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POSTGRADUATE THESIS

INTERNET OF THINGS INDUSTRY 4.0

CHRISTOS LIAKOS
MCSE19014

AIMILIOS CHRISTOS PANAGOPOULOS
MCSE19015

LECTURER PROFESSOR: PANAGIOTIS A. KARKAZIS, ASSISTANT PROFESSOR

POSTGRADUATE THESIS

Industry 4.0 (I4.0) is the evolution of the smart factories in the application framework of Internet of Things (IoT). The I4.0 model aims on the interconnection of the structural elements of the production chain (machines, sensors, humans e.tc.). For the gathering and processing of useful information, targeting the automated decisions, problems solving in real time and the flexible adjustment of the production process. On this approach, the methodologies and the models supported by the I4.0 applications will be studied, and a pilot application for handling the production in a factory will be created.

CHRISTOS LIAKOS
MCSE19014

AIMILIOS CHRISTOS PANAGOPOULOS
MCSE19015

LECTURER PROFESSOR:

PANAGIOTIS A. KARKAZIS, ASSISTANT PROFESSOR

EXAMINATION COMMITEE:

ADONIS BOGRIS, ASSOCIATE PROFESSOR
MIRIDAKIS NIKOLAOS, ASSOCIATE PROFESSOR

DATE OF EXAMINATION 14/07/2022

Antonios Bogris

Digitally signed by Antonios Bogris
Date: 2022.07.15 16:12:06 +03'00'

Panagiotis Karkazis

Digitally signed by Panagiotis Karkazis
Date: 2022.07.15 13:38:33 +03'00'

Nikolaos Myridakis

Digitally signed by Nikolaos Myridakis
Date: 2022.07.15 17:16:02 +03'00'

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ABSTRACT

The term "Industry 4.0" highlights the fourth industrial revolution, as a new standard that enables the Internet of Things (IoT) to be introduced into the natural workflow. The vision of Industry 4.0 points out the use of large, interconnected machines, in the formation of intelligent production lines, capable of exchanging information autonomously and controlling one machine over the other. This introduces an autonomous operation of an intelligent factory via this Cyber Physical System.

The main purpose of this thesis is to introduce the fundamental principles and characteristics of Industry 4.0 and the impact it will have on the supply chain, to increase cooperation between suppliers, producers, customers, and transparency in production steps by the end of their whole working cycle.

By introducing the digitization, process automation and the need to restructure the production line and supply chain management structure, is a call for us to comprehend the positive aspects and potential downsides, posed by introducing these technological breakthroughs, which accompany Industry 4.0. The analysis of the role of human resources in the new productive environment is also very important.

In these various forms of digital and automated transformation that are imminent due to Industry 4.0, the whole point of this dissertation also intends to break down the key aspects of all Digital Twin systems.

Digital Twin (DT) systems represent the concept of using tools and technologies to "map" data (bits) from physical objects (individuals). The dynamics it offers are that it can reveal the physical condition of people (things, devices, components, machines and people), the current state of processes performed in real time, the current state of human resources and also offer transparency to any other information concerning the above.

In this thesis, the methodologies will be studied, the models implemented by the current applications of I4.0, in addition, a pilot application will be designed and implemented for the production management in a factory as the model of I4.0 provides the interconnection of the structural elements of the production chain. (Machines, sensors, people, etc.) To collect and process useful information in order to make automated decisions, solve problems in real time and flexibly adapt the production process.

With the support of the present digital solutions and their attributes, the significance of this research lies in the surplus provided by the distinctive technologies both to manufacturing businesses as a whole and customers. Time to delivery and production costs are the attributes that would be decreasing, whereas the profits for the businesses and the environmental impact are positively increasing.

Contents

1. Introduction

In an increasingly globalized society, the rapid technical advancement in the fields that consist of the technology of information and communication, enables the sharing of real time data. In this environment, the technologically advanced nations, attempt to establish individual policies to boost the fields of industry aiming to be updated, well prepared and dynamically competitive in this fast pace changing world-wide market. Furthermore, the industry goals connected to sustain industry competition can be equaled and referred to social goals, particularly satisfying a nation's human and social requirements.

After industrialization, the endeavor to increase competitiveness through technical diversification allows for a larger and more inventive research area.

We are already confronted with a new generation of organizational and industrial technologies that are transforming the way industry is connected to the society, engaging with human resources and labor approach.

The goal of this paper is hence to portray the system that oversees the term of the industrial revolution (Industry 4.0), incorporating the expansion to its primary operational goals, the examination of the obstacles and the prospects faced.

The industry is starting to retain the total arrangements given by the Internet of Things (IoT). Businesses are starting to plan noteworthy changes in their trade demonstration. The system integration within the beneficial framework for the trade of information, permits the realization of arrangements that offer unused benefits in a way that's understandable to all partners. As an example, is the swift reaction to changes within the global market which has the benefit of not causing instabilities. Industry 4.0 came from the necessity to establish a new manufacturing paradigm, particularly in industrialized areas or countries.

Increased global financial rivalry from businesses with technological capabilities and cheap operational costs has put such pressure on industrialized countries and third-world businesses. It has resulted to the necessity of creating and implement national policies to mitigate the negative impacts of rivalry from other nations, as well as to improve the local industrial sector and promote innovative goods and services with high added value in international markets. Differentiation from rivals, cost reduction, and more effective use of resources are all difficulties that the new manufacturing model must confront.

With this approach, the definition of Industry 4.0 depicts the description of a fundamental new term, which characterizes the development towards a decentralized production model from a control-centric industrial production paradigm. This leads to permitting the formation of exceedingly adaptable and individualized production processes, where standard productive departments vanish, making way to the creation of new practices, based on new technologically supported and interconnected forms and areas. These processes also bring about changes in value-added processes and require reorganization in the division of labor.

2. Fourth Industrial Revolution (I4.0)

In the 1970s, the industry began to incorporate information technology and telecommunications. However, the fundamental concepts of Industry 4.0 were initially articulated in 2011. In the same year, the German government launched a strategic effort that was incorporated in the "Action Plan for the High-Tech Strategy through 2020" [1]. Similar techniques have been advocated in other developed countries, such as the United Kingdom. In Europe, the same expression is "Future factories," in U.S.A, "Industrial Internet," and in China, "Internet Plus." Despite widespread interest in Industry 4.0, the common definition of it is not yet agreed. There is one statement that covers it: "the integration of sophisticated machines and devices with networks of sensors and the relevant software programs, which are used to anticipate, supervise, and design better commercial and/or social results" . Another meaning states "an advanced level of organization and administration in the value chain during the product's cycle from start to end."

It is also known as a "shared word which includes technology and approaches of the organization's value chain. "As a result, the notion of Industry 4.0 may be seen as a future-oriented approach for increasing competitiveness. It aims on improving product value chain via the use of autonomous operation and progressive production [2].

It focuses on the development and execution of antagonistic merchandise and services, as well as the management of robust and adaptable supply and systems of production.

To enable the growth of automation, Cyber Physical Systems (CPS) technical ideas may be utilized to have an autonomous function and communicate with their working surroundings via microcontrollers, sensors, and transmission interfaces. Yet, the presentation of CPS and IoT, where objects must go through a preparation process, a design-process, programming, development, as well as work on tools and labor, if necessary, leads to the imminent arrival of a 4th Industrial Revolution.

CPS and IoT are comparable in that they both use the same basic architecture. It does, however, demonstrate a higher level of integration and alignment of various data. Industry 4.0 is distinguished by the ideas of intelligent products, machinery, and improved interoperability. Primary goal of the intelligent product is to transform the system's product from a static to a dynamic component. Products in this kind of systems have the capability of memorizing and storing the working data and specific needs, and they may enquire the necessary resources and coordinate manufacturing routines to accomplish those.

The Smart Machine idea focuses on the replacement of the old production hierarchy with a decentralized one that organizes production on its own, with a concentration on CPS systems. In such a system, interconnectivity and well-formed descriptions enable communication among autonomous components, whilst unit-level AI enables communication with other devices, introducing flexibility and modularity to the production chain.

This results in the autonomous organization of the machinery within the production network, automated assimilation, and the addition of new production units without planning or even replacement.

Lastly, the EO (Enhanced Operator) has the responsibility on how the system automates knowledge handling, leading to increased adaptability and flexibility of the elements in the production line. This type of person is tasked with developing new jobs, such as defining specifications, monitoring, and checking production methods. It can intervene manually in the autonomously structured manufacturing system at the same time. It offers assistance through mobile, adaptable interfaces and user-friendly support systems. It helps him reach his full potential and take on the role of a strategic decision-maker. He is also familiar with adaptable problem-solving techniques in situations of growing technological complexity.

2.1 Where did it start

Back in the 1970s and 1980s, the promotion of machines as the future of production and the primary answer to the insecurity of the human component in the production line generated widespread anxiety. The fear was that robotic machines would eventually play a significant part in production and, because they were first effective in big industries, should lead to the introduction of an automated production line throughout the whole industry.
Automation origins from 1980s, when the quest for efficiency in manufacturing resulted to a minor need of common working positions, and this was considered as the termination of people consisting of the assembly chain. Surely, none of the foregoing was proven, despite the fact that many people have lost their employment over time. The development of computers, computation, and semi-intelligent robots replaced many employees, resulting in the emergence of computer engineering and robotics. However, the unification between physical and digitalized worlds, represents the fourth industrial revolution. This opens up new opportunities and does not necessarily imply a reduction in the industry's size.
Industry 4.0 began as a new German strategy for transitioning the industrial state of the country to the age of Intelligent Manufacturing Systems (IMS). They are regarded as the later phase of industrialization because they use of models and standards of production considered novel, and new techniques to alter the old industry to an intelligent one. In reality, Germany has established a nationwide training program. They run CPS systems and provide education and technical training to vendors, colleges, and schools.
The term "Industrial Internet" was used by GE (General Electric) to characterize the Industrial Internet of Things (IIoT) or Industry 4.0. By integrating appropriate mechanical sensors, services at the server level (middle ware), software and computer systems and systems, the Industrial Internet provides a way to improve the existing image of the result and the internal organization of the operations and critical productive elements of a productive enterprise. Available in data centers or through cloud computing (Fig. 1).
As a consequence, it offers a way for the growth of business processes by providing feedback on the outcomes produced from the gathering of huge data sets using advanced analytical data.

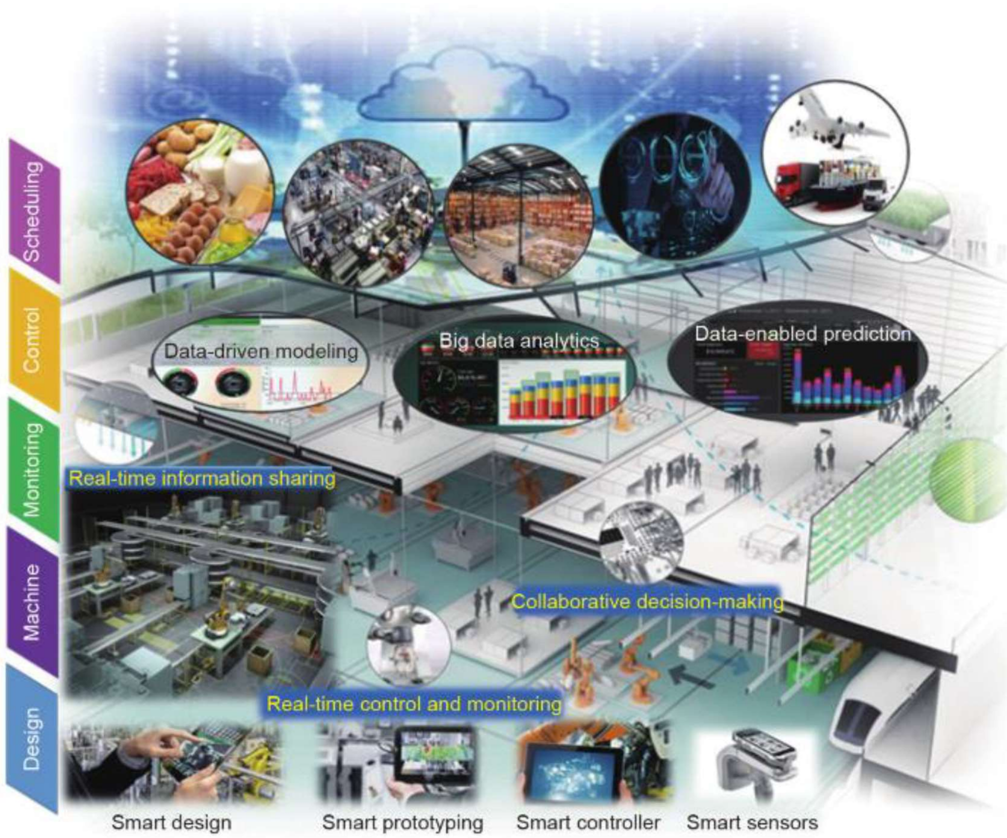


Fig. 1 The overall context of Industry 4.0 IMS

2.2 First aspects of Industry 4.0

The earliest industrial revolution begun in the United Kingdom, nearly two centuries ago. After the United States, Europe commenced a transition from rural to industrial civilization [3]. Industry 4.0 as a historical event was initially stated in German in 2011 in the course of the "Hannover Fair" event, as a plan for creating a new approach for the country's financial strategy based on cutting-edge technological techniques, representing the commence of the Fourth Industrial Revolution [4, 5]. Robots and machinery have substituted the labor, which indicates that the direction of the tasks is not handled by a person in control.

By 2012, the correspondence between industrial robots and workers in the German state was at 27.3% [6]. The impending Industry 4.0 indicates a comprehensive interconnected association that will exist between numerous business entities. Every region of organization adapts its composition in response to the alteration of the network's related parts. Furthermore, there are expenses and pollutants the eventually can be decreased. Particularly, each collaborating part impacts the network of the future business that may accomplish self-organization and send reactions instantly, and in the economic sector creates the highest return for all those participating with restrained sharing assets or budget [7].

2.3 Structural basis of Industry 4.0

Industry 4.0 has been regarded as a catchall term for technology and organizational concepts through the value chain. The CPS control real work scenarios, produce a digitally visualized duplicate of the natural environment, and autonomously determine inside intelligent factories. Relatively, IoT and CPS interact and collaborate in-between as well as with the persons involved.

The Internet of Services (IOS) is used by members of the production line to supply and consume services internally and through the organization [8, 9, 10]. This smart factory concept, which is already starting to materialize, shows a novel path for manufacturing. Intelligent components are easily identified, will always be tracked. They are aware of their past and current condition, along with taking alternate pathways towards the desired status. There is a vertical networking between the embedded manufacturing systems and business processes within the organizations. There is a horizontal connection to distributed networks which are capable of being controlled through the whole business cycle. Furthermore, they trigger and need an engineered approach across the production line [11]. Industry 4.0 may be divided into three fundamental components that involve connectivity and cooperation, along with data analysis as important aspects:

- Transformation via digitization and integration of the vertically and horizontally connected set of activities carried out by the company.
- Output and service offerings are becoming digitized.
- Digital business models that are innovative [12].

The primary aspect points out the "horizontal integration," which occurs among businesses through the value chain and the data-sharing to create resource assimilation, allowing companies to achieve continuous collaboration and bring out goods and services in actual time. The set of activities that are "vertically integrated" are grounded on the smart factory, inside the chain that consists the systems of manufacture, from the needs to the mode of the aforementioned services, to achieve customized production instead of the traditional fixed production technique (for example, a line of production). Vertical integration can be aided by a variety of services, including integrated digital product lifecycle management, product design, digital evaluation, and virtual manufacturing[13]. The aspect that comes in second, is the expansion of the current output line with detailed depiction of the digitalized goods. This constitutes of network connectivity for regular conduct and data engagement, along with the bespoken product creation. The last part includes the provided interconnectivity established by an orientation towards service with architectural reference [14].

2.4 Industry 4.0 Fundamentals, Design Principles and Sustainability

Many Industry 4.0 scenarios have been implemented and evaluated by research institutes and companies. Their findings will have an impact on the design of Industry 4.0. According to [15], seven design concepts are being driven to assist firms interested in developing an Industry 4.0 strategy. The fundamentals related to I4.0, lead towards several advances in terms of sustainable production [16]. The following are included in the first 6 composition regulations, plus the major and significant environmental impacts:

- **Interoperability**

CPS and people are linked in Industry 4.0 companies via Internet of Things and Internet of Services. Specifications shall be a critical element regarding the contact of Cyber Physical Systems from diverse producers. This point is an essential facilitator of I4.0. In 2013, DIN and VDE, the German Commission for Electrical, Electronic, and Information Technologies acknowledged the demand and issued the “German Standardization Roadmap.” Interoperability related to the Smart Factory KL factory implies that every CPS inside the factory (work piece transporters, stations for setup. goods) may interact with one another "through open networks and semantic descriptions."

- **Decentralization**

Increased interest for particular items proves to be harder for centrally regulating the setup. CPS can make choices on their own thanks to embedded computers. Only in the event of failure are responsibilities allocated to a higher level. Nonetheless, in order to assure quality and make tracing feasible, the monitoring process is always important for the entire setup. Because of the increasing demand for specific items, is leading to an increased difficulty of regulating with a centralized approach the organization. Cyber Physical Systems can take actions by themselves thanks to embedded computers. Only in the event of a failure are responsibilities allocated to a higher level. Nonetheless, for quality assurance and traceability, the entire system must be always monitored. Decentralization in the context of the Smart Factory KL facility implies that RFID tags "inform" the working instruments on which actions will be required. As a result, central planning and control are no longer required.

- **Virtualization**

Because of virtualization, CPS can audit physical processes. The data form the sensors are linked to virtualized plants and simulators. This results to a digital replica referring to the actual environment being generated. Because of virtualization, CPS can audit working procedures. This results to generating of a digital replica of the actual environment. A virtual model of Smart Factory KL facility comprises the state of every CPS. If a failure occurs, a person is potentially alerted. Furthermore, all required data, as an example: future actions or precautions for safety, are supplied. In this case people have increased ability to deal with possible increasing technical complexity.

- **Real-Time Capability**

Collection and evaluation of data on the spot for regulatory actions. The production state is constantly audited and assessed. As a result, the plant may respond to a machine failure by rerouting goods to another machine. Data gathering and study on the spot is required for organizational functions. The state of the factory is constantly tracked and evaluated in the Smart Factory KL. As a result, the plant may respond to a machine failure by rerouting goods to another machine.

- **Modularity**

Modular systems may comply with altering demands by flexibly restoring or extending single components. As a result, modular systems may be quickly altered in during periodic modifications or adjustments on product qualities. Individual modules of modular systems can be replaced or expanded with the aim of adapting to the altering requirements. This means that when seasonal variations or changes in product qualities may occur, modular systems may be quickly modified. New modules may be added to the Smart Factory plant utilizing the Plug and Play approach. These are detected and used through the system right away, thanks to standardized software and hardware interfaces.

- **Service Orientation**

The companies, the Cyber Physical Systems, as well as individual services can be accessible via the Internet of Services and may be used by more participants. These are provided both internally and externally. Every CPS provides its functionality similar to an enclosed service through the web. The consequence is an operation process which is specified to the product and can possibly be built to tailor RFID tag's need that are specifically requested by the customers. A service-oriented design underpins the Smart Factory facility. All CPS provide encapsulated web services for their functions. With consequence being a specific approach on the operation of the processes towards the product, which may be built using the RFID tag's based on the criteria of the customer.

