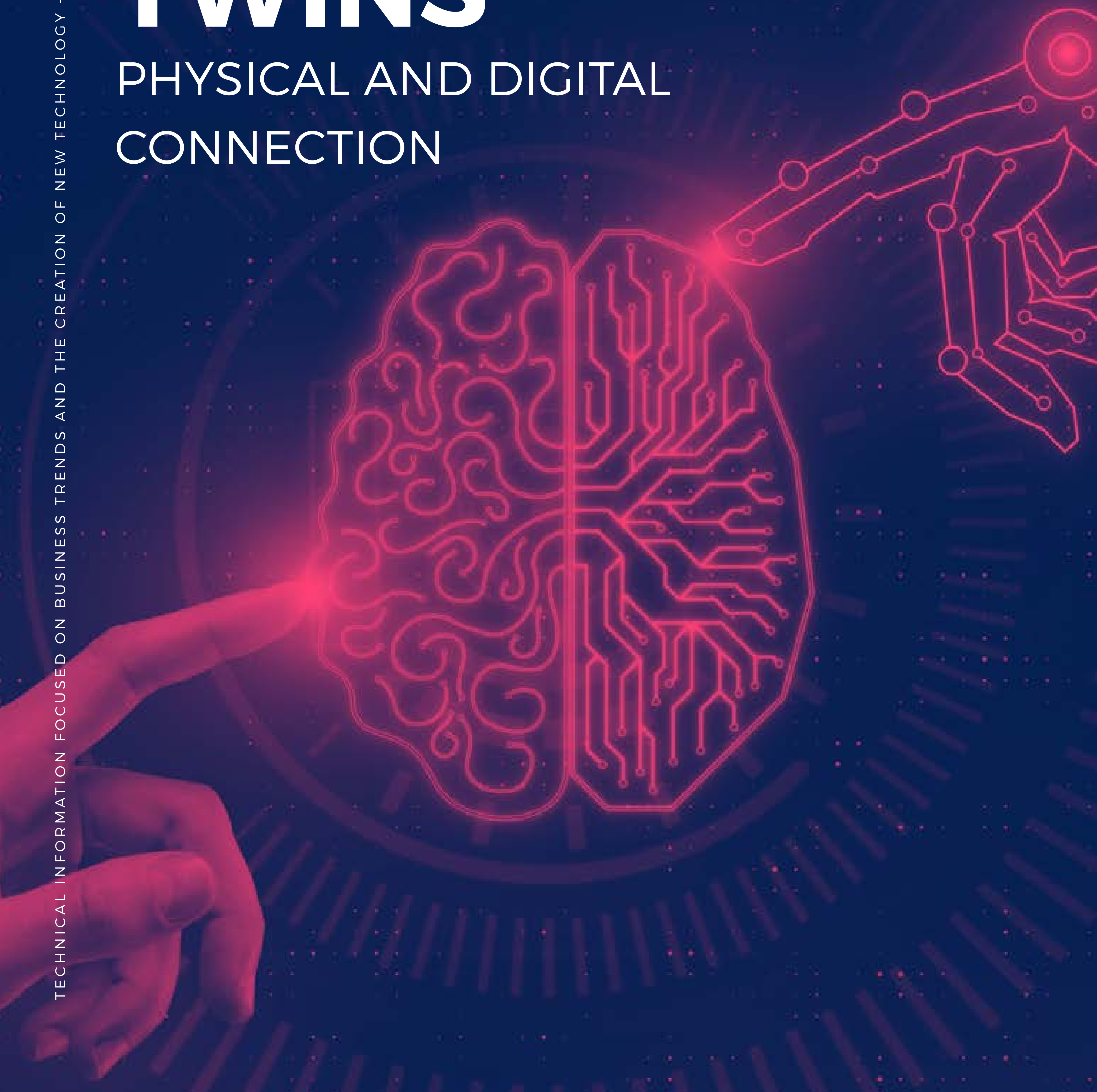
DIGITAL TWINS

PHYSICAL AND DIGITAL CONNECTION

TECHNICAL INFORMATION FOCUSED ON BUSINESS TRENDS AND THE CREATION OF NEW TECHNOLOGY - BASED COMPANIES



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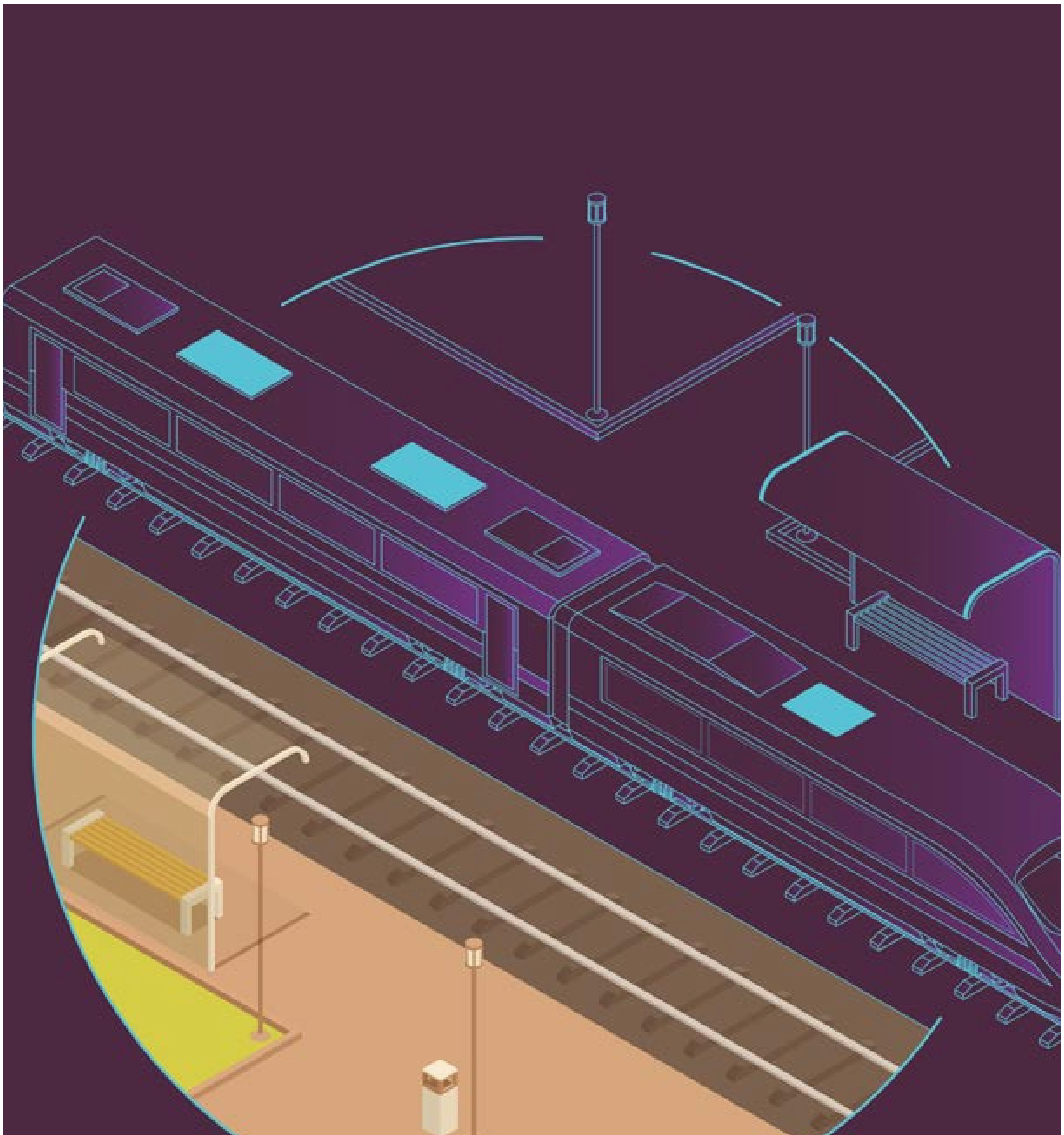


1. INTRODUCTION

Dig*ital Twins r*epresent one of the most promising technologies today and are one of the virtual processes for seamless cyber-physical integration. This technology allows you to "augment" the real world by creating virtual representations of physical entities.

Photo by macrovector on freepik

Keywords: Continuous learning, Cyber-Physical Integration, Digital Transition, Digital Twins, Forecasting problems, Improved maintenance, Industry 4.0, Real-time monitoring and optimization, Real-time simulation, Self-evolving systems.

1.1. What is a Digital Twin?

A Digital Twin (Digital Twin Consortium®, 2022) (Microsol Resources, 2021) is a virtual copy of an entity in the physical world that is updated in real-time. To make this possible, the physical entity is equipped with sensors that allow it to obtain various types of data in real-time, to update its Digital Twin, and allow various types of simulations. The results of these simulations may help to identify potential improvements that can later be applied to physical entities.

Fig. 1.1. Figure from SumitAwinash available at WIKIMEDIA COMMONS.

The model of a Digital Twin (DT), as initially presented by Dr. Michael Grives (Grieves & Thomas, 2015) is composed of three parts: a physical entity, a virtual entity and the connections between them.

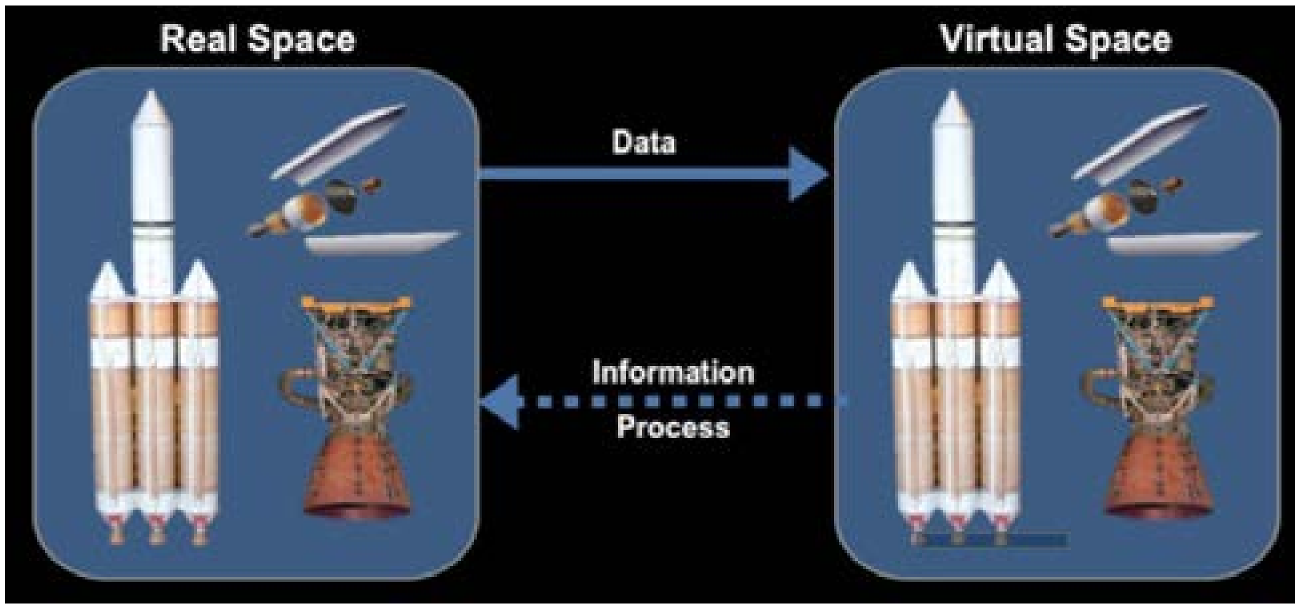


Fig. 1.2. Figure from Wilmjakob available at WIKIMEDIA COMMONS.

Due to the expansion of this technology to different areas and with the proliferation of the Internet of Things (IoT) there was a need to also expand the initial model. For this purpose, Tao et al. (2019) presented a model of five entities to include data and services (and the respective connections between these new entities), thus resulting in: physical entities, virtual entities, services, data and connections.

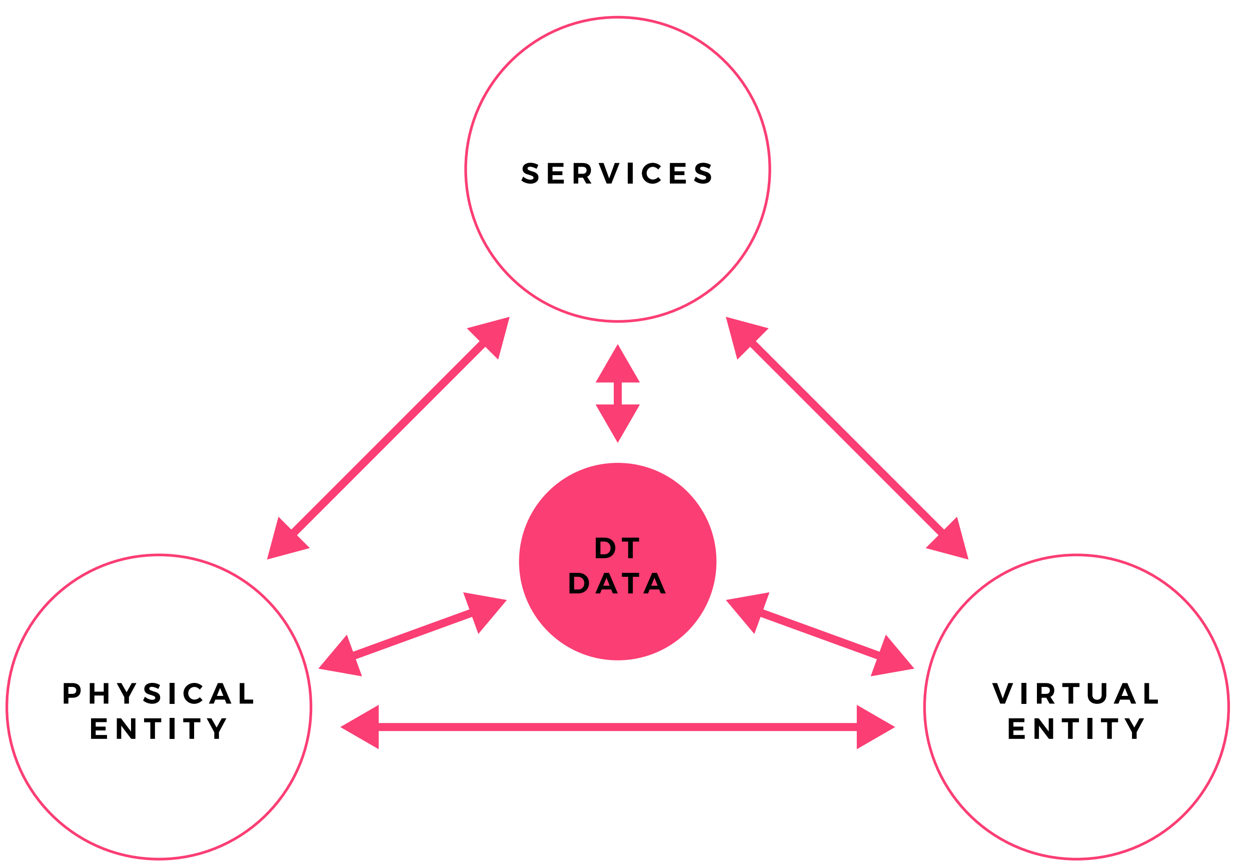


Fig. 1.3. Digital Twin of 5 entities, based on Tao et al. (2019).

