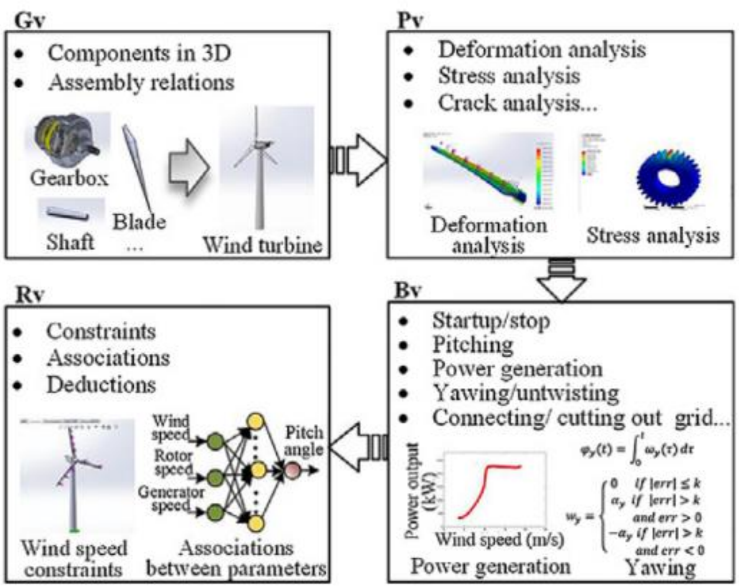


Figure 22 Virtual Wind Turbine Model (Tao et al., 2018, pp. 170)

3.2.3 Service Model (Ss).

The function of the SS is to optimize the functions of the PE and provide reliability to the VE by ensuring that the parameter of the VE and set correctly to mirror the PE in order to maintain the desired performance of this last one. The function integrates the SS, what the PE and VE would do, the input, data introduced to the VE and the PE, then output, data generated from the PE and the VE, another element is the quality, here is about the information a generated in the VE and the measures taken in the PE, and lastly the state, how the services are among the PE and VE (Tao et al., 2018) (Qi et al., 2019).

3.2.4 Digital Twin Data (DD).

The DD refers to the information generated from the PE when this is carrying on its primary function, then is the data generated from the simulation in the VE, as well includes the SS data generation, other data comes from the expert domains and the data generated from the one created when the data mention is integrated and use to create new types information (Qi et al., 2019).

3.2.5 Connection Model (CN).

The CN is one of the most critical elements on the DT, as this is how the interaction among the other four elements will be, the PE and the VE, the PE and SS, the PE and DD, the VE and SS, the VE and DD, the DD and SS. Figure 23 shows the interaction of the five dimensions of the DT Model (Tao et al., 2018) (Qi et al., 2019).

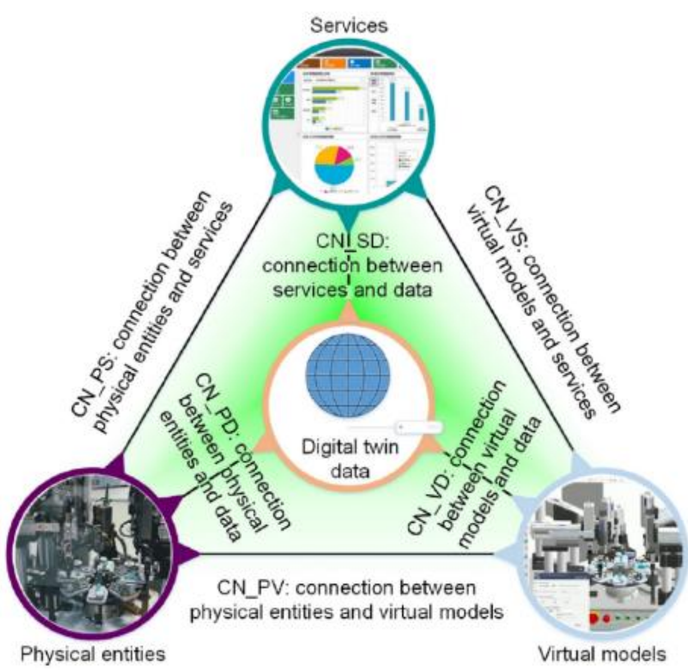


Figure 23 Five Dimension Digital Twin Model (Qi et al., 2019, pp. 5)

3.2.6 Building Blocks of DT.

Even though these five dimensions identify a DT, for its building blocks, four main ones are defined, which are the Physical Entity Platform (PEP), Virtual Entity Platform (VEP), Data Management Platform (DMP), and Service Platform (SP) (Josifovska, Yigitbas, and Engels, 2019). Figure 24 shows how these four elements are interrelated, as could be observed in the two primary environments, the physical and virtual one, each encompasses the corresponding blocks, where the cyber one involves the VEP, DMP, and SP, while the physical is restricted to the PEP (Josifovska, Yigitbas, and Engels, 2019).

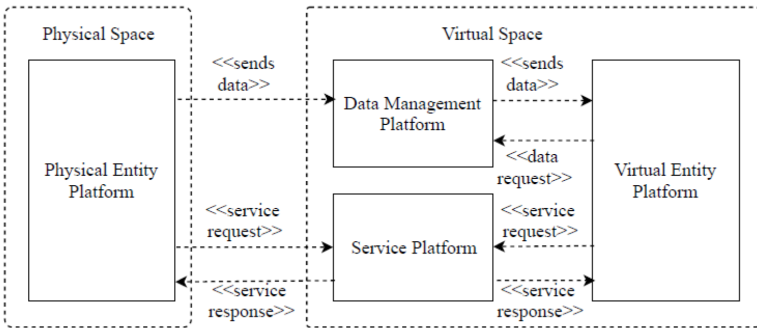


Figure 24 Interrelation among the Building Blocks of the Digital Twin Framework (Josifovska, Yigitbas, and Engels, 2019)

- Physical Entity Platform.

This block observed in figure 24, is limited to the Physical World. These include the physical entities such as the object, nodes, and humans. The physical object refers to a product that cannot communicate and does not perform a process in the physical space, but it can have sensors to be observed. The physical nodes are the sensors and actuators that could collect information and affect the physical environment and communicate with other nodes, with the primary objective of observing the physical object. Finally, the human interacts in the process not appropriately as being digitally twin, but as to how the decisions affect the physical environments observed through the nodes (Josifovska, Yigitbas, and Engels, 2019).

- Virtual Entity Platform.

The composition of this block comes with the integration of various models, which would aid in creating a high-fidelity virtual twin. First, these models could be classified as geometric. This relates to the shapes and measures of the physical entity. Then the physical model refers to the capabilities that the physical object has. The subsequent behavioral model is about how the communication of the physical entities is carried on. Another of the models is the rule model, which relates to the domains of knowledge, which can provide the constraints, permissions, and association of the system, and finally, the process model is used to determine the process that the physical entity would have in a CPS (Josifovska, Yigitbas, and Engels, 2019).

- Data Management Platform.

The objective of this block is the information, how it is collected, the use it will have, and the storage of data. That is carried out by implementing different data models that allow the data to be integrated, processed, cleansed, and analyzed (Josifovska, Yigitbas, and Engels, 2019).

- Service Platform.

The main goal of this block is to facilitate the optimization of the processes. The service model is applied for both the physical and virtual entities platform. The service model for the physical entity platform allows for monitoring, analysis, and enhanced physical environment. For the Virtual entity platform, this block provides control, optimization, testing, validation, and virtual space calibration (Josifovska, Yigitbas, and Engels, 2019).

3.2.7 Types of Digital Twin.

As the DTs are develop depending on which function they would have, a classification has been proposed. Dividing it into three elemental ones which are Digital Twin Prototype (DTP), Digital Twin Instance (DTI), and Digital Twin Aggregate (DA), all of them working in a Digital Twin Environment (DE) (Grieves and Vickers, 2016b), (Grieves and Vickers, 2016a), (LA and LA, 2020), (Autiosalo et al., 2017).

- Digital Twin Prototype (DTP).

The DTP is created before there is a physical asset to represent. The intention is to represent the future physical object with simulations, test different materials, forms, or shapes to produce an excellent asset/product. In order to achieve this, there are some requirements such as 3D models, bills of materials (BOM), bills of processes, bills of services and bills of disposal (Grieves and Vickers, 2016b), (Grieves and Vickers, 2016a), (LA and LA, 2020), (Hofbauer, Sangl and Engelhardt, 2019), (Raghunathan, 2019).

- Digital Twin Instance (DTI).

The DTI refers to when the physical object is connected to a virtual twin. It would interact during the lifecycle of the asset; this type could come upon a new establish PE, in which the DTI will come from the DTP, and as the asset goes into production with the different sensors and communication technology, feeding it with the data produced by the PE. Another option could be set for a PE that has already been in the operation and maintenance stage of the lifecycle, and the previous information will feed the DTI. As mention with the new asset/PE, it will be connected through different technologies. The DTI will use the operation and maintenance data to reflect as reliable as possible the physical asset (Grieves and Vickers, 2016b), (Grieves and Vickers, 2016a), (LA and LA, 2020), (Hofbauer, Sangl and Engelhardt, 2019), (Raghunathan, 2019).

- Digital Twin Aggregate (DTA).

The DTA is the collection of DTIs, where the DTA would not directly receive information from the PE but from the DTIs, and this information will provide an overall picture of the whole chain production or development of a product, allowing to evaluate the performance of the factory or process. In figure 25, is shown an example of what is DTP, DTI, and DTA (Grieves and Vickers, 2016b) (Hofbauer, Sangl and Engelhardt, 2019).

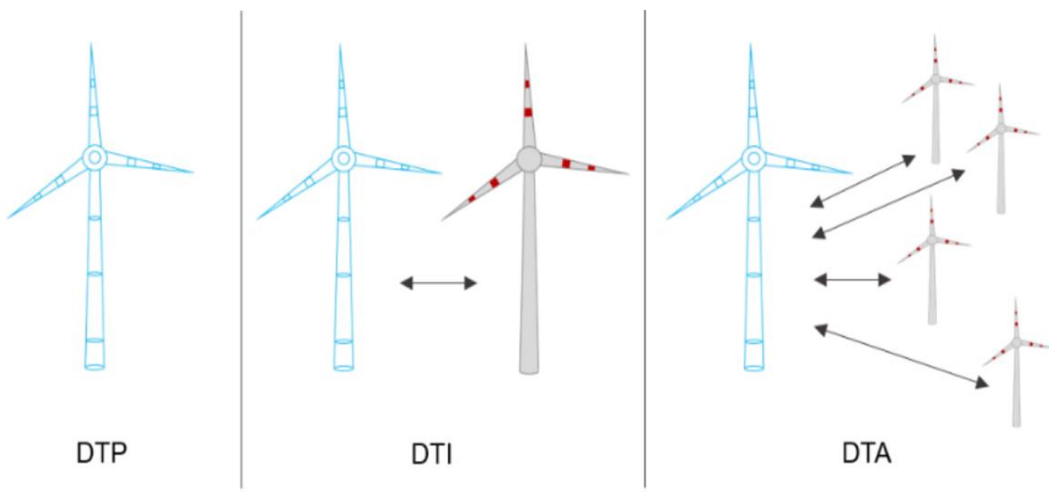


Figure 25 Types of Digital Twin (Hofbauer, Sangl and Engelhardt, 2019, pp.77)

3.2.8 Digital Twin and Digital Thread.

The DT requires the use of a Digital Thread. They go hand in hand as the digital twin is capable of creating information and the digital thread captures and delivers information of an asset according to the lifecycle stage in which the PE is at that moment (Fei Tao, Meng Zhang, and Nee, 2019c, pp.20–21) (Miskinis, 2018), a definition for the digital thread is *"a communication framework that tracks an asset's data throughout its lifecycle. Data from traditionally disparate and siloed systems, whether structured or unstructured, all flows into this framework to create a comprehensive view of an asset."* (SCHULDENFREI, 2020).

The Digital Thread purpose is to improve digitalization and follows the product lifecycle from design to disposal. During this time, its interaction with the DT is essential to complement the operation of this last one. As could be observed in figure 26, where it is noticeable that the data gathered by the digital thread is feeding the DT so this could run analysis, performance and predict the future states of the physical asset, then the data generated will feed the Digital Thread (LIN, 2017) (Fei Tao, Meng Zhang, and Nee, 2019c, pp.20–21).