- **Security**

ICT technology will be used for data transmission and processing in Industry 4.0. The security and privacy of information must be prioritized in data interchange procedures that use both hardware and software.

A wide range of important elements are covered in I4.0 for long-term industrialized growth. Industry 4.0 aims to provide major advances by incorporating different technological concepts into its fundamentals.
The ideals that make up industry's sustainable operation include various aspects. For example, mining of waste, sensitive handling of the available assets of nature, adequate physical material usage, effective energy consumption and dynamic adjustment of plant times. It is notable that some of these qualities have been enhanced, and have been used to date, in part through production processes already in use by the industry in a historical context. However, the ability of Industry 4.0 to make them a reality and practice in production, mainly consists of virtualizing

effectively with relevant digitalization and adaption of existing technologies, which do not only promote production but also promote environmental consciousness.

3. Technologies Implemented in the context of I.4.0

Over the past several years, global recession has transformed the industry's viewpoint, focusing now to the genuine profit it generates. Businesses aiming towards relocation, to reduce labor costs, have taken measures toward the restoration of their competitive mentality. A significant part of this transition has been performed by the German Manufacturing Strategy, which has initiated measures to preserve and promote its relevance as "precursors" in the industrial sector [17]. The terminology "Industry 4.0' was introduced and it offered great promises to confront the newest industrial systems difficulties. It enables and strengthens the technology movement, changes livelihood, introduces new production methods, and renovates the companies towards digitalization. The objective of I4.0 is to improve the level of automation, which will bring the physical into the virtual world [18], to achieve a greater operational productivity and efficiency. Computing and interconnection will be integrated into the conventional industries. Several authoritative sources [19] say that I4.0, which consists of integration, adaptability, optimization, service-orientation, in conjunction with all the new technologies parting with it are linked to CPS grounded on the integration of knowledge and divergent data. These are the smart working parts that move from an instrument to another instrument of the plant, in actual time communication in-between them, from a production perspective. In this context, I4.0, employing flexible and cooperative systems for solving issues and taking best decisions, will make manufacturing intelligent and adaptive [20]. The industrial situation is well developed to create smart goods, intelligent processes [21]. Companies are planning to promote digitization through collaborating with consumers and suppliers in digital ecosystems [22].

3.1. Reference Model of I4.0

Many organizations worked together to establish the I4.0 model of reference. The creation of a joint terminology as well as an organized scheme [23] explains basic grounds of I4.0, this 3D model in Fig. 2.

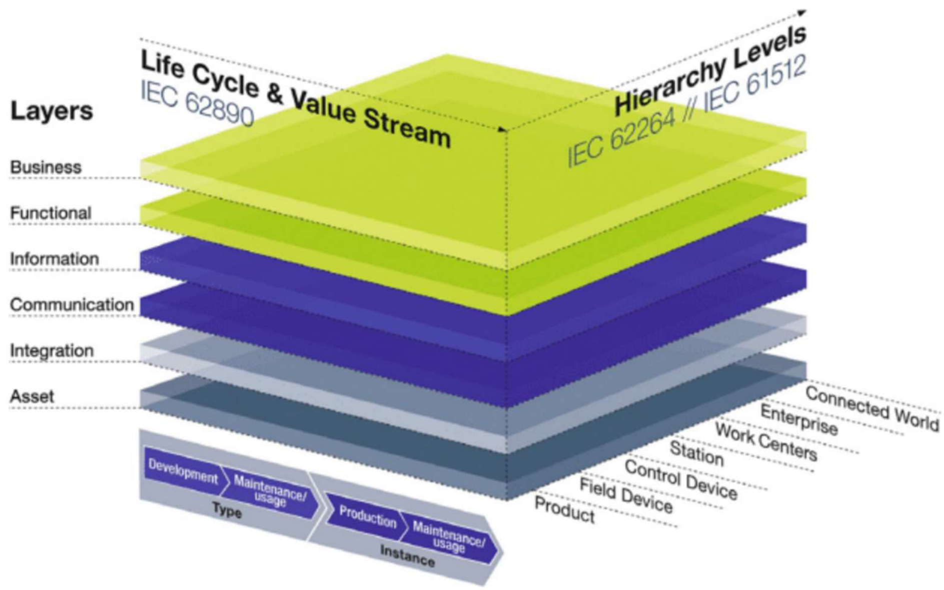


Fig. 2 Architecture Model for I4.0

The aim is to support the introduction of I4.0 technology [24]. The Reference Architectural Model (RAMI4.0) of I4.0 should allow the identification and closure of the gaps, loopholes, and overlaps between the existing standards. On the left side, the corresponding value flow is shown of IEC 62,890 [25] the cycle of life for the facilities and output. Differences between instance and type are well described in RAMI4.0. The hierarchical layers in the IEC 62264 standard are shown to the right, which reflect functions specified by the various groups, from the "Product" (i.e., a work piece) to "Connect World' levels through the hierarchy of business layers. The "Link World" comes as the latest phase in the industry 4.0 in which companies, clients and those who supply may connect via IoT or IoS [26]. The levels seen vertically point on all areas of company digitization which are integrated.

For instance, "asset-layer" refers to physical elements like robot-guided machinery, components, registers, and recordings as well as individuals who are connected to the digital setup through a "level of integration".

Digital items, like software or ideas, also offer processed information for asset digitalization under 'Integration Layer'. These can be devices that are attached to the hardware, or even technical processes assisted by computers. Elements link to information technology (IT). This layer also involves people through HMI. In the virtual realm the 'Communication Layer' with the role of communication standards is reflected through the enabler [27] for each major occurrence. It uses uniform data size and specified protocols and provides services at the "Integration and Information Layer," in order to handle as well as combine various input in usable information on a consistent basis. The "functional layer" to enable formal function descriptions also accepts and transforms events for data accessibility on the following layer. It offers a platform for horizontal integration of a number of services that may be accessed remotely, which means data integrity is required. It facilitates corporate procedures. The logic of rules and decisions is generated (on a lower layer in certain instances), and the 'Business Layer' depicts how the company's setup is and enables linkages between various business models. It guarantees the objectives' rectitude within the working flow. All key characteristics of I4.0 can be mapped, so that things like machines may be classified according to models. This approach enables progressive migration from today's manufacturing settings to future production environments. I4.0 is built as RAMI4.0 for the first time and is registered under DINSPEC 91345 in Germany. This is the first composition.

3.2 The Key Technologies of I4.0

I4.0 consists of advanced techniques regarding automated handling and scanning, electrical components, and Information Technology in production. I4.0 focuses on developing smart systems which communicate, that can handle interactions between machines as well as with humans, which address data flows arising in smart and distributed system interactions seen by the angle of managing production and services. Industry 4.0 emphasizes independent interoperability, flexibility, policymaking, efficiency, and cost reduction among other features [28]. In a close range of important fields, implementation of I4.0 should be multidisciplinary. Several writers of the I4.0 sub-sections described nine pillars (also known as building components). The human factor which is enhanced by the progress of the expertise of colleagues, is a crucial point in achieving I4.0 Framework integration [29].

3.2.1 The Industrial Internet of Things

Connection made between "internet" and 'things' for IT, is the IoT on the IT, as is the network of networks, the "Internet". A worldwide computer system using TCP/IP (Standard Internet Protocol suit), linked to PC networking. A "thing' could be something as an item or an individual as separately identifiable from reality. Today, for example, IoT is widely utilized in transport, healthcare, or public services. Things and people take part in a setup of the IoT, by being "online". The Internet connection is a very simple network. Inside this network, individually identifiable items exchange information [30].The progression of mobile devices has increased IoT. The main innovation enabling technology may vary and be the IoT connection via Radio Frequency, Wireless Sensor Network (WSN), software supporting IoT applications and/or SDN [31]. Fig. 2 illustrates the related technological approaches for IoT for various purposes; for adjusting production patterns, utilizing a digital duplicate of the real environment, and exploiting information form the sensors, digitized data may be employed.

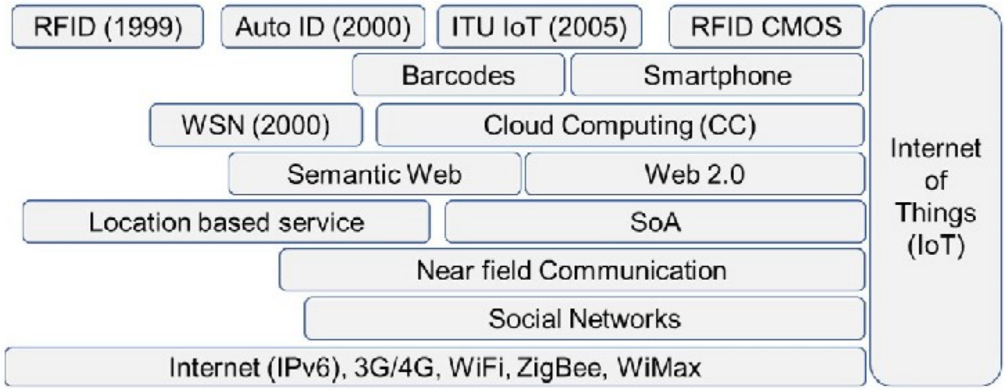


Fig.3 Technologies Associated with IoT

Things controlled and virtualized by I4.0 might be the whole line of production consisting of diverse systems (e.g., machines and associated assets). Moreover, the nature of the IoT is diverse and decentralized [32]. Regarding the architecture of IoT Design, [33] set a layer-linked logical framework for the classification and characterization of IoT technology and for CPS identification. The most frequent layering of IoT design in the atypical network, according to various publications, consists of four principal levels as shown in Fig. 4 seen below in detail:

1. Sensing layer to sensitively identifying different states of "things" and integrate, for example sensors, as various sorts of "things".
2. The Network Layers are the architecture supporting "Network Layer' which supports the sent information from the "Sensing Layer" over wired or wireless networks. This layer automatically detects and maps objects in the network, so that any form of "things" may be connected for data sharing and exchange.
3. Service Layer uses the services and applications required by users or apps for middleware technologies. This layer ensures interoperability between diverse devices and performs important activities such as search and communication information engines, data storage, exchange, and data management, as well as an ontology database.
4. The interface layer facilitates the interconnection and handling of "things' and displays information which allows the user to engage clearly with the system. The IIOT (Industrial Internet of Things) sets up the connectivity to the internet of factory items like machinery, as opposed to IoT-based users with reference to industrial environment which requires available and reliable live data stream [34]. Increased production efficiency using the BD analysis, for instance when integrating the gathered sensor information from a factory supporting platforms of IoT. An example IoT consisting of wired and wireless connections and increased value through extra monitoring, analysis, and optimization is displayed in Fig. 4. The IOS is a logical development of IoT whereas overall connection of the important service elements and their interaction, becomes a key base of SF.

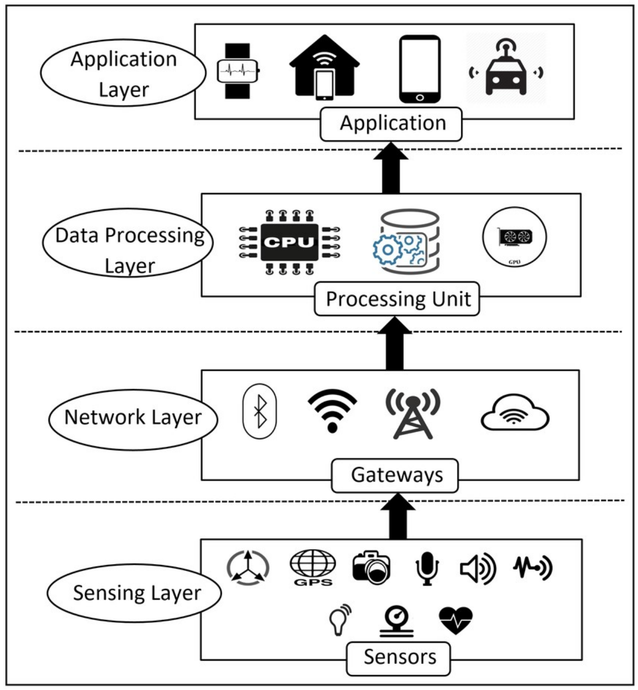


Fig. 4 IoT Architectural Layers

3.2.2 Cloud Computing

As a substitute to IT-resource outsourcing technologies for businesses Cloud Computing is an option. It was identified that CCs for SMEs as an assortment of resources with quick elasticity and measurable service, self-service when needed, and extensive interconnectivity. Endorsing Cloud Computing offers plenty opportunities such as reduced costs, with an example being additional costs to a company to remove IT infrastructures, dynamically scale user's resource rationalization service by solely using actual computing resources, or flexibility upon moving any kind of internet-connected device, e.g., a tablet. This means IoT-related technology from any point worldwide [35]. This allows the cloud to access four different types of services: public (typically located in a data center, maintained by suppliers and accessible to the public) private (same location and particular benefit), hybrid (commercial and public cloud combination [36]), and communities (communities with definite and mutual concerns). All the above is considered in Cloud Computing (CC) with a role of a service. The specific type of services forms a scheme of layers or kinds of CC-structured service-models as illustrated in Figure 5. Furthermore, synopsis management shows the following [37] in Figure 6:

- Service Infrastructure (IaaS) means that cloud service providers, provide users virtual servers, networks or storage with fundamental computing resources, and users can deploy and operate arbitrary software into the cloud that may consist of software-guided systems of operation.

- Platform as a Service (PaaS) is the place consumers create, operate apps utilizing cloud infrastructure programming languages. With the advantage of being scalable, servers with speed, as well as storage may therefore be obtained. By using remote IT platforms, users may create, execute, and distribute their own apps. There is no question of the availability and maintenance of the resource on this tier.
- Applications reside in and work on a cloud architecture in Software as a Service (SaaS) [38]. Accessible via the web browser and applications from many client devices. The aim is to eliminate the service apps for each users' local devices, therefore delivering excellent user efficiency and performance. This category offers a cheaper cost of ownership for programs (software) [39].

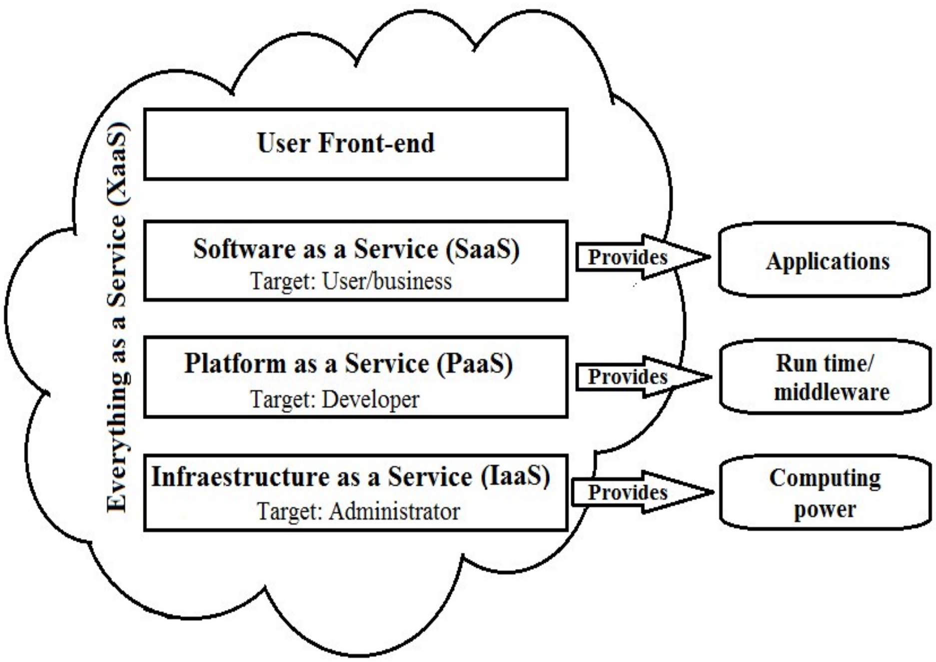


Fig.5 Everything as a Service in CC models

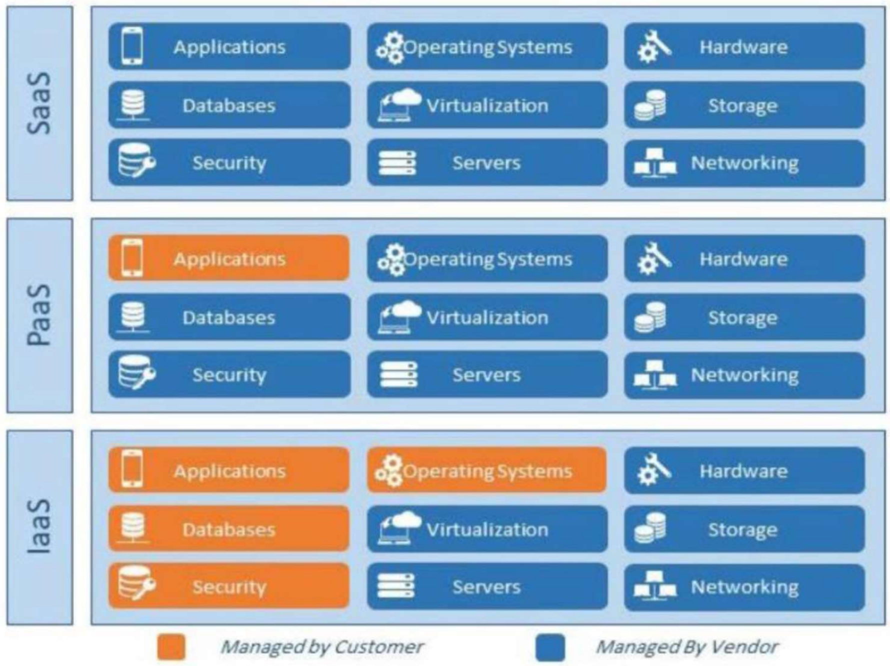


Fig.6 Management overview in CC models

XaaS (referring to "Everything as a Service") layer manages communication amongst the top layers and user interface. Cloud Manufacturing (CMfg), a design that uses CC technology to improve present manufacturing processes, has been suggested with a view to the production settings. There are two ways to cloud production:

1. Manufacturing: manufacturing CC – use of CC applications directly in the manufacturing process, web-based production apps or computer-aided applications is only some of the examples of possible CC systems deployments. This is carried out on two tiers of CC service corresponding to both SaaS and PaaS [40].
2. CMfg systems as the whole new cloud service type based on the Cloud-based service-oriented architecture (SOA). The degree of IaaS on the CC system is reflected. A new computer and service-orientated manufacturing mode like CMfg [41] emerges from the integration of sophisticated technologies. A technology like CMfg allows customers to request services at every step of a product life cycle, from design, production, management, etc.

The service-oriented approach [42] and its tendency towards changing manufacture from manufacture-oriented towards service-oriented [43] are the key features of CMfg. in Fig. 7 a short CMfg model consists of three types of stakeholders: suppliers, operators, and consumers, working together to ensure a sustainable CMfg system operation is presented:

- Providers — possess and supply manufacturing resources and capabilities. For the sharing of products, supplier's postproduction resources to the CMfg platform throughout the product cycle and receive production tasks from the cloud platform as well. Everything under the sole supervision of the operator is turned into services.