Digital Twins digitally represent complex real environments, allowing them to be monitored and controlled in an innovative approach.

1.2. Advantages of Digital Twins

There are several advantages associated with Digital Twins (Siemens, 2019), represented in Fig. 1.4. Although some of the advantages are also present in other systems, the reality is that the use of Digital Twins makes them have an even greater impact on the DTs. An example of this is simulations, which are essential tools for training or even for decision-making. The simulations in the Digital Twins are even more relevant since they consider data obtained in real-time.

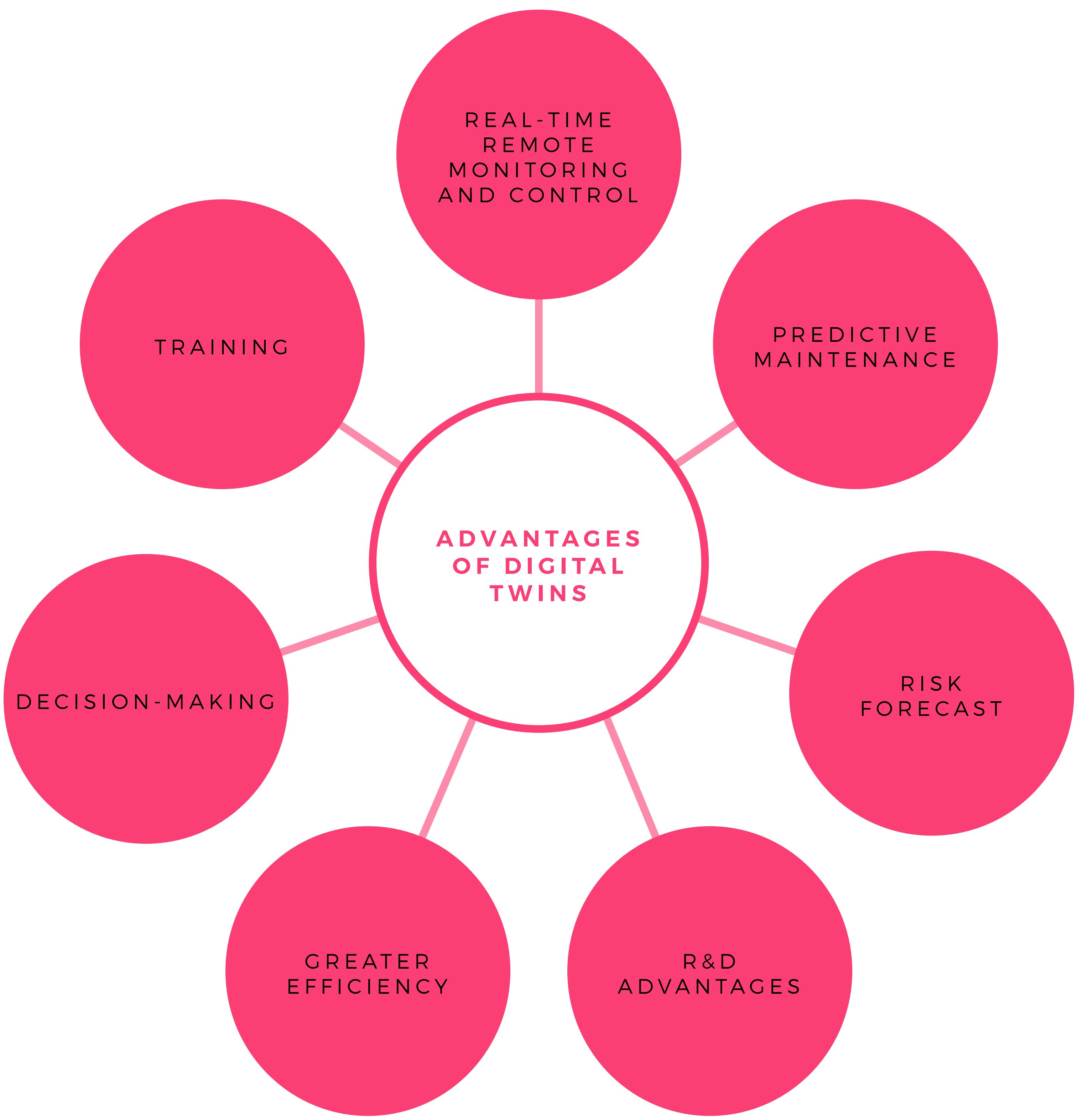


Fig. 1.4. Advantages of Digital Twins.

Thanks to the Internet of Things and the use of digital twins, it becomes possible to remotely monitor and control the various components of physical entities. This advantage is especially important, as it is often difficult to have a real-time global picture of a complex system. This feature also results in efficiency gains. Thus, it is possible to simplify these processes of monitoring and controlling complex systems with Digital Twins, which can be accessed from anywhere. In terms of Research and Development (R&D), the use of Digital Twins brings several advantages, since it allows several products to be tested even before starting their development, which in turn also helps in decision making.

The fact that the Digital Twins use Artificial Intelligence techniques and allow simulations to be run in real-time, also means that it is possible not only to forecast risks but also to carry out preventive maintenance, acting even before any problems in the system occur. Finally, Digital Twins can also be used for training, preventing potential damage from expensive equipment and ensuring greater safety.

1.3. The evolution of the Digital Twins

According to the literature, although Digital Twins have only recently played a more predominant role, their use dates back to the 1960s in NASA's aerospace missions.

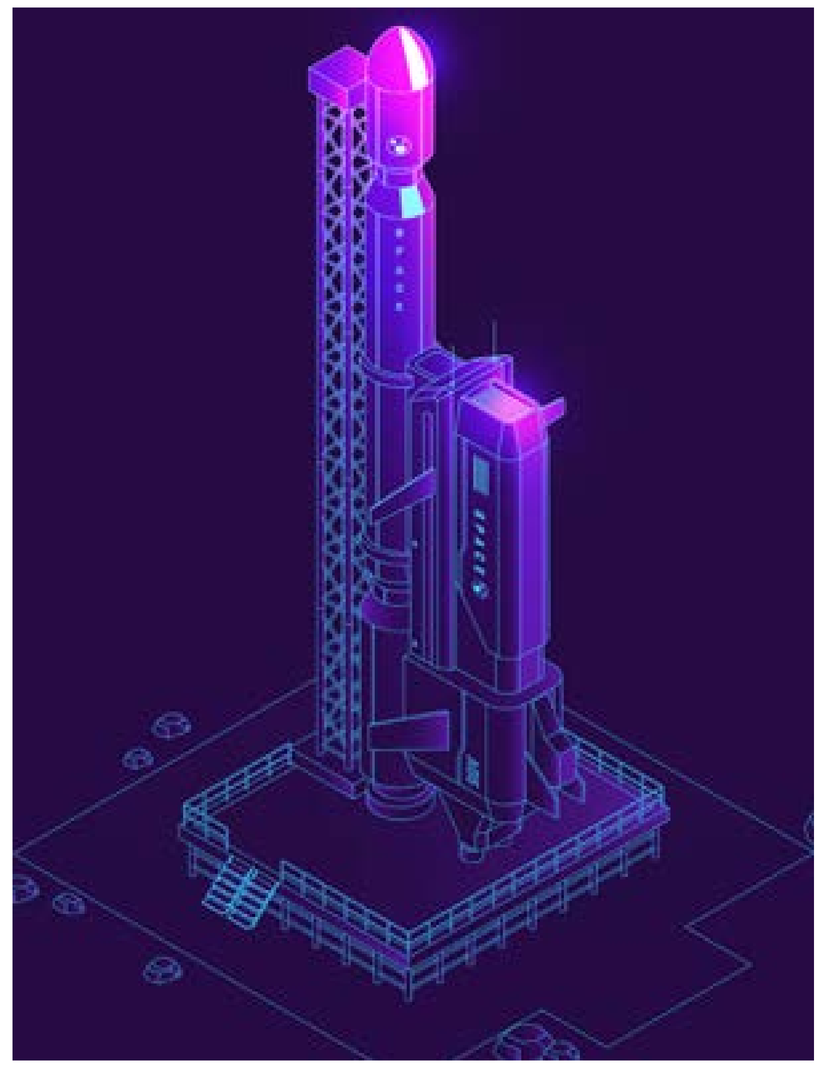


Fig. 1.5. Digital twin simulation technology isometric illustration (fonte: freepik.com).

There are, however, several other studies where his technology can be identified: in the book Mirror Worlds by David Gelernter (Gelernter, 1993); in the credit given to Dr. Michael Grieves for applying the concept to the manufacturing industry in 2002; in the definition of the term "digital twin" by NASA in 2010. Currently, the term Digital Twin is widespread and Digital Twins were identified in 2019 by Gartner (a consulting firm) as one of the "strategic technology top 10 trends for 2020" (Gartner, 2019).

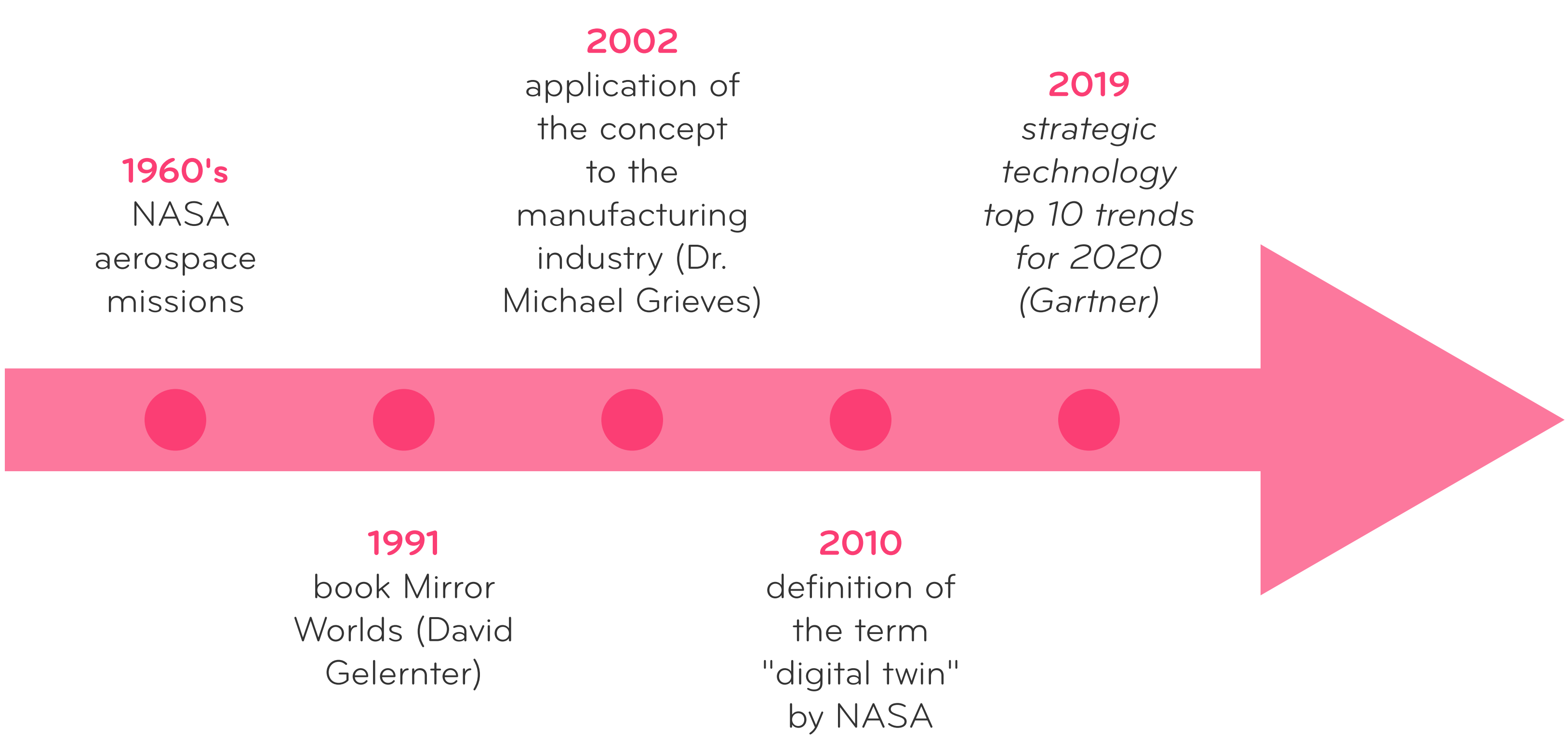


Fig. 1.6. The evolution of the Digital Twins.