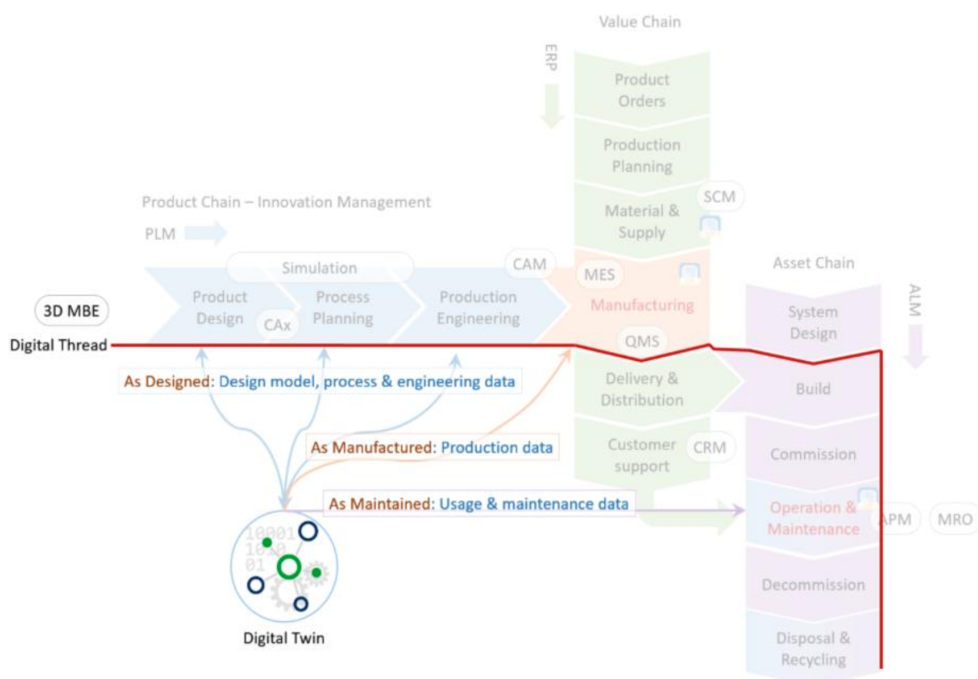


Figure 26 Digital Thread and DT (LIN, 2017)

3.3 The Digital Twin and Cyber-Physical System.

The CPS and DT capabilities had been described above, and it could be noticed that both share the main characteristics such as physical entity, virtual environment, and connectivity network. As could be observed in figure 27, the CPS encompasses the DT, as the CPS looks for both environments, the physical one and the virtual one (Lu et al., 2019, pp. 2). Meanwhile, the DT mainly focuses on the virtual entity recreated from a physical object, and it still needs its physical entity in order to be feed with data and process it to know the current state of the physical object as well as to predict the future conditions based on computational models and operational parameters that would allow accomplishing the business objectives along with obtaining the maximum value from managing the asset (Tao et al., 2019).

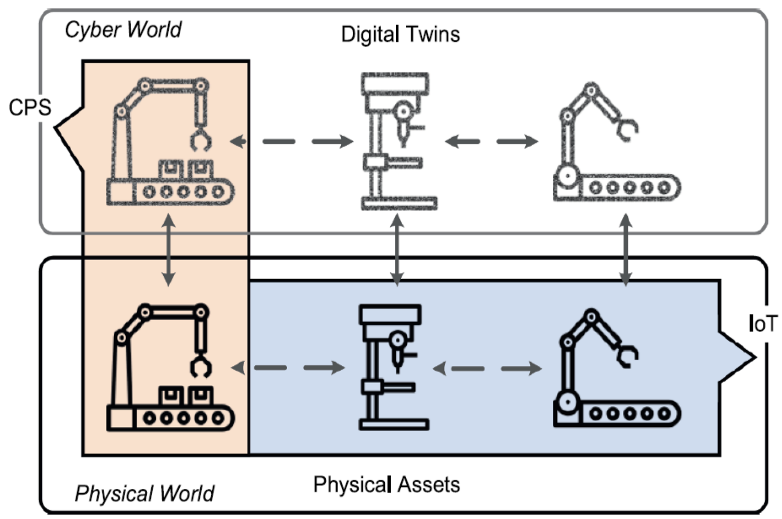


Figure 27 Relationship between CPS and DT (Lu et al., 2019, pp. 2)

Figure 27 also shows the IoT involvement. IoT acts in the physical environment through sensors and actuators and creates the link for data collection and transmission. The information recollected is used in different computational models, which create new data presented to the stakeholders through different types of charts and tables. With this data, asset managers are available to determine the optimal decision to improve the business and the asset's value, as could be observed in figure 28 (Tao et al., 2019, pp. 655). The decisions made by the stakeholders are also included in the cyber environment. For example, it could go from a decision affecting many devices; here, the function goes to the CPS as the interaction is one-many. Now the virtual environment that facilitates the interaction of the information and collection of the same single device is where the DT interacts one-one, as it only interacts with the twins virtual to physical and vice-versa (Tao et al., 2019) (Lu et al., 2019).

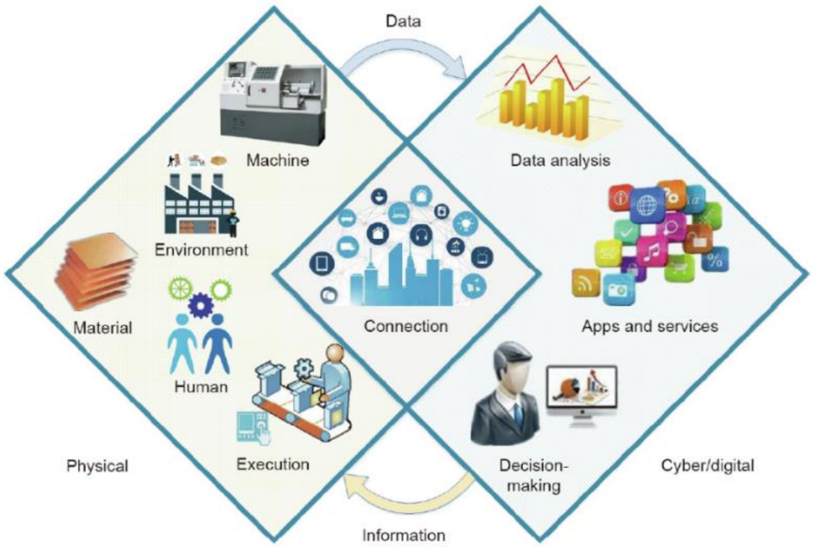


Figure 28 Interaction Between Cyber-Physical environments (Tao et al., 2019, pp. 655)

3.3.1 Three-level production systems.

Industries can be synthesized into three central systems for the production it begins with a unit level, a system, and finally a system of systems in the physical environment, while the CPS and DT had to adapt this division to the cyber world, as to how the interaction between the physical and digital environment will go (Tao et al., 2019).

- Unit Level.

Refers to what is considered the minor component in a production system or equipment. From the point of CPS, the unit level can represent the equipment along with the sensors and actuators and the embedded systems. The data collected from these elements allows optimizing the equipment management. Now for the DT, the unit level is equal to the one of its physical twin; this means that the small physical component of the equipment is virtually recreated, representing the physical form, measures, and function, all also based on the operational status(Tao et al., 2019).
At the unit level, the CPS and DT can have the same physical entity, and both change according to the physical environment (Tao et al., 2019).

- System Level.

This level is the integration of multiple-unit level elements. The goals pursued in this level are to enhance the use of materials, observe the interaction among equipment and the effects they have on each other regarding risk, possible optimization, and improve the management of these assets.

A system-level CPS contains the same elements as in a unit level in the cyber environment, while in the physical environment, now it can contain the production line or be a smart factory, where many types of equipment collaborate. For the DT, the physical world is similar to the one in the CPS; the difference is on the cyber level. Therefore, in order to have a system-level DT requires the collaboration of unit-level models of equipment or a product (Tao et al., 2019).

- System of System-Level.

A system of system-level (SoS) consists of the interaction of system-level models. The primary intention is to create an intelligent service platform that would provide interoperability, optimization, and connectivity. The SoS of a CPS focuses on enterprise-level collaboration and interoperation, and this level allows creating interaction among supply chain, commerce, and production. The SoS level for a DT is associated with the product's life-cycle, where the center is on the data collected and created during the different stages of the life-cycle. The goal is to look for innovation and enhance quality, and these would bring to the business savings in terms of money and time. Figure 29 shows the three levels from a manufacturing point of view (Tao et al., 2019).

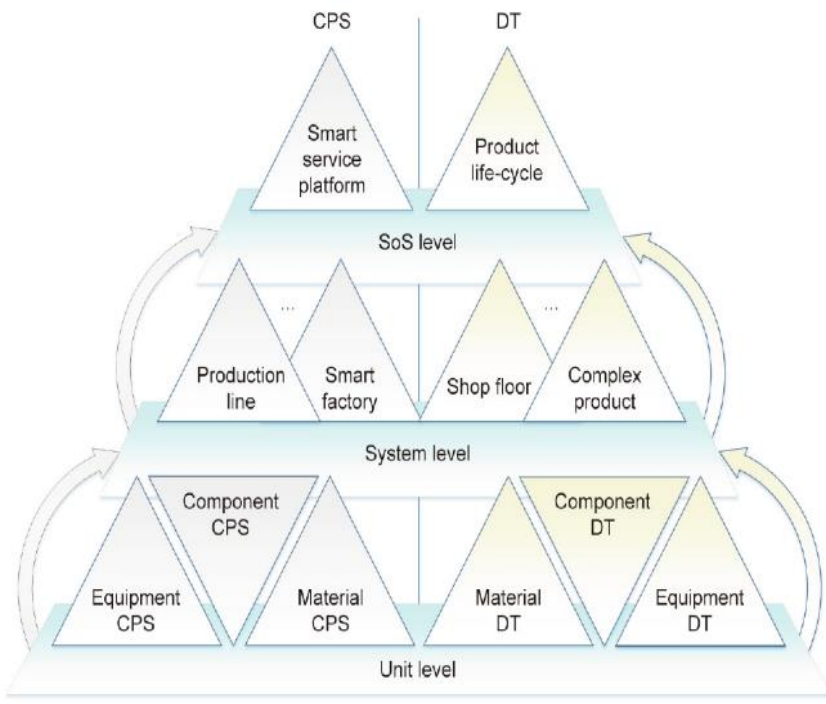


Figure 29 Hierarchical levels of CPS and DTs in manufacturing (Tao et al., 2019, pp. 657)

3.4 Review of application CPS and DT.

3.4.1 The Construction industry.

For this sector, the main focus for digital systems had been Building Information Modelling (BIM) that has been in used since CAD-Designs appear (FutureBridge, 2020) (Azhar, Khalfan, and Maqsood, 2015). Now with the application of DT, there has been confusion in both terms, sometimes using them as synonyms, but as stated previously, one of the most significant differences revolves around the capability for DT to use real-time data to monitor the current state of the asset, while the BIM is more relevant for the phase of design and construction (Dooley and Camposano, 2020) (Sacks et al., 2020).

As an example for BIM in the magazine *"Building Digital Twins"* Ph.D., Ken Dooley, and José Carlos Camposano discussed with stakeholders the integration that BIM had to have in their business and the limitations that this modeling has shown and where the DT can bring a solution. In this research, the authors divided the stakeholders into groups shown in figure 30.

Figure 30 Stakeholders for buildings (Dooley and Camposano, 2020, pp. 11)

By identifying these stakeholders, the authors recognize the struggles they have to manage their assets and proposed four digital solutions, which are *"The As-built digital twin, the Building Services digital twin, the Interactive Floorplan digital twin and the Business Intelligence Dashboard digital twin"* (Dooley and Camposano, 2020). Afterward, the authors give case studies for applications of the proposed solutions.

Another paper from the Australian BIM Advisory Board (ABAB) focuses on how applying the DT and BIM would bring value to cities and help on reaching the brand of Smart City. Here they present definitions in DT and BIMs (Product and Service) and the difference between them. Also, they discuss how the development of BIMs applying real-time connection would provide the stage for having a DT of the building(s). As well here, the ABAB presents a case study on a Bridge in Sydney, where the advantages are mostly related to maintenance of the Asset. In this paper, the ABAB also presents cases from other cities applying DT and BIM. Then they show the most common facets of frameworks to evaluate DT: maturity, complexity, vitality, and use cases. Furthermore, they how the DT is providing value gains at the level of organization, and them on Government levels and present what the current developments on Australia related to DT and BIM to provide the country with what is named in the paper as "A national digital twin for Australia" (Scotland et al., 2021).

In the paper *"Construction with digital win information systems"* (Sacks et al., 2020), the authors proposed a new term Digital Twin Construction (DTC), "*is a new mode for managing production in construction that leverages the data streaming from a variety of site monitoring technologies and artificially intelligent functions to provide accurate status information and to proactively analyze and optimize ongoing design, planning, and production."* (Sacks et al., 2020, pp. e14-1). Figure 31 shows what the authors observed in the workflow for the DTC and the integration of the functional DT.