- Operator(s) – operating and service-providing actions to customers, providers as well as external suppliers or customers on the CMfg platform.
  Customers can obtain on-demand high quality, sustainable production services via the cloud platform. Providers are authorized to publish their resources and capacities via the cloud platform technologies.
- Consumers May subscribe to the CMfg service platform for accessible manufacturing computing services [44]. Consumers, including consumer companies and separate customers, set requirements towards the CMfg, for example, designing, testing, even simulating actions under the sole supervision of the operator, as well as receiving the performance results of their orders.

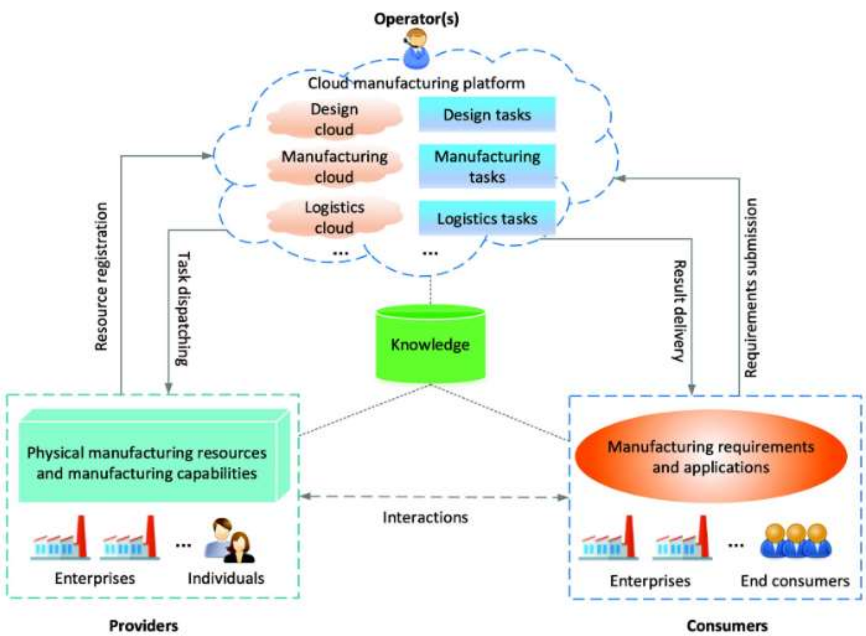


Fig. 7 CMfg model

CMfg is a knowledge-based production model. For example, data and their policies, essential for various lifecycle services and activities such as service creation, administration as well as applications [45]. The approach uses CC, BD, IoT, CPS, networked, serviced, virtual and virtual businesses. The concept of CMfg includes:
CMfg's cooperation, allocation as well as administration of production assets, e.g., manufacturing appliances, programs, etc. may be enabled and supported by companies [46] and these firms may be brought into the cloud in a pay-as-you-go way and become available to potential consumers. CMfg allows the advice and execution, smart mapping, and service search. In the form of a scalable, flexible, and affordable service, CMfg may offer decreased maintenance costs and supports. The CMfg Service Platform also offers manufacturing tasks as services.
Cloud Data Center holds computer resources, while manufacturing resources are owned by various firms [47]. High-tech computer, software licenses or software

updates need not be invested by makers or consumers [48]. A CMfg platform that integrates 3D printing resources and services like modeling, 3D printers, programs, etc. Due to tight relationship between 3D printers and 3D models, the necessity of addressing platforms that manage the libraries of the models as well as integrating devices online in building CMfg 3D printing service platform. In general, SMEs are looking for new technologies like low-cost cloud technologies as a first approach for investment, knowledge scarcity and corresponding assistance on technical attributes. Small and medium sized businesses implement a great security and safety standard relating to the needs of their customers. These data show that it is not the best option to have free access to all services of the cloud in this case. [49] suggested a CMfg system adapted to satisfy demands of small and medium enterprises, considering a structural approach of a hybrid cloud. The hypersensitive information is kept in a non-public cloud with software integration. Public and private cloud data interoperability on the CMfg is also recognized at various levels.

3.2.3 Big Data

Vast information amounts of various sorts are to emerge by the different things linked. This large quantity of semi-structured and unstructured data is able to explain big data (BD). Keeping this information would increase costs for analysis and storage [50] in order to derive the corresponding value. Connecting additional things online (hardware), as well as the application of new technological breakthroughs can bring value possibilities to companies in the internet age of everything.

Big Data (BD) is described by data gathering or storing; however, data analysis is key feature of Big Data because it has little value without it [51]. BD can give systematic advice for associated product lifecycles for the manufacturing operations, achieve cost-effective and fault-free operations [52] and aid decision makers and/or operational problems.

The use as a "time limit" describing huge volumes of data consisting of velocity, variety and complexity need a technical progress of gathering, storing, dispensing, handling, and analyzing the information, provides a business benefit .[53] [54] BD is presented by the Tech America Foundation as a "term limitation." For improved insights, BD requires cost-effective, creative information processing.

The initial idea was established on volume [55], variety, and velocity, also referred to as 3-Vs, depending on Big Data definition, which are differentiated to being processed traditionally.

These were the three elements that developed as a shared paradigm for data management problems. In addition, other aspects after being explored, are added in order to characterize in a more proper way: to analyze constantly huge volumes of unregulated information gathered by media corresponding to video, audio, text or other. Veracity, Vision, Volatility, Verification, Validation, Variability and Value [56]. The following figure with the description of the dimensions:

V's	
Volume	vast volume of data that consumes big storage or consists of huge collections. BD sizes that consist of multiple terabytes and petabytes are stated
Variety	various types of data, generated from a large sources and formats variety, and multi-dimensional data fields contents. It refers to the structural heterogeneity in a dataset
Velocity	rapid production. Generation, analysis, delivery, and data creation measured by its frequency. It refers to the data generation rate and the speed for analyzing and acting upon
Veracity	represents the unreliability in some data sources. Some data requires BD analysis to gain reliable prediction
Vision	only a purposeful process should send data generation. The likelihood of data generation process is addressed in this dimension
Volatility	a limited useful life can characterize data generated. The data lifecycle concept is addressed by this dimension. It ensures the replenishment of the outdated data with new data
Verification	conformity of the data generated by a specification set. It ensures the conformity of the engineering measurements
Validation	the vision conformity of the data generated. Behind the process, the transparency of assumptions and connections are ensured; Variability – data flow rates measured by its variation. Variability and Complexity was added as two additional dimensions of BD
Value	through extraction and transformation, defines how far BD generates economically worthy insights and benefits. Value as a defining BD attribute

Fig.8 Big Data Dimensions

The layer below produces data straightly derived by the machinery and the handlers in a framework established by the tiers of a manufacturing company. For a company, this information is extremely significant and provides valuable information for the usage and analysis that enables the company to adapt and provide flexibility at its highest levels. BD analytics is a vital element in digital production that plays as a technological facilitator. In addition, BD analytics are used as the foundation for customizing massive business demands.
As already said, Big Data is analyzing data sent by the Internet of Things, aiming to deliver results from data sets acquired. This means that IoT data is part of the BD and BD can't continue without IoT exploration. In addition, Cloud Computing and Big Data have a two-sided approach: Big Data being considered as absorption of Cloud Computing whereas the opposite supplies the necessary framework of Information Technology.

3.2.4 Simulation

A technological advancement is being made via digitally simulating that helps with comprehension of the scalability of systems in businesses, in order to successfully realize digital production, an important and powerful instrument. This technique, that handles the complex nature of the systems, addresses components parting unsure issues which cannot be handled by common mathematical models [57], addresses the present difficulty of the manufacturing business. The usefulness of the simulation is extraordinary and obvious for a tailored product production environment. Simulation allows validation trials on the design and configuration of goods, processes or systems [58]. Costs reduction, development cycles reduction and product quality enhancement are helped by simulation modelling. Manufacturers have used modeling and simulation to assess their processes and help decision-making. In approaching numerous practical real-world challenges of manufacturing, simulation tools have already proven their effectiveness. Simulation is described as a time, system, or a real-world process operating imitation. The fields of simulation focus on the methodologies and the instruments used. It employs the artificial history and observation of a system which draws conclusions about the functional characteristics a physical structure represents.

By simulation, based on the usage of original modeling, fictional systems and fictional operation modeling, the model creation can be implemented. This contributes through behavior analysis to better assess and comprehend model systems or processes [59, 60]. Simulation modeling contributes to enhancing the complicated and adaptable products to gain insight into complex systems and allows novel approaches, guidelines of the resources and procedures to be tested prior to their actual implementation so that the data and know-how can be gathered avoiding any interference on the actual system-operation. Types of simulation models in categorization, dimensions, and variances are shown in Fig. 10

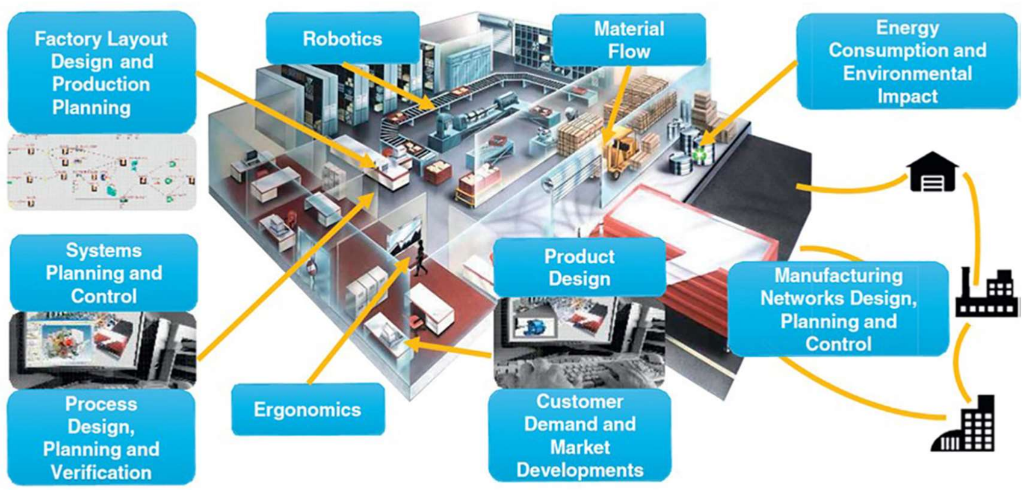


Fig.9 Types of simulation models

Creating the correct sort of duplicate for the actual system is a multi-parameter outcome, for example static patterns for modeling an approach with inactivity and changing patterns by studying the compliance of something that evolves constantly. The opportunity for simulation has played a key role in the design assessment (known as off-line) and on how the operation process performs (known as on-line) of a production structure. The prevalence of long-term design decisions in installation layouts, configuration of system size, adjustable and essential production systems is a common practice. Off-line simulation is of little importance in the simulation process and offers advantages for studying and analyzing what-if situations. The process that takes decisions is limited, and the run-time of simulating is being taken by processes handling the operation where the systems manufacture, for example production planning and planning, real-time control, operational policy, and maintenance activities. This is a significant point.

The number of companies that are systematically related to online simulation, all have access to actions on the amounts generated, the activity complications, and the simulation proximity. For example, while simulating online with a connected computer network, it is feasible that the shop floor behavior to be estimated and production system logic controls to be emulated and/or determined [61]. The objective for decision makers is optimum or close to designing optimal solutions. This optimization is feasible because the vast decision room may be searched systematically without any limits or conditions stated.
In accordance with the computer simulation paradigm, the search for designing optimally a certain system is being done by an optimized simulator. This program can optimize control decisions and support decision-making in real time for dynamic and unpredictable situations. This may be achieved by achieving the requisite calculative efficiency [62].
Real-time simulation online, compared to conventional simulation, may swiftly evaluate behavior of the users and the systems so that the user can "virtually" design and construct a unique simulation. A real-time simulation is done by running one computer with a physical system, thereby feeding the simulation model with IoT-enabled real-time data. [63] The Virtual Factory is a highly realistic simulation from a producer (VF). A VF can be regarded an industrial environment of cooperation with a view to representing virtually a business as well as a simulated plant [64]. Real factories simulation models have been certified by the VF vision, with the aim to produce data and to be operated in real-works formats. With the basis being on the Digital Twin idea as an example, it provides an elaborated faithfulness in simulating and has a key role within Industry 4.0. It extends simulation into the value chain of a production line and combines actual model-simulated data to improve production. This also affects the performance maintenance in regard to the real information. Simulation-based technology is the key function of a digital plant strategy that enables experiments and validation of many models, processes, and products of the production system [65].

3.2.5. Augmented Reality

By using Augmented Reality (AR) in everyday life, new challenges emerge. The goal of AR consists of increasing people’s productivity by equipping necessary knowledge for particular jobs. This new technology offers strong instruments, which function like Human Machine Interaction [66]. One may come across the technological approach of Augmented Reality in a lot of industries, for example, entertainment, marketing, tourism. Recently, AR use is increasing across many production areas as developing technology evolves. The AR technological approach broadens the view of operators by laying down fake environmental data, in which their items complete the actual world [67]. AR may utilize any sort of hardware provided that an interaction with the senses of humans is in place [68]. With Augmented Reality, the capacity to replicate and recycle digital information and knowledge simultaneously, supports assembly activities that might lead to closure of gaps, for example between product development and production operations [69].

The idea of AR is that two scenarios are combined:

1. Digital process of real-life
2. Digital additions of artificially created objects

AR system features are defined as:

1. Capability of combining physical and virtual things
2. Capability of aligning the physical and the virtual things
3. Capability of running interactively, digitally, and at the time of the event.

Using standard hardware, the usage of AR has a great benefit. In other situations, the glass component of see-through might be costlier [70]. Another important advantage in the industrial context on resources is that the Augmented Reality gives scalable and data on actual time, which means that very much of the administrative work may be excluded. [71] On the basis of environmental factors, the software for the AR system, which is selected and obviously differs, for example, in the military environment the appropriate application is zero connectivity, different from the business environment, which requires remote assistance connectivity. Electronic devices are a key component of an AR system to see a real-world mix of virtual components directly or indirectly. The relevant elements may be:

- Capture image element: enough webcams
- Display: to display the pictures obtained by the capture image's virtual information.

In principle, three device types can be utilized with optical options:

- video and optical hand-holder,
- spatial head-wearing
- Projections or holograms.

The unit that completes the process is generating the planned digital data. Enabling components - for activating virtual data display, for example sensors, QR markers, GPS locations, pictures, etc. These AR devices are used as follows in the table to enable the user to view information [72]:

Video	Common digital view for real and virtual worlds
Optical	View with direct overlay of virtual objects in real world
Retinal	Laser light usage for projecting directly virtual objects on the screen
Hologram	Photo-metric emulsion usage to mix real world with virtual objects
Projection	Digital projector usage to project virtual objects on real world objects

AR devices usage

Based on S.P.C (Statistical Process Control) and methodologies of 6σ (Six Sigma), there was a development of an Augmented Reality system solution for production monitoring, related to product quality. By reporting in actual time, it leverages AR on promoting upgraded information, reported based on monitored support of managerial actions. To obtain data, a CAQ system-connection was implemented. The data analysis program CAQ utilized (QDA) for quality - enables the user to validate qualitative objectives. Wirelessly linked to QDA software, the measuring equipment utilized. The QDA program produces reports and automatically exports them to the AR application as a digital record. A tablet was the application's portable apparatus. A decrease of audit times is one of the greatest benefits of this instrument. Maintenance is one of AR's most successful areas. It improves human performance in the execution of technical maintenance activities as well as aids decision making for maintenance [73].

An example of AR's use of HHD (Hand-Held Display) is performing activities to maintain status during a one-by-one product mounting operation. AR program has a written explanation on operation on the bottom where the left-right options are. The subject of diagnostics is another example for the application of AR technology. The usage of an HHD is also a significant example. Flaw analysis and tracking had been performed using an illustration which was three-dimensional. Positioning of the flaws was shown as well as the kind and magnitude of the problems may be observed in a clearer way. Using a tablet and highlighter [74] the operator may then detect, locate, and identify problems.

3.2.6 Additive Manufacturing

Innovations in assets as well as services demand a rigorous, extended analysis and improvement which Industry 4.0 enables using new technology such as virtual reality reproduction. However, in the following stage, there is a production process, which might be a barrier to competition with its associated expenses. The paradigm containing additive fabrication (AM) is increasingly being explored and leads to very practical applications for the actual industry [75]. AM has the potential to replace many current production methods. AM offers new goods, novel production lines and processes with the technological usage. The collective term AM [76] is a collection of technologies allowing ' 3D printing' of actual items. Without customary surpluses, products as single species may be created, thus it is a great benefit. Alternative identical definitions are quick prototyping, scalable production, production based on layers, digitally supported production, can also be referred to by AM technology [77]. AM processes are categorized in seven different types according to ISO/ASTM standard 52900:2015 52900:2015 Standards of the International Organization for Standardization (ISO) (ASTM standard F2792). Kim defines AM technology as a technique for generating a 3D-Object based on materials being deposits on a computer-controlled system. The following can be stated as to some possible advantages of AM [78]:

- Produced components made straight by Computer-Aided Design (finalized components requiring minimum or lack of further processing).
- Personalization by avoiding additional tools, eventually production costs. The production of complicated geometries (certain geometries cannot be obtained in traditional procedures unless divided into multiple sections).
- Manufacture of hollow components or structures for grids (with reduced weight).
- Maximizing use of material towards the approach of "zero waste'.
- Smaller operating footprint related to vast amount components.
- Production on demand and outstanding scalability.

The AM workflow includes the creation of the genomic trial, the design of computer assets, designing of products, models of processing Nanoscale (biological), micro (electronics), macro (individual items) and bigger scalable product (individual) (such as architectural products). In order to produce 3D, in multi-materials or in multifunction, high-resolution features in the form of high-development complicated 3D, [79] new methods, e.g., 3-Dimensional as well as 4-Dimensional printing (AM with intelligent materials) in a high-resolution process. AM technology will ultimately extend into super-advanced technological fields and replace present technologies soon.

3.2.7 Horizontal and Vertical Systems Integration

Operations related to manufacturing, marketing, as well as logistics must design, in line with the information flows by considering automation levels on a collaborative system integration scenario. This also includes the operations of the engineers. Integrating the systems via I4.0 usually is being done in 2 ways: horizontally and vertically. Those two forms of interconnection allow real-time data exchange. The integration of horizontal systems is an inter-contracted integration that creates a linked ecosystem inside the same value producing network for multiple firms that use datasets to enhance the value chain. There must be some kind of independent platform which creates such systems to support an interoperability based on industry standards which enables data or information to be exchanged [80]. Vertical integration is an intra-company integration, networked manufacturing system that is the basis of information exchange and collaboration across many hierarchical levels such as company plan, production schedule or management. Vertical Integration 'digitizes' all processes throughout the whole business, considering all production data accessible in real-time, e.g., quality management, process efficiency and planning. This enables vertical integration to transition to SF in a high level and flexible manner, allowing manufacturing in tiny lot sizes and customized goods. The norms must be the basis of the vertical integration is vital to point out. The I4.0 paradigm in manufacturing systems has a different dimension, according to various writers. The whole lifetime of the product considers horizontal and vertical integrations. The integration of this kind has a basis of vertically as well as horizontally attached components [81]. The breadth of the end-to-end digital integration as a perspective of global digitalized approach where the streaming of a digital model which is defined by interaction and persistence, closes the gap amongst the designing of a product, the manufacture, as well as the end-consumer [82], the purchase and end-of-life of organic matter regarding the system. Final phase includes re-use, re-producing, restoration removal and transportation of products through the different states [83]. Relationship between the three forms of manufacturing system integration, taking into consideration vertical integration, horizontal integration across companies, and integration between design, production, and logistics.