Digital Twins currently have a significant impact on digital transformation and are one of the technologies of considerable relevance in Industry 4.0. Currently, in the industry, there is a huge dependence on the internet, electronic systems and devices, and technological advantages are a necessity for companies. It is in this context of transformation that the advantages of Digital Twins become more evident, allowing the virtualization of systems and improving their operation and performance. This brings enormous gains, not only economic but also in terms of improving process safety, reducing waste and optimizing resources, thus also contributing to reducing environmental impact.

Nowadays the Digital Twins are included in the digital strategies of several countries and even more globally, as is the example of Destination Earth (DestinE) (European Commission, 2021), which is part of the Green Deal (European Commission, 2022) and the European Commission's Digital Strategy (European Commission, 2022). This latest initiative aims to develop a high-precision digital model of the Earth to model, monitor and simulate natural phenomena and related human activities (European Commission, 2021). In DestinE, several Digital Twins will be used to allow access to data from constant observation and simulations that allow providing realistic forecasts to anticipate possible future scenarios (ex.: natural disasters, extreme weather events, among many others).

The rapid evolution of technology with increased computing power and learning capabilities, based on Artificial Intelligence, makes Digital Twins constantly evolving. Thus, these will have an increasing number of features and will allow us to obtain more and better predictions that can improve products and services, being increasingly present in our lives.

2. DIGITAL TWINS

Digital Twins represent physical world assets. They are dynamic digital entities that are up-to-date with their physical counterparts and allow for simulations using real-time data. They allow the digital representation of complex physical environments, efficiently allowing their monitoring and control, constituting a fundamental part of the digital transition.

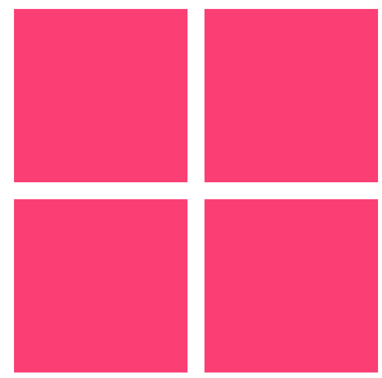
Photo by Steve Johnson on unsplash

2.1. Types of Digital Twins

Digital Twins can be classified into different types according to the level of integration: a) component twins/parts twins; b) asset twins; c) system/unit twins; and, d) process twins.

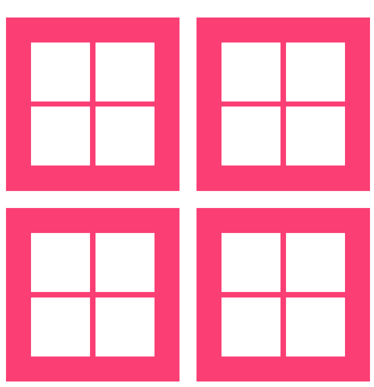
a) Component/part

The most basic part of a Digital Twin represents a single key component that has a direct impact on function or performance.
Example: a car engine.



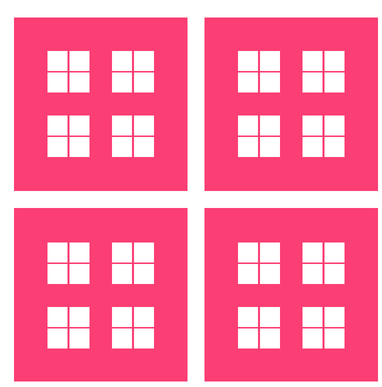
b) Asset

Asset corresponds to the next level of integration in which they can be made up of several components working together and functioning as a single entity. Another alternative is for the asset to receive information from various components.
Example: an automobile.



c) System/unit

At the next level of the hierarchy are the systems that aggregate various assets, revealing an entirely functional system.
Example: one of the phases of the production line, such as painting the chassis.



d) Process

Processes reveal how the various systems work together. Processes will only be effective if all components, assets and systems fulfil their purpose.
Example: the entire factory production line.

Fig. 2.1. Types of Digital Twins.

All levels of integration are important and it is necessary to go up and down through the different levels (as a kind of zoom) for the use of Digital Twins for monitoring and control to be effective.

2.2. The characteristics of Digital Twins

Digital Twins have several properties that characterize them and distinguish them from other technologies.

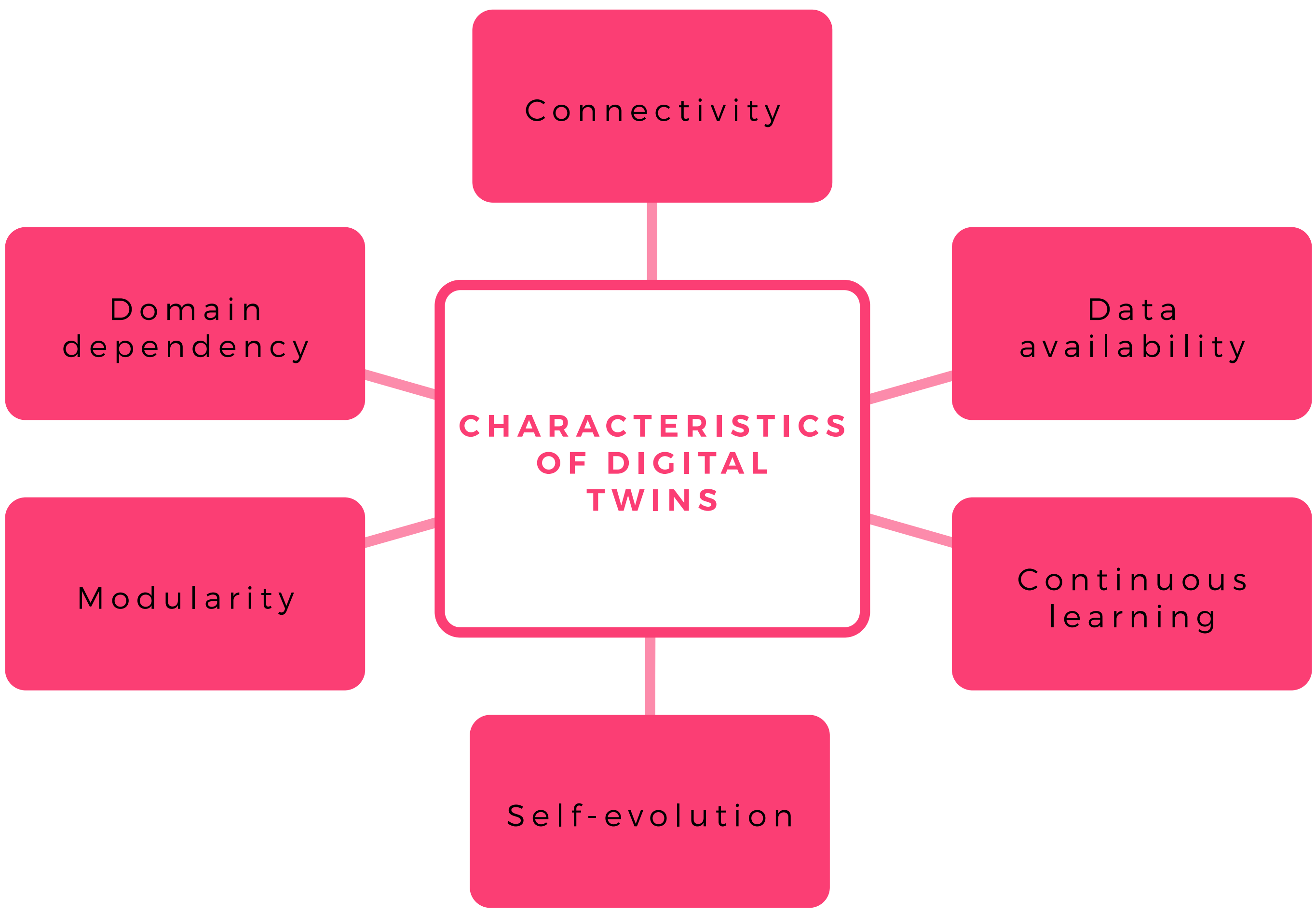


Fig. 2.2. Characteristics of Digital Twins.

One of these features is connectivity, which is possible through the use of IoT devices to make the connection between the physical entity and its Digital Twin. This connectivity ensures realtime data availability, which must be homogenized and dissociated from the physical entity so that they can be used in Digital Twins. This **data availability** must also be present at different moments in time, to have access to real-time data but also to previous data. In turn, the digital twins' capacity for **continuous learning**, made through machine learning techniques (a subarea of artificial intelligence that allows improving the functioning of machines through experience), allows them to self-evolve, reprogramming themselves automatically to improve the functioning and performance of physical entities. Another feature, modularity, is also essential for Digital Twins, allowing to optimize the systems more efficiently, analyzing the contribution of each module to the final performance and optimizing them (ex.: when verifying that a module does not contribute as it should, one could try to improve its operating parameters or even replace it). Finally, as the Digital Twins represent physical entities, there is a correspondence between the characteristics or services available in the physical entity and the DT (domain dependency).

2.3. How do Digital Twins work?

A Digital Twin obtains information through sensors placed in its physical component. This allows accessing data in real-time (present) allowing at all times to know the status of a certain machine or system. The obtained data can be stored in a database, thus obtaining a history (past). This data can in turn also be used as a source for machine learning algorithms to be used to make predictions or to make simulations (future), in real-time, thus anticipating possible problems or anomalies with a system. The result of these simulations can then be applied to physical entities to improve their functioning and performance.

PAST	PRESENT	FUTURE
• Data history • Database (ex: local, *cloud*)	• Data obtained from sensors • Real-time	• Machine learning • Simulations

Fig. 2.3. Features of Digital Twins.

2.4. Simulations vs. Digital Twins

Simulations have long been used for the most diverse purposes, which generally use past data and are often performed offline, however, Digital Twins are also based on data obtained in real-time.

Another difference between simulations and Digital Twins relates to the dimension to which they are applied. While simulations usually aim to study one process, Digital Twins aim to study several processes which are often related to each other. More than that, the Digital Twins also allow you to run an unlimited number of simulations.

Digital Twins also allow the results of the various simulations that run and their relationship with the real data to be used as input data for new simulations, iteratively improving their operation and performance, and contributing to greater systems efficiency. These characteristics of Digital Twins allow them to predict future states and act preventively before some anomalies happen.

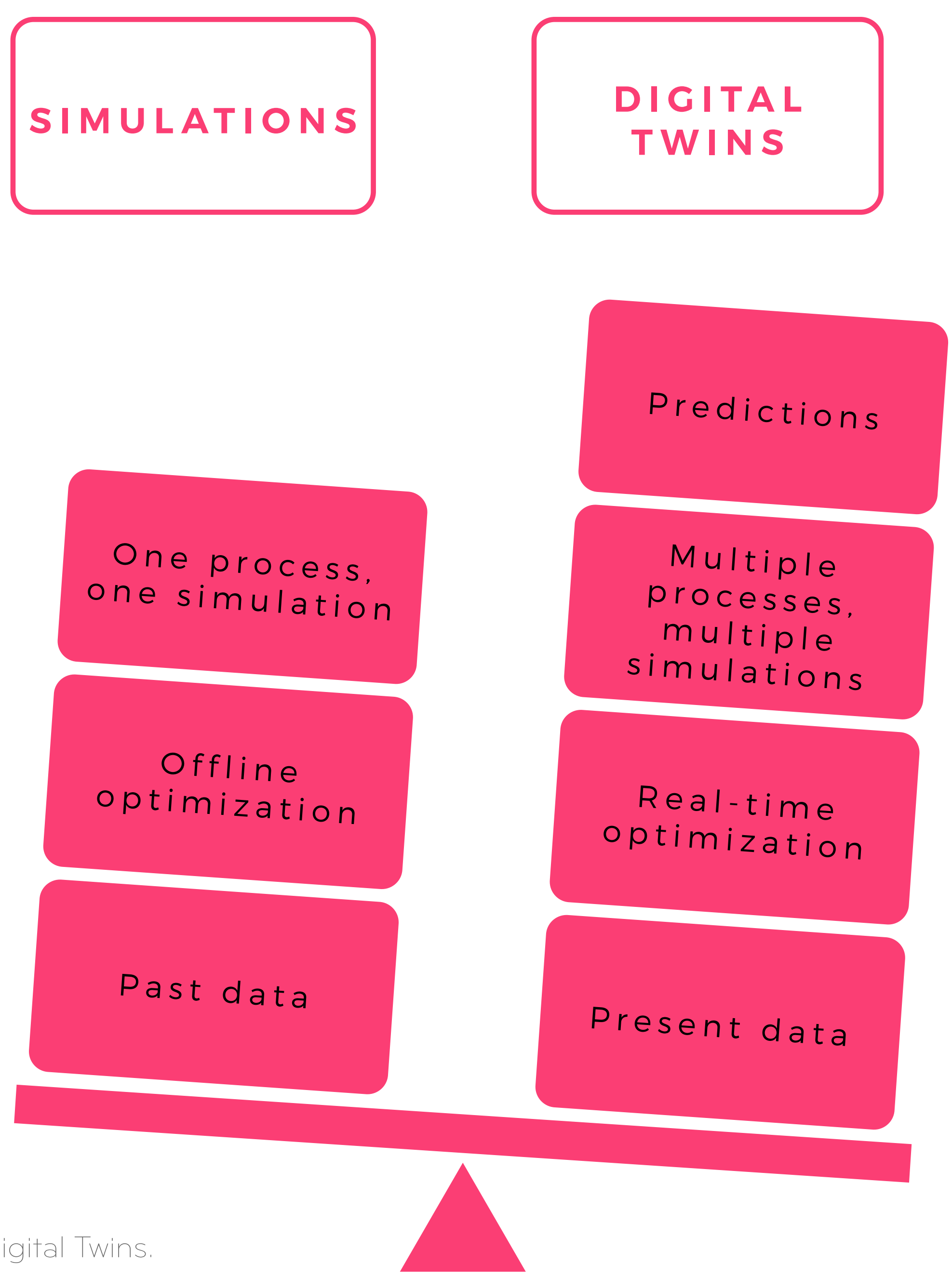


Fig. 2.4. Simulations vs. Digital Twins.