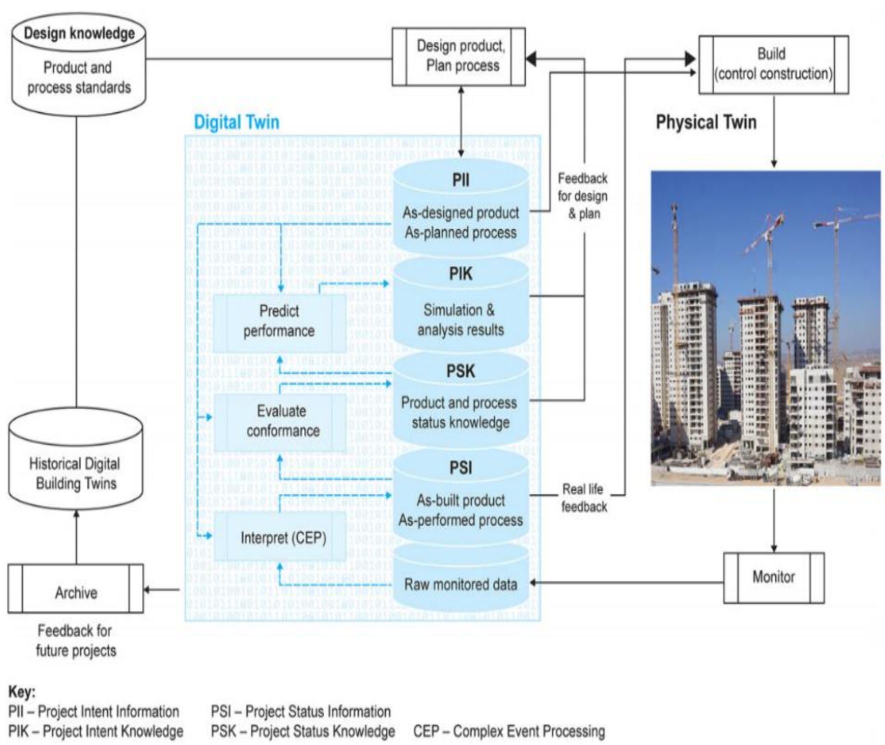


Figure 31 DTC workflow process (Sacks et al., 2020, pp. e14-15)

Then in figure 32, the development of applying the DT looks from the lifecycle perspective for the physical entity and the virtual one.

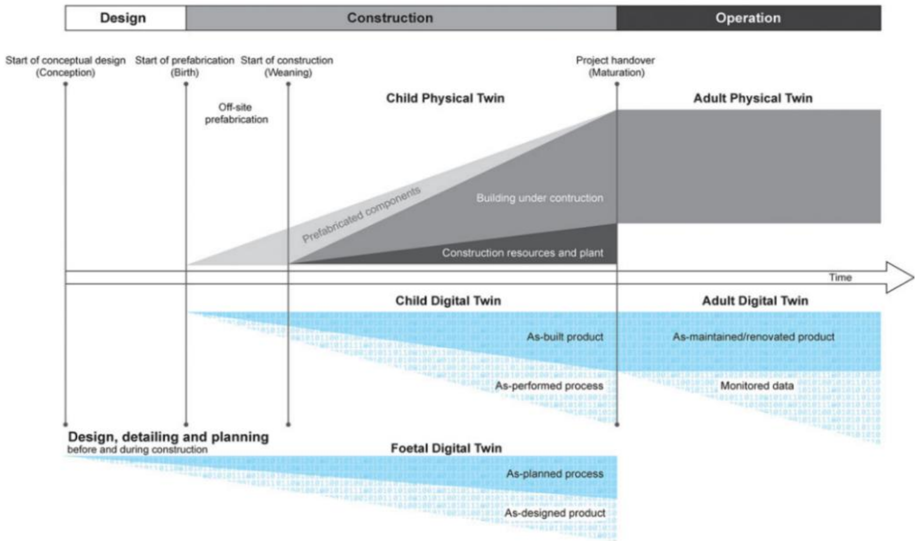


Figure 32 Lifecycle of the physical and digital building twins (Sacks et al., 2020, pp.e-14-16)

3.4.2 Health Industry.

The aim of this sector is in the near future be capable of having a DT of a human that is connected to the person in the physical world, allowing the medical staff and the individuals to follow the health status, thus predicting future illness that might arise and track the spread of diseases as to provide the appropriate medical treatment that each patient would require (Barricelli et al., 2020) (Miskinis, 2018a) (Fuller et al., 2020).

In the present stage of technology development, the application of DT for the health sector is encounter mostly in relation to BIMs as (SIEMENS and Malkwitz, 2018b) present in their paper where they exemplified how the DT helps on the tracking of utilities, personal moves, and patients location, where it is mentioned that the advantages could "*reduce liability and improve security, reduce operating costs, save time, added patient value through a better room utilization, and analysis and planning"* (SIEMENS and Malkwitz, 2018b), figure 33, provides an example of location.

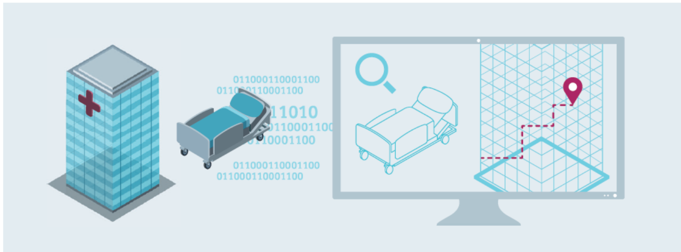


Figure 33 Patient and asset tracking enabled by the digital twin (SIEMENS and Malkwitz, 2018b, pp. 12).

Another application is mentioned by (Miskinis, 2018a), which provides information on the development of a *"Living Heart, which is the first realistic virtual model of a human organ accounting for blood flow, mechanics and electricity. The software is capable of turning a 2D scan of a human into an accurate full-dimensional model of an individual's heart."* (Miskinis, 2018a), developed by the company (Dassault Systemes, 2020).

3.4.3 Energy Industry.

In this sector, the DTs are being employed to improve the operation and maintenance of the assets aiming to enhance the life and value of an asset (Walters, 2019) (GUNJAN, 2018), along with this is coming what is being named Energy 4.0 (Velickov, 2020) as in reference to Industry 4.0 (Steindl et al., 2020). As for what DT is bringing to this sector, examples could be, as mentioned by (GUNJAN, 2018), that GE CEO claims to have saved the company almost 1 Billion dollars in 2017 by using its PREFIX platform and related artificial intelligence applications. The paper "*Digital Twin Framework and Its Application to Power Grid Online Analysis"* by (Zhou, Yan, and Feng, 2019), is an explanation of what DT is what, which are the applications it could have, the features that the DT has that provide value to the application on the power grid digitalization (Zhou, Yan, and Feng, 2019). (Walters, 2019) gives insights on its paper "*How Digital Twins Will Drive Innovation in the Energy Sector"* on how BENTLEY company is aiming to provide services for its customers to provide them with energy management through DT applications.
Now in the following are mentioned the two primary industries related to the energy sector which are:

- Oil and gas (O&G).

  For this industry, we refer to papers such as the *"Digital Twin for the Oil and Gas Industry: Overview, Research Trends, Opportunities, and Challenges"* (Wanasinghe et al., 2020). Here researchers collected information on the different DT and the current state applications in the industry of O&G; where are the main areas to apply the DT inside this industry to gain the most value. Another paper is Oil and *"Gas digital twins after twenty years. How can they be made sustainable, maintainable and useful?"* (Cameron, Waaler, and Komulainen, 2018). Where the authors provide brief introductions to the DT and how it has been involved in the O&G industry under the name of online use and updating of an integrated asset model, it presents brief information on how the DT has been developed in the manufacturing industry and what are the challenges that the DT has to address in order to accomplish its objectives.

- Renewable Energies.

As many countries and companies around the world look for what is named net-zero carbon energy transition, the growth in the sector for green energies is growing at a fast pace being the wind, solar and hydro forces are the primary sources in this sector (Velickov, 2020), all of this as part of the plans agreed in UN energy transition for 2030 and the Paris Agreements (Hübner, 2020).
In the paper *"Sustainable Energy and Digitalisation: Practices and Perspectives in Asia-Pacific"* by (Hübner, 2020), the author presents future insights for the energy sector from a world perspective. It explains the current situation for countries in Asia as China, Japan, Singapore, South Korea, among other countries that are looking for the goal of net-zero carbon emissions, which impact would provide the application of digital transformation. The author presents cases for different companies in the world as examples for solar, wind energy and how the future outcomes of doing this transition would look for the world and Asia.

For DT application in the wind energy sector, companies such as GE focus on delivering a solution for maintenance and operation through the management of individual wind turbines and what are being called wind farms that consist of many wind turbines, and what benefits it would have for the industry, on the article *"The French Connection: Digital Twins From Paris Will Protect Wind Turbines Against Battering North Atlantic Gales"* is presented an example of how GE applies the DT tool they had developed to provide business values and be on route to accomplish the Paris Agreements (GE Renewable Energy, 2021) (GE Renewable Energy, 2021b) (Pomerantz, 2018). In another article by (Pal, 2020) *"How digital twins could transform the wind energy industry,"* the author comments on what are the benefits that the application DT would provide to the operator of the wind farms like remote control operations, following elements degradation, and have a view over the life-cycle, as well comments on what data modeling could bring for manufacturing.

As for Solar energy, Pratiti Technologies presents its analytics solutions in the article *"Solar Digital Twin – Importance of Digital Twin in Renewable Energy"* (Tappe, 2020). In the Hydor sector, an article by (Arch et al., 2019) named *"The digital revolution of hydropower in Latin American countries",* in this paper the authors give an introduction to what implies digital transformation, how to implemented and which values it could bring, then they present data on what is the current stage on hydropower production for Latin American countries, and give and economic analyzes on what could be the economic benefits for the future its digital transformation is applied, following they present importance of digitalization of process and what are the technologies that could provide the most benefits for the power production, also include cases studies from some countries to show the current state of the industry in those countries and mentioned what could be the value earnings the companies would have by applying digital solutions, after data on what could the economical benefits are into digital transformation and what are the challenges that Latin American countries have to face to fully implement this solutions.

3.4.4 Manufacturing Industry.

The industries involved in this sector have been involved with DT developments along with the CPS. Here the DT and CPS have been evolving at a fast-paced due to the implementation of technology solutions related to Industry 4.0. (Zhong et al., 2017) (Bazaz, Lohtander, and Varis, 2019), (Fei Tao, Meng Zhang, and Nee, 2019a, p.ix)

The book on *"Digital Twin Driven Smart Manufacturing"* (Fei Tao, Meng Zhang, and Nee, 2019). Where the authors give an introduction what DT, which technologies are involved, conceived frameworks on how the floor of manufacturing is on the virtual world and the physical one. As well present case studies of applications are, how it is the current state on the DT and the creation of the CPS, they also provide chapters on the major technologies that are providing and would provide the basis to build the DT and the CPS. Furthermore, more articles related to the topic of CPS and DT in which the industries look for total automation of their shop floors that will lead to what is named intelligent manufacturing, providing value for stakeholders, shareholders and the assets, bringing the industry to the most optimize production and maintenance process, along with the full view of the asset life-cycle perspective, as to mention some *"Industry 4.0 and the digital twin Manufacturing meets its match"* by (Parrot and Warshaw, 2017), *"About The Importance of Autonomy and Digital Twins for the Future of Manufacturing"* by (Rosen et al., 2015), *"Digital Twins and Cyber-Physical Systems toward Smart Manufacturing and Industry 4.0: Correlation and Comparison* (Tao et al., 2019a), *"DIGITAL TWIN FOR SMART MANUFACTURING: THE SIMULATION ASPECT"* (Shao et al., 2019), *"5-Dimensional Definition for a Manufacturing Digital Twin"* (Bazaz, Lohtander and Varis, 2019),*" Framework for a digital twin in manufacturing: Scope and requirements"* (Shao and Helu, 2020).

3.5 General challenges in CPS and DT applications.

In order to identify how the Digital Twin(DT) and the Cyber-Physical Systems(CPS) can affect the industries, the challenges would be from the point of Human side, the Organization, and Technology. This combination, known as Human-Technology-Organization(HTO), provides a simplified view of what issues could arise and are present in developing and integrating DT and CPS in the industries. The Human refers to how the operators, managers, and shareholders involved in the business have to how work-loads, ergonomics, and working environment could affect the company's objectives and value. Organization point refers to policies already in place and changes necessary, management structure as to whom is taking which decisions, shareholder and stakeholders objectives, the international standards that the business has to follow, the economic benefits or setbacks of the industry. Finally, Technology is about the new solutions that are placed on the market, which the main goal is to facilitate and enhance the task carried out in the workplace, but not all changes would bring value to the industry, so companies have to be careful in their approach to new technologies.