3.2.8 Autonomous Robots

The example of manufacturing moves quickly from mass production to custom manufacturing, e.g., an automated production which requires robots. This tendency aims towards an adaptive productivity for a larger range in size, with the optimum concentration on batch size. It affects manufacturing systems. Robots are now important in manufacturing processes that want to reach increased areas of flexibility [84]. With this regard, microprocessors ability as well as AI, alongside their capabilities to grow smarter is defined by the combination of processing, communication, control, autonomy, and social capabilities. Adaptive and adaptable AI robots can enable manufacture of diverse items and hence decrease production costs. Moreover, a robot can likewise be regarded as an AI. Procedures such as product creation, manufacture and assembly are processes that are extremely helpful for adaptive robots in production systems. It is essential to mention that completely autonomous robots decide themselves to carry out tasks without human intervention in a continuously changing environment [85]. With regards to autonomous robotic characteristics, industrial and non-industrial settings, unstructured applications in dirty or dangerous industries can be enhanced in close cooperation with an Autonomous Industrial Robot (AIR). Developed a collaborative strategy for a multiple autonomous robot comprised of robots galvanizing and spraying. By deploying several autonomous industrial robots that function as a team, a wider range of production applications may be achieved. A further multi-robot method in a collaborative assembly sequence that covers the setup of the robot for the grab of assembly pieces and the construction of complicated structures such as chairs [86]. The notion of collaborative robotics also brings robots close to people. The concept of SF involves intimate cooperation between collaborative robotics (cobots) and humans. These collaborative robots are a type focused on interacting in close co-operation directly and physically with people. The feasibility of manual guidance is based on the restrictions that already exist [87]. Humanity barrier breaks down for industrial firms, providing greater cost and flexibility in solutions [88].

3.3.9 Cybersecurity

Devices are connected more and more online every year. Thus, idle things will be the major data origin. This creates numerous open options, such as Internet of Things, cloud databases, VMs and so on, which increase the vulnerability of individuals to compromised information in manufacturing companies. As corporate borders are unclear, the risk scenario becomes a reality. A novel approach on data safety, cyber security (CS) [89] is spreading to industry settings and IoT through a "cyber" phase. CS is a technology that protects, detects, and reacts to attacks. In each point in the production process, IoT must be built on security communication and security interoperability between installations must be guaranteed as they are the core components. I4.0 technological setups must make it possible to create a safe cyber environment that benefits CS. Direct attacks on industrial control systems by criminals and software can be seriously impaired (ICS). These industrial ICS mainly include supervision control systems (SCADA), DCS, Cyber Physical Systems or PLCs. These ICS are mostly controlled by industries. CS is a technology that protects, detects, and reacts to attacks [90]. Manufacturing may be terminated by cyber-attacks, and firms are thus losing money, but the major concern are cyber-attacks aimed at systems which operate security that can pose grave risk to operators' well-being [91]. A different approach on production environments with respect to possible intrusions e.g., changing the design of a file (CAD files, tolerances-related), modifying production processes (CAM), functionality of machines, process-manipulation / manufacture of process information (such as maintenance indications of machines). Such assaults may postpone product introduction, force changed items to be manufactured, damage consumer confidence, or raise the cost of guarantee. Internal and / or external sources could be the cyber assault.

In Fig. 10 an internal cyber assault can be performed, wirelessly, through humans or physically through the systems. ICS security's urgency must be addressed automatically. For a range of industry assaults, the Automatic Incident Response can be facilitated by Software Defined Network and Network-Function Virtualization (SDN & NFV). An architecture in private clouds allows the incident response to ICS (cost-effective investment). Both make it feasible detecting and replacing malfunctioning assets by virtually implementing these systems through automated incident response. These technological approaches have been designed to increase network visibility, network capacity, networking as well as software-controlled functionalities rather than intermediate hardware boxes. The integration of the SDN and NFV, however, demonstrates a comprehensive strategy for the new ICS protection solutions [92]. The idea of IEC/ISA-62433 deep-seated defense, with the inclusion of the three measurements, the multilayer security ICS approach, as techno-logical, organizational, and human-centered. This idea must be subject to security checks on networking as well as on the level of the systems. Updating security controls is constantly required, as presented below:

- Device level - when new security patches have been installed.
- Network level – when new threats have been updated with firewall signatures.
- Network level.
- Level of plant/factory - with the real log sources analysis and surveillance.

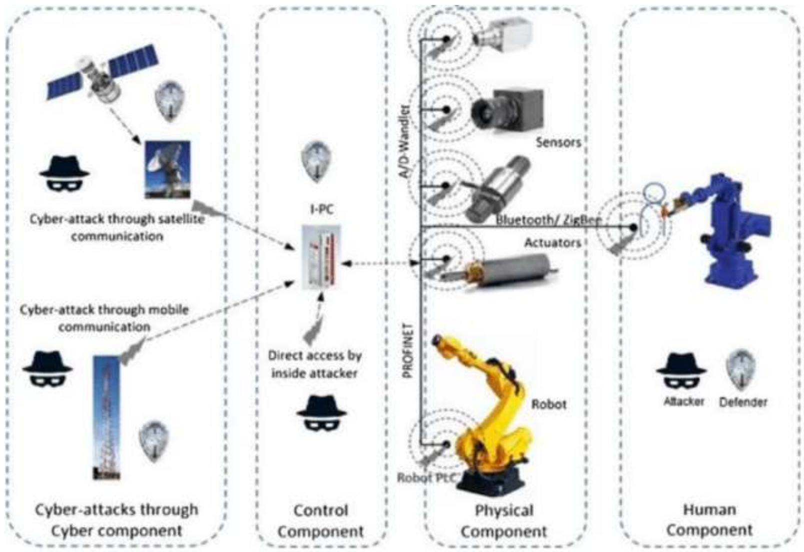


Fig. 10 Cyber-attack routes in an industrial Scanning

4. Digital Twin

Manufacturing is entering the new digital era alongside with all the technological advancements. Against the backdrop of digitalization, the industries are confronted with global difficulties as digital technologies progress rapidly [93]. Strategic approaches on manufacture as well as the equivalent Chinese effort have been initiated. The goal these methods have are related to attaining intelligent production [94], which is usually referred to as intelligent production. A comprehensive comparison, however, shows that the notion of intelligent production and intelligent production differs. Since the 1980s, intelligent production has been in use as the confluence of manufacturing and artificial intelligence [95]. However, with AI evolving, intelligent technological advancements (e.g., IoT) [96], are gaining center stage in smart manufacturing [97], such as Cloud Computing, Big-Data Analytics, Cyber-Physical Systems as well as Digital Twins. Manufacturing shifts from intelligent manufacturing based on knowledge to intelligent smart production based on data and knowledge where the word "smart" points at generation and data usage. This means that intelligent production is regarded as a novel production which stresses modern ICTs usage as well as advanced data analytics [98]. The phrase "smart manufacturing" alludes to a production in a future status that creates intelligence in conjunction with models-driven simulation and optimization for transmitting and analyzing data in real-time on all areas of production [99]. In addition to being its core, cyber physical integration is a key requirement for smart production. CPS and DT Shave have been given special attention by academics, business, and the government, as the preferred way of this integration. The specialization of the main CPS and DT technologies might be termed smart manufacturing. CPS systems combine the cyber world with the dynamic physical environment, are multifaceted and complicated. CPS grants services via assimilation and co-operation of computation, communication, and control, mentioned here 3Cs [100].

Physical and computer processes are highly interconnected with intense connections and feedback loops. To achieve real things monitoring in a full-scale and business-appropriate manner [101], there is a parallel achievement of cyber-physical assimilation and ongoing interactions. The DT is another cyber-physical integration idea. To replicate conduct in real time while offering data [102], a Digital Twin produces high-faithful virtual physical object representations in virtual space. A DT represents a bidirectional dynamic mapping process, it breaks boundaries and offers a comprehensive digital footprint of items throughout the product life cycle. DTs therefore let firms to forecast and identify physical problems, optimize production processes, and deliver better goods [103] sooner and more correctly. Cyber-physical integration is described by CPS as well as DTs. We should investigate and analysis CPS-DT distinctions, including their origins, cyber-physical mapping, hierarchical models, to emphasize the difference and link between CPS and DT, and core elements.

4.1 Fourth Industrial Revolution and IoT

The fast growth of technology related to electronics, IT and sophisticated manufacture, transfers manufacturing modes to smart modes, deriving out of digital breakthroughs. This new age of technology characterized by CPS that include virtual reality approaches [104]. The new challenges have steadily reduced the advantages of conventional manufacturers. Smart technology of manufacture is therefore the high-tech field in which industrialized countries are paying greater attention. Proposals on the field are Europe 2020, Industry 4.0, and China production 2025. The US has progressively sped up the reindustrialization and reflow in production [105]. The revolution of smart manufacturing has a significant and enduring impact on future international production. There is a big necessity of building an intelligent line of business to accomplish advanced production using interconnectivity and the data, within the context of intelligent manufacturing. Additional consideration should be taken of the state of play and of production requirements when implementing a smart factory. Due to the various features of the area of production and information, many technological difficulties still need to be resolved to speed up the route of intelligent manufacturing.
These are the major aims:

- Physical equipment must be supplemented with support for the capture of real-time information at the physical resource layer, and communication devices should enable high speed information transfer. The workshop should make it easy to reconfigure and modify. In order to satisfy the Internet of Things criteria, the information of underlying equipment must be upgraded (IoT).
- The Industrial Internet of Thing (IIoT) network layer should promote highly flexible, scalable, and new data protocols and formats while the Industrial-processing Wireless Sensor Networks (IWSNs) are creating new prospects in the development of industrial networks. Aiming on guaranteeing network QoS (Quality of Service), reliable communication as well as cooperation between equipment, other relevant technologies need to also be a part of it.
- The cloud platform would need to have the ability of evaluating different data in the data application layer. Therefore, ontology is used in modeling the clever factory, which can offer the ability to organize, learn and adapt themselves. In addition, data analysis may offer background of AI, whereas data mining should have the capability to optimize and maintain ongoing activities.

4.2 IoT Ascent

Having already mentioned it, Germany calls "Industry 4.0" [106] the growth of Internet of Things. IoT constitutes the essential idea in integrating all intelligent devices that are part of large intelligent projects. The digitalization of the World Wide Web and portable technology which is highly interconnected brought transformation on traditional company paradigms. [107]

IT products/service manufacturers and producers of conventional items were confronted with how to boost demand growth. The solution was found in the emergence of a new technological age, marked by the global interconnectedness between economic and social activities and the provision of systems consisting of mobile networking and sensors [108]. The interconnections of communities, online media, hardware, sensors, cloud-systems as well as microprocessors were therefore created in a "complexity cross"[109]. In short, IoT is crucial if there is a connection to the Internet, to a gadget or even a life span. Each item may be connected and networked, and various business models incorporating internet and connection will have to be created within companies [110]. In this mode, the 'intelligent economy' changes the way additional value is created. Production sources may shift, but the Internet will provide more services. Smart mobility, automotive and other examples of industrial Internet, mechanical engineering and heavy industries are already evident nowadays. For example, in smart homes where a refrigerator and a gaming console with IP numbers may be included along with a TV. The internet now is connected through personal computers, tablets, and smartphones to more than 1 billion people. In future, it is anticipated to be linked to small devices, such as simple or sophisticated sensor systems and micro-computers, which for several years or decades can operate independently without any extra power and above all, the gadgets will communicate over the web [111]. In all industrial industries, the smart, connected product breakthrough is obvious. Companies that have not been engaged in the production of IoT device development [112] now enter this market. Based on the research, Internet of Things categorization of the applications could be as follows:

- Intelligent framework: Intelligent gadgets become part of the building. This assists on enhancing infrastructure operations flexibility, dependability, and efficiency. Its value added includes decreased expenses and requirements for manpower, as well as improving security. In order to manage the linked house, Apple built a smartphone application. These apps enable the control remotely of door statuses which are online connected, temperature adjustment, refrigeration food supply control, etc. They will play a significant part in the mobility control of smart cities (e.g., parking availability surveillance, traffic control).
- Healthcare: patients are monitored, and information is sent to physicians via sensors (e.g., incorporated into home or smartphone applications). T-shirts that measure burnt calories, movement sensing, and heart rate and so on have begun being manufactured. The produced data is sent to smartphones. [113].

- Supply chains/logistics: by giving more detailed and current information than it presently is decreasing counterfeit, and improved usage IoT may enhance the logistics and supply chain efficiencies. [114]
- Security/privacy: The different applications and hardware are wirelessly connected and information vulnerability to intrusion rises in the public system and so the transmission of data should be encrypted. No unauthorized access must be granted for data transport and preservation in clouds [115].

4.3 Origin and development of CPS and DTs

The cheap cost and enhanced power of new ITs have made a major contribution on the emerging need of utilizing both Cyber Psychical Systems and Digital Twins, with the transformation from conventional to new IT. By being the preferred approach to integrate digital and physical to smart production, they radically transform conventional production processes, as well as business models.

4.3.1 Origin and development of CPS

Cyber-Physical System was generated back in 2006 by extensively applying the usage of embedded systems and was created by NSF as a concept to describe systems more sophisticated which cannot be represented in standard IT terminology [116]. The highest priority problem in research funding in the United States was subsequently identified as CPS. The basis and cornerstone of I 4.0 are grounded on Cyber Physical Systems, presented firstly in Germany [117]. CPS may undoubtedly offer enormous economic advantages and substantial changes to present industrial operations. Current research on CPS nevertheless concentrates largely on discussion of idea, design, technology, and challenges [118] whereas CPS instances are still very early in engineering practice. Compared to embedded systems, sensors and IoT technology, CPS is fundamental since it does not refer directly to implementing techniques or applications. The NSF's statement that the CPS research effort will explore new scientific underpinnings and technologies [119] therefore should be categorized scientifically rather than an engineering category.

4.3.2 Origin and development of DTs

In 2003, during a presentation on Product Lifecycle Management, Michael Grieves presented the term “Digital Twin”. At the time, due to the limits and immature nature of the technology, practically there was no availability of theoretical or practical applications. NASA as well as U.S. Air Force have used Digital Twins to resolve challenges of the increasingly complicated engineering system for the preservation of health and remaining usable life expectancy of aerospace vehicles [120]. Progress in the new IT sector currently allows DTs to develop. DTs have now opened an approach in synchronizing physical and digital activity, making it a hot area of analysis. Recent applications include product design, manufacturing line design, optimizing processes and forecasting in several industries [121]. DTs are also recently being used in numerous big companies, such as GE, Siemens, Bosch etc., where DT's industrial practices, are employed to enhance product performance, production flexibility and competitiveness. From this point of view, DT's engineering applications are everywhere.

4.3.3 Recapitulation

Both CPS and DT profited from developments in new ITs from the standpoint of their genesis and development and made them appear almost at the same time. Both have received substantial interest from scientists in related disciplines and from professionals of business as viable ways of attaining cyber-physical integration. CPS are like a scientific category compared with each other. On the other hand, DTs are like an engineering category. Engineering systems can attain improved accuracy and better management in industrial operations using DT technology.

4.4 Mapping between physical and cyber/digital worlds in CPS and DTs

The notion of employing a digital copy of a device to carry out physical-world performance is characterized as a Digital Twin. CPS has the definition of integrating computational and physical processes. CPS and DTs both comprise the production's real as well as digital component. First part comprises of several production resources of manufacture, that can sum up as "human/machine/material/environment" as illustrated in Fig. 11. These physical resources are employed for production. Including smart data management, analytics, and computer capability [122], the digital component has different omnipresent apps and services. Services and applications offer broad functionality to enhance productivity for manufacturing participants. The physical component receives and senses data, makes choices based on the digital element and analyses and transforms data in the digital part, making decisions thereafter. The digital component can influence real processes through this extensive connection and vise-versa impact digital processes [123]. As a paradigm we have users with authorization that may check actual machine handling and observe a controlled device's run-time status (e.g., computer numerical control) [124].

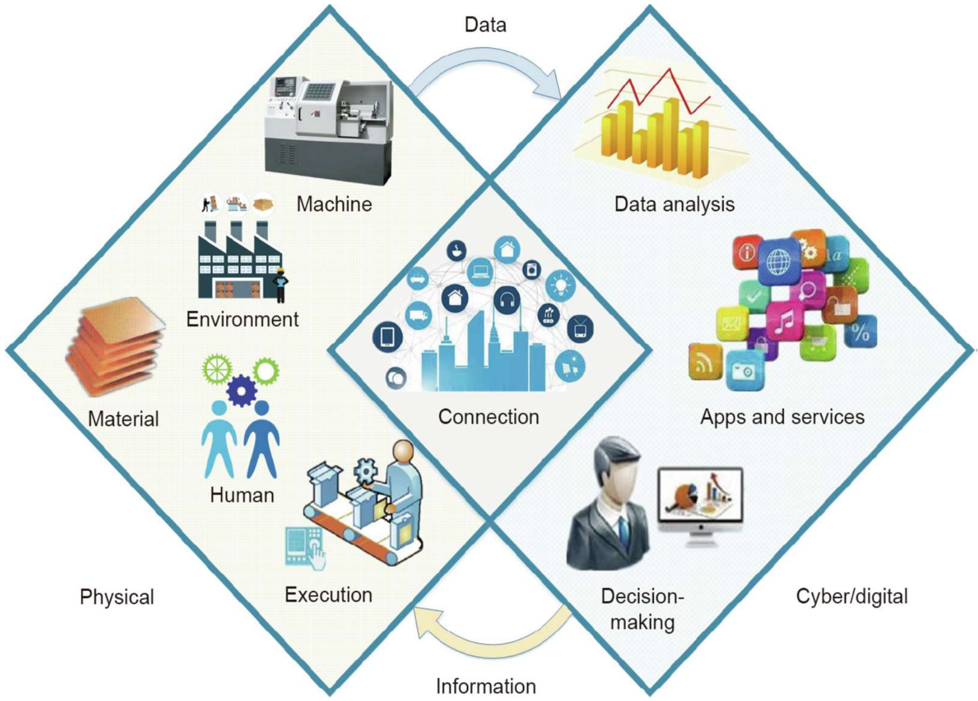


Fig. 11 The mapping and interaction between physical world and cyber world.