3. THE IMPACT OF *DIGITAL TWINS* ON ORGANIZATIONS

Digital T*wins in organ*izations is seen as a solution to improve production efficiency and visibility of how functions, processes, services, equipment, and the various operational and performance indicators can interact. It provides intelligent information continuously and in real-time. It thus allows organizations to adapt and improve their processes, creating future business opportunities and generating additional revenue.

Photo by [TheDigitalArtist] on [Pixabay]

3.1. Benefits of Digital Twins in Developing New Products

Digital Twins can be the virtual representation of processes or products. The various sensors introduced in the physical elements allow to perceive and predict the performance, presenting several performance indicators throughout the life cycle of the respective manufacturing process or the creation of a product. Using this information, the Digital Twin constantly develops and updates any changes to the physical twin throughout its lifecycle (Figure 3.1), giving technicians a complete and intelligent real-time view of production, allowing them to optimize processes and products (Mevea, 2018).

This situation is even more critical when companies create new products based on previous products or adapted to new scenarios, physical conditions, and other challenges.

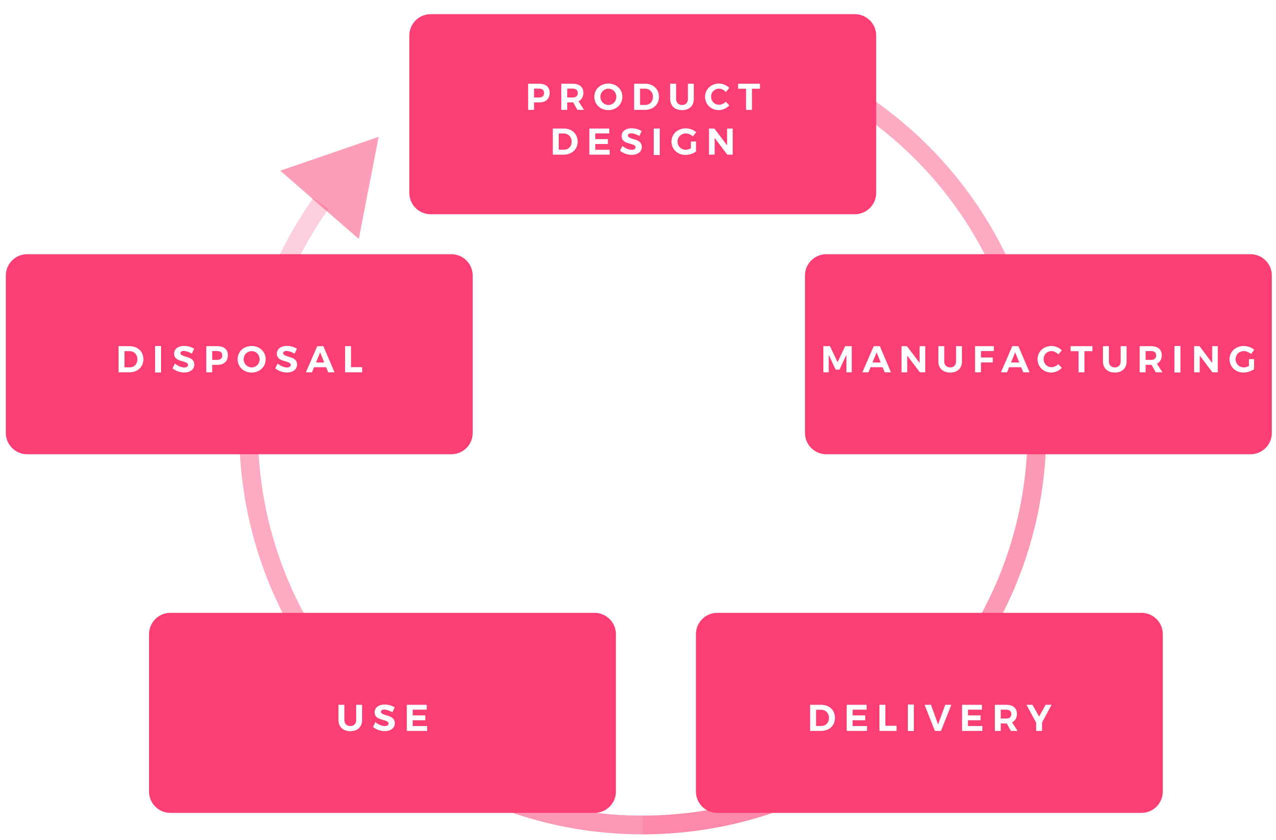


Fig. 3.1. Lifecycle of a physical and digital product

Using the same intelligent and predictive information, Digital Twins can guarantee the performance and quality of a "new" product without the need to create multiple scenarios and prototypes that consume time and resources, allowing for faster and more efficient responses to consumers and customers. With Digital Twins, entire systems of virtual prototypes can be simulated, tested, and tuned long before a real, physical prototype is built and tested, facilitating product design creation and innovation.

3.2. What are the benefits of using Digital Twins in Industry 4.0?

Industry 4.0 is the name of the most recent industrial revolution, in which manufacturing processes are being developed and controlled by digital and computerized systems and solutions. By developing a digital database, companies can present a complete record of their products in a digital format. "Digitization" possibilities the improvement of physical products through digital interfaces and innovative services. The massive introduction of Digital Twins systems in the various processes and future products may improve the technological development of Industry 4.0. (SAP Digital Supply Chain, 2020).

Because Digital Twins can have a constant digital representation of their real or physical products, it is possible to capture complete records from their conception/design, through its development and production, maintenance and end of life. Therefore, as mentioned in Lo study (Lo, 2021), Developing and using Digital Twins in the conception and design of a product will not only serve to optimize creative processes (i.e. aid in design decisions, maximize project performance, predict product features, etc.) but can be beneficial for future events (e.g. manufacturing planning, product quality monitoring, recycling management, etc.). At each of these stages in a product's lifecycle, the Digital Twin can empower industries with rapid problem-solving analysis, detection of defects, and prediction of a product's lifespan. These actions reduce costs and increase efficiency. Any task can be optimized using a Digital Twin. (Siemens, 2019).

A Digital Twin can help in advance and in a predictive way what are the challenges of adding an element or process in where the employees, machines, and structures are, and all industrial processes are carried out (factory floor). By using a Digital Twin to simulate various interconnected and related processes, companies can analyze the results of these simulations and create production methodologies that will remain efficient and productive, regardless of the existing heterogeneous conditions on the shop floor. This constant and detailed information on the equipment, captured by the various sensors installed, can also be used to prevent or anticipate the failures of the various components of industrial equipment, thus adjusting regular and preventive maintenance to ensure that there are no unexpected breakdowns in operation on production lines that are highly dependent on continuous processes, making them more efficient and productive, while reducing costs and work accidents. Simulations can be fulfilled to increase the level of technical knowledge of maintenance workers before their intervention. This simulation can be achieved with the help of Virtual Reality (VR) and Augmented Reality (AR) techniques, creating personalized training to increase the performance of the most challenging and complicated tasks. Thanks to the collaborative access facilitated by the Digital Twins, any new information collected during unscheduled or emergency corrective maintenance can be used to adjust and improve new or existing processes or products. This real-time update will serve as a basis for all products that share the same information, thus reducing other operational crises, emergency corrective maintenance, and increasing industrial production. The analysis of this shared information using advanced techniques of machine learning and artificial intelligence can guarantee the reduction of defects in machines that present greater wear on some components. As a result, companies can easily optimize and manage maintenance processes, while reducing the costs of replacement parts, and saving waste with defective products.

In the study by Wagner (Wagner, 2019), the authors state that the continuous connection between the Digital Twins is the key to success and achieving higher levels of progress and excellence in operational aspects to maintain industrial competitiveness.

Table 3.1 summarizes the main advantages of using Digital Twins in Industry 4.0. These advantages are evident in several categories. Increasing the quality and longevity of the products developed; improving the maintenance and performance of equipment and systems throughout their useful life; reducing costs in many cross-cutting areas of the industry, increasing worker safety, and improving customer satisfaction.

Table 3.1.Advantages of using digital twins in industry 4.0.

CATEGORY	BENEFITS
Quality	• Improved product quality; • Reduction of product defects caused by the wear of production machines. • More understanding of the processes that contribute to the long-term degradation of elements or products.
Operations	• Increases operational status awareness based on its adaptive Digital Twin; • Increases the performance by continually and dynamically adapting the devices, processes, and systems; • Extends the life of equipment; • Increase the technical knowledge of employees who perform maintenance through Digital Twins, VR, and AR.
Costs	• Reduction in the cost of emergency corrective maintenance; • Cost reduction in design and production of real prototypes; • Cost reduction for the creation of a new product; • Cost reduction in customer warranty services.
Safety	• Reduces the risk of personal accidents at work.
Warranty and customer satisfaction	• Provide real-time information about products, to enable quick and effective solutions; • Proactively and more accurately determine warranty issues and customer complaints; • Ability to identify products or equipment that need to be upgraded before the customer is aware of failures.

3.3. How Digital Twins can create new business opportunities

While Digital Twins have reduced efficiency and cost results in various industrial processes, the results are not immediate. Digitizing a business can be demanding, and the benefits of implementing Digital Twin solutions in existing industrial processes may be difficult in the short term (Wang, Lee, & Hsu , 2020). These benefits are even more invisible in the past when creating a Digital Twin was very expensive. However, with the evolution of digital storage systems, the reduction of computing costs, and the experience gained in other projects, the creation of Digital Twins has been increasing in several areas (industry, transport, construction, public services, health, and military).), creating several business opportunities (Tao, et al., 2018). Recent research suggests that the total market value for Digital twin systems was around US$3.1 billion in the year 2020, which is expected to increase to US$48.2 billion by the year 2026 (Leng, 2021).

Today, there are some recent companies such as Twaice (Twaice, 2019), and Cognata (Cognata, 2021), that are innovating in agriculture, automotive and smart cities using Digital Twins. Twaice uses Digital Twins to create the future of mobility, increasing battery life while reducing the costs of developing and testing new batteries. Cognata company uses Digital Twins to improve autonomous driving and simulation of advanced assistance systems for vehicle drivers. Gartner Research Vice President David Cearley says: "Over time, digital representations of virtually every aspect of our world will be dynamically interlinked with their real-world counterparts and with each other and infused with AI-based capabilities (AI) to enable advanced simulation, operation and analysis" (Panetta, 2017).

When considering the advantages that a Digital Twin offers, companies should focus on the performance and efficiency metrics that could be boosted by its creation, such as quality level, product guarantee, operational or manufacturing costs, problem identification and constant innovation (Deloitte, 2017). These metrics have the potential to impact a business. However, to take advantage of this potential, it is necessary to ensure that the Digital Twin is specific in its functions and objectives (Singh, 2021). As soon as the first objectives are reached, enthusiasm increases, and business opportunities arise based on the solid and advantageous experience already observed. Small and medium-sized companies should start with small prototypes that allow them to test solutions, refine them and calibrate all the processes involved in this digital transformation (Brossard, Chaigne, Corbo, Mühlreiter, & Stein, 2022). In addition, companies need to hire employees that know how to use the large-scale information expected and produced by a Digital Twin, as well as to purchase software and communications devices that fit Digital Twin's needs.

4. SOLUTIONS, TRENDS AND OPPORTUNITIES

At a time when the global market requires constant products and services' changing and updating, in an increasingly shorter period of time, companies have made a race to digitization and Digital Twins *in particular,* in order to maximize productivity and customer satisfaction, but also to have greater and finer control over processes, simulations and forecasts.

Photo by Josh Hild on Unsplash

The economy's globalization has brought multiple opportunities but also huge demands where productivity and competitiveness (Bom, 2019) are the main buzzwords. On the other hand, customers and consumers are more demanding than ever and are looking for experiences that exceed their expectations, even going as far as the awe phenomenon (Rodrigues, 2019). All the pressure created by these, and many other challenges has led companies and organizations to modernize themselves, through Digital Twins, to better understand, monitor and optimize the functions of the organization's physical entities, as well as the involved processes (El Saddik, 2018). In this way, companies and organizations have now an instantaneous and future view of their behavior with advantages in cost reduction, productivity, problems' anticipation, resources' optimization, among others. All this is now possible through the transmission of data between the physical and virtual worlds (Digital Twins).

4.1. Opportunities and use cases

Throughout history, the industry has gone through several phases, also called revolutions, from its mechanization in the mid-eighteenth century, through mass production, automation and today with the inclusion of technologies such as the Internet of Things, Artificial Intelligence, Big Data, Cloud and Cyber-Physical Systems.

It is in the last industrial revolution, the fourth, that Digital Twins appear, more specifically in the "Cyber" part of Cyber-physical systems and promise an enormous potential and benefit for all types of industries, even for those that, until now, seemed to have little affinity with digitalization and automation, as is the case of the construction industry (Kan, 2019). According to Kan et al., the Digital Twin concept (for masses) has existed since 2002 and was effectively used for the first time in the aeronautical industry. Since then, it has been adopted by other business sectors, such as agriculture, drilling for fluid extraction, industrial robotics, logistics and supply chain, product design, and many more, based on successful capabilities to support various use cases such as:

- Real-time monitoring;
- Service life prediction;
- Ensuring product reliability;;
- Quality optimization;
- Improved maintenance;
- Analytical capacity;
- Future performance prediction.