3.5.1 Human Factors.

- Human-Machine Interaction.- As the operators of the physical asset move the interaction to the cyber environment, this could bring an issue where the operators might not have a complete picture of the physical asset due to set their trust in the virtual twin (Van Woensel, Kurrer, and Kritikos, 2016) (Kaivo-oja et al., 2020). Moreover, despite being able to give a virtual asset representation, the DT applications can not measure and fully recreate all conditions that the physical asset might encounter. Thus it would rely on the operator to fill up the variance of data that can not be registered for the intelligent sensors and devices that collect the information produced from the asset. As well, the stakeholder had to interact with third-party software. Where the virtual twin of the physical asset is created or set to function, this means economic and time cost of training and software development for the industries, where the employees are interacting with the physical asset, and if not training proper could create a risk where data is lost, or even the physical asset might get affected (Van Woensel, Kurrer, and Kritikos, 2016) (Kyriakidis et al., 2017) (Kaivo-oja et al., 2020).

- Psychological.- This point relates to the mental workloads that stakeholders have to deal with, the integration of DT and CPS is creating data in an amount that only computational models are able to manage. However, this leads the stakeholders to over-analyze and delayed decisions; this can allow a small situation to become a more significant issue that could cost the asset and probably harm lives. On the other hand, the decision-making could be forced to be done in short timing, it would allow being responsive, but the solution could not be optimal and would lead to an unwanted situation later (Kyriakidis et al., 2017) (Ashibani and Mahmoud, 2017). Another related trouble is that the CPS and DT require the operators to feed the systems with the work done in order to complement the data for the virtual environment, but this might lead to data loss due to the fact that employees would not want to expose themselves on the work not done, for fear of retaliation from the managers as to why the work is delayed or have not been done (Van Woensel, Kurrer, and Kritikos, 2016) (Ashibani and Mahmoud, 2017).

- Skills.- The main change that the DT and CPS bring is to facilitate the automation of processes. Automation is prompting a change in operations from the perspective that now the employees are moving from being involved in the process to be observant of the same one, the issue that comes is that human attention is easily derailed towards something else, leading to misinterpret or miss a warning signal (Ashibani and Mahmoud, 2017) (Van Woensel, Kurrer, and Kritikos, 2016). Also, the interaction of a cross-sea of an enterprise is facilitated by the virtual environment and communication technologies. However, it leads the overseas operator not to be fully connected with the physical asset and would create a lack of understanding of the physical asset's operational range or condition (Ashibani and Mahmoud, 2017).

- Human error potential.- Industries always have to deal with the situation that humans commit mistakes, primarily unintentional, and that have cost organizations from some thousands of dollars to millions to repairs damage in their business and the society (Health and Safety Executive, 2020). The integration of DT and CPS industries intent to reduce the mistakes by helping in the automation of processes inside the business and reduce the human interaction; this does not mean firing employees but is more on transitioning workers from being physically in the middle of the operation to be observers and decision-makers (Torres, Nadeau and Landau, 2021) (Pearce and CGEIT, 2020). However, these changes might help eliminate some risks as any new technological solution comes with its potential hazards (Ceesay, Myers, and Watters, 2018) (Torres, Nadeau, and Landau, 2021). Among the human errors that could affect the digital systems is employees, who are not well trained in how to protect the data they manage. It could mean they could have easy to hack passwords or connect to the company systems in insecure ports or places that would allow for third parties to invade the virtual environment of an industry, which could endanger the physical asset or even the entire businesses (Axelrod, 2013) (Ceesay, Myers and Watters, 2018) (Pearce and CGEIT, 2020). Another potential error is capturing data a small data misplaced or not enter into a virtual environment could lead to having a mismatch between the cyber world and the physical one being represented (Ceesay, Myers and Watters, 2018) (Pearce and CGEIT, 2020).

- Technological generational gap.- The DT and CPS are improving the automation in the industries, and these bring new levels of complexity that might be hard for managers and senior-level who belong to a generation that is not fully technologically wise. It could lead to issues where the older generation inside the industry could understand these new systems (TAPIA, 2016) (Zetlin, 2017). Another point is the factor that DT and CPS provide employees in base levels of the organizations with more decision power, thus somehow diminishing the positions of senior-level and managers (TAPIA, 2016) (Zetlin, 2017) (Newman, 2017) (Technology, 2020).

3.5.2 Organization Factors.

- International, National, and Internal policy.- When new solutions are implemented into business, there is a need for internal policy changes and the adaptation of international ones in order to protect the business, the asset, shareholders, stakeholders, and the environment surrounding the industry. The DT and CPS enable a cyber environment where the main issue is data management and protection. Also, define a path on how the virtual environment is going to be integrated and what work has to be carried out when a new physical asset has to be added to the existing cyber world of the industry or, in case necessary, how to evolve the existing virtual environment into a DT and finally grow the business into a total CPS. As well, industries have to deal with the risk of the cyber-world. In order to do this, the cybersecurity measures have to be integrated into the business, and those companies that do not level up their advances in the cyber environment with the protection of cybersecurity would allow having entry points in the virtual space that would allow for hackers to stole data, could damage the physical asset, the employees or even the entire business.

- Economic and enterprise risk.- In any industry, the main objective is to create revenues. These come from selling products or services, time-saving in processes, branding, and their commitment to the environment in recent years. The CPS could allow managers and shareholders to have a clear view of how the business is doing in all these terms with the aim to succeed financially, the risk in this view is that it could create overloading of work in the employees and the physical assets, that would lead to being impacted later down due to failure of equipment or risk event due to employees fatigue. Another point mentioned before is how business information has to be protected from cybercrimes that in 2020 reached almost one trillion dollars losses in the global economy (Smith, Lostri and Lewis, 2020) (Riley, 2020). The loss of value is not only from companies paying to recover data from ransom hacking but also is from shutdowns that occur due to phenomena the time it takes to recover control over the cyber-systems generate expenses to the industry and could harm customers, employees, surroundings, and the asset in the physical world (Riley, 2020) (Smith, Lostri and Lewis, 2020).

- Organizational structures.- As the policies evolve to adapt to the CPS and DT implementations, another effect of these changes is in the structure of the companies meaning, which roles are to be changed, the working space evolution, the job functionalities that are needed, and the employees capabilities which could match the new needs that are going to be integrated by the union of the cyber and physical environment. Another factor that increased the complexity is, as mentioned before, the customer-centric approach, thus also the customer has a level structure in the cyber environment and the physical one. One of the most complex challenges brought to the organization structure is the decision making, in silo mentalities or pyramidal organizations to choose a solution or what has to be done takes times as the approval of the action to follow has to reach the appropriate level manager or decision-maker, the cyber environment and the disponibility of data can provide more stakeholders with power over decisions making or even some decisions could be taken by the digital solutions, and this would create confusion inside the industry structure where the manager position has to be re-imagined as to which functions it will carry on. Also the baseline employees functions have to adapt some functions to make decisions based in the main goals of the business (Aghina et al., 2018).

- Business Partnerships. Adapting and using DT solutions and establishing total CPS in organizations, as mentioned before, creates a complex interactive cyber environment where companies interact with more than one or two partners to accomplish the business goals. However, this interaction increases the risk of industries' complaints about who owns which data, software, or expertise. Also, having so many participants could generate cybersecurity issues if one of the involved parties has not the same level measure as the others ones in the industry (Herterich, Uebernickel, and Brenner, 2015) (NIST and U.S. Department of Commerce, 2013) (Frazzon et al., 2013) (Colombo et al., 2017) (Rudtsch et al., 2014).

- Management Changes.- The integration of cyber environments has enabled the adaptation of boundaryless management in organizations. The foundations of boundaryless management in this type of structure organization aim is to tear down barriers such as the geographic location of the stakeholders, shareholders, the physical assets, and where data is stored. Also, the functions carried out, and even allow to involve higher rank stakeholder or managers in the processes along with level base employees, it seems this type of organizational system provides help in to deal with the complexity created by the digital solutions (Hirschhorn and Gilmore, 1992) (Thoppil, 2020) (Johansson et al., 2017). Now, as with any implementation that affects the management, issues are rising for managers and employees. From the managers' perspective, struggles came to approach with operators, who are located in other countries this means for them to know a bit about the culture and national work rules where he/she is located. On the other hand, employees might struggle to realize who has the power decision over the asset or process as DT and CPS provide everyone to have the data in almost real-time and that there would be the inclusion of high-ranked managers that only participation could be of know what is happening but the manager that decides would be someone below the ranks (Hirschhorn and Gilmore, 1992) (Johansson et al., 2017) (SHRM, 2021).

3.5.3 Technology Factors.

- Complexity Increased.- A company incorporates cyber solutions into their business, aiming to facilitate the work. However, these digital solutions bring complexity levels of connections that are difficult to follow, as more devices got a digital twin and connected to other virtual entities in the enterprise. As an example, we could look at the following figure 34 (Blanco et al., 2018), the image gives an overlook of the digital construction environment, where many ports are denoted and follow a specific path is quite hard, many industries have similar or even more complex virtual spaces, that as said earlier could allow hackers to enter the systems, and with such levels of structure, it takes time to identify the dot that is causing harm to the business.

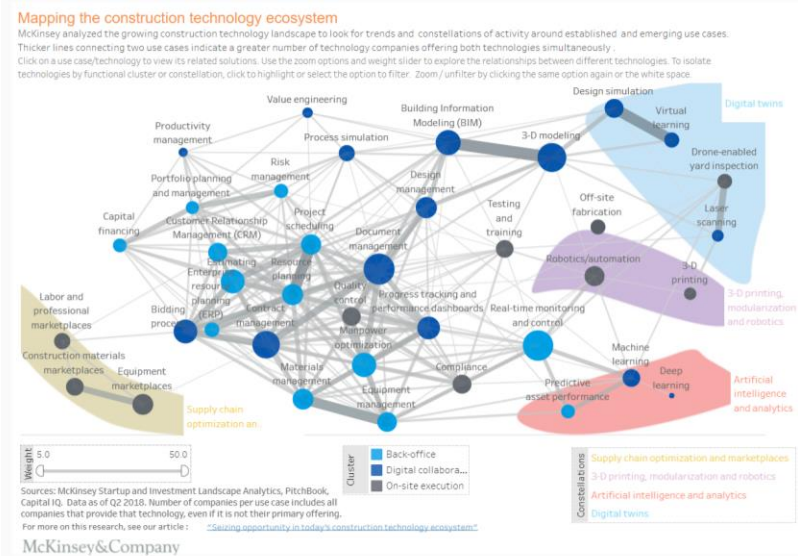


Figure 34 The construction technology ecosystem (Blanco et al., 2018)

- Fast technological evolutions.- The industries are constantly on the lookout for solutions that would facilitate the production process. In search of innovation, many companies jump out to the newest technology without considering its effects on the inner policies, organization, security, and economic cost. For example, now, the CPS and DT require sensing technologies to monitor and integrate the physical world into the cyber environment and vice versa. However, if the shareholders and stakeholders do not analyze which level they are currently in the digital environment, it would lead to missing matches on the technologies implemented. It is one common mistake and costly for industries jumping into digital transformation.

- Technology Interdependence.- Industries are connecting all the levels of their processes and assets with the implementation of DT and creating a suitable environment for CPS (Monsone and Jósvai, 2019) (Bécue et al., 2020) (Bailey, Leonardi and Chong, 2010). The DT and CPS's ability to interact with their physical counterparts is crucial for the correct operation of both. Although it might imply having the newest technology on sensing devices, companies must ensure that their cyber systems are compatible with the new sensors and the software they brought from the manufacturer. Then, as for the physical environment, matching the hardware sensors with the asset has to be of interest to stakeholders. In both cases, a mismatching would mean to carry on extra expenses for changing software and rewiring the hardware or even for the company to re-buy a whole set of devices that match their cyber-systems and physical asset (Bailey, Leonardi and Chong, 2010) (Monsone and Jósvai, 2019) (Bécue et al., 2020) (Doz, Angelmar, and Prahalad, 1985).

- System Integration.- Among the main goals of developing a digital environment is to interconnect physical devices, virtualize the process and create a focused enterprise on customers' needs, all integrated into the structure of CPS. Now interconnecting software and hardware might be an easy task when dealing with one unit. However, in enterprise-level equipment of different manufacturers and even different types of devices, if the organization does not address the differences, it would lead to economic cost on re-adapting their system to fully interconnect all their devices and the virtual environment (altexsost, 2021) (Srinivas and Bhan, 2021) (SIEMENS, 2021) (HeadChannel, 2020) (Muller, 2011). Also, in an environment of DT, there has to exist cohesion; otherwise, it can lead to misassumptions that would finally make the wrong decision. The next issue to integrate the CPS and DT is that the organizations' data management have the premises to protect their information, and therefore, the establishment of cybersecurity measures is a must. Then even if the primary industry is well protected, if the surrounding businesses sharing the data are not able to cope with the security level systems, it could create an entry point for a hacker or rival organization to steal sensitive information of the business (Anthony David Giordano, 2011, pp.45–64) (HeadChannel, 2021a) (HeadChannel, 2021b) (Montgomery, 2013) (Muller, 2011).