4.4.1 Cyber–physical mapping in CPS

Physical systems are added to new capabilities through computer and network interacting extensively on the production line, is the main aspect of Cyber Physical Systems. With aim on providing real time sensors and controlling dynamically on complicated structures, the CPS feature is tightly integrated [125] amongst 3Cs. The stronger computer and communication skills in the cyber world are emphasized in CPS, compared to DTs, which can improve physical precision and efficiency. In addition, all CPS architectures that researchers support focus not on mirrored models, but on control, whether it is a three-tier, five-level [126] or an architecture based on service [127]. As with DTs, CPS has crucial feedback loops. The operations of the CPS are enabled through bilateral mapping, live streaming, and effective cooperation amongst the two different environments. More than one physical object may however be affected by the computer system. For instance, a structure can contain several hardware parts. Interaction amongst the two environments of CPS hence is multidirectional.

4.4.2 Digital–physical mapping in DTs

DT's objective is to present an overview of an asset, product, or system physically as well as functionally. The first is the creation of high-faithful duplicate digital models to represent the form, system roles, behaviors, regulations that comply with those of reality in a similar manner [128]. In shape and structure, the duplicates do not only correspond to every actual piece, but may also imitate their space-time status, behaviors, functions, etc. [129]. The digital duplicates and the real things look similar, twin-alike, copied representation and they behave in the same way. In addition, the models can optimize their operations and adapt the physical process directly via feedback in the digital environment. The real things with their digital duplicates grow together through bi-directional dynamic mapping. The link between these two realities generates a Digital Twin, thereby produces an ideal match. A digital duplicate that includes geometrical, structural, and functional qualities, combining the relevant regulations as well which in total serves as an individual real thing. [130]

4.4.3 Control in CPS and DTs

Control's purpose is preserving a system in reaction to disruptions at an acceptable level of regular operation. Control is the CPS and DT's main function. CPS is of critical importance, for instance, for cyber–physical interaction. A DT is co-developed through either a products or a system's virtual model and physical process during their life cycle. CPS and DTs controls contain two aspects: real properties and procedures that affect the digital duplicate as well as management of physical properties or procedures in the digital duplicate itself. The physical environment is dynamic for the former portion of the control, and one asset can have dynamically changing characteristics on different timeframes or moments. In order to ensure consistency, real-time physical information is gathered via sensors that are then transmitted to the digital environment, to synchronize the digital framework, aiming on imitating the actual procedure and the growth, physical data drive virtual models, especially for a DT. The digital environment gathers the information to calculate the control factor and transmit the result towards the physical executional sensors/systems for the later phase of the control [131]. For instance, future conditions and faults can be forecasted by mathematical models and associated computational tools, which enable the generation of improved service and management solutions in advance. Thus, cyber physical interactive control may eliminate some disturbances, including dangers of an unanticipated and malevolent character. [132]

4.4.4 Recapitulation

As illustrated through preceding theories, CPS and DTs guide us on intelligent production by creating a loop amongst the digital and real environments with the basis of sensor status, live analytics, decisions based on science, and accurate implementation. Nonetheless, Digital Twins give an increased natural as well as efficient technique on enhanced engineering thanks to its virtual models. The capacity of DTs to deliver associated solutions can be increased by constant data integration. The employment of virtual models as supplements can enhance the configuration and functionality of CPS, making Digital-Twin the basic technological approach for CPS build-up. Combining CPS and DTs, assists producers to manage more accurately, better, and effectively.

4.5 Hierarchical Model of CPS & DTs in production

Intelligent production is a high-valued process that involves several areas. Starting on designing toward production level, ending at transportation or services. The CPS and DT scanning are separated by unit level, system level, and System level Status (SOS) according to importance and magnitude from a hierarchical point of view.

4.5.1 Unit level

Unit level points towards the units of the production, e.g., RFID component or device (sensor) and the environmental factor [133]. This level also addresses the tiniest unit involved in the production. The physical components of these production elements are CPS and DT unit levels. For instance, the CPS level can be regarded CPS for the machinery with sensors and embedded systems. The unit levels provide for more efficient and resilient machinery by the flow of data and data processing [134]. CPS and DT unit levels share the same material and component physical subjects, including equipment. Both can emerge in the cyber-physical interaction process together with physical processing, assembly, and integration. On the other hand, DT unit level needs to be developed by description and modeling of all the various characteristics that consist of the real asset at a unit level (form, data, condition etc.). In addition, DT can do very accurate visual simulation, as DT focuses more on model building, such as geometry, rule, behavior and other.

4.5.2 System level

On the level, numerous CPS or DT unit levels are connected and interoperable through a multiple industrial network, allowing a broader spectrum of data flow and resources to be coordinated. Incorporation of numerous CPS or DT unit levels is at this level a CPS or DT system level [135]. The system level of CPS or DT is a reproduction of workflow, which means that it can be a line of production or even a manufacturing business. Based on the closed sensory/analytical/decision/execution loop, CPS or DT systems can optimally allocate production resources, and can enhance the efficiency of co-operation between different resources. CPS and DTs at system level share the same physical production system at system level. The virtual components of a CPS are little distinctive in comparison to the components of a CPS system level. Nonetheless, DT system level virtual templates must be developed through numerous model-level integration and cooperation. In addition, complex products might be regarded as system-level DT. For example, a motor DT is utilized to examine the current condition, predictions, and deterioration, whereas a wing DT is utilized to assess flight altitude [136] as a case, in the scenario where the airplane is composed of different things. The different units linked with each other model the end Digital Twin as a product with complexity.

4.5.3 SoS level

On the previous level, the creation of an intelligent service platform can provide the basis for cross-system connection, the interoperability and the joint optimization among system levels CPS or DTs. The SoS level is formed through numerous system level CPS and DTs with the interference of the service platform. In comparison to the CPS system and the CPS software-level, the focus is on integrating business and associating it through the company. The company could offer a range of cooperative functions including cooperation on trade, cooperation with the supply chain and co-operation in the field of manufacture [137]. Joint effort between manufacturing, designing and service organizations, for example, can activate adaptations, intelligent scheme, maintaining the hardware remotely etc. In terms of Digital Twin, the option for simulating and continuous flow throughout the entire life cycle from one phase to the next are key. A SoS-level DT is therefore an integration of several phases in the production line. This data pulls together all components of the product life cycle that might be relevant in different periods of the ongoing process or the ones that will follow [138]. It is the layout of the basis for creative products while monitoring closely the quality. As a paradigm, production and maintenance information can also contribute to the development of the following generation. A SoS-level DT can compress the designing and it can dramatically minimize time and financial costs.

4.5.4 Recapitulation

Implementing a Digital Twin is a complex and long-lasting process. It can be applied by following the 3 stages according to the hierarchical structure. Firstly, by creating it on unit level. Intelligent evaluation, control and status overview can be carried out based on the DT unit. The next stage is to develop the system level. The system level can be formed on several unit levels, allowing intelligent production. Finally, the SOS level is achieved because of unit level and system level.

4.6 Function implementation of CPS and DTs

Cyber Physical Systems and Digital Twins are intended to establish assimilation between the virtual and the real world, which is advantageous for intelligent production. However, each one has its own emphasis in the execution of functions. Sensors and actuators have been viewed as the major modules by CPS, and data and model systems are built on a model-driven system engineering approach. The new IT, which supplies its technical bases, is not separating both the CPS and DTs.

4.6.1 Function implementation of CPS

CPS integrates technologies that provide accurate overview, cooperation from distance, automatic control as well as various tasks for physical processes. Physical processes are tightly interlinked with CPS. Data comes from intelligence. For data interchange, which is the most significant component of CPS [139], the hardware parts that provide the data have the job of interacting with the actual field, because they are responsible for perceiving physical and environmental situations and executing control commands. The enormous gathering of data as well as status identification is conducted via numerous sensors shared on the actual hardware to be able to interact between the two different worlds. Preset criteria are the basis of generating the control requests and acceptable check definition through data management, processing, and analysis inside the virtual environment. The findings consist of feedback from the actuators which perform control operations to respond to alterations. Data & Control busses support live communication and information transaction. Any changes in physical process using sensors and actuators (for example, behavior, circumstances) trigger changes between the virtual environment and the opposite way. They can therefore be regarded as key aspects of CPS. [140]

4.6.2 Function implementation of DTs

Main concept of Digital Twin is generating a digital replica of real devices, to replicate condition and behavior, to analyze and model their behavior, finally providing feedback to prevent and control their future status and behavior. Due to the dynamic change in the status, behavior and qualities of the physical environment, continuous production of all data types takes place, consumed, and saved up till a product is available [141]. To maintain consistency, the DT includes complete components, the whole business and process information. Models that include geometry, structure, material qualities, regulations, procedure, etc. allow the digitalization and display of the system and process of production. In combination with analysis of data, DT helps producers to foresee, decide rationally and manufacture in a more precise manner. In addition, the models generate fresh data throughout the co-evolution of models and physical processes. These provide transmission and registration methods to analyze and forecast behavior of tools, machinery or systems based on live data, historical data, experience, and model data. Models and data can therefore be viewed as the DT's essential elements. [142]

4.5.3 Integration of CPS and DTs with new IT

Nobody can nowadays define the novel Information Technology, with regards to smart and industrial technology integration. It is a vertical as well as a horizontal IT integration between many companies or sectors. Essential components include IoT, CC, BDA, and AI. A considerable number of different types of data owing to digitalization [143] are being generated by the production resources. Due to the IoT, data may be saved and computed in real time. CC can easily satisfy the needs of data computing and storage by uniformly supplying resources and Big Data Technology may efficiently exploit usable data to improve information value and meet the dynamically increasing challenges. In emerging information technologies, the IT components are essential parts. The progress has been profoundly influenced by the CPS and DTs. CPS is a vital part of the new IT, first and foremost. The IoT and technologies of manufacture via the cloud mean unique CPS in production, whereas the Big Data are additionally intriguing inside these applications [144]. By means of intelligent processes, CPS is a development of embedded Computing Systems through an IoT architectural approach. By integrating the CPS to the cloud, we can reveal cases and workflows that meet I4.0 requirements [145]. Artificial Intelligence gives the opportunity throughout the entire system to behave as a human. As for DT, the management of industrial IoT is regarded a novel way. Integrating cloud technology with DTs ensures that storage, computing, and communication are scalable. Also, crucial foundations for a DT are the relevant algorithms supporting the technologies.

New IT plays an essential role in the examination of prospective operations by several analysts. DTs are faster and easier to integrate new IT than CPS. In addition, several firms, including GE, Bosch etc. have introduced new IT into their applications [146].

4.6.3 Recapitulation

The functionality of the two approaches attempts to improve the efficiency, robustness, and intelligence of physical processes. Different applications have been highlighted by their respective emphasis (For example DT models, data etc.). Both must, however, be included into new IT.

4.7 Correlation and comparison of CPS and DTs

CPS and DTs are seen in a wide sense and describe a merger of the virtual and real world. They have similar features. CPS and DTs, however, are not the same. As mentioned before, this part presents a correlation and comparison with a quick overview in detail. CPS and DTs have been suggested about at the same period. The DT received little consideration until 2012, when the DT Concept began to be used. As stated by Gill, however, CPS has attracted governmental and academic regard and I4.0 has listed CPS. DTs became popular following a few of years of development. CPS is closer to a scientifically approached case, while DTs closer to a category of engineering. In the process, the real and the virtual worlds are involved in both CPS and DTs. Cyber-physical interaction and control make it possible to manage and operate physically in an accurate and superior way. Regarding the Internet world, however, the focus is given to CPS and DTs. DTs are directed towards the digital replica that allows matching inside the DT, and on the other hand CPS stress the capacity of 3C that leads to one-to-many matching processes. In terms of function, sensors and actuators allow data transmission and control interchange amongst real and virtual environments. Models, by comparison, play a key function in a DT in the interpretation and prediction of the real-time performance on different input basis. Sensors and actuators can thus be regarded as central parts of CPS, whereas models and data are those of DT. The hierarchical levels are divided from a hierarchical point of view. However, given that the basic emphasis is different, they contain separate structural items on every layer. In the end, both increase the capabilities of manufacture by giving optimum solutions to help implement the intelligent manufacturing process by integrating them into modern IT.

4.8 Material and Methods: Current Technologies Deployed in Digital Twin

A digital twin system is about integrating diverse technological advancements which are integrated and lead to the development of many roles. The following sub-sections detail the technology utilized in the proposal model to highlight its position in the DT and the issues associated with their installation as well as usage.

4.8.1 Industrial Internet of Things and Digital Twin

Using IoT systems in a practical application recently has led to accelerated advancement and spread because of the increasing number of embedded sensors, low-power Wireless Communications and signal processing methods. IoT allows connections between the actual environment and the virtual one, replicating objects and processes, collecting information, AI and giving instructions to the associated objectives in real time. Digital Twin depicts a physical process' dynamic digital replica. Digital Twin's backbone mechanism is IoT to collect live data and multiple sources. As the amount of data collected with IoT-sensors increases, the more a Digital Twin may imitate the physical thing. The potential challenges of research can be summed up below.

- To begin with, DT reaches the limit of sensing capacities into the actual environment. The industrial IoT is more practicable with sensing techniques that control physical metrics in industrial contexts and utilize fewer resources. Lightweight and robust monitoring can be supported using wireless and battery-free sensors. In recent years, many research motivations have arisen as regards how to expand wireless signals [147] and how to prolong battery life [148].
- Second, the processing of massive networks requires a computer architectural update to reduce the processing time, for example collaborative edge computing [149], and enabling a source restricted IoT mechanism with novel analytical technique is of vital importance, e.g., a thorough understanding [150] to reduce cloud architecture effort and bandwidth saving.
- Thirdly, implementing properly a DT (i.e., wide-scale low-power networks and communication; wireless software-defined etc.) requires effective data communication processes interspersed in the relevant radio chip. [151]

4.8.2 Simulation Technology and Digital Twin

Even though simulation in engineering is established to explore clear and known issues, the core limit must be understood. Most simulation software therefore answers one particular request exactly. Nonetheless, while the intricate model reproduction procedure changes a single part on the outcomes, a new phase of simulation setup is occasionally necessary in complicated data exchange systems. [152] Contrarily, DT is utilized in real time throughout the life cycle, as it represents an actual physical thing digitally. A digital twin can depict the condition of the thing in real time by numerous sensors relating the actual thing to a digital duplicate. Therefore, their joint application consists of a key factor of effective control as well as surveillance. This gives life to digital twins using simulation techniques and makes them testable [153]. Therefore, a Digital Twin Simulation Interface (DTSI) is essential to address products and their simulation phase requirements. For that purpose, data should be kept using appropriate data models in a structured manner. The DTSI can understand numerous attributes and ongoing phases in real time and of updating the actual system with digital model upgrades. To monitor, regulate and improve real operations, prevent failure, and increase efficiency owing to the simulation process, the DT needs to always be side by side with the real environment.

4.8.3 Machine Learning and Digital Twin

For real manufacturing plants, DT utilizes live data. In smart plants, Machine Learning Models (MLM) are a pillar of Digital Twins, where the digitization of production systems is closely linked. Actual data gaining intelligence, upskilled, and evaluated and verify their success are required in the machine learning models. Digital Twin will work in parallel with true production facilities and simulates new production conditions by applying validated machine learning models to find improvements that are possible. Digital Twin is of central importance in the prediction of harmful circumstances at the facility, when the machine learning model cannot be tested with true data, as it checks the actual sensibility of the MLM. The Digital Twin allows operators to use generated data to test the model without real hazards for workers. The approved MLM afterwards forecasts known states that are useable to simulate industrial modifications on the DT. Thus, the DT is effective in enhancing machine learning model capabilities and likewise automates the Digital Twin MLM. In the context of DT, two primary assessments create the MLM complexity:

- Data availability. Machine learning depends on data, and an appropriate machine learning model cannot be developed and implemented without the right amounts and quality of data. Data analyzing, visualizing and integrity inspections, data quality validation and data meaning comprehension are vital. Industrial organizations, with multiple analog PLCs (Programmable Logic Controllers) as well as some digital monitoring systems, nowadays often lack digital data.
- Complicated setting alongside with the human factor. Various industrial contexts are complicated and involve procedures, assets, and individuals that partially interact by linear correlations of a work cycle, partially by non-linear, perplexing, or unforeseen relations. Because of their variety and irregularity, industries are systems challenging on simulation and prediction.[154]

4.8.4 Augmented and Virtual Reality and Digital Twin

The Augmented Reality (AR) and the Virtual Reality (VR) are among those who profit from DT because it gives a digital and actual picture of the environment where past and live data flows are built into the human presence [155]. However, the challenging thing is to offer the end-user easily and intuitively the correct information, given the vast volume of data produced by the DT replica. The Augmented Reality isn't replacing the actual environment, thought it permits the ability of viewing by including digitally created items that overlap. Furthermore, it allows users to engage with the actual world to execute certain tasks or to be warned of prospective dangers [156]. The incorporation within Industry 4.0 of these enabling technologies emphasizes their importance to modern factories [157]. The following three main blocks consist in general of an architecture integrating Digital Twin with AR/VR:

1. Calibration: All past processed data is crucial to achieve definite and perceptive visualization using relevant gadgets. Digitally created replicas need to be exactly aligned with the real part to effectively handle it. Calibration is called this process.
2. Control process: Control process is a highly crucial feature for these systems while it enables both parts of DT to be interacted by the user. The respective information can be utilized to strengthen the overall control of the actual part by using the Augmented Reality apparatus after reading the information throughout the increasing process.
3. Augmented process: Users must deliver definite and perceptive Augmented Reality visualization of information by the DT through these devices in an increased procedure. They usually gather information by the digital part and appropriately show it to the user following the calibration phase. Using the existing technology, AR in production presents certain obstacles. You can categorize them in four different types:
   i) Real-time data: an immense number of live information is transferred amongst the production procedure, the cloud, and the Virtual Reality apparatus. All that must be administered to correctly back operators.
   ii) 3D and 2D modeling: for the quality of AR use, it is highly important to recognize, track and follow target object(s).
   iii) Reliability: There is a chaotic production environment, thus this system must be sufficiently trustworthy and durable to perform the jobs.
   iv) User cooperation: Manufacture jobs should be carried out simultaneously by numerous users and operators in order to enable data sharing between multiple devices, the VR infrastructure needs to be sufficiently adaptable.

4.8.5 Cloud Technology and Digital Twin

DT provides BDA methodologies from several sensor kinds on the real system. It is vital to use several computing algorithms which can provide the interactive simulations to build up a DT for a procedure or component of an industrial plant. Each approach demands certain computing resources. One option is to employ a high flexibility cloud infrastructure on the one hand, and high processing efficiency [158] on the other. By using the “Container-as-a-Service" concept must thus be used for managing a high volume of information on the one hand through the cloud, and to support the execution of the algorithm on the other. DT has a series of sophisticated processes consisting of math, computing, and software models, which allow real-time and real process synchronization between Sustainability2020, 12 and 10887 virtual systems. Some companies do offer "Container-as-a-Service" (e.g., IBM, Amazon, and Microsoft Azure) for Digital Twin installation. Detailed information on some of them:

- IBM Watson IoT creates DT for IBM [159].
- DT is referred by Amazon as a JSON file, with data transmission through REST or MQTT architectural approach [160].
- Azure IoT creates the DT by representing it with JSON file [161].

The most known issues based on a DT during the design phase are the data privacy, the security and last but not least the connectivity. The amount of data needs to be stored safely, not to be reached or available to external sources and the connection must be granted for it.