The capabilities offered by Digital Twins are common to most, if not all, business sectors, which suggests that they will bring enormous potential across the entire value chain, regardless of the target sector, in terms of process efficiency, quality, safety, costs and end consumer satisfaction.

4.2 Real applications

The Digital Twins concept, although still relatively recent, is now widespread across a large part of the market in different sectors of the economy, either through real commercial applications or through research projects. In this section some of these real cases are presented.

Aeronautics

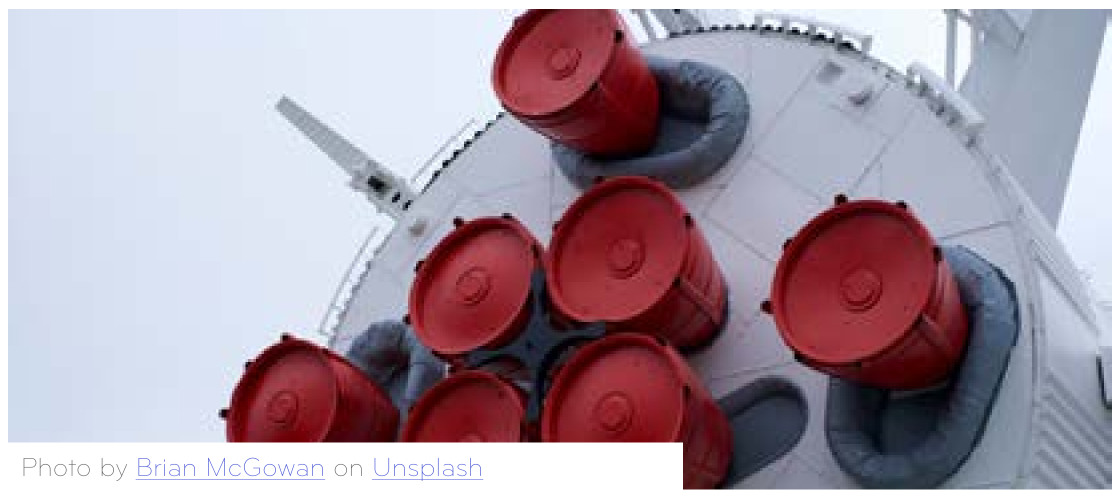


Photo by Brian McGowan on Unsplash

Fig. 4.1. Digital Twin of a jet engine.

The Digital Twins, since their appearance, have always played a leading role in this sector, from the Apollo 13 mission, where the simulator/Digital Twin on Earth helped to solve problems, to the most contemporary construction companies, such as Rolls Royce. This company from the aviation sector uses virtual replicas of its jet engines and through the inclusion of sensors in the real engines and satellite connections, the company is able to know, in real-time, the engine's behavior as well as predicting maintenance timetables. This information is crucial to reduce downtime and increase engine reliability.

Construction

Photo by Tom Chen on Unsplash

Fig. 4.2. Digital Twin of a set of buildings.

The Digital Built Britain Center is a partnership between the English Department of Business, Energy and Industrial Strategy (BEIS) and the University of Cambridge with a view to digitizing all built assets in order to find solutions for a better and more optimized use by citizens.

Wind farms

Photo by Appolinary Kalashnikova on Unsplash

Fig. 4.3. Digital Twin of a wind turbine.

The German company SAP, known for its business software solutions for operations and customer relationship management, offers Digital Twins for wind turbines. The solution allows intervention and maintenance prediction in addition to monitoring the state of the physical infrastructure. Furthermore, it is possible to perform simulations (for different wind angles) for energy production and to maximize the infrastructure useful life.

Supply chain

Photo by Tom Chen on Unsplash

Fig. 4.4. Digital Twin of a supply chain

The River Logic American company, which is dedicated to planning and decision support, presents several success stories, including one from a giant American snack company, with about 20 factories, more than 100 packaging lines and more than 200 distributors. This company was only responding to 90% of the orders for its most successful product. Among other benefits, River Logic's Digital Twins solution allowed savings of around $332,000 per week and the opportunity to handle more orders (now with enough stock).

Mobility

Photo by Obi - @pixel6propix on Unsplash

Fig. 4.5. Digital Twin of an electric car propulsion system.

The German company TWAICE uses Digital Twins to create solutions for customers relying on software with predictive analytics with artificial intelligence, to optimize the development and operation (performance over the years) of lithium-ion batteries.

Autonomous driving

Photo by Cognata on Cognata.com

Fig. 4.6 *Digital Twin* of an autonomous vehicle.

The Cognata company provides car simulation for the ADAS system (Advanced Driver Assistance System) and for autonomous vehicles based on Digital Twins.

Petrochemical industry

Photo by Emmaus Studio on Unsplash

Fig. 4.7. Digital Twin of a petrochemical plant

Royal Dutch Shell has, by 2024, the creation of a Digital Twin for its petrochemical complex in Singapore, with expected targets of a 25% increase in productivity, reliability, and safety, with a strong focus on anticipating potential problems before taking place.

Smart building

Photo by Microsoft on technologyrecord.com

Fig. 4.8 Microsoft creates *digital twin* in Singapure

Microsoft launched a project to create a Digital Twin for its subsidiary at Frasers Tower, in Singapore, where the main objective is to monitor and optimize energy consumption, noise, space, air conditioning and lighting.

These are just some real examples of the use of Digital Twins in different business sectors. As this concept can be applied throughout the product development cycle, and even during product usage, many more real cases will appear in the near future. For more details related to Digital Twins, we suggest the video "Siemens: AI and Digital Twins for Manufacturing (CxOTalk)" indicated in the reference (CXOTALK, 2019), with Dr. Norbert Gaus, responsible for research and development for the automation and digitalization areas at Siemens.

4.3. Future trends and expectations

The success resulting from the applicability of the Digital Twins concept in reputable multinational companies, such as Rolls Royce, often serves as a decision accelerator for many other companies. However, in an opinion article, PA Consulting (PA Consulting, 2022) reports complaints regarding the expected results in relation to Digital Twins. In this sense, PA Consulting warns that there are at least three critical success steps that companies must respect in order to take real advantage of Digital Twins, they are:

i) understand very well what the Digital Twins are and what they are not, as well as the capabilities they offer;

ii) identify and understand the problem to be solved with the Digital Twins and the related action plan;

iii) understand how far the Digital Twins can go.

Considering that the widespread application of Digital Twins is still in its infancy, an encouraging future is foreseen towards the maturity of the technology, but also in relation to new use forms. For example, the renowned Gartner recently pointed out the use of Digital Twins not only to solve specific problems, but to create the Digital Twin of a company, or group of companies as a whole (Marc Kerremans, 2021) governments (Finnerty, 2019) or even for the Earth planet itself (Stöcker, 2017). Lheureux et al. (Benoit Lheureux, 2020), also point out that Digital Twins and the IoT are the solution for the recovery and cost reduction of companies after the COVID-19 pandemic.

However, there are also warnings for best practices that CIOs should adopt to minimize the risk of failure concerning Digital Twins. Goasduff et al. (Goasduff, 2018) warn about some key challenges such as the use of good practices (documentation) in the construction and modification of the Digital Twins' support models. On the other hand, the process of adopting solutions based on Digital Twins must involve all sectors of the target company since, sooner or later, different ways and working models may appear which may bring a big impact on employee's community. The same authors also warn that the life of Digital Twins is many times longer than that of the entities that create them. Therefore, it is very important to adopt nonproprietary Digital Twin solutions based on international standards, with open source, etc.

Moreover, there are also risks and difficulties associated with the usage of Digital Twins. First, the complexity of the solution may be too expensive for certain companies. On the other hand, when a company is financially robust enough to adopt a Digital Twins-based solution, it also adopts certain types of associated problems. Royal HaskoningDHV Digital (Royal HaskoningDHV Digital, 2022), a company that specializes in leveraging data, warns about four major areas of concern:

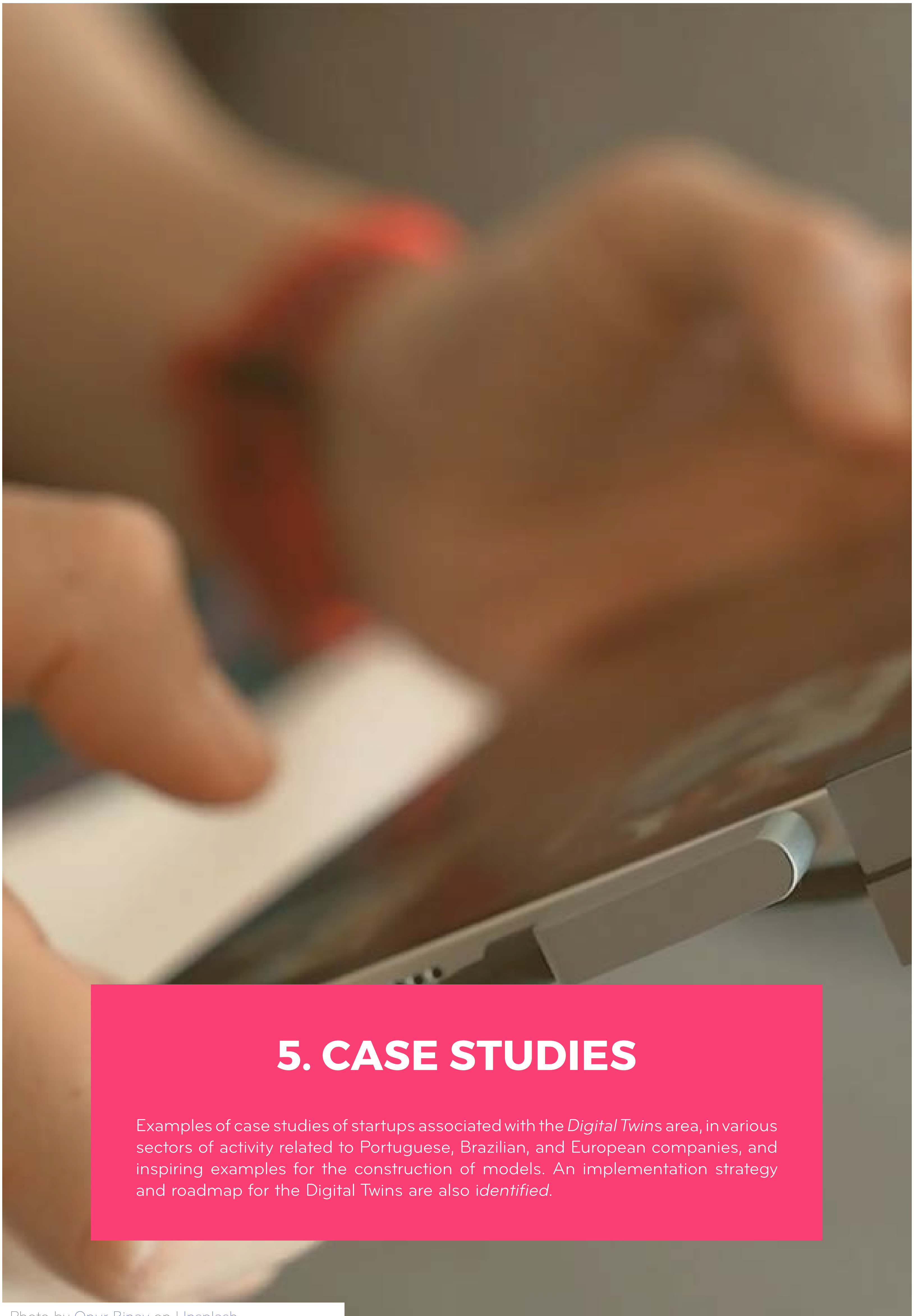
System access
If an outsider has access to the Digital Twin he or she may obtain important data as well as gain access and control of the associated physical object or infrastructure.

Theft of intellectual property
An outsider could gain access to the machines that support the execution of the Digital Twin and do reverse engineer in order to reproduce the Digital Twin to be sailed to competing companies.

Out of privacy regulation
Given that Digital Twins handle a large amount and variety of data, it is necessary to ensure compatibility with the current General Data Protection Regulation (GDPR), which in certain situations may be difficult to obtain.

Data integrity
Given, again, the Digital Twins' total reliance on data, the entire system of data acquisition, interpretation and processing should provide strong guarantees of data integrity (no accidental or purposeful modification).

All these concerns should not inhibit the expansion of Digital Twins. As has always been the case, when someone takes a technological step forward, there are always (new) concerns and latent threats. It is up to us, or those who depends on technology, to develop efforts to nullify or mitigate these types of threats.



5. CASE STUDIES

Examples of case studies of startups associated with the *Digital Twins* area, in various sectors of activity related to Portuguese, Brazilian, and European companies, and inspiring examples for the construction of models. An implementation strategy and roadmap for the Digital Twins are also i*dentified.*

Photo by Onur Binay on Unsplash

In this chapter, case studies of companies linked to the digital twins' area in the various sectors of activity are referred to and some inspiring examples are also shown for the construction of models and, on the other hand, an implementation strategy and roadmap for the digital twins.

5.1. Case studies of Portuguese companies

As an example, Altice is already developing solutions for industry 4.0-based digital twins that are suppoted by 5G communications. These solutions allow companies to model the entire factory in 3D and allow it to perform processing analysis and optimize processes to work in the physical dimension.

Virtual Twin, is a Portuguese company with a representation in Brazil, that develops several projects related to virtual visits in various environments (monuments, refrigeration industry e substation industry).