- Reliability and Security.- Industries need to assess the risk that any new technology would bring to their business and processes, either by which risks are eliminated or minimize as well as the new threats that are being brought (Yaacoub et al., 2020) (Lazarova-Molnar, Mohamed and Shaker, 2017) (Cardenas et al., 2019). The CPS and DT are bringing new threats to the industries. One side is the effects of the virtual environment over the physical ones, and the most significant impact comes from control of physical equipment without the need to be next to it. Also, human interaction is hard to predict by computer modeling. On the other hand, is the interaction of the physical entities with the cyber environment, as organizations increase the devices connected in their digital world, also increases the possibility for their system to be hacked (Ashibani and Mahmoud, 2017b) (Cardenas et al., 2019) (Yaacoub et al., 2020) (Lazarova-Molnar, Mohamed and Shaker, 2017).

3.5.4 Work process.

- Workflow Logic.-Organizations have to create a path for the process of works done and delivery between phases and employees. The cyber systems now allow that employees work on their task in a determined time and then moves the work to the next phase in the chain(Kissflow, 2017) (Kissflow, 2019) (Seiger et al., 2019), and these have brought mobility and speed up processes in the companies (Seiger, 2018). However, the integration of DT and CPS brings up issues like confusion for employees as they are moved up from one line of a process to another. Adding to the challenges is to follow up the data packages in cyber systems as industries carry on operations overseas could prove hard to track. Another challenge comes to hide in the ability of the system to have many users working in the virtual environment, which could lead for some people to overlap their task creating duplicate data, or even the loss of information due to employees believing it is some else responsibility to update information in the cyber system due to the overlap of responsibilities (Seiger et al., 2017) (Seiger, 2018) (Kozsik et al., 2013).

- Interphase in work processes.- The virtual environment that CPS is providing for industries connects not only private industries but also has to be capable to be involved in the smart cities development of its own DT and cyber environment (Bolton et al., 2018), where the compatibility of software and hardware of different brands and technologies is a must. The cloud sharing data on the ongoing development needs to have restrictions and limitations on both sides, the private and public sectors (Kalluri, Chronopoulos and Kozine, 2020) (Piantanida et al., 2014). For example, the private sector is on its rights to protect its sensitive and operational secrets for the business to compete. On the other hand, governments must protect their citizens primarily and the infrastructure that is being created. While Industries risk losing operational secrets towards other industries, governments look to implement a connected network of industries. These imply the development or growth towards an innovative city network to have the services for its inhabitants, and structures could be an opening door for cyber terrorism that could cost from losing some services to tragedies with the loss of several human lives (Juma and Shaalan, 2019) (Lom, Pribyl, and Svitek, 2016).

- Decision Support Systems.- The integration of DT is providing more data to the virtual environment could improve computer programs that help in the decision of the industry (CFI, 2021) (Segal, 2021) (Salama and Eltawil, 2018). However, as industries connect more physical devices into their virtual environment, managers and employees have to deal with assets that might have to be adapted towards connecting to the digital environment. Another issue is for companies to get their managers and employees to trust solutions proposed by the decision support system (Freier and Schumann, 2019) (Salama and Eltawil, 2018).

- Roles and responsibilities.- The virtual environment is allowing everyone across the organization to have access to more information about the business (Hamburg, 2019) (de la Boutetière, Montagner and Reich, 2018) (Bécue et al., 2020b) (Deloitte MCS, 2018). Despite industries have employees been more involved in the decisions process of the organization, thus leading to take over some management responsibilities, it is affecting management position employees as they try to figure out what is going to be their role in the CPS of the industry (Basford and Schaninger, 2016) (Deloitte MCS, 2018) (Hamburg, 2019) (Bécue et al., 2020b). Another factor is as base level employees have more responsibilities, it might lead the company to open up for people either delaying decisions due to that they do not feel prepared to take it or take a rush decision that could endanger the business (Bécue et al., 2020b) (Manyika, 2017).

Chapter 4: Recommendations for mitigating the Challenges in DT and CPS.

Figure 35 shows disruptive technologies that could help mitigate some of the challenges industries have to deal with when implementing the Digital Twin (DT) and Cyber-physical systems(CPS). The five trends mentioned in figure 35 are terms that are being conceived in recent years, most of them. The first observed trend IoB is mentioned to have begun been studied by a retired professor Gote Nyman in 2012 (Nyman, 2021a) (Nyman, 2021b), but it has just made into the technological trends of 2021 in Gartner's paper *"Top Strategic Technology Trends for 2021"* (Burke, 2020b). Moving into the trends, the Network Organization has been around the longest, but its integration has been recently on the growth due to the IoT development and integration (Miller, Okamoto and Page, 2016) (Hixon, 2020). The following trend, Cybersecurity Mesh this can be considered one of the newest term as it is still not a proper definition to what it is, Gartner is mention to have put these trend in the spot for industries there is no clear authorship for these concept as its base is cybersecurity itself (Burke, 2020a) (Solutions, 2020) (Mathiue, 2020). The next trend is AI Engineering, this concept is considered to be relatively new, but it began with the AI term, which is dated back to 1943 by McCullough and Pitt in their work *"Artificial Neurons."* (Brown, 2020), and from this point, the AI has been evolving along with the capabilities of machines mostly related to the computational and robotic area to this term that is most related to a new field of studies for the human (Brown, 2020) (Carnegie Mellon University, 2019) (TECHSLANG, 2020). Finally, the hyperautomation is considered to be a successor or the next step for automation, and this term has been brought to light by Gartner (Burke, 2020c) (YEC, 2020), but it is linked to the development of Industry 4.0 and related technologies like IoT and IIoT (bizagi, 2020).

Technology Trends	• Challenges areas it could aid
Internet Of Behaviours (IoB)	• Human Factors • Organization • Work process
Netwok Organization Structure	• Work Process • Organization • Human factor
Cyber Security Mesh	• Technology • Human Factor • Organization • Work process
AI Engineering	• Technology • Human Factor • Work Process
Hyperautomation	• Tecnology • Work Process • Organization • Human Factor

Figure 35 Disruptive Technologies and which factor challenges they could help to mitigate.

4.1 Internet of Behaviors (IoB).

The industries already have embraced the Internet of Things (IoT), which allows devices to connect, create and share data allowing companies to maximize the value that assets could provide to the organization. Nevertheless, organizations driving changes towards integrating DT and later on CPS, where the center is the focus in the customer, needs to evolve its IoT approach in order to include the data from the clients, this evolution or increased on the capacity of IoT is being named Internet of Behavior (IoB) (Todaro, 2021). The IoB's primary focus is to interpret data in order to comprehend what makes the customer choose the product or services from a specific business and adapt the industry to the client's needs. Figure 36 shows the advantages of IoB (IOTDESIGN PRO, 2021). Now the main issue arising with the implementation of IoB is on ethical grounds as the data managed might be used to prompt certain comportment that users could interpret as manipulative and invasion of their privacy.

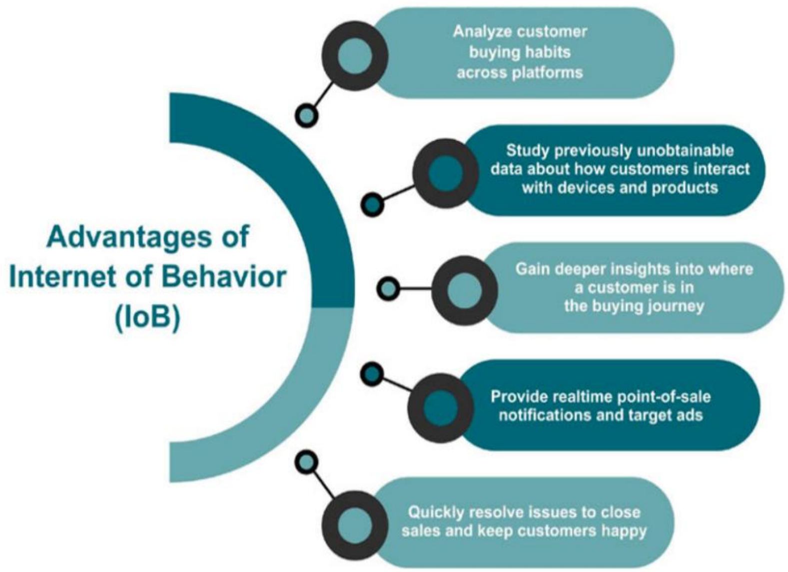


Figure 36 IoB Advantages (IOTDESIGN PRO, 2021).

Figure 37 shows how it could look at the development of IoB in an operational context, and this gives a big picture of what it could bring to the systems, what issues it has to approach in order to function, and evaluation of the system (Stary, 2020).

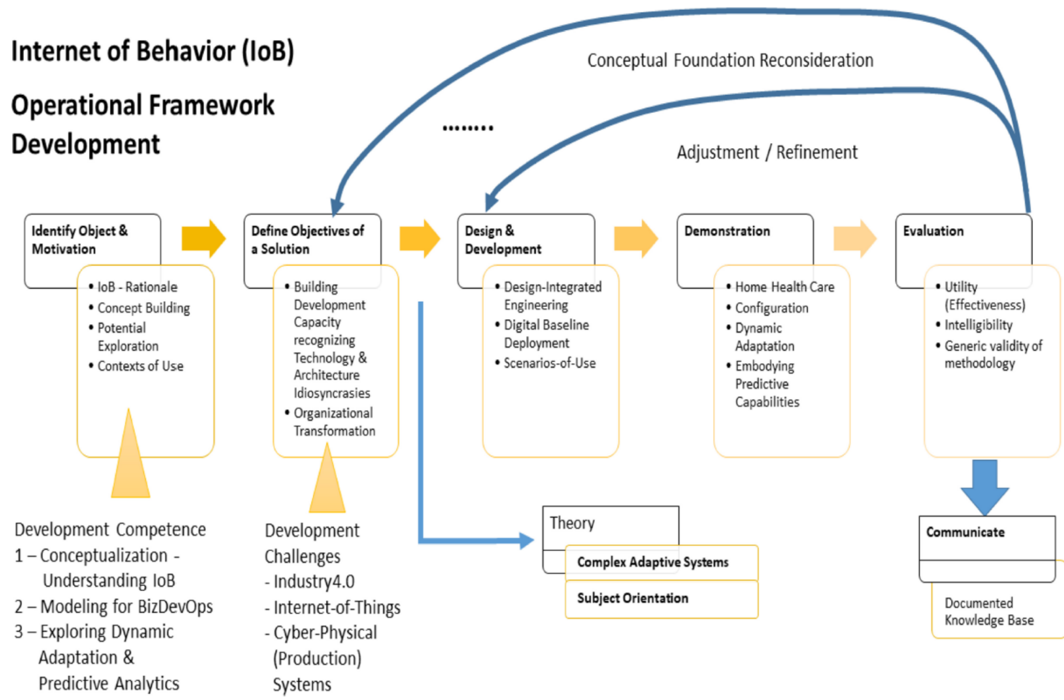


Figure 37 Design-science based approach to IoB implementation as transformation space (Stary, 2020, pp. 116)

4.1.1 IoB in the DT and CPS.

Now in the following table 2, it is mention which factors challenges could be minimized or eliminated for industries if they embrace the IoB or mention what is going to be able to bring as it is the next step of IoT. Beginning from the point that the IoB main focus is human conduct, industries need to implement this to assess the human side of their businesses primarily in order to enhance the working environment for their employees, and it can also provide corporations insight into how they interact with other business and the surrounding environment (communities, governments, nature, etc.).

Table 2 Benefits IoB could bring to CPS and DT.

IoB Benefits		
Human Factor:	Organization:	Work Process:
• Analyze and predict the Human-Machine Interaction . • Assess the stakeholders physical and mental health. • Provide evalutaion on the training methods and how to enhanced them. • Understand the customer needs form the business and how it interacts with the virtual enviroment.	• Facilitate the evalution in SWOT analysis, A/B testing among other similar techniques. • Possibility to spot weakness in how policies and rules that need to be either update or does not work anymore for the industry. • Observed and analyzed the cloud cross interaction with suppliers, customers and other entities.	• Assess the job in task and space where the candidate has to carry on the work, so companies could create an equiliabrated working space. • Evaluate the operators through the different stages and find what they might be lacking to complete or carry on their task.