DT presented a promising possibility to integrate the cyber and physical worlds into the manufacturing industry and smart production. DT functionality can be enlarged using the service-orientated architecture. DT can be very applicable in the fields of design, production, and PHM through services. In combination of DT and services, it explains to what degree different digital twin assets are contained and used as services. The research is now only in its infancy. Further effort is required to enhance and extend DT modelling and servicing approaches.

5. Implementation Technologies Analysis of Digital Twins

The digital twin refers to digital replicas of every single thing and technologies, of potentially real physical assets (physical twins). Digital representation presents the consistence as well as the dynamically changing attributes of a physical twin's behavior. The DTs are built on semantically based models that get updates with live sensor data which can be simulated for prognostic evaluation [162]. Digital Twins are interconnected with other I4.0 technologies, as previously presented, the CPS and IoT [163], which provide a paradigm of evolution in intelligent factories smart production. Every single day, IoT technologies gain pace and carry on offering numerous applications that facilitate live overview, analysis as well as decision-making. In order to achieve the actual goal of I4.0 and one of the main technological aspects behind the DTs, Industrial IoT is one of the fundamental foundations. Through an array of IoT middleware off-the-shelf solutions, companies can choose either open source or licensed company applications based on actual needs. For DTs, Eclipse Ditto and Microsoft Azure Digital Twin, both open source and licensed solutions have become available. Open-Source software discloses public inspection, use, and enhancement source code [164]. Open-source software fosters co-operation and reinforcement, with the advantage of being free of charge, lower development costs for software, decreased market time and extensive support, and ability to grow and strengthen. With simple access and flexibility for subsequent extension, they are generally the first choice for research and practice. But industry typically has a tough decision to make amongst the two solutions. At present, industry and academics are faced with a difficulty of "closing the gap" between research and application. However, in today's digital era the technological stack choices are endless, risking standardization as well as compatibility. The value of using the digital twins in smart manufacturing is evident [165]. As international researchers work to accomplish Digital Twin academically, the established technology platforms can be "closed source", but not publicly available. Commercially, high-end technology companies are partly able to enable digital twin technologies, but cross platform unification takes a significant level of expenditure. This gives us the possibility to collaborate with academia and industry, with the expedited development and support via open-source platforms. We propose in this work an open-source toolkit aimed to combine two open-source solutions with DT data architectural layer. Using a dataset, we test the performance of the toolbox.

5.1 Related Work

Offering crucial software capabilities for the use of I4.0 (i.e., management of events and DT) open-source software has been recognized. Currying problems and potential, where 1,000+ open source IoT platforms [166] accessible. Examples consist of Eclipse software such as Kuksa, Hono, Hawkbit etc. A study has been made on the use of various technologies towards transfer, display, and management of data, on open-source solutions, libraries, as well as displays, interchange, and analysis of data. Remarkable micro-service architectural approaches including Apache Kafka, Rabbit MQ, log stash and Influx DB are derived. Today, the industry is making use of open-source technology through collaborative development of IT and OT (Operational Technology) solutions. These platforms are collectively designed to allow digital double-data capabilities including IoT data collection, digital depiction and administration, live data analysis as well as viewing. These architectural approaches are shown in Microsoft's open-source industry data, which is benchmarked with universal testing tools for the understanding of scaling capacity like the 'Apache J Meter.

5.2 Open-Source Architecture

Hereby an architectural presentation of the open-source frameworks for DT and IIoT follows. A short summary is added for the 3 that were chosen. By combining them we get an architectural approach for the DT:

- **Eclipse Ditto** is an IoT technology which implements DTs. It mirrors DTs in the digital counterpart with the actual thing. It maintains the synchronization and is providing API through the web, gives authorized only accesses and provides integration of back-end setups while enabling various interactions.
- **ITwin.js** is a container of iModel which exchanges data linked to the devices and their product life cycle. Their creation enables facilitation of distributing data disregarding where it comes from or what kind it is.
- **CPS Twinning** generates and executes DTs which replicate whole CPS. It enables automatic generation of digital worlds for DTs based only on how they are specified.

5.3 Comparison of Technologies

Over the internet there are many different software solutions to create, operate and support various Digital Twin models. Some are complete platforms providing an end-to-end setup, and others are separate tools to support diverse functionalities that can be integrated in different and more flexible implementations and/or scenarios. As our main goal is to set up a pilot DT application, the research process included the open-source software supporting the different approaches. After extended research, the final comparison, as presented below, was based upon the architecture of the provided application, from which we extracted the attributes that could be implemented in our pilot program.

5.3.1 Technologies

In this section the different open-source software frameworks implementing DT, will be presented with a short description of the setup and their architecture.

5.3.1.1 iTwin.js (iModel)

The architectural approach of iTwin.js framework aims to support services with basis on iModel that run on the cloud or locally, as well as applications on the web, desktop and/or mobile. Its goal is also to re-use the logic of the business and HTML GUI through the applications. The 2 architectural layers are presented in the figure below:

Backend	Frontend
Application Backend (TypeScript) iTwin.js Backend Framework (TypeScript) JavaScript Runtime with C++ Interoperability iTwin.js Native Libraries (C++)	Application Frontend (TypeScript/JavaScript) iTwin.js Frontend Framework (TypeScript) HTML GUI Web Browser

Fig.12 iTwin Layers

iTwin.js backend consists of Node.js programs. JavaScript Engine as well as N-API for creating Node add-ons via C++ are being provided by these programs. In that way iTwin.js Native Libraries can be seen by the relevant backend framework. Mobile apps are written in TypeScript and the relevant APIs are seen from the @bentley/imodeljs-backend. It is worth to be noted that the architectural setup is similar amongst Agents and backends so that the Web Applications can be interacting. [167]
The frontends are running in web browser environments while utilizing HTML GUI in order to present. The APIs seen from the @bentley/imodeljs-frontend use Remote Procedure Calls (RPC) to call services that exist in the backend.
Web Apps transmit data between the backend and the frontend through HTTPS.

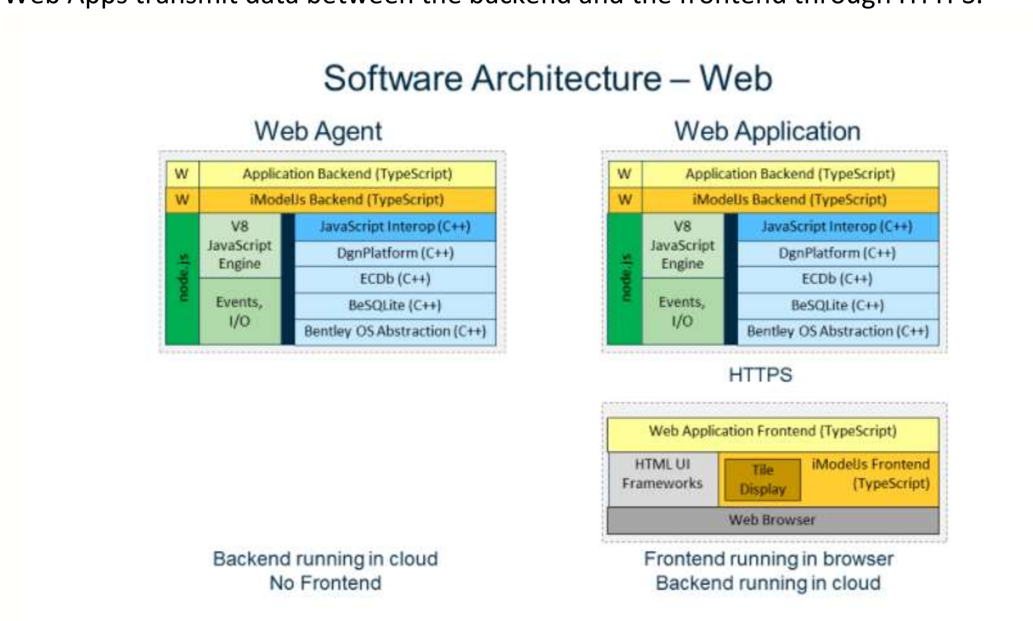
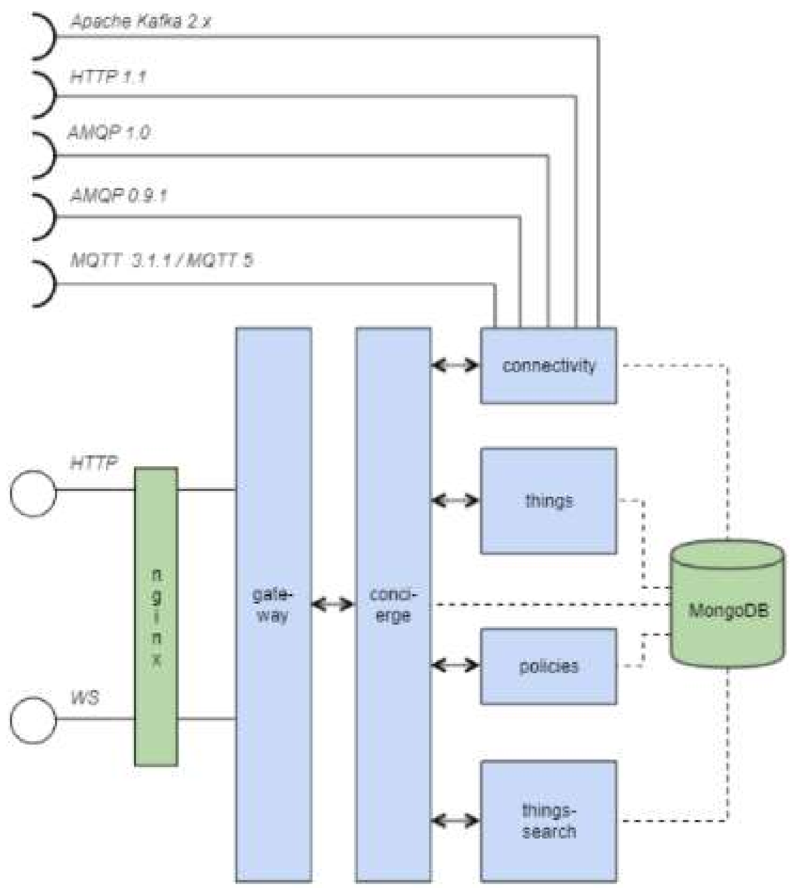


Fig. 13 Software Architecture - Web

5.3.1.2 Eclipse Ditto

The architecture describes the overall architecture of Eclipse Ditto and in detail which sub-components fulfill the relevant responsibilities. [168]
This overview shows the Ditto services (components), the externally provided and consumed API endpoints, the external dependencies (MongoDB and nginx) and the relations of the services to each other.



Ditto services in blue and context with nginx as reverse proxy and MongoDB

Fig.14 Ditto Eclipse Architecture

The components have the following tasks:

- Policies: persistence of Policies
- Things: persistence of Things and Features
- Things-Search: tracking changes to Things, Features, Policies and updating an optimized search index + executes queries on this search index
- Concierge: orchestrates and authorizes the backing persistence services
- Gateway: provides HTTP and WebSocket API
- Connectivity: sends Ditto Protocol messages to external message brokers and receives messages from them.

Supported transport protocols are AMQP 1.0 (e.g., Eclipse Hono), AMQP 0.9.1 (e.g., RabbitMQ), MQTT 3.1.1 (e.g., Eclipse Mosquitto), plain HTTP or Apache Kafka 2.x. Ditto consists of multiple "microservices" as shown in the above component view. A "microservice" in Ditto is defined as:

- has its own data store which only this microservice may access and write to
- has an API in form of signals (commands, command responses, events)
- can be accessed by other services only via the defined signals

All microservices can communicate asynchronously in a Ditto cluster. Communication is done via Akka remoting which means that each service acts as server, providing a TCP endpoint, as well as client sending data to other services.
Therefore, it is required that all Ditto microservices can reach each other's port 2551. Another consequence is that all messages which are sent between Ditto microservices are in a way serializable and de-serializable. All Ditto signals can be serialized from Java objects to JSON representation and de-serialized back from JSON to Java objects.

5.3.1.3 CPS Twinning

The PSE (Production System Engineering) process has set up the specifications for the CPS which are to be followed as long as it is working. The process can also be facilitated with Automation (AML) as an example, for information communication.
Based on CPS Twinning numerous scenarios could be created varying between intrusion detection to machine learning and data analytics. [169]

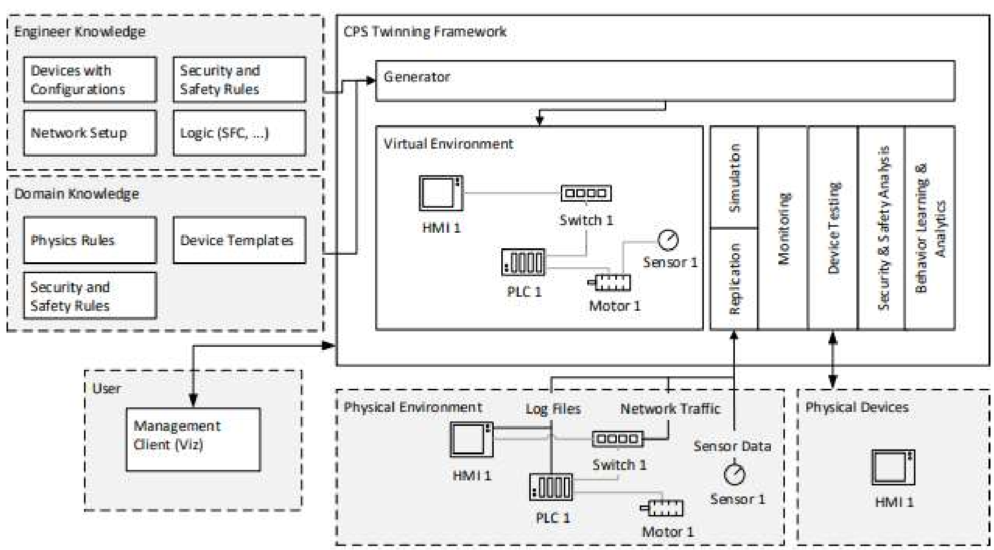


Fig. 15 Architecture of CPS twinning

In the figure above, the architecture of the framework consists of 2 components that visualize the generator and the virtual environment. The generator module takes engineer and domain-specific knowledge as input to create the virtual environment. When DTs and network topology generation is complete, the virtual environment has two options for operation. One option is that the virtual environment creates a simulation mode where DTs have an independent operation in distinction to the physical environment. The other option is the replication mode documents events of the physical environment and then virtually creates clones. The framework includes additional setups which could be triggered by the user randomly, i.e., Device Testing. Based on the attributes describing the architecture, further analysis was also done in regard to the framework which is being proposed by the different vendors. As a result, based also on the table added below, we choose for the creation of our theoretical application, the framework provided by Eclipse Ditto. The main reasons for this choice are the following:

- The flexibility, scalability, and the abstract approach of the "Thing" (Digital Twin), the Eclipse Ditto provides. In this case a "Thing" can be anything from a sensor, a status to a complete machine representation. ITwin.js approach has the scalability towards 2D and 3D models which are not the requirement here. CPS Twinning approaches the DT as a generator of statuses towards the security of a CPS system.
- The backend development in this thesis is not a requirement. The only open source that provides the backend development is iTwin.js. Ditto frees IoT solutions from the need of implementing and operating a custom back end. Instead by using Eclipse Ditto, the focus can turn towards business needs, device connection with the backend and the creation of business programs, which in this case is main focus point in our thesis. CPS Twinning does not provide a backend development solution as its approach is focused on the "real time" security data stream.
- When it comes to the Frontend development, the different programming languages supported led us to exclude the CPS Twinning as the C programming language is not object-oriented which aids us on the setup. Java, JavaScript as well as C++, do all provide us with the facilitation of the Digital Twin creation process.
- Finally, a comparison was made between the different APIs supported by the different Digital Twin open-source frameworks. The REST-like HTTP API of Eclipse Ditto has the advantage of the setup simplification. The variety of the JavaScript APIs of iTwin.js, offers a wide aspect of different solutions and has the benefit of flexibility. Mininet Python API, which is used in the CPS Twinning solution, has the drawback of not being able to proceed with the creation of DTs for wireless devices, as it lacks virtualizing the relevant networks.

	Eclipse DITTO	iMODEL.js	CPS Twinning
Digital Twin Approach	Thing	Infrastructure Digital Twin (2D,3D applications)	CPS Digital Twins (Security-aware environment)
Backend Development	-	ECSQL	-
Frontend Development	Java, Javascript	Javascript , Typescript (C++)	C
API	JSON-based, REST-like API, HTTP API	iTwin.js Javascript API	Mininet Python API

Comparison Table of Technologies

6. Business Process Model and Notation (BPMN)

BPMN standard has been developed by OMG (Object Management Group) as a standard with aim to give a notation which is comprehensive by business users. From analysts to developers to the responsible persons that overview and manage the business processes. A connection is being implemented amongst the design and the implementation processes [170,171].

6.1 Introduction to Workflow Platform (CAMUNDA)

Camunda Business Process Management platform (BPM) is an open-source tool. Aiming on Java developers with the needed software development setup and provides alignment between business and IT through the process design. It is an engine that is being implemented in Java VM. It adds on the process implementation while giving the ability to add actual workflow management, operations as well as live overview. It offers significant flexibility with regards to architecture, deployment options, programming languages and supported infrastructure. Below we will be covering Camunda process engine implementation options, supported infrastructure specifications, hardware sizing and recommended database management systems.

6.2 Process Engine Implementation Options

The flexibility of Camunda BPM is demonstrated with this sampling of implementation options. Typically, initial forays with Camunda use Spring Boot or a shared container, though Docker, is becoming a more popular option. All options work equally well and as a result there is not one specific recommended implementation option. There is no need to stick to one approach for all use cases. Given the licensing flexibility one can create as many environments as needed in any topology required. Only execution metrics in the production environments count toward the license. No need to count CPUs or servers. Development and QA environments are unlimited.

Embedded Process Engine (Microservice):

The process engine comes as an addition to the relevant library of the created application. By that it could be turned on or off with ease while the app is running. There is the possibility to execute numerous embedded process engines above the common database.

Shared, Container-Managed Process Engine:

It starts within the runtime container (Servlet Container, Application Server), being given like a container service and can be used by all applications deployed within the container.

Standalone (Remote) Process Engine Server:

It is provided as a network service. Various apps can interact with it through remote communication, usually via the built-in REST API. Other channels are also feasible; however, they need individual implementation.

Cluster Model

Aiming on providing scalability it may be shared with various nodes within the cluster. Every single instance connects to the common database. Session state is not being maintained individually through transmissions. When a transmission is being run, the full state is being shared with the common database. A possibility arises to guide requests that are working within the same instance towards other cluster nodes. In this model managing is described mostly by simplicity.

Multi-Tenancy Models

To serve multiple, independent parties through a single Camunda installation, multi-tenancy models are being supported as follows:
Table-level data and Row-level data
There is the ability to choose the model that matchers the data separation needs. The APIs offer accessibility to processes and relevant data specifically towards every tenant.

Supported Infrastructure Options
The Camunda BPM platform can be run in any Java-runnable environment and has support in the environments that follow.