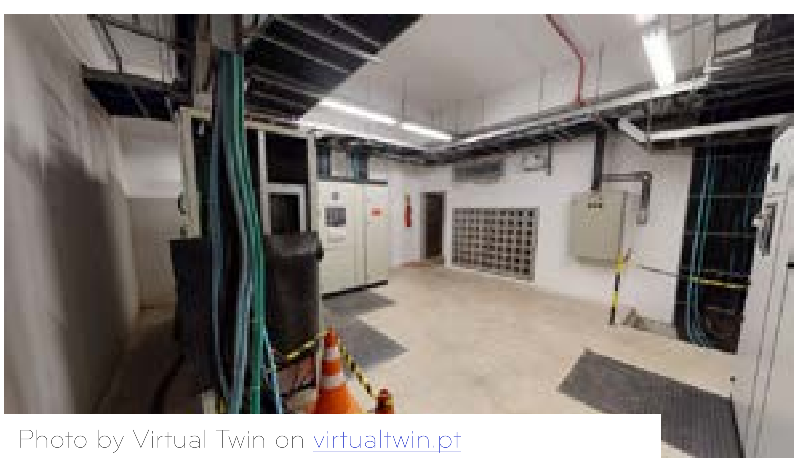


Photo by Virtual Twin on virtualtwin.pt

Aura Light Portugal has the Digital Twin City which is based on the construction of a virtual model of the city, supported by data collected at the moment by a great diversity of sensors. This virtual model permits to safely and in beforehand simulate various types of events, anticipating all the problems generated with it.

Photo by Aura Light Portugal on Facebook

Foundry (Foundry, 2022), with headquarters in Portugal (Porto) and a branch in Brazil (in São Paulo) represents an example of how Industry 4.0 is modeled with digital twins. This example is based on 3D scanning, modeling, interaction with equipment and workers, and production management through real-time monitoring and 3D optimization (often supported by virtual reality). Figure 5.1 presents the general diagram of Industry 4.0 with digital twins modeling.

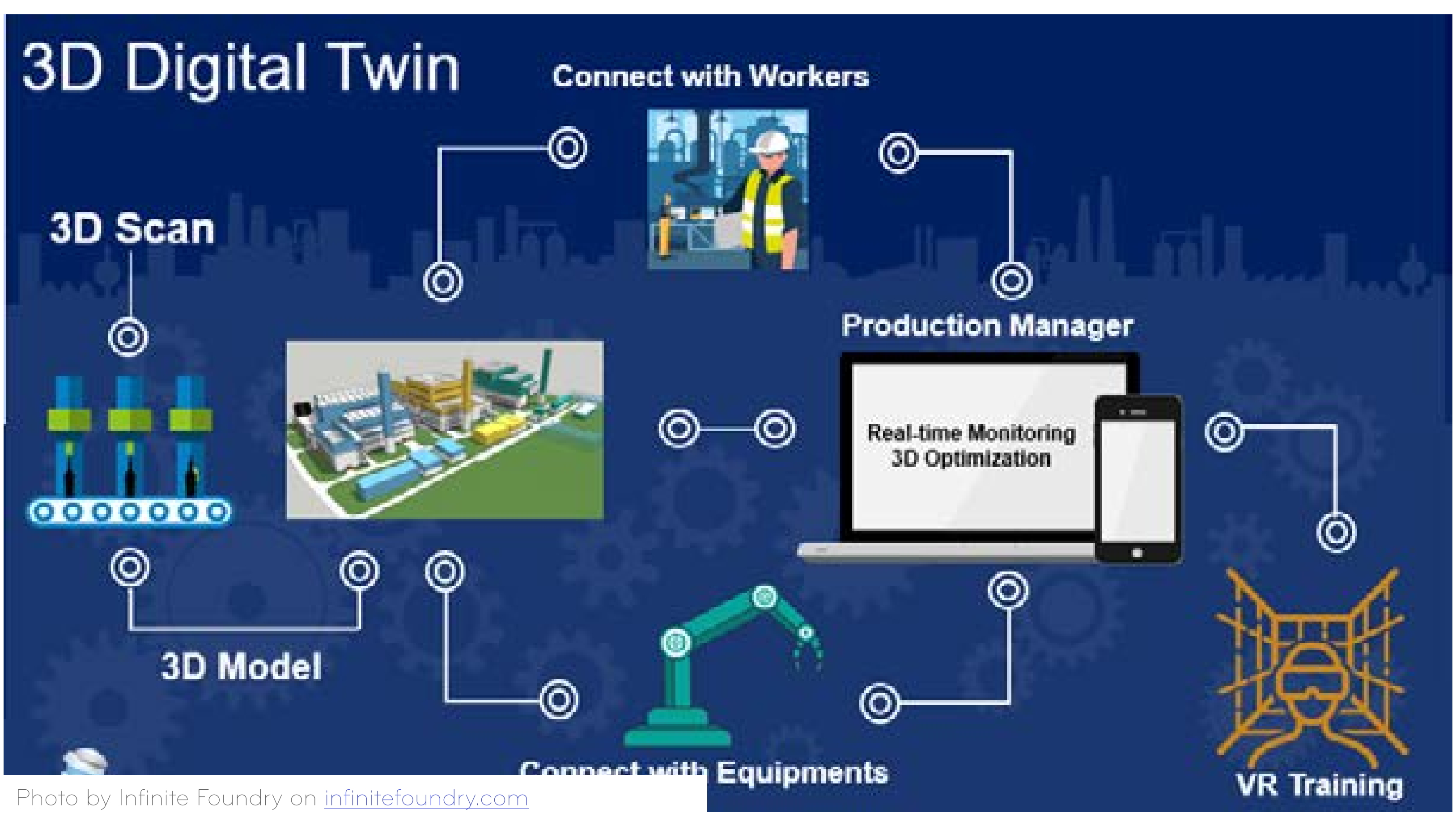


Photo by Infinite Foundry on infinitefoundry.com

Figure 5.1 Example of a general industry 4.0 diagram with the implementation *of digital twins*

The work developed by this company has 3 stages:

1. 3D Project Design

Where laser scanning is developed inside a part of the industry to have an accurate 3D model. This model includes architecture, furniture and structures, and production equipment (Figure 5.2).

Figure 5.2 3D model built through laser scanning

Photo by Infinite Foundry on infinitefoundry.com

2. 3D Production Monitoring

To monitor the production, the 3D model is connected to obtain the 3D animation of the manufacturing process in real time to allow an assessment of possible manufacturing problems (Figure 5.3).

Figure 5.3 3D model for production monitoring

Photo by Infinite Foundry on infinitefoundry.com

3. 3D Operational Optimization

Simulation of optimization scenarios to improve operational efficiency and the possibility of validating these scenarios through training that uses virtual reality for an efficient implementation (Figure 5.4)

Figure 5.4 3D model for operational optimization.

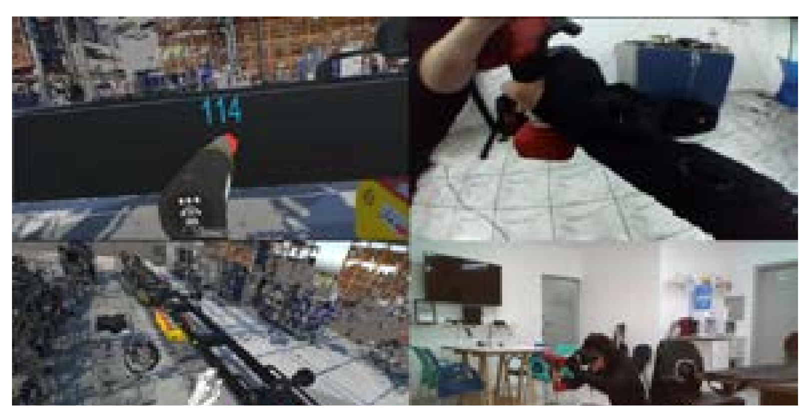


Photo by Infinite Foundry on infinitefoundry.com

Other optimization models can be consulted at (https://www.infinitefoundry.com/monitoring/).

Cosmotech is a company that has digital twins solutions for the industry. For further details, a webinar on the potential of digital twins is presented by the company Cosmotech.

Another example in the energy field is applied by AT&S, where the potential of using digital twins is shown. In the field of the automotive industry, the application at Renault also makes it possible to maximize the financial return on production. Cosmotech is a memberof the digital twin consortium. This consortium has a very interesting glossary on the subject and can be consulted at https://www.digitaltwinconsortium.org/glossary/glossary.html#aggregation. Also some initiatives of this consortium can be acessed.

5.2. Case studies of international companies

Internationally the bug 5 companies that are at the top of the development of solutions for digital twins are:

GE Digital

GE Digital offers digital twin asset, network and process solutions for aviation, oil and gas, power generation, electrical grids and manufacturing operations. GE Digital's software uses machine learning and advanced analytics to monitor large amounts of industrial data (in real time), e.g., from HMI/SCADA systems, time series, alarms, events, and other data obtained from sensors in the environment. IoT.

GE Digital has a set of documentation and video that allows to learn the fundamentals of how digital twins models should be built, scaling their execution across assets and systems to create a digital twin, and discover the best practices on how to gain value from these digital twins, in order to predict the performance degradation of physical systems and to improve the reliability of the whole system.