As the IoB will exist in the virtual environment, DT and CPS must handle the information via human-machine interaction and the machine-machine interaction, and this last one is managed mainly through the IoT. However, an asset could be affected by the human interaction and is the human part that IoB could integrate to protect the operators and the business.

Imagine the following case a person who, for some reason, did not take breakfast because he/she wake up late. On the way home there is traffic due to the population or an accident and this lead for the employee to arrive late at work, now these operator is arriving with hunger, frustrated or even a bit angry due to the traffic jam add to this that he/she has to deal with the being late at the job. The main issue here is that if this employee is involved in a dangerous part of the working chain, the risk that he/she makes a mistake is higher than in a typical routine day for him/her.

Now the IoB could help track the employee's state of mind due to the connection to the virtual world if there was an accident on the road to work. Also, as people are connected to social media and other applications, it could lead the system to known by the preference on music or food what is the most likely state of mind of the person. For example, think on a typical routine day where nothing terrible or exciting happens everyone has the music choice for those days, also the food a person chooses, even outfit selected, the same happens in bad, or good days, every person is or has constructed this virtual representation of likes or dislikes based on our emotions or mental status. It could help the organizations to prepare ahead so the worker that is under stress or having a hard day might be observed by health and security supervisors at the minimum or provide him/her with the help necessary to avoid an unwanted situation, even a slight chance to move them that day to a task that would not be too dangerous for the human and the assets.

4.2 Network Structure Organization.

The virtual environment that companies are developing to implement a fully CPS encompasses customers, suppliers for hardware and software services, shareholders and stakeholders in place, and also across seas, governmental institutions (DelVecchio, 2020). The interaction in the cyber environment requires industries to adapt their organizational structure to one that can follow up the fast-changing environment of the digital world. For example, access to data allows stakeholders to make decisions on a more daily basis than previously, therefore a silo structure, where a decision was relegated to higher levels delaying the process or work to be done, might not be the best organizational structure for the digital transformation industries are going through (Cross, Parise, and Weiss, 2007) (Minnaar, 2017). Instead, an organizational structure that could deal with the new accessibility of information across the business and allows teams to be empowered comes with the network structure. The network structure is design to aid teams to be connected, share information, and communicate rapidly across the organization (Umar, 2019) (Hixon, 2020) (lumen learning, 2019). Figure 38 shows the contrast between a traditional structure and the network one, where been agile and adaptive is prioritize and allows to have a customer-centric approach (AMC, 2018) (Minnaar, 2017) (Umar, 2019) (Hixon, 2020).

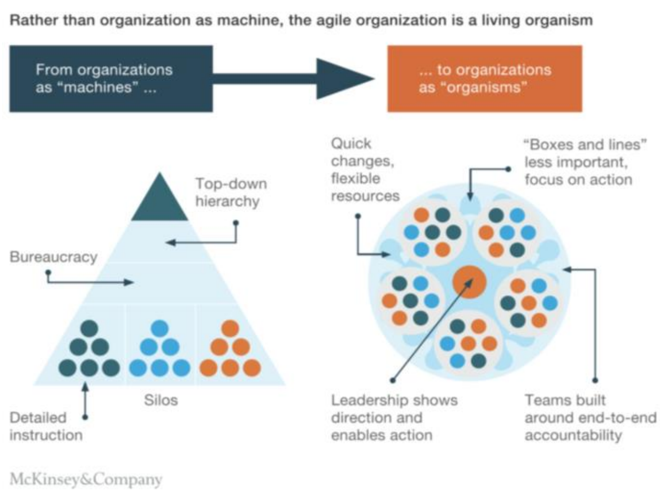


Figure 38 Traditional organization to Network organization (Umar, 2019)

Figure 39 shows how a network structure could look, where the industries are open to different sectors that work individually, sharing data among them in order to accomplish the primary objectives established by shareholders and the CEO (Williams, 2017).

Figure 39 Network Structure Organization (Williams, 2017)

Some of the main characteristics of the network structure organization are (Miller, Okamoto and Page, 2016) (Minnaar, 2017) (Hixon, 2020):

- Decentralization of the authority, teams have increased decision power and ability to work more freely.
- Customer approach similar to one of the main features of the cyber-physical systems, where the client is at the center.
- The employees could shift from one unit to another in order to share their knowledge and experience across the business.
- There has to be a core objective for the whole enterprise that aims to link the different groups, and now a team can almost freely decide how to carry on the task within the limitations of policies and rules.
- The groups have to be multidisciplinary to allow them to solve issues in creative ways and also make it the movement of teams or members in the business.

4.2.1 Network Structure in DT and CPS

Figure 40 shows the impact that network structure could have for industries using DT and building their CPS. Although the main impacts might be observed in the organization, work process, and human factors, the virtual environment is helping or forcing corporations to adopt this type of structural organization.

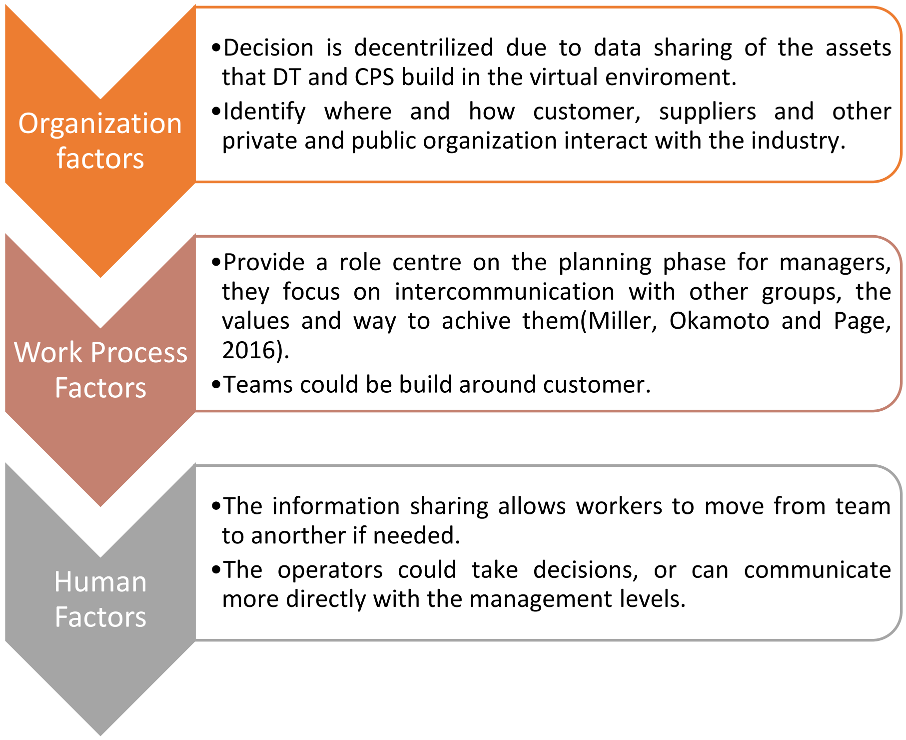


Figure 40 Possible benefits from Network Structure Organization

Industries adapting to these models would help them understand how the digital environment behaves and partially represent it. The main noticeable change is how managers are going to be perceived and what their new functions they must carry where employees would reach them more for counseling and know the status of projects. Also, managers are going to have the liberty to model groups within the companies policies but with enough freedom that it would aid teams to thrive in the face of challenges. And finally, the employees in the Network Organization are available to share their knowledge of the fieldwork and what could be improved for them to achieve the industry goals.

4.3 Cyber-Security Mesh.

Industries are not only losing billions of dollars due to cyberattacks (Smith, Lostri, and Lewis, 2020) (Riley, 2020) but also invest billions in cybersecurity (Columbus, 2020a) (Kovacs, 2021) (Columbus, 2020b) (Crawley, 2020). As industries have created networks protecting their offices, warehouses, and devices, the Covid-19 pandemic has exposed a new threat to business as employees were forced to work from their houses, and it has created new possible entry nodes in the virtual environment of organizations that could result in costly damages (STEFANINI, 2021b). A countermeasure on the rising is the cybersecurity mesh mentioned in Gartner's top trend technologies for 2021 (Burke, 2020). Due to being a recent term, there is no clear definition for it, but some authors coincide that the main feature is to build a secure area around a node that could be an asset or person (STEFANINI, 2021a) (STEFANINI, 2021b) (Solutions, 2020) (Townsend, 2021) (Ayers, 2021) (Mathiue, 2020).

Figure 41 shows what the cybersecurity mesh could bring for the systems and enterprises (STEFANINI, 2021b). In the image could be noticed that the main objective is to create minor access points that could be managed more easily by the IT security department of the organization, allowing them to fast track and isolated a node that is under attack or could be a threat for the whole cyber environment of the industry (Mathiue, 2020) (Ayers, 2021) (E-SPIN, 2021) (Rao, 2021).

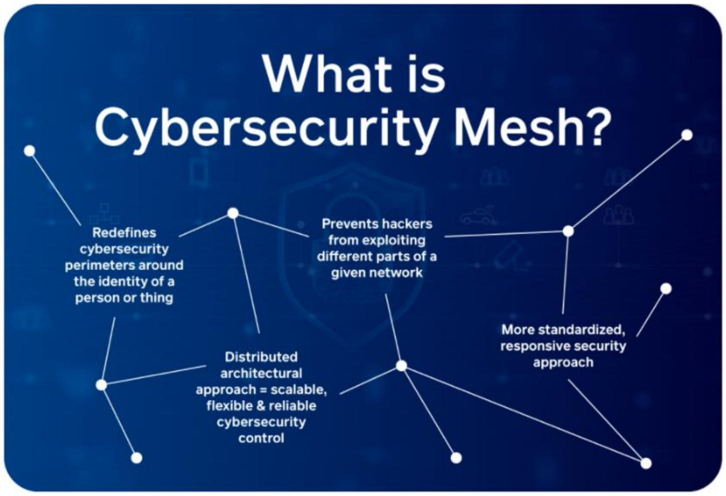


Figure 41 Cybersecurity Mesh (STEFANINI, 2021b)

Some advantages that the cybersecurity mesh might bring for the industries could be observed in figure 42 (STEFANINI, 2021b), the impact it could have on Identity Access Management (IAM), how it will help in the decentralization process that industries are embracing, and parameters to prove the identity of the users as well as to identify unauthorized users (STEFANINI, 2021b) (Townsend, 2021) (Rao, 2021).

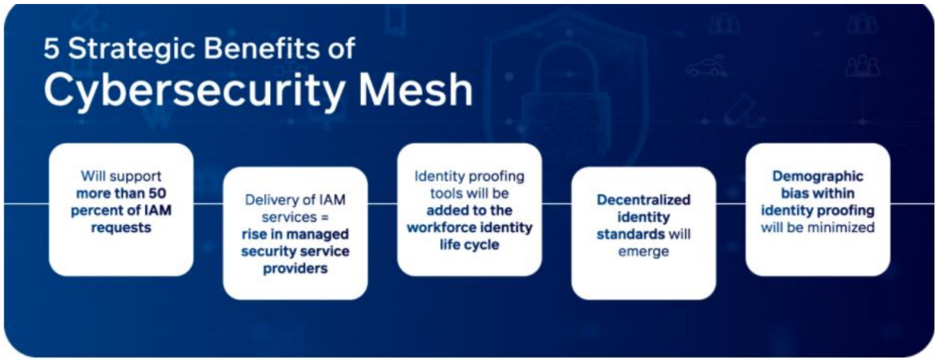


Figure 42 Strategic Benefits of Cybersecurity Mesh (STEFANINI, 2021b)

4.3.1 Cybersecurity Mesh in DT and CPS.

The following figure 43 observes the possible benefits that integrating the Cybersecurity Mesh could provide for the development of DT and CPS in the industries. The DT exists in the virtual environment, and one of the main issues concerns is how to protect it in the cyber world and from attacks in the physical environment that could tamper with the data collection and its physical twin. The CPS would benefit from these mainly for the decentralization to nodes that would protect entries instead of building a firewall over firewalls, allowing the IT department to know from where an attack is coming and avoid intruding into the cyber environment of the organization.

Technology Factor	Human Factor	Organization Factor	Work Process Factor
• Redesing of cybersecurity to protect users and assets located in remote areas. • IT security deparment could spot potential threats and isolate them. • Track users in the network of the organization system.	• Spot a employee that could be under threat of hacking. • Allows the worker to carry on taks in different locations. • Reduce the potential of human error by adding extra security.	• Helps organizatiopns to adopt the boundaryless approach. • Improve in policies for cybersecurity approach. • Gives more power control to the IT deparment to rapidly respond to a threat.	• Adds support to the employees to acces the organizatin network. • Everyone in the organization network can be identify suppliers, customers, employees, other business and govermental agencies.