Containers for Runtime Components

Application-Embedded Process Engine:

- All Java application servers
- Camunda Spring Boot Starter: embedded Tomcat

Container-Managed Process Engine and Web Applications:

- Apache Tomcat 7.0 / 8.0 / 9.0
- JBoss EAP 6.4 / 7.0 / 7.1 / 7.2
- Wildly Application Server 10.1 / 11.0 / 12.0 / 13.0 / 14.0 / 15.0 / 16.0 / 17.0 / 18.0
- IBM WebSphere Application Server 8.5 / 9.0.
- Oracle WebLogic 12c (12R1,12R2).

Docker

Pre-built Docker images of Camunda Enterprise are available via registry.camunda.cloud. Packaging the components shown below, the Camunda docker images are suitable for the remote process engine architecture.

Hardware and Sizing Process Engine

High Availability: It is recommended to run the process engine on at least two nodes to ensure high availability. The nodes need not to create a server cluster of an application. It is sufficient to connect two of them with a common database.
Virtualization: Camunda can be executed in virtualized environments. This does not impact licensing since licenses are not bound to CPU cores.
Resource requirements are based on expected workloads. Listed below are Camunda's recommendations:

small	Supports most use cases, typical server configuration 1-2 CPU cores, 1-8 GB RAM
medium	Higher volume environments averaging more than 100 instances per second, typical server configuration 2-4 CPU cores, 4-16 GB RAM
large	Extreme volume environment or one where CPU intensive code has been deployed, typical server configuration 4-64 CPU, 16-128 GB RAM

Camunda's Recommendations

A cluster of two small servers should suffice most common projects. Larger configurations should be considered when:

- The system needs to handle more than 100 process instances/second.
- The system needs to support CPU intense delegation code or locally running services like data aggregation or transformation.
- The code or deployment call for unique requirements.

Load testing of deployed applications is the best approach for determining hardware sizing.
In addition, depending on the container the system requires approximately 500MB - 1GB of disk space. Camunda recommends at least 2GB of storage to store enough logs for troubleshooting purposes.

Database Management Systems

To ensure availability, databases should be clustered and running on at least two nodes at any given time.

Recommended Database types

A large variety of database management systems (DBMS) is supported. Camunda recommends Oracle or PostgreSQL for production and H2 for development.

Supported Database types

- MySQL 5.6 / 5.7 .
- MariaDB 10.0 / 10.2 / 10.3 .
- Oracle 11g / 12c / 18c / 19c.
- IBM DB2 10.5 / 11.1 (excluding IBM z/OS for all versions).
- PostgreSQL 9.4 / 9.6 / 10.4 / 10.7 / 11.1 / 11.2 .
- Amazon Aurora PostgreSQL compatible with PostgreSQL 9.6 / 10.4 / 10.7.
- Microsoft SQL Server 2012/2014/2016/2017.
- H2 1.4 (not recommended for production or Cluster Mode).

Database Clustering and Replication

Virtually duplicated database is supported, as well as the clustered, while the data transmission amongst Camunda BPM and the database cluster matches the relevant non-clustered or duplicated configuration. This ensures the reaction to reading on the respective level.

Java

Java runtimes are supported as long as the application server or container supports them.

Database Sizing

The database capacity is dependent on the following:

1. **History Level:** Deactivating History releases capacity where solely runtime data is kept in the database. However, it is advised to keep it to "FULL" to get the maximum audit logging from the process engine.
2. **Process Variables** need to be edited in the database (i.e., with JSON). By activating History Level "FULL" the entry is added into history tables while a variable is altered by keeping stored the previous value. Depending on alterations and storage of variable, additional capacity is required.

6.3 Camunda Platform Attributes

End-to-end Orchestration

Design, automate, and improve all components of the entire business process end-to-end – across different technologies, systems, infrastructures, people, and devices.

Open Architecture

Fit into diverse and complex enterprise environments and technology stacks with Camunda's open and scalable architecture. It provides a highly scalable platform based on open components that can be easily integrated with the most common technical architectures or frameworks.

Standards-based Business-IT Collaboration

Rest assured that your business processes run exactly the way you want, by relying on the power of BPMN and DMN standards as a common language, for developers and business stakeholders alike, throughout the entire process of automation lifecycle.

Developer-friendly Approach

The Camunda platform and tools are easy to get started and use in the environment right away, with full public access to all docs, open APIs to integrate with just about anything, and a vibrant community of 100,000 developers.

BPMN importance

Business Process Model and Notation (BPMN) is a worldwide standard for process modeling and a vital part of success in alignment between IT and business.

BPMN usage is increasing and in universities BPMN is added as a subject. The following points justify it:

Standard

BPMN is institution owned established by world-wide standards. It is supported by various software applications, which means that the dependency on specific products is not that high.

Simplicity

The logic supporting BPMN consists of simplicity giving the option to commence utilizing the notation in short time.

Power of expression

With BPMN the functionality of a process can be described in detail. This can be challenging in comparison to process description. The detailed and thorough modeling is feasible, however, not obligatory.

Implementation in IT

BPMN development aims on supporting the Process Automation. The aid provided by BPMN is highly relevant to the importance of IT in a business. [172,173]

7. Pilot Implementation on Ditto and Camunda

7.1 Business Organization Chart Based on Digital Twin

In order to create novel business patterns and enhancing opportunities for work communities, exchanging information among organizations, building key knowledge as well as valuable points and data transfer to each of the members of these communities. A necessary structural change on the parts of the organization of companies/productive assets needs to be applied. The impact of it, of the management and on efficiently communicating as well as production are important for this restructuring. An experimental stage is carried out in an organization chart of this kind.

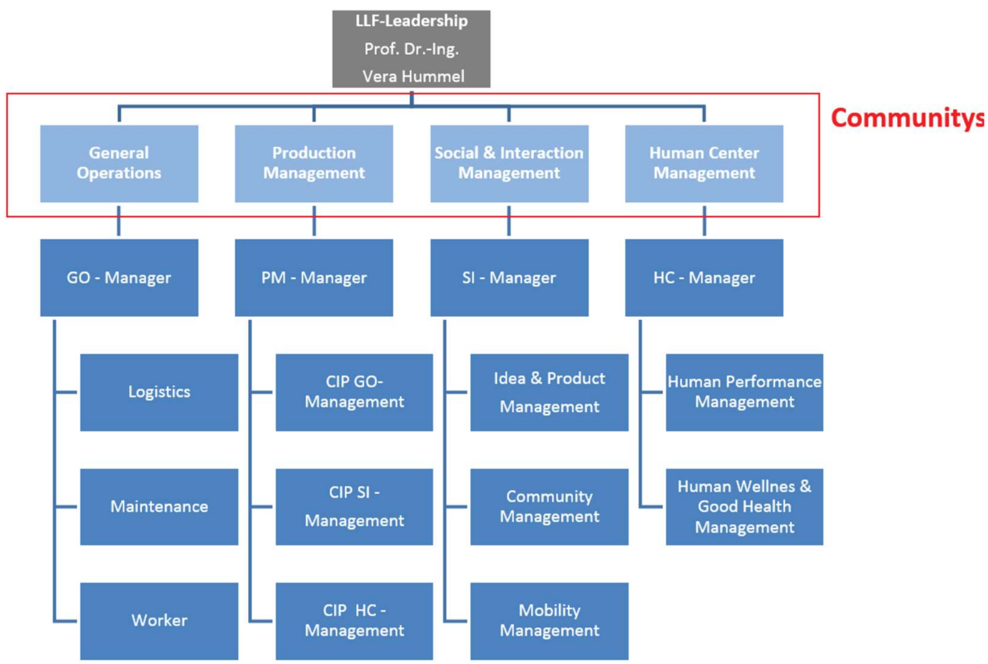


Fig. 16 Communities

Different meetings are held in the industrial unit under the organizational units. Certain difficulties, such as data supply to simulate the production lifecycle and integrate in the database for future analysis for know-how acquisition, need to be resolved at these meetings and structures. Development and display of variables according to a certain situation [174]:

- current data and data of the past
- error and operation history
- forecast performance and other production-related metrics
- performance of workers and machines
- stress and learning curves
- upgrade of product process
- adapt business processes and functions to all of the above

Employees apply for the following week under a new work model individually. Working shifts are to be recorded in the application for a specific schedule of shifts. Working hours can be altered on a daily basis according to demand.

Meetings across departments can be held from anywhere in the world, something already required in the modern international industry. These meetings are facilitated by modern technical tools, with control and interaction panels for reading, receiving, and transferring data from all over the world and via mobile devices.

In these mobile conferences and teleconference sessions, Digital Twin has a significant role to play. The digital image and data interchange makes it possible to directly synchronize the DT with the real manufacturing system – sensors – real things. Simultaneous digital and real model optimization ensures that the meetings take place as quickly as possible.

7.2 Characteristics for the production management in a factory and the implementation with DT

Despite the significant heterogeneity and the quality of the database for the manufacturing of DT data at the manufacturing level, attempts are made to establish a digital pair for the fidelity of the goods and to decrease their cost and production time in the manufacturing sector. A DT needs to be created and validated in order to provide accurate forecasts on the spatial data and time changes in parameters affecting the structure and properties of the components, because of their complexity and geometry. A digitally efficient DT's fundamental building block calculates the different fields and parameters, which contribute to this method.

A DT system that can identify key aspects with structural effect on assets based on scientific principles is one resource that has to be developed. Ideally the framework allows users to define any combined process parameters and to rapidly receive significant variables such as transitional temperature fields, time and space changes, and solidification parameters. This procedure Digital Twin system will substitute or decrease costly and time-consuming physical trials, using fast affordable numerical tests when confirmed with sufficient experimental data.

7.3 Value of DT's

The Value of DTs is summarized below:

- **Enhanced Visibility:** They offer 3D modeling that is being live updated so it can be aligned with the relevant physical parts. Product and system overview can be monitored directly by the staff directly which gives enhanced visibility.
- **Time to Market Reduction:** When it comes to new product design, DT gives the opportunity to check the overall behavior in advance and by this way avoid possible malfunctions which lead to narrowed timeframe of the finalized product to go live .User experience can also be enabled via the digital replica generation through the DT, substituting the final product.
- **Optimal Operation Maintenance:** In order to maintain the optimal operation, the DT ensures the options to visualize the actual performance and state of a physical asset. In this way alterations and changed can be quickly implemented through the analysis of the performance under various conditions. This is being done via the connection of the virtualized models inside the DT.
- **Energy Consumption Reduction:** Due to the real-time analysis of the status of a component via the DT, replacements can quickly take place to avoid degradation leading to reduced energy consumption. Furthermore, DT interconnectivity can also be implemented. These leads to an alignment and proper workload distribution aiming on reducing the energy consumption.
- **Maintenance Cost Reduction:** With the information generated by the components, a prediction of a failure can take place. Prediction of possible failure well ahead by the DT through combination of digital and physical parts, leads to reduction of downtime and maintenance costs.
- **User Engagement Increase:** For design schemes optimization, user interaction with digital replicas through the DT which leads to an analysis of product behavior and user reactions. In this way the end-product can be improved based on the data provided in order to be adjusted to the end-users' wish and convenience.
- **Information Technologies Fusion:** Various IT aspects (i.e., Big Data, IoT, 3D modeling etc.) can be included and adapted by the DT to achieve accomplishment towards the complexity of products. This capability gives vast options and power to designers on simulating with all the gathered data by taking advantage the IT.

7.4 Relationships amongst Digital Twins in Systems

To which extent a DT is abstracted depends on the design of it in the relevant scenarios in which it is implemented. A discrete DT comes as a sole unit which includes data and value, with no need to go much deeper. An example in this case can be a single component of an industrial machinery. The assembly of these DTs with aim to form a composite DT is shown in Fig.17 expanding vertically which gives the description of the increasing towards multiple units. A composite DT is a result of combining discrete DTs representing a unit consisting of several parts. The actual composition can be done on various levels. A factory plant DT as an example may contain multiple diverse composite DTs.

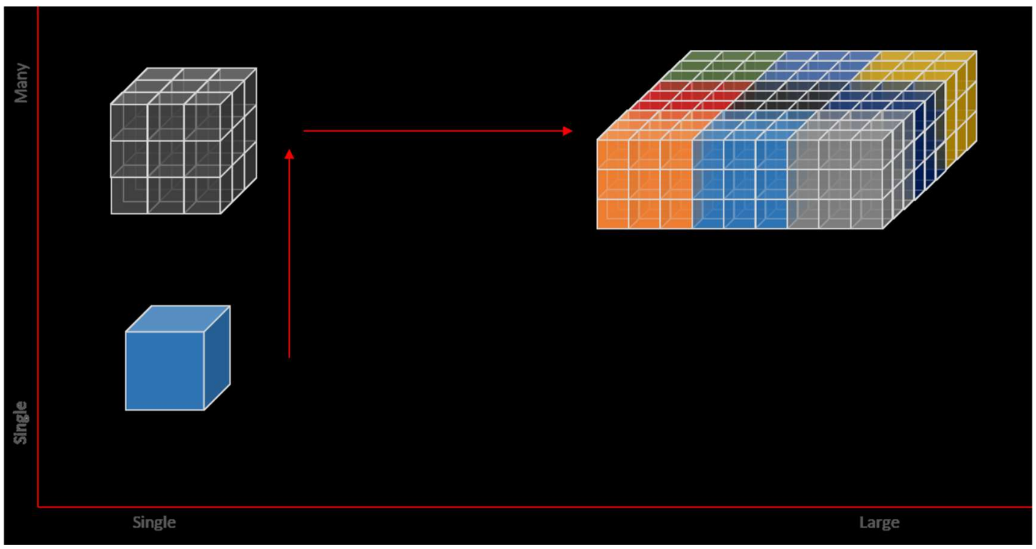


Fig.17 Creation of a composite digital twin

The composition relationship amongst DTs can be described by the following:

- **Hierarchical:** As in the real environment, component DTs brought together lead to an equipment DT, then these brought together can form a production line DT etc.
- **Associational:** DTs can be associated with each-other as an end-to-end communication.
- **Peer-to-peer:** This relationship can be found in a component group with analogous constitution that operate identical functions. Upon analyzing that, it means the summed-up contribution of each component's production from every asset of the component

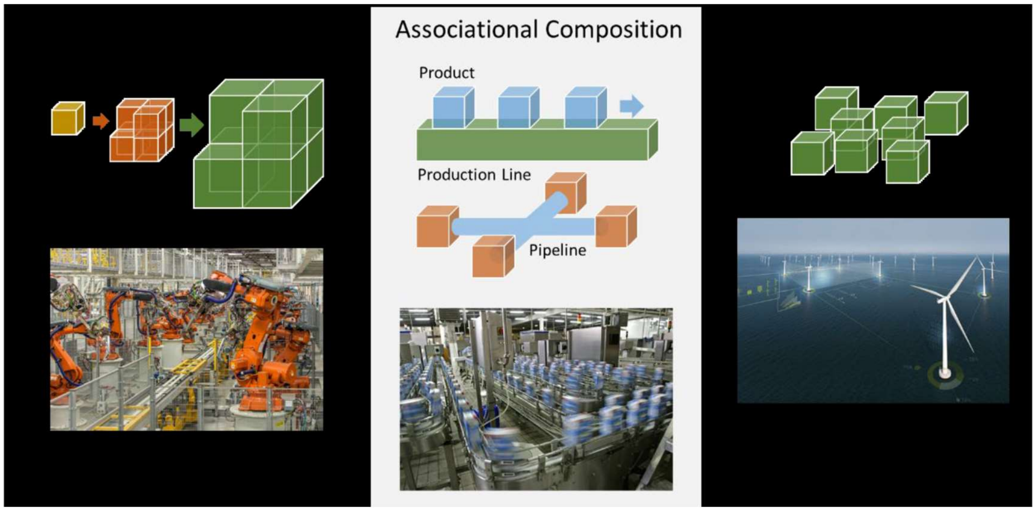


Fig 18 Relationship between digital twins in a composition

7.5 Pilot Implementation Analysis

This thesis's approach has been made based on a model of Offset Printing Company. This is based on the fact that printing technology, when it comes to large-scale productions, is one of the less digitally advanced fields and there is a high potential of adapting the advantages a DT has to offer.
For our pilot implementation we used as example an existing business with multiple end-products. Our approach will focus on case scenarios which can be scalable and flexible as the application runs and evolves. The approach was mainly based on the processes that cover all the three main printing phases that are presented below:

Offset printing company setup

The overall printing process consists of three main separate phases:

1. PrePress
2. Press
3. PostPress

PrePress

Prepress is the terminology used to define the processes that take place as a first step before printing and finishing. As several publications these days are published both in print and digital media, multiple common processes are generally referred to as premedia services.
The prepress processes may take place at single location, like large publishing or printing house, or at different places. In general, only a handful actions occur at a publisher's end, while others take place at a dedicated prepress company (which are also known as service bureaus or trade shops).

Design: Since the advent of desktop publishing, several people in the printing industry don't take design to be a prepress task.
The design process consists of the below:
Preparation of data, which comprises of copyediting and product photography. Making the layout is done by using one of the principal computer design applications. Sometimes also tools like Microsoft Office or Publisher can be used. There is also an extensive range of specialized applications which are available for tasks like database publishing. The rectification sequence contains processes like proofreading and image retouching, for which Adobe Photoshop is the best application available in the market.

The output data, pages or complete flats have to be ripped or rendered. This process also includes:

- Transparency flattening: transparency effects like drop shadows behind text need to be fixed.
- Screening
- Trapping
- Managing colors
- Color partition

Fig.19 Lithographic Machine

Exchanging data like the final layout can still happen with the help of a DVD. In the past there were used original layout file(s) and associated images, fonts and other data. Nowadays, PDF files are used instead. Additionally, the use of internet has increased the submitted jobs. This is also known as web-to-print, where the data exchange is purely dependent on page content.

Press

After Prepress, the next phase is Press. During printing, accuracy is crucial for both quality and timely delivery, so projects only go to press after they have passed the pre-press and plate making stages, which will result in cutting out any need for costly reprints. There are several different kinds of printing process, and the choice of process depends on the kind of job.
Machine printers may specialize in one printing process. Most of them are computer controlled.

Fig.20 Printing Machine

A machine printer's tasks can include:

- Preparing the paper or card so that it runs smoothly through the machine.
- Positioning the printing plates in the press and taking trial prints to ensure everything is correctly placed.
- Loading the machine with inks and making sure colors are reproduced correctly.
- Maintaining quality checks during the running of the press.

Fig.21 Printing Machine

Looking out for problems, such as paper jams, to avoid machine downtime
Routine maintenance and cleaning of the press.

Post Press

Post Press is a crucial part of any printing process, and it takes place after the actual printing. It helps in determining the final look, shape and feel of the printed product. Post press consists of several sub processes that are implemented depending upon the type of the project and the job being handled.


Fig.22 Binding Machine
Some of the basic types of post press operations in printing industry which are often used are as follows:

- Cutting: This is one of the most common operations of post press which is used in almost all projects. For this purpose, the machines which used are known as “guillotine cutter” or “paper cutter”. These are special machines which are used for cutting large substrates of web-type into different sheets or pages. These machines differ in sizes, features, abilities, capacities and configurations, because they are built for individual purposes.