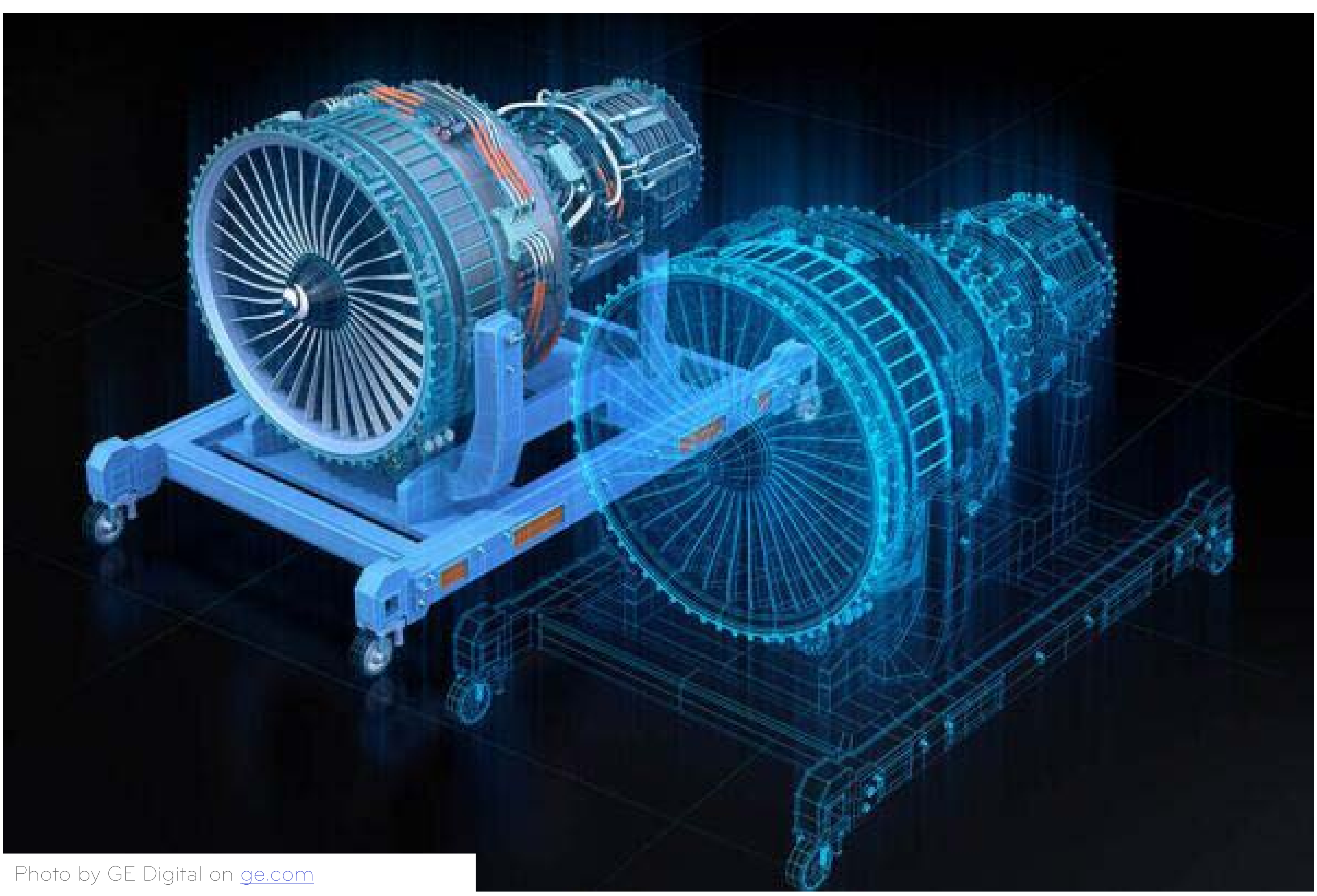


Photo by GE Digital on ge.com

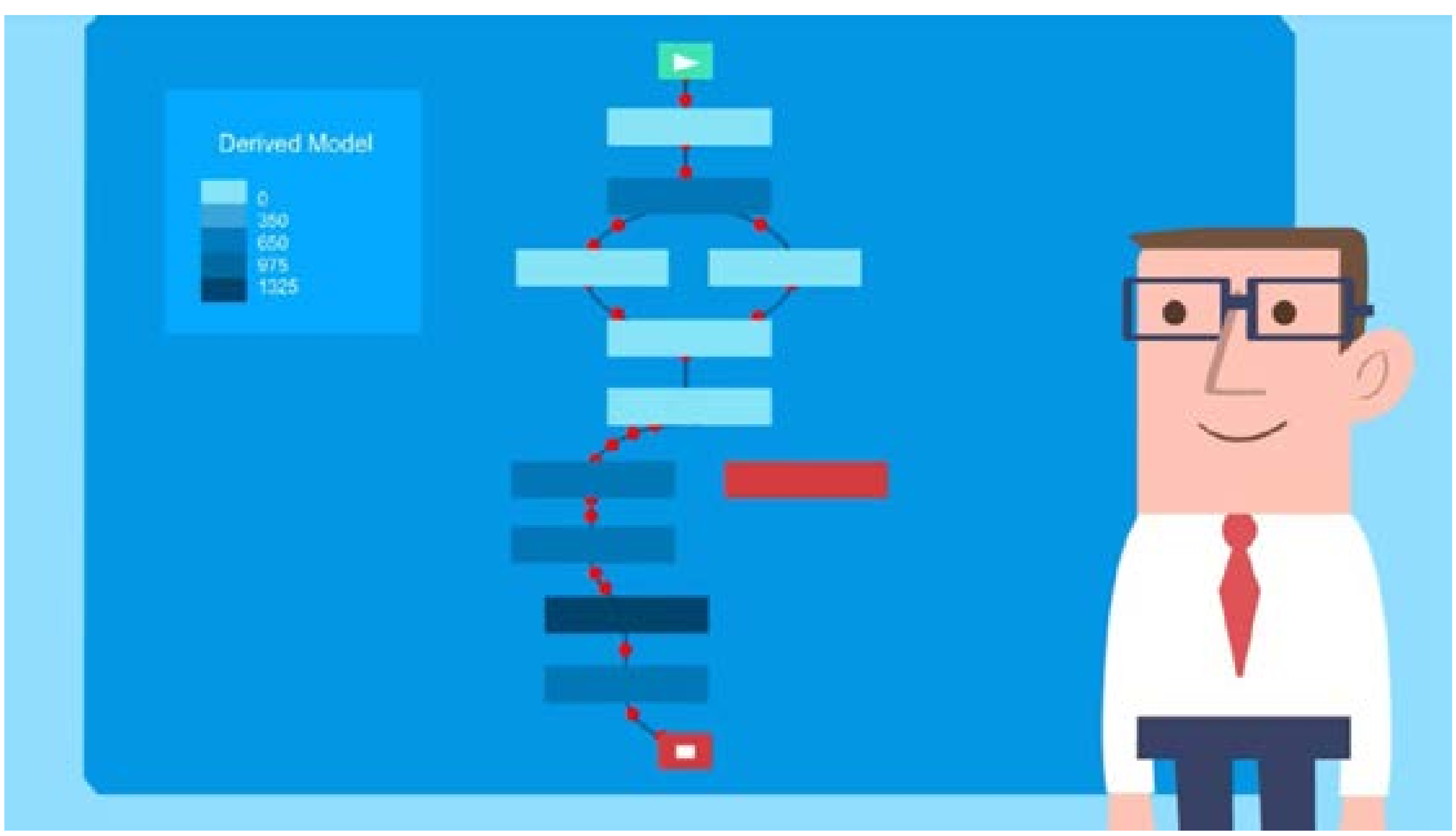
IBM

IBM offers several products, including IBM Digital Twins Exchange, IBM Systems Engineering Design and a suite of IBM applications. IBM technologies are used in automobile manufacturing, aircraft production, carriage design, civil construction, general manufacturing, engineering and power utilities, among others.

An example of a digital twin product used by IBM is the myInvenio (Process Mining) which helps to discover and analyze a company's processes in the real world.

Photo by IBM on ibm.com

Photo by IBM on ibm.com



Available on Youtube

MICROSOFT

Microsoft Corporation offers the Azure Digital Twin, with a state-of-the-art IoT solution that helps to create digital representations of corporate processes, places, buildings, agriculture, people, etc. It also contributes to the development of solutions to optimize operations and costs with forecast events at an industrial level.

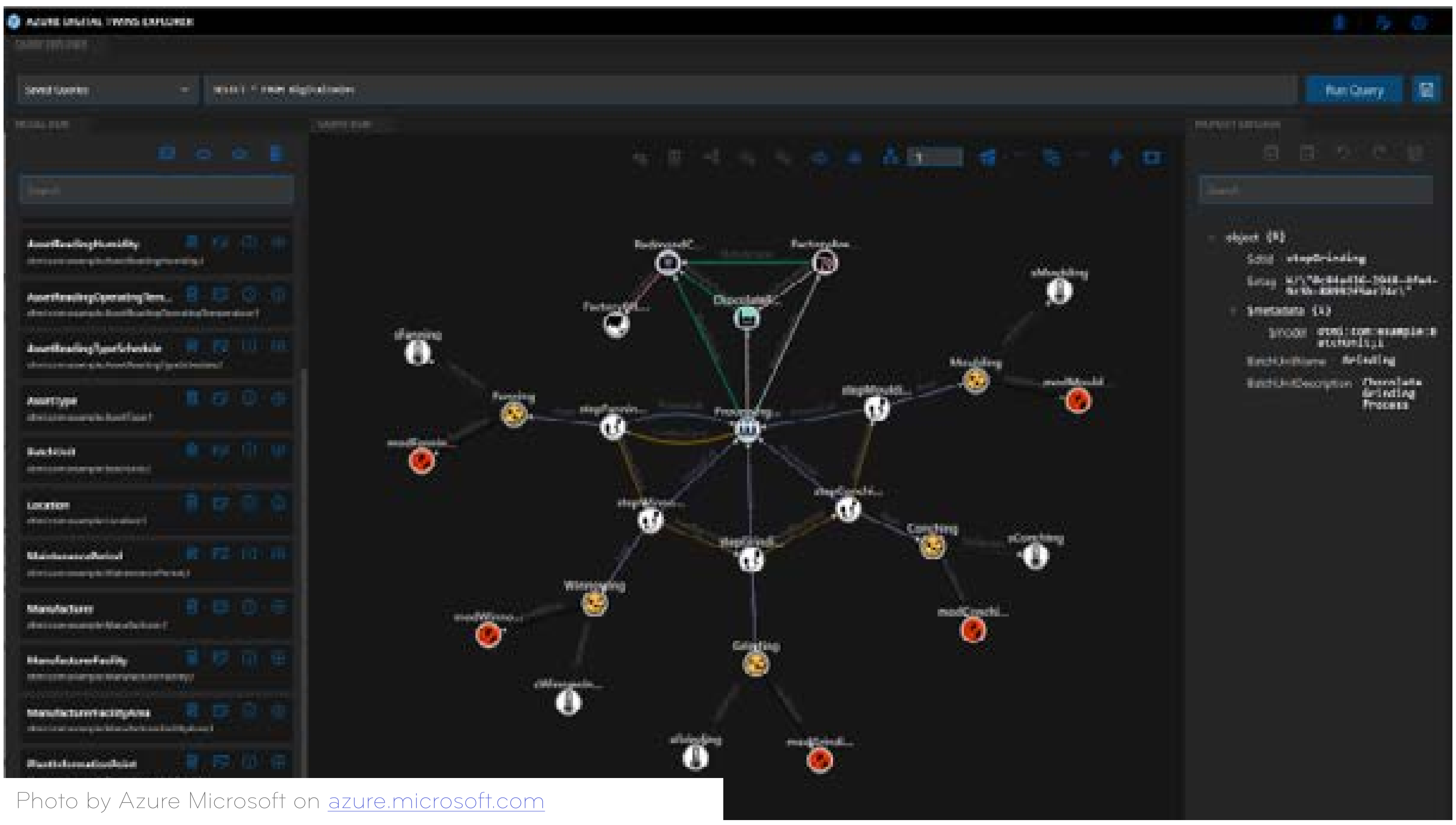


Photo by Azure Microsoft on azure.microsoft.com

Available on Youtube

SIEMENS

Siemens AG offers the Digital Twins Platform that supports the development of new products and provides a virtual digital link that allows customers to evaluate the performance of products, supporting manufacturing and production planning.

Operational data is acquired, analyzed, and executed to evaluate the company's performance.

Sensors installed on physical objects evaluate operating conditions and performance in real time and the occurrence of variations. For example, Simatic's real-time location solutions were introduced by Siemens AG (RTLS). These solutions incorporate SieTrace software, which provides real-time location data.

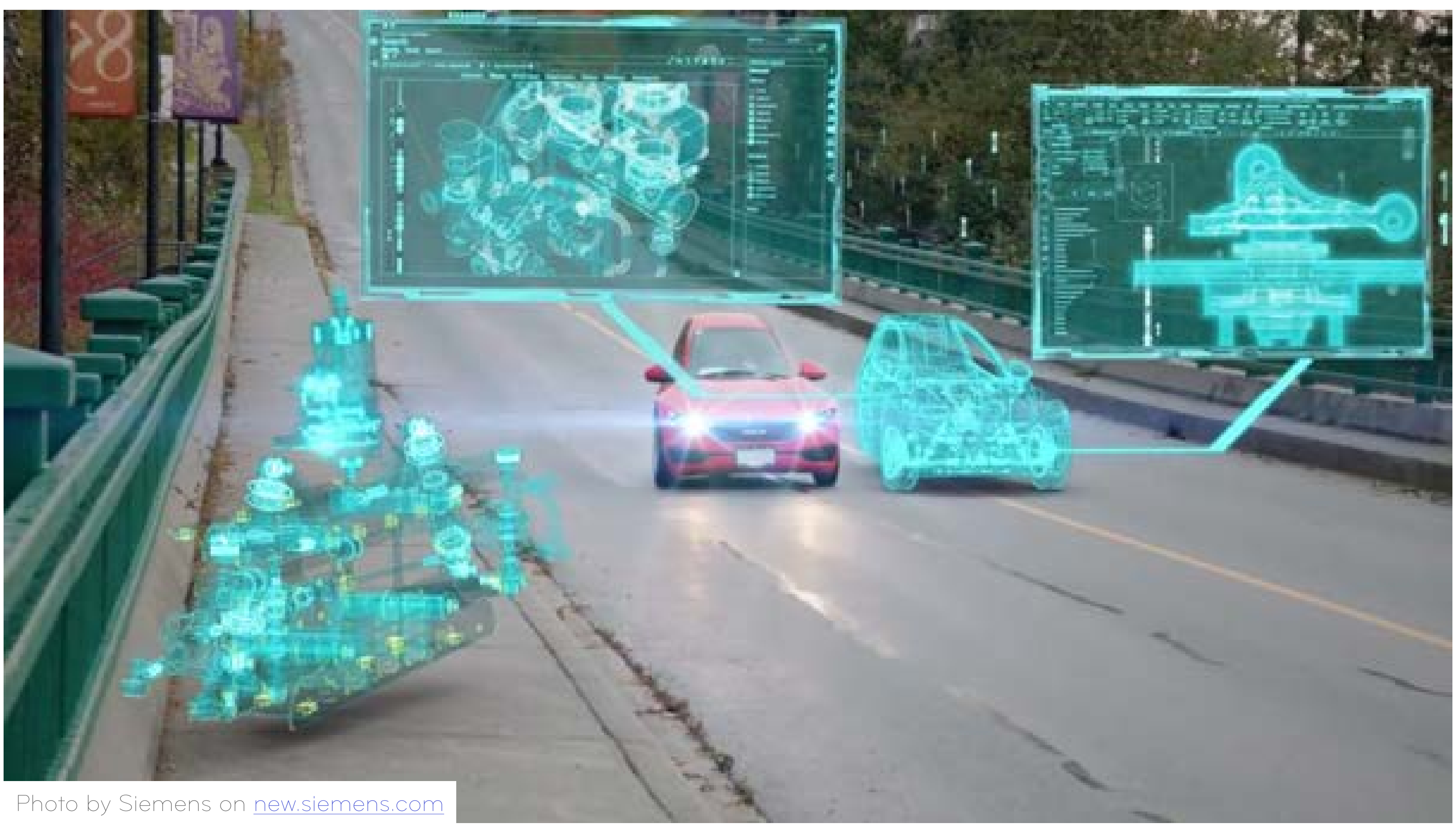
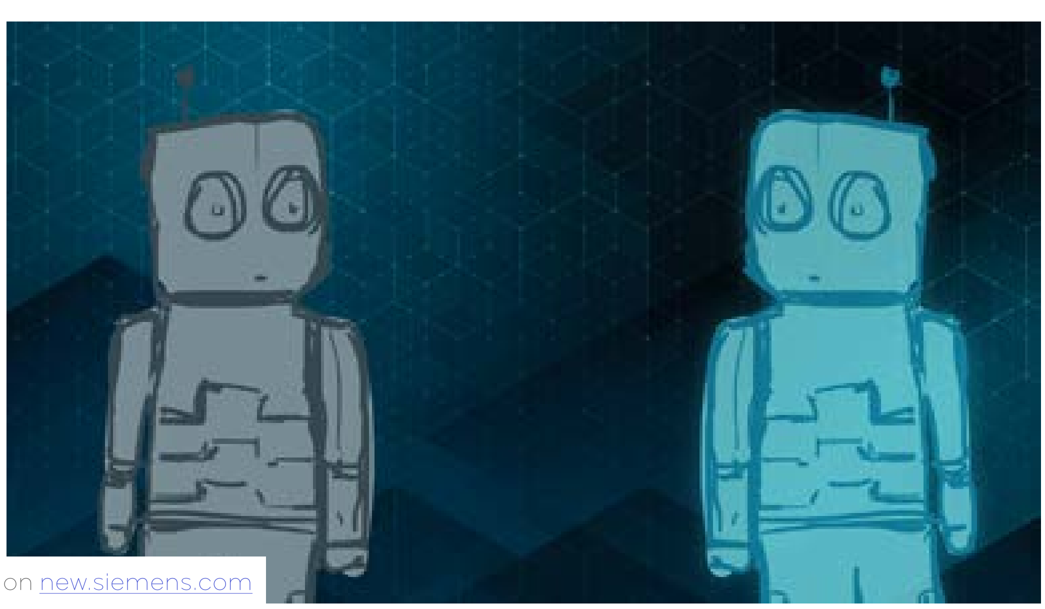


Photo by Siemens on new.siemens.com



Animation by Siemens on new.siemens.com

ANSYS Inc.

The Digital Twins product made available by ANSYS Inc. allows you to create virtual prototypes of real-world systems. Ansys twin builder is the company's solution that allows you to assist in simulation-based creation, allowing you to improve productivity, create a virtual prototype of a deployed system, integrate real-world data and manage complex assets.