Figure 43 Cybersecurity benefits for DT and CPS

Today industries are searching for the best cybersecurity model to let the companies resist and avoid monetary losses and tampering with their physical assets. Here, the Cybersecurity Mesh comes to aid the industries, as more work is done remotely from home or other places due to the Covid-19 pandemic taking industries and their employees unprepared for the threat that is working outside the protected environment were the offices. Now the IT departments have to work harder to keep the employees following the protocols to protect their data privacy, and the company one, this is done by the worker mostly unintentionally due that people tend to use passwords that are easily hacked, thus leaving an opening for a cyberthreat to the organization. Now the cybersecurity mesh comes to give the ability to the IT department to isolated the entry point from where the attack is coming and with this protecting the rest of the industry while the cybersecurity department tries to retake control over the hacked point.

4.4 Artificial Intelligence Engineering

The notion of artificial intelligence (AI) has been around since the late ’50s (Duggal, 2021). The evolution of computational systems has aided in the development and integration of AI systems in the industries. The main objective for AI is to have a machine capable of imitating the human way of thinking and learning but with the enhancements of carrying on more tasks within (Intelligent Project Solutions, 2020) (TECHSLANG, 2020) (Duggal, 2021), and also endure demanding conditions that a person is not able to or that is exposed to much time would endanger the life of the human. The most recent advances in AI systems could be observed by the smartphone assistants such as Alexa and Siri, among others, also the automatic response chats which implementation is increasing to help customers in web sites or even assist them with some technical problems, as well helping with the evolution of robots (Intelligent Project Solutions, 2020) (Duggal, 2021). Furthermore, the development of machine learning has aided to increase the capabilities of AI’s. Today the deep learning approach in which systems are capable of self-learning and perform more tasks is given a new extension to AI. Figure 44 shows a description of AI and how it encapsulates machine learning and deep learning to differentiate its capabilities (Intelligent Project Solutions, 2020).

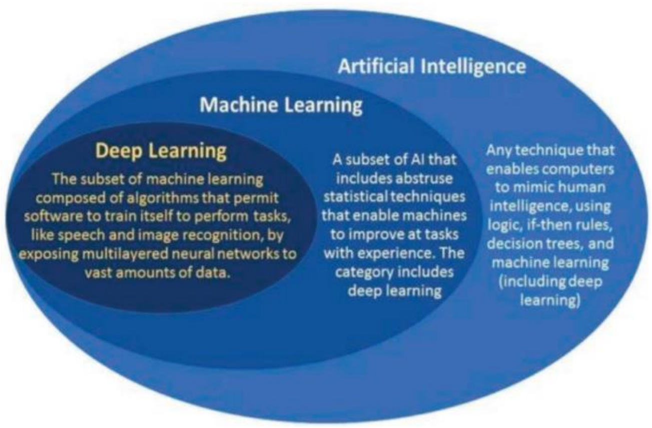


Figure 44 Artificial intelligence and its subsets: machine learning and deep learning (Intelligent Project Solutions, 2020)

The following figure 45 shows the most prominent fields and technologies in which AI is involved and their description (Intelligent Project Solutions, 2020). These four ones are the base for the next generation of machines that would interact without almost no need for human interaction or removed the human from the loop of the work process.

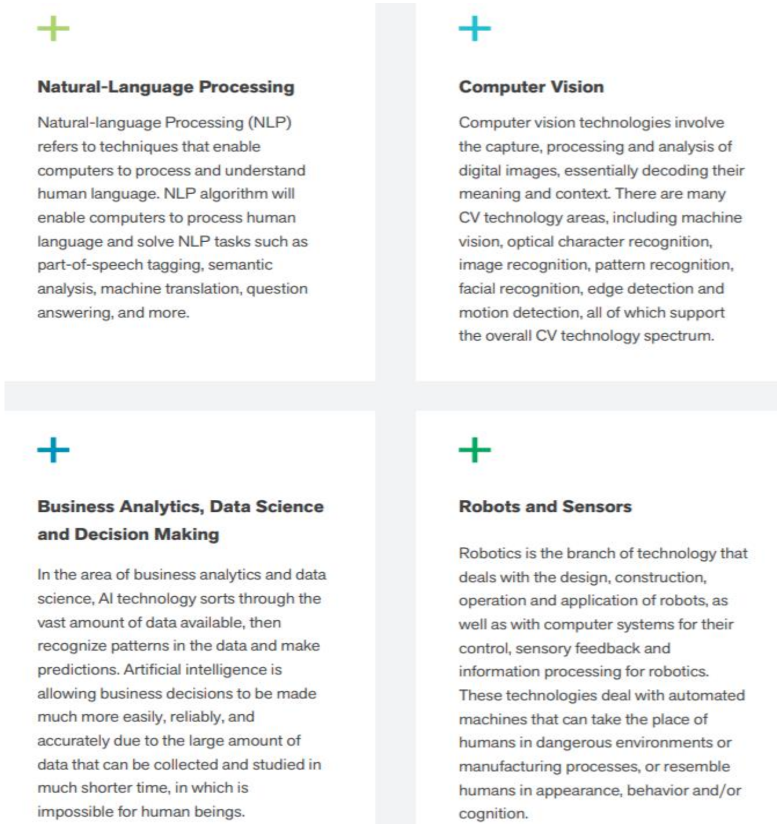


Figure 45 Key AI Technologies (Intelligent Project Solutions, 2020)

Moving in the AI developments, a new term or discipline is coming to light with the increased capabilities of the software and machines, that is AI Engineering which can be defined as *"the use of algorithms, computer programming, neural networks, and other technologies in the development of AI applications and techniques. These techniques and applications will typically have practical uses in commerce, science, and other aspects of life."* (Brown, 2020), and as *"an emergent discipline focused on developing tools, systems, and processes to enable the application of artificial intelligence in real-world contexts."* (Carnegie Mellon University, 2019).

In the paper "AI Engineering: 11 Foundational Practices" by (Horneman, Mellinger, and Ozkaya, 2019), there they present how industries can approach the implementation of AI Engineering by firstly addressing the need for it and to which processes, then they assess some points related to the development and the security of the system as well as the interaction of users, moving on the following points address how to update and adapt the AI for years, and finally the interaction of the AI software with changes on policies and the effects on the ethics, the following table 3 list the 11 foundations.

Table 3 AI Engineering 11 Foundational Practices (Horneman, Mellinger and Ozkaya, 2019)

AI Engineering: 11 Foundational Practices
1. Ensure the person has a problem that both can and should be solved by AI.
2. Include highly integrated subject matter experts, data scientists, and data architects in the software engineering teams.
3. Take data seriously to prevent it from consuming the project.
4. Choose algorithms based on what is needed for the model to do, not on their popularity.
5. Secure AI systems by applying highly integrated monitoring and mitigation strategies.
6. Define checkpoints to account for the potential needs of recovery, traceability, and decision justification.
7. Incorporate user experience and interaction to validate and evolve models and architecture constantly.
8. Design for the interpretation of the inherent ambiguity in the output.
9. Implement loosely coupled solutions that can be extended or replaced to adapt to ruthless and inevitable data, model changes, and algorithm innovations.
10. Commit sufficient time and expertise for constant and enduring change over the life of the system.
11. Treat ethics as both a software design consideration and a policy concern.

As well the Software Engineering Institute of the Carnegie Mellon University has implemented three central cores for AI engineering, which are (Carnegie Mellon University, 2019):

- Human-Centred AI.- The goal here is to know the users and how the AI will interact with them.
- Scalable AI.- Here is about the adaptability of an AI to aid in other systems.
- Robust and secure AI.- As with any cyber system, the concern on cybersecurity requires the AI to go in trials and updates so it can be utilized in the virtual environment.

4.4.1 AI Engineering in DT and CPS.

Now the DT is giving organizations the ability to recollect the data of a physical asset in real-time. Also, store it, and use it in mathematical modelings integrated into the systems to produce new information that can predict the future states of a physical asset. The operator would be able to prevent damages to the equipment or create practical calendars for maintenance, to establish precise parameters for production so the asset is not overwhelmed or poorly utilized, thinking on the function that the DT it could be fair to compare it with an AI system or be included as one type of AI.

The following figure 46 shows the possible benefits that AI engineering could bring to the DT and CPS. It focuses on three primary factors: the technological approach as integrating AI requires modifying, updating, or acquiring the hardware and software to implement the AI solutions. The next is on the human factor as the primary intention of AI is to imitate a person's way of thinking, and finally, the work process as the AI will affect the way tasks carry on and remove employees from dangerous work areas.

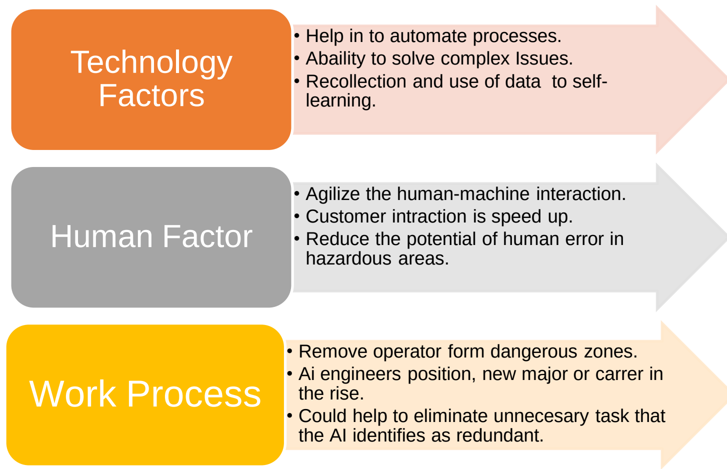


Figure 46 possible benefits that AI engineering could bring to the DT and CPS

AI is observed for many as something for the future without understanding that it is already in here. Therefore industries must know at which level they are implementing these technologies and how they can improve their use in their processes. Thus, they must begin to include AI engineers in their automation processes and prepare their employees to embrace it and reduce the fear of jobs that might be lost to the idea of the change of task carry on along with the responsibilities.

4.5 Hyperautomation

Gartner presents this term as one of the leading trend technologies for 2021 (Burke, 2020). However, it is not an exactly new approach for industries as the process of automation has existed before, and companies that are leaders in the digital transformation are ahead on the implementation of hyperautomation (Agrawal, Mehta and Ramakrishna, 2020) (YEC, 2020). Now on the hyperautomation in the Garnetr Top Trend technology Brochure (Burke, 2020, p.12) mentions, *“Hyperautomation is irreversible and inevitable. Everything that can and should be automated will be automated.”*

Hyperautomation is mainly the fusion of other technologies where the center is around the Robotic Process Automation (RPA) (YEC, 2020) (Agrawal, Mehta and Ramakrishna, 2020), which, as could be observed in figure 47 it adds technologies such as AI, Machine Learning (ML), Intelligent Business Management (IBPM).

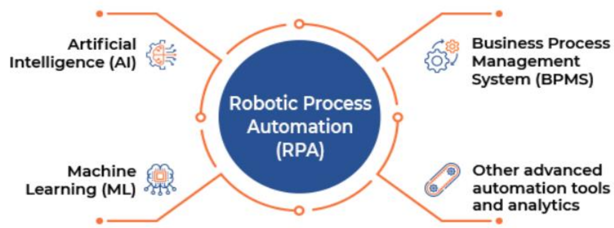


Figure 47 The core of Hyperautomation (Nividous, 2020)

Figure 48 shows a simple path from automation to hyperautomation (Nividous, 2020) (Hockenberger, 2020).

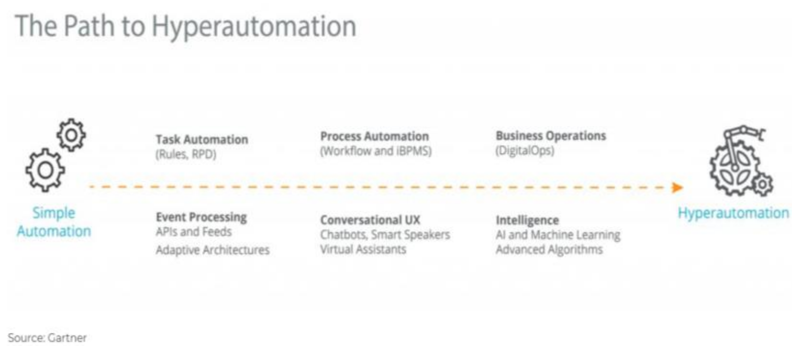


Figure 48 Path to Hyperautomation (Hockenberger, 2020)

In the paper "HyperautomationThe next frontier" from Deloitte by (Agrawal, Mehta, and Ramakrishna, 2020), they proposed how it would look the interaction on a hyperautomation process as could be observed in figure 49, where everything begins with the RPA and moves to Machine learning, AI and the chatbots, which use is increasing for customer service (Agrawal, Mehta and Ramakrishna, 2020, p. 11).

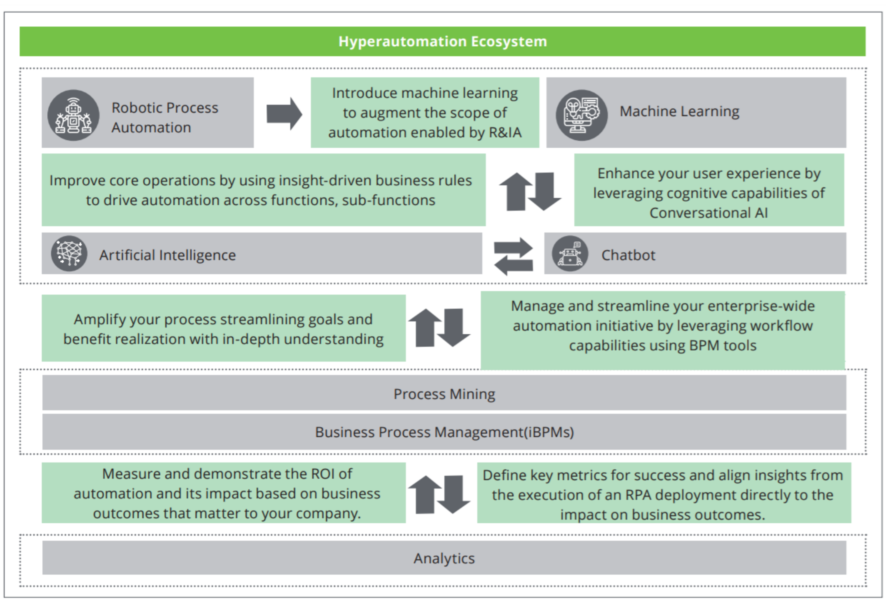


Figure 49 Hyperautomation Ecosystem (Agrawal, Mehta and Ramakrishna, 2020, p. 11)

4.5.1 Hyperautomation in the DT and CPS

The virtual environments are also developed the automation process increase in the physical environment. The same occurs in vice-versa as the automation of process occurs in the physical world, the cyber environment grows independent, as could be observed in figure 50, where the interaction of the human, the AI technologies, and the DT can be noticed as the automation increases in an organization (HILLERMANN, 2020).

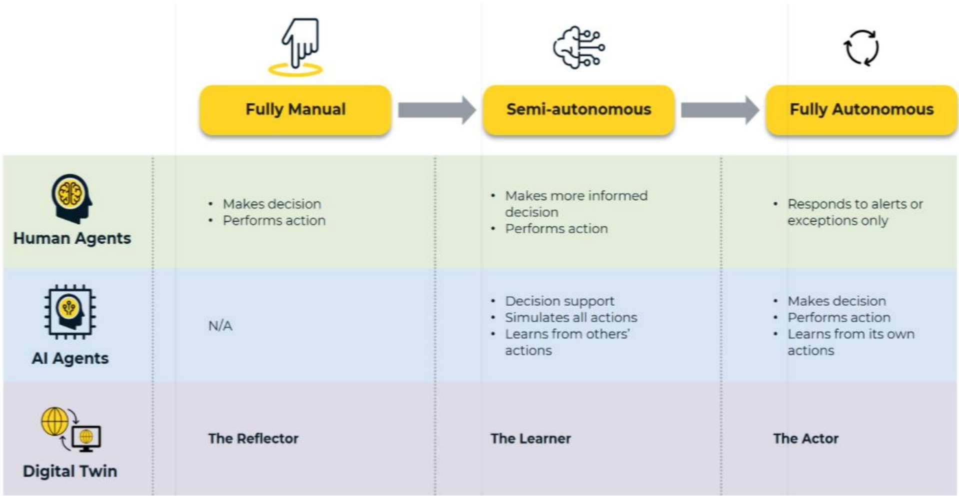


Figure 50 Digital twins at each stage of automation capability (HILLERMANN, 2020)

In figure 50, the DT is classified into three different modes (HILLERMANN, 2020):

- The Reflector.- is only the representation of the physical asset, where the primary function relies on data capturing in nearly real-time.
- The Learner.- here, the DT can use the data from the previous model or use knowledge domains to develop simulating models, which results in helping the machine learning so the systems could help in the decision affecting the physical twin.
- The Actor.- In this mode, the DT Learner gains the capability to act in the physical environment without the need for human interaction, and this requires an Ai system to have the ability of self-training with the machine learning and deep learning process.

The following figure 51 shows the positive impact that hyperautomation might have on the CPS and DT. According to what has been mentioned, hyperautomation could affect the factors of technology, organization, work process, and the human aspect, as it integrates many technologies for its development.

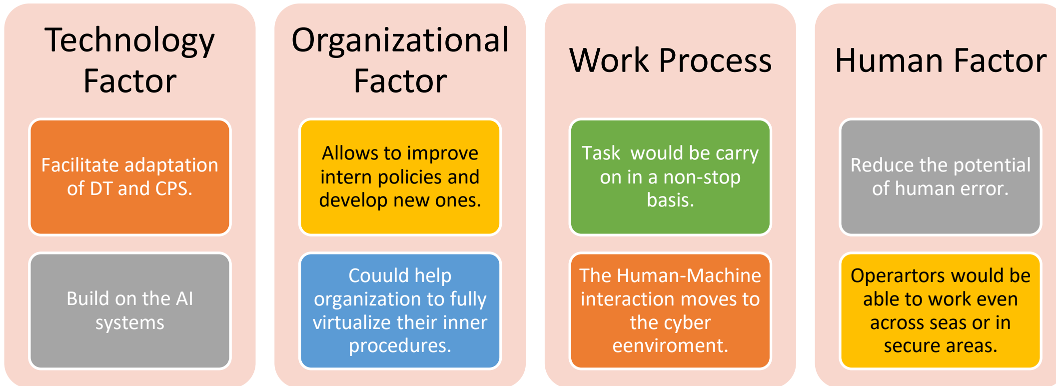


Figure 51 Possible benefits of Hyperautomation in DT and CPS

Hyperautomation is not something companies can avoid as they integrate more digital solutions such as DT and develop CPS towards connecting their process and enterprise levels at a global scale. The virtual environment is aiding companies to waste time and money in their process, and with this knowledge, industries are improving their processes to achieve a sustainable point, where environment and business economic growth can be achieved together. However, as mentioned in AI, many level base employees struggle to accept the change because industries force most of these changes instead of evaluating and learning how the organization can thrive in adopting new technologies and the skills that workers would require to evolve along with the industry.

Chapter 5: Discussion

5.1 Reflection of the project

The research began by addressing in concrete the topics related to the AM and the integration of the terminologies for the digital transformation, as there is still confusion among industries about what being digital means.

Then the project sets what defines a CPS and a DT and how they interact in the processes, where it outlines that the DT is aiding to close the gap between the cyber and the physical environment for the CPS. Furthermore, observing the building blocks is noticeable the similarities between both, what changes I the extension they covered as the DT is for one asset, in contrast, the CPS encompasses the industry at levels of ERP.

Afterward, examples of research on applications in construction, health, and energy sectors aim to understand where the DT uses stand, and it is noticed that construction due to the BIM models seems to have a bit more papers, but these models are previous implementations or base for the DT implementation as the BIM would be part one of the parts of DT. Then for the health sector, the motivation is to have a virtual twin of the patients in the near future to have a virtual twin of patients that would help them know about the person's health condition without the need for him/her to attend the hospital physically unless necessary. Finally, in what concerns the energy sector as oil companies swap from fossil fuels to renewables, they need to assess the condition of the current assets and has a virtual environment that can add the new assets that are being integrated along with the capability to control their pieces of equipment in distances that could go even to overseas, and in addition to this capability is the reduction of personnel in high-risk zones, and as well it is highly linked to the city development for the grid for electric distribution to the population, as cities have to cover their annual consumption and the future needs.

The findings on the papers for the applications help identify challenges that the author presents in a four-category division on an HTO and Work Process basis. Many of the issues found have strong relation towards cybersecurity, management, and the employee moving out of endangering areas of the processes. However, the main issues still concern the human side of industries even in these technologies that are trying to reduce the human interaction but still are designed by people, which imply that they would have an error in the inner programming of DT and CPS.

After the author in the projects comes with five recommendations and the solutions that could be brought once they integrate the DT and CPS from a perspective of HTO and Work Process, it can be related to some of the challenges found and how these recommendations tackle them. Furthermore, most recommendations are in the development phase except for the Network Organization, which is included as it is finally coming handful for the organizations to implement due to the development of a virtual environment.

Finally, as highlighting points, the authors enlist the following:

- There is a need for organizations to understand a DT, a CPS, and which elements composed them. For example, a 3D CAD model is just a component of both, but these do not carry any task as DT and CPS are capable.
- Adapting the DT and CPS industries must evaluate themselves, and this means they should know how mature is their management organization concerning innovation maturity.
- The development of a CPS and Dt requires companies to include the daily operators of the asset, as they will work with these cyber environments and their physical counterparts.
- The Pandemic Covid-19 has made organizations jump in the adoption of DT and increase their CPS regardless their organization is ready or not.
- DT must be considered a new tool to add in the AM for businesses seeking to gain the most value out of their physical assets.

5.2 Lessons Learned

One of the first findings during the research is the difference that exists in what digitalization means for the industries and the general public as there is confusion between digitization, digitalization, and digital transformation. Therefore, the research presents a simplified definition for each.

Moving in the research, the way to construct a CPS and DT that might seem similar, each encompasses different levels of the organizations in CPS point of view and the asset or product of DT that ends up feeding or enhancing the development of the CPS. Nevertheless, as reading on the applications is worth pointing out, the extent of the DT and CPS has aid industries during the Covid-19 to move their workforces from the offices to their homes.

Finally, to get to know what the future will bring in terms of technology and changes for organization and management, also it can be noticed how these trends interact even among them, to name the most obvious one is the Hyperautomation that relies on the advances of technologies in both the physical and cyber environment so that it could be developed.

5.3 Challenges

The main challenge has come in the how to approach the use of DT and CPS as many related disciplines and concepts are surrounding these technological trends, and as the author does not have a domain in the programming or construction of DT and CPS. Another challenge came with selecting the papers that could help identify the problems brought by the DT and CPS as many could be named but not all enter the HTO and Work Process approach. Finally, in the selection of trends, something similar happened as there is always new technology, but the increased restriction that some technology trends do not have much research works done on them apart from some principles or in what is the base technology that is going to build up from.

5.4 Future Work

From the author's perspective, this project could be the basis for research on how a DT goes from conception to maturity of its physical twin and its integration with the CPS. These would provide a more detailed image of how the developers and users confront the different issues that arise along with the integration of the DT. Another approach is to evaluate the recommendations proposed in this work and if they genuinely have a positive in the DT and CPS integration, and which risks are brought by these technological trends.

Chapter 6: Conclusion

The project's main aim was set to know what challenges are brought by the DT and CPS in the AM from the point of view of HTO and the Work Process. Despite there are many that could be added, the author considered the ones who seem to have a more significant impact on the DT and CPS integration, with that as base the recommendations were selected in order to tackle most of the challenges mentioned in this work and possibly some others that are not included.

As organizations adopt the DT and CPS to known the state of their assets and processes, industries require to know what type of digital solution they are aiming for in order to complement their AM strategies already in place and what it implies to bring the digital transformation to their business as there is a misconception on this term and the extends it covers.

Then in the atmosphere for the DT and CPS development to know the related terms to it have been fundamental to understand the basics on what are the DT and CPS, as they seem to be so similar due to their approach to connecting the physical and the virtual world but each has different implementations as the DT is focused primarily in a single device or asset, the CPS comes to observe a digital environment from ERP of the organizations, these means that in the base level it might be similar to the DT but as the industry overlooks on a broader point its processes the CPS begun to be composed of even various DT, so to allows having an intelligent service platform. However, on the other hand, the DT is attached to a singular asset or product that is the one feeding the virtual twin.

Moving on in the world of today, the industries implementing DT and CPS are many, thus focusing on the main such as Construction, Health, and Energy which is the basis for societies and have the need to provide faster, better servicer or products for their customer with the aim of the AM, where these industries seek to maximize the value of their physical asset.

In the end, there is a must for industries to integrate DT and CPS into their work environment, first to enhance their AM practices, on second to facilitate the change towards remote working and with that reduce the exposure of the workers in complex process or areas of the work. Finally, they would aid organizations to find points of optimization in their processes, which imply parts that could be automated and build resilience in their businesses.

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