Some of the company's applications include power electronics, gas-liquid systems, electric motors, pollution control and heat exchangers.

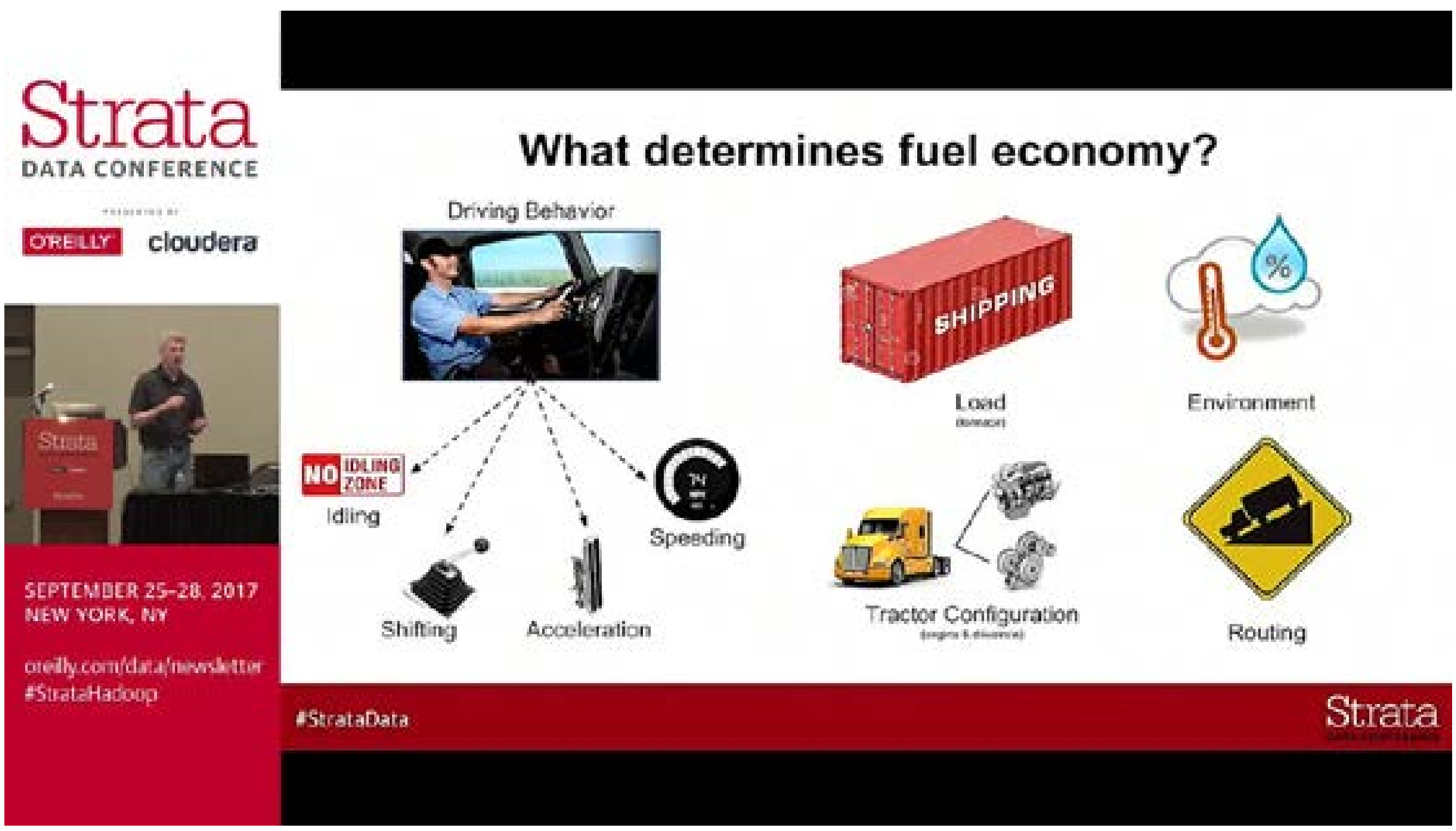
The company's specializations include digital prototyping, design optimization, engineering simulation and structural analysis.

Available on Vidyard

5.3. Inspirational videos for building digital twin models

In this section are presented some inspiring videos for the construction of digital twin models.

The video from Vnomics Corp. presented by Lloyd Palum explains how to build a Digital Twins model with some fundamental concepts for its construction.



Kai Waehner's video presents how IoT architecture can be integrated into Digital Twins models with Apache Kafka.

Javier Marin's video presents a tutorial on how to create a Digital Twin in Python a simple but functional way. This example is based on a Li-ion battery. This model allows the analysis and prediction of battery behavior and can be integrated into a virtual visual system.

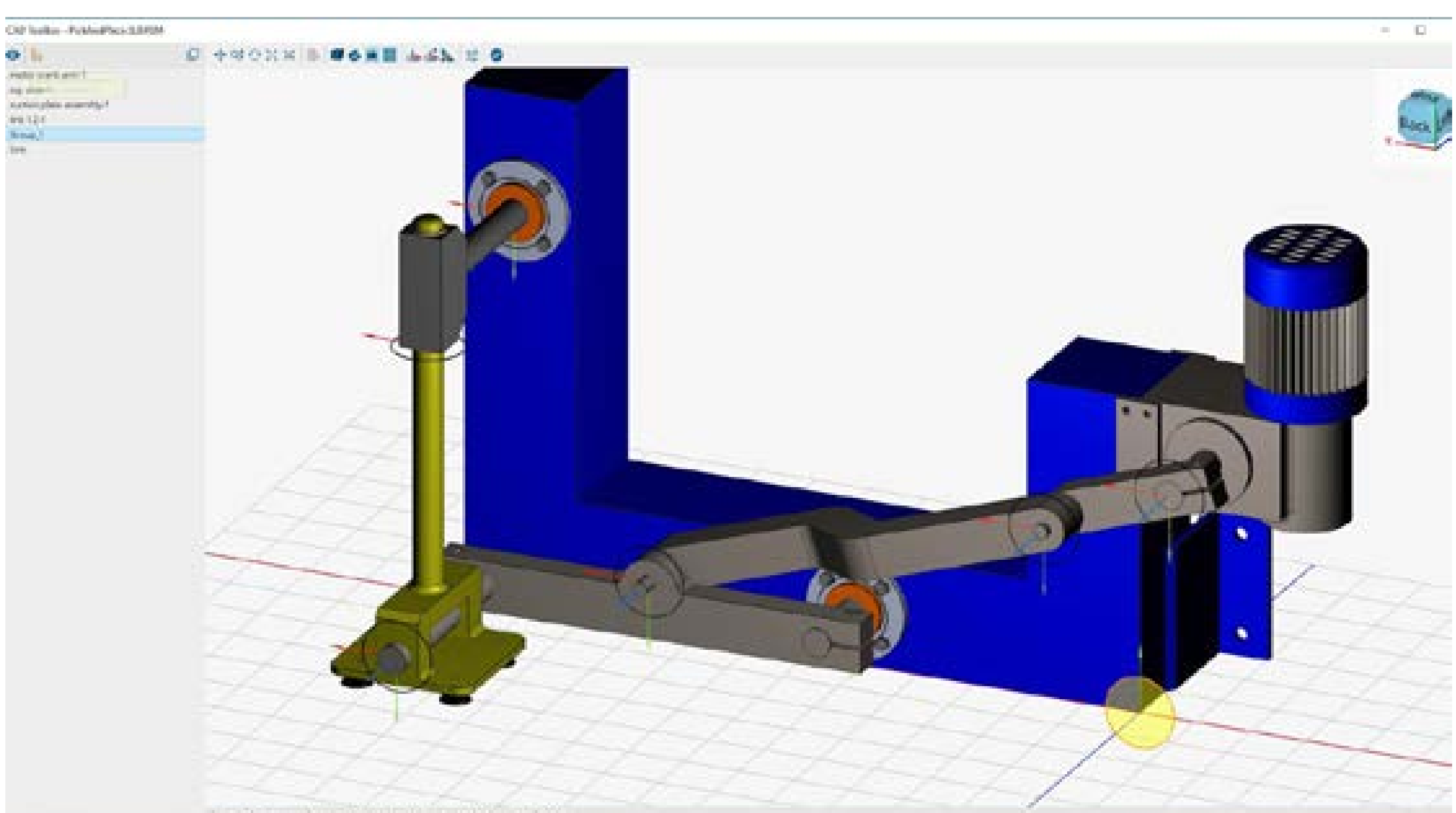
```
#Define inputs and outputs

# input: the simulation capacity
X_in = (dfb['C. Capacity'])

# output: difference between experimental values and simulation
X_out = (dfb['Capacity']) - (dfb['C. Capacity'])

X_in_train, X_in_test, X_out_train, X_out_test = train_test_split(X_in, X_out, test_size=0.33)
```

A set of essential steps to create a digital twin are presented by VirtualCommissioning.com, supported by CAD tool for model building and digital model analysis.



A tool like WRLD allows anyone to build digital twin models quickly and easily, using SDKs, APIs and smart location services. These tools contain 3D maps allowing to create internal and external virtual environments, in which the data acquired through sensors, systems, mobile devices and location services can be visualized with high precision.

5.4. Define the strategy and roadmap for the implementation of digital twins

This section intends to define a strategy for the implementation of *digital twins*. The number of cases and the detail of the products of a given company can be a challenge for the implementation of digital twins. The possibility for companies to analyze trends and measure occurrences through digital twins can benefit production processes, with analysis of the simulation before its implementation in an industrial context.

With DTs the processes and data from real objects are directly linked with their virtual representation, delivering a constant flow of data, which is used to predict, simulate and provide useful insights. Therefore, there is a clear domain dependency between DTs and their physical counterparts. For generating relevant outputs to the area where they are going to be implemented, it is necessary to define effective strategies which involve several steps.

Table 3.2. *Roadmap*

STEPS	DESCRIPTION
Objectives	Modeling through digital, identifying the best practices and trends for digital twins.
Evaluation and prioritization of the physical and virtual elements	After defining the objectives, it is necessary to make an assessment and define the prioritization of the physical and virtual elements that make up a DT system.
Implementation Plan	It is also important to verify the minimum level of sophistication of the model that can generate value for the organization, (typically, considering low development times and a quick return on investment). Preferably, having a modular digital twins model with sustainable growth that can extend while generating value. As advice, it is not effective to aim to develop a very complex system because, generally, it translates into high development times and when it is ready for use, there is a risk that another solution will appear on the market.
Third-party testing	Is vital for evaluating the functionality and integration of the system, so that adjustments can be made before making the product available to the customer.
Strengths assessment	Consider, e.g., the development method, governance, data strategy, business processes, and system complexity.

STEPS	DESCRIPTION
Specialized human resources	Accessing appropriate **talent and skills** and ensuring that technicians are properly trained makes a difference to a successful execution of a digital twins project.
Step-by-step planning	For implementing digital twins is indispensable for developing a minimally viable product to be considered for testing. Once you have this product, it is necessary to get substantive feedback and be able to verify that it meets the initial prerequisites and proceed with modifications/ improvements according to the initial objectives.

As a summary, it is important to keep the optimization and implementation of digital twins, according to the analysis made to the **minimally viable product** and define an (internal and external) training and recruitment strategy for the development of digital twins according to the initial objectives, or even its generalization with the adoption of more complementary modules to maximize performance.

Glossary

- ***Digital Twin***
  It is a virtual copy, or digital twin, of an entity in the physical/real world, which is updated in real time through the use of sensors.

- **Simulations**
  It is a digital modeling of products or processes for testing. However, they do not have real-time information on the real or physical product.

- ***Internet of Things* (IoT)**
  The Internet of Things describes a communication network of physical objects through the use of sensors and actuators that allow interaction with the physical environment. These "things" share their information with other devices on the Internet.

- **Artificial intelligence**
  Refers to systems or machines that mimic human intelligence when performing jobs and interactively improve based on the information they gather.

- **Preventive Maintenance**
  Planned maintenance actions or jobs that prevent defects and failures from occurring in equipment or machines before they do.

- **Corrective Maintenance**
  Unplanned maintenance actions or jobs that are carried out after checking for defects or failures in equipment or machines.

- **Factory floor**
  It is the place where employees, machines, and structures are, and where all industrial processes are executed.

- **Digital Transformation**
  It is an act of transformation in companies and organizations in order to introduce or increase the use of digital technologies to solve problems and modernize processes.

- **Industry 4.0**
  It refers to the fourth industrial revolution and represents the integration of different digital technologies into industrial processes, such as artificial intelligence, the internet of things, robotics, and cloud computing.

- ***Machine Learning***
  A sub-area of artificial intelligence that makes it possible to improve the functioning of machines through experience and the use of collected data.

- **Monitoring**
  It is a physical or virtual process that performs surveillance actions at certain values that can be measured or evaluated in systems or machines, helping administrators with the health status of their structures.

- **Life Cycle**
  It is the set of processes that occur from the design of a product to its end of life.

- ***Virtual Reality*** **(VR)**
  It is a simulated experience, real or imagined, that uses computer modeling, artificial three-dimensional vision, and other sensory equipment to interact with a human being

- ***Augmented Reality*** **(AR)**
  It is an interactive experience where objects existing in the real world are enhanced or altered through the use of visual, auditory, or sensory digital elements presented through technological devices.

- **Reliability**
  Represents the confidence that one has about the performance of a particular system or machine.

- **Forecast**
  Ability to predict that a certain event will happen.

- **Efficiency**
  Ability to perform a certain job or action with a certain satisfaction or expectation.

- **Metrics**
  It is a quantifiable measure of performance that allows analyzing or evaluating the result of a job, process, or action.

- **Performance**
  It is the evaluation of a certain job, process, or action using quantifiable measures (metrics)

- **Business model**
  Integrated view of the process of identifying and using resources, skills and partnerships to create and deliver value to its customers and shareholders.

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