- Folding: This activity is performed mostly in printing workshops for pamphlets, magazines, and product boxes. There are mainly three types of folders used in print shops – bone folder, knife folder and buckle folder. Knife folders use knifes to force the paper getting into the roller for folding.

- Binding: In this category, the printed material or pages are put together.

Three most common binding techniques which are used are- adhesive binding, side binding and saddle binding. [175]

Fig.23 Binding Machine

We have taken into consideration the following attributes as main points:

- Machinery
- Materials
- Space
- Humans/workers

On the next step, we set up the software which will be used to implement the business model based on Digital Twins created of the aforementioned points.
The software setup has been divided in two parts as presented previously:

1. Business Process Management (BPM)
2. Digital Twin (DT)

The first part is implemented through Camunda, and the second part is consisted of the Eclipse Ditto framework for DTs.

7.5.2 Software Setup

Both frameworks supporting our implementation were installed in Linux environment supported by Ubuntu operating system. The first installation was the Eclipse Ditto framework with docker compose. The second was Camunda by installing the software with docker.

Eclipse Ditto Setup

1) Installation of JDK

```
sudo apt-get install default-jdk
```

2) Installation of Apache Maven

```
Sudo apt-get update (important for updating the package index)
Sudo apt install maven (Maven installation)
Mvn -version (version verification)
```

3) Installation of Docker

```
Sudo apt-get remove docker docker-engine docker.io container
  runc (Old version uninstall)
Sudo apt-get install \
  apt-transport-https \
  ca-certificate \
  curl \
gnupg-agent \
software-properties-common
(Packages installation to allow apt to use repository over
  HTTPS
```

```
curl -fsSL https://download.docker.com/linux/ubuntu/gpg | sudo
  apt-key add -
sudo apt-key fingerprint 0EBFCD88
pub rsa4096 2017-02-22 [SCEA] 9DC8 5822 9FC7 DD38 854A E2D8
  8D81 803C 0EBF CD88 uid [unknown] Docker Release (CE deb)
  <docker@docker.com> sub rsa4096 2017-02-22 [S]
(Adding the official GPG key of Docker)
sudo add-apt-repository \
"deb [arch=amd64] https://download.docker.com/linux/ubuntu \
 $(lsb_release -cs) \
  stable"
(Setting up stable repository)
```

```
sudo apt-get install docker-ce docker-ce-cli containerd.io

(Installing Docker CE latest version and containerd)

sudo docker run hello-world

(Verifying that Docker CE is properly installed)
```

Eclipse Ditto Installation

1) Eclipse Ditto Download

```
git clone https://github.com/eclipse/ditto.git
```

2) Docker Building

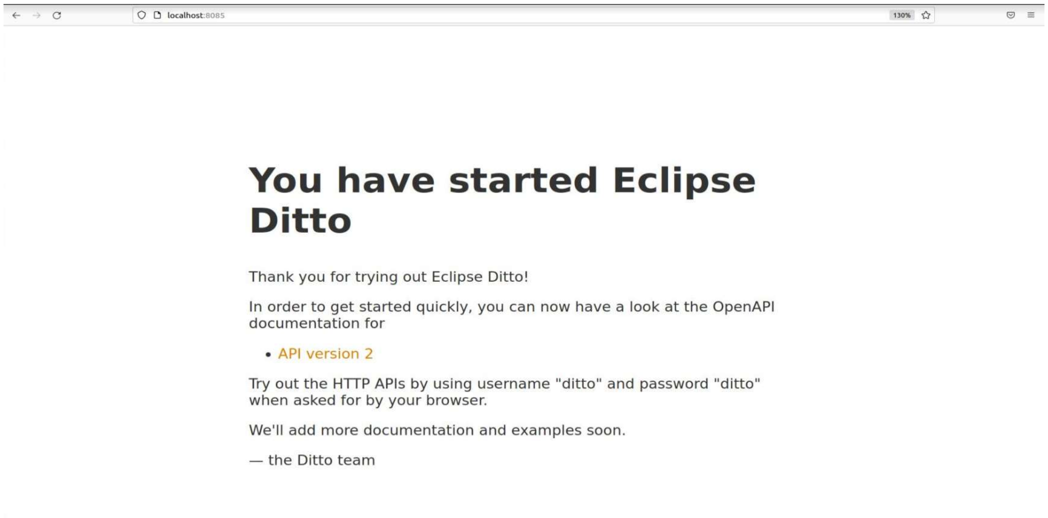
```
# Start up the Docker image with maven:
docker run -it --rm --name mvn-ditto \ -v
  /var/run/docker.sock:/var/run/docker.sock \ -v
  "$PWD":/usr/src/mymaven -w /usr/src/mymaven \ -u root \
  maven:3.5.0-jdk-8 \ /bin/bash
# from within the Docker image, build the Docker images:
mvn clean install -Pdocker-build-image \ -
  Ddocker.daemon.url=unix:///var/run/docker.sock
# Docker images are now available on your Docker host
```

3) Start Ditto

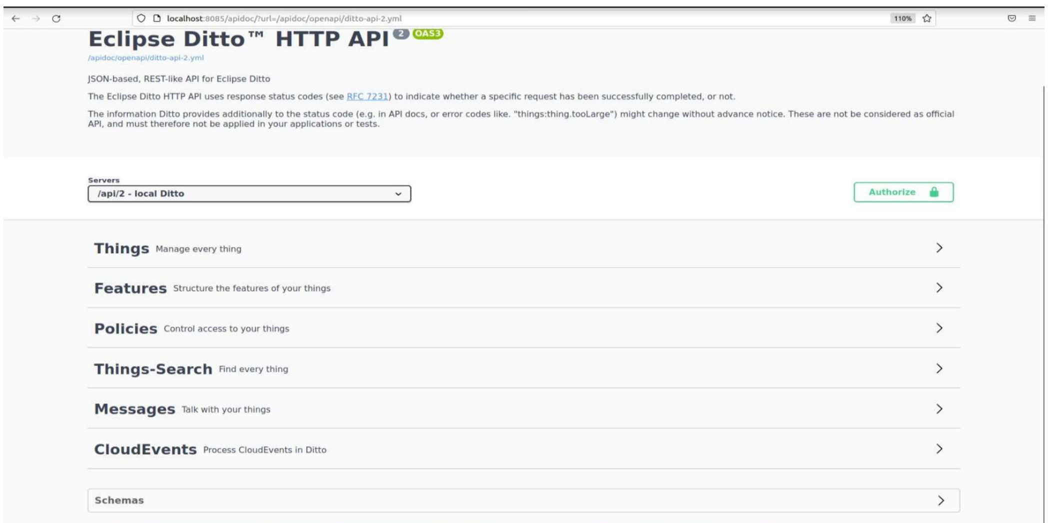
```
# switch to the deployment/docker/ directory: cd
  deployment/docker/ docker-compose up –d
```

For visualization:

```
http://localhost:8085/
```



Fig,24 Eclipse Ditto FrontPage



Fig,25 Eclipse Ditto API

Camunda Setup

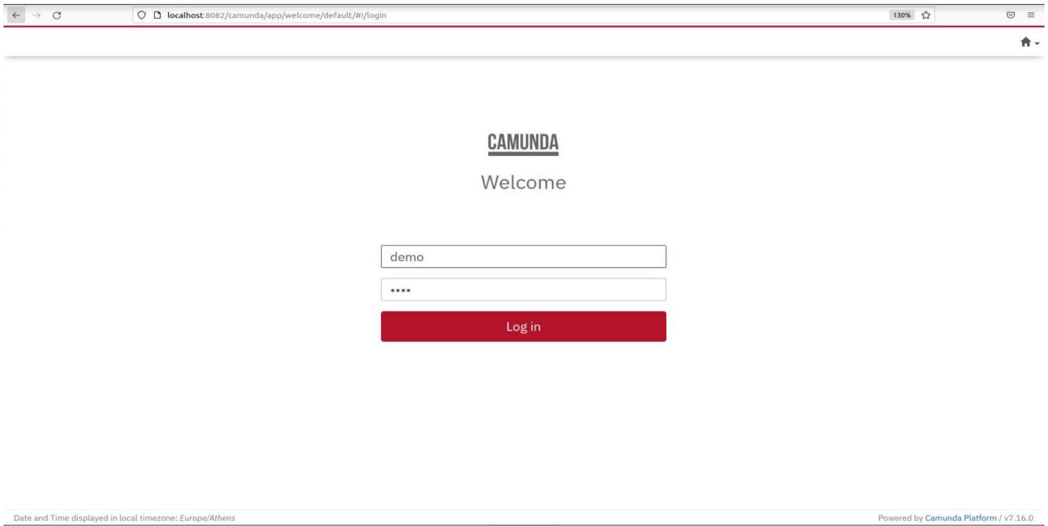
Installation of Camunda

```
docker pull camunda/camunda-bpm-platform --> install docker
docker run -d --name camunda -p 8082:8080 camunda/camunda-bpm-
  platform:latest
```

For visualization:

```
http://localhost:8082/
```

After the installation of Camunda, we start Camunda Modeler to proceed with creating our business process diagrams.



Fig,26 Camunda's Log in Page

7.6 Test case approach

The positive aspect of Camunda is that is is an open-source tool, supporting micro-service architectures with REST API. Hence, the cooperation with Python is solid and easy to scale.

As the main items in that consist of the business process are tasks, the interface allows the completion of them either by end-users or services. Services have the possibility to be implemented by external services as well. These types of tasks are named external tasks. External Tasks are service tasks whose execution differs particularly from the execution of other service tasks. The execution works in a way that units of work are polled from the engine before being completed [176].

The process diagram presented below consists of seven external service tasks. The communication with the relevant Camunda diagram is supported by the package PyCamunda, which is a module that grants accessibility to the REST API. From the various classes of PyCamunda [177] the present thesis takes advantage of two. The FetchAndLock and the Complete classes. The first is to fetch and lock the external tasks from the diagram and the second to complete them.

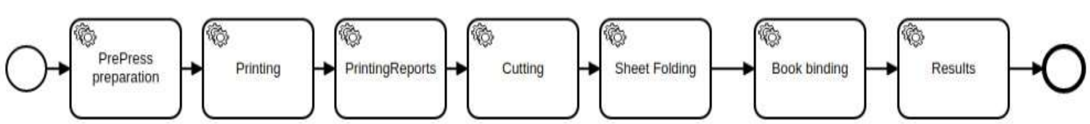


Fig.27 Camunda's Printing Process

One process instance is utilized of pycamunda.externaltask.FetchAndLock. The instance is called when we want the next external task to be called from the diagram. The async_response_timeout performs the activation of long polling, generating an avoidance of repetitive requests to the diagram.
The pycamunda.externaltask.Complete instance is updated with the relevant id. Additionally, with the creation of dictionaries a bridge takes place amongst the respective task topics to the functions. Upon fetching, these will be implemented.
With the subscription to specific topics based on functions for every topic, and by parsing the relevant variables needed, the worker locks the fetched tasks. In that way, there will be no overriding by fetching same tasks.
With fetch_and_lock PyCamunda returns pycamunda.externaltask.ExternalTask instances. These contain the variables we requested from the process instance. These are added as an assertion to the topics. Then the modified variables are returned to the process of the diagram in a dictionary. Failure handling is also added with timeouts.

```
# -*- coding: utf-8 -*-
import typing
import pycamunda.externaltask
import pycamunda.variable

class ExternalTaskException(Exception):
    def __init__(
        self, *args, message: str, details: str = '',
  retry_timeout: int = 10000, **kwargs
    ):
        """Exception to be raised when a service task fails.

        :param message: Error message that describes the
  reason of the failure.
        :param details: Error description.
        :param retry_timeout: Timeout in milliseconds until
  the external task becomes available.
        """
        super().__init__(*args, **kwargs)
        self.message = message
        self.details = details
        self.retry_timeout = retry_timeout

class Worker:
    def __init__(
        self,
        url: str,
        worker_id: str,
        max_tasks: int = 1,
        async_response_timeout: int = 5000
    ):
        """Worker that fetches and completes external Camunda
  service tasks.

        :param url: Camunda Rest engine URL.
        :param worker_id: Id of the worker.
```

```
        :param max_tasks: Maximum number of tasks the worker
fetches at once.
        :param async_response_timeout: Long polling in
milliseconds.
        """
        self.fetch_and_lock =
pycamunda.externaltask.FetchAndLock(
            url, worker_id, max_tasks,
async_response_timeout=async_response_timeout
        )
        self.complete_task = pycamunda.externaltask.Complete(
            url, id_=None, worker_id=worker_id
        )
        self.stopped = False
        self.topic_funcs = {}

        self.handle_failure =
pycamunda.externaltask.HandleFailure(
            url,
            id_=None,
            worker_id=worker_id,
            error_message='',
            error_details='',
            retries=0,
            retry_timeout=0
        )
        self.handle_bpmnerror =
pycamunda.externaltask.HandleBPMNError (

            url,
            id_=None,
            worker_id=worker_id,

            error_code='',
            error_message='',

        )

        self.stopped = False
        self.topic_funcs = {}

  def subscribe(
        self,
        topic: str,
        func: typing.Callable,
        lock_duration: int = 10000,
        variables: typing.Iterable[str] = None,
        deserialize_values: bool = False
  ):
        """Subscribe the worker to a certain topic.

        :param topic: The topic to subscribe to.
        :param func: The callable that is executed for a task
of the respective topic.
```

```
        :param lock_duration: Duration the fetched tasks are
locked for this worker in milliseconds.
        :param variables: Variables to request from the
Camunda process instance.
        :param deserialize_values: Whether serializable
variables values are deserialized on server
                                side.
        """
        self.fetch_and_lock.add_topic(topic, lock_duration,
variables, deserialize_values)
        self.topic_funcs[topic] = func

    def unsubscribe(self, topic):
        """Unsubscribe the worker from a topic.

        :param topic: The topic to unsubscribe from.
        """
        for i, topic_ in
enumerate(self.fetch_and_lock.topics):
            if topic_['topicName'] == topic:
                del self.fetch_and_lock.topics[i]
                break

    def run(self):
        """Run the worker."""
        while not self.stopped:
            tasks = self.fetch_and_lock()

            for task in tasks:
                try:
                    return_variables =
self.topic_funcs[task.topic_name](**task.variables)
                except ExternalTaskException as exc:
                    self.handle_failure.id_ = task.id_
                    self.handle_failure.error_message =
exc.message
                    self.handle_failure.error_details =
exc.details
                    self.handle_failure.retry_timeout =
exc.retry_timeout
                    if task.retries is None:
                        self.handle_failure.retries = 2
                    else:
                        self.handle_failure.retries =
task.retries - 1
                    self.handle_failure()
                else:
                    self.complete_task.variables = {}
                    self.complete_task.id_ = task.id_
                    for variable, value in
return_variables.items():

self.complete_task.add_variable(name=variable, value=value)
                    self.complete_task()
```

7.6.1 Use case approach

In order to be able to proceed with the proof of concept and implement it successfully to add value to our approach, comprehending the actual workflow of the business was of major importance. Aiming to simulate it as close as possible to the real-time data produced, the calculations and DT-sensor attributes, had to be based on the literacy covering the offset printing environment. There were restrictions on implementing sensors in the business' production line to obtain real-time data and retrieve the business reports from previously completed jobs. Hence, the simulation of the attributes' values was setup according to the standards and limits of the ideal production line environmental and machinery attributes. [178].
The approach to be presented has the aim to prove the successful functionality of the digitized workflow of the production line by referring to 3 test case scenarios.

1. Un-interrupted scenario
2. Environmental error scenario
3. Machinery error scenario

As a first step, the BPMN process was set up to cover all the phases of the production line as previously mentioned and will be presented in detail below. Each process task was added as a Camunda Service Task [179], creating a relevant job for the process instance which then waits until a job worker subscribes and completes it.
The application solution is implemented in Python Programming Language as there is a solution covered by a REST API client supporting the workflow engine Camunda [180] The implementation of the communication between the program and the Camunda workflow via the worker, who handles each and every service task of the workflow, is widely covered by different solutions. The approach in the present thesis was based on the offered setup in GitHub [181], which has a repository of a simple example process with 2 service tasks.

<u>PrePress Service Task</u>

Fig.28 Camunda's Pre-Press Process

Standards taken into consideration for the setup:

1. Book orders to be processed are in color
2. Each side of paper sheet to be produced needs 4 lithographic plates
3. Each side of paper sheet contains 16 pages

Description of the steps implemented and covered in task:

1. Book order triggers the process with the overall quantity of the order via manual input
2. Calculation of the total amount of paper sheets to be printed to cover the demand
3. Calculation of the total amount of lithographic plates that need to be produced to cover the printing process
4. Calculation of the paper sheets per book

Press Task

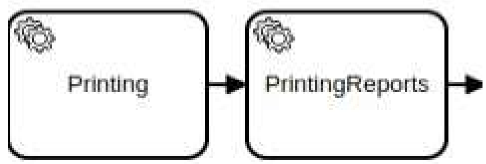


Fig.29 Camunda's Press Process

Standards taken into consideration for the setup as the impact of deviations to the end product can be affecting the overall production and the product:

1. Approved environmental attributes:
   1.1 Area temperature 20-24 °C
   1.2 Area humidity 50-60 %
2. Approved machinery attributes:
   2.1 Printing machine temperature 30-80 °C
   2.2 Water temperature 8-12 °C
   2.3 Water pH 4,8-5,2
   2.4 Water hardness 11-13 °dH
   2.5 Alcohol level in ink 3-15%

Description of the steps implemented and covered in task:

Check of the environmental sensors affecting production (temperature and humidity). Also, checks of the machinery sensors which could affect production such as machine temperature, water specifics and alcohol content by calling the Digital Twin during the printing process. Any discrepancy terminates the printing process to ensure quality.

Post Press Tasks

Fig.30 Camunda's Post Press Process

Standards taken into consideration for the setup as the impact of deviations to the end product can be affecting the overall production and the product per process:
Firstly, the cutting process. As an important job in our production line, if these machinery characteristics are not in ideal conditions, it will cause a delay and have a quality impact to the end product.

The features of the cutting process are the following:

- on-off_sensor
- blade_temp_sensor
- blade_pressure_sensor
- cutting_process_sensor

One more process that is very important is the folding process.
The features of the cutting process are the following:

- on-off_sensor
- knife_folding_temp_sensor
- folding_pressure_sensor

And the last one process is the binding process that give us the final product.
The features that this process has are the following:

- on-off_sensor
- cover_sensor
- melt_glue_temp_sensor
- book_cover_availability

7.7 Use Case Scenarios

For the creation of the respective Digital Twins, a common policy for the user Ditto is created that has read and write permissions for all the things, messages and the policy itself. Then the upload this is being implemented to the Ditto API.
The relevant policy will be the following and by completing a PUT request with curl. PUT request data is passed with the -d parameter. If you give -d and omit -X, curl will automatically choose the HTTP POST method. The -X PUT option explictheitly tells curl to select the HTTP PUT method instead of POST. The data type for the curl request is set using the -H command-line option.

```
curl -X PUT 'http://localhost:8085/api/2/policies/one:policy'
  -u 'ditto:ditto' -H 'Content-Type: application/json' -d '{
    "entries": {
        "owner": {
            "subjects": {
                "nginx:ditto": {
                    "type": "nginx basic auth user"
                }
            },
            "resources": {
                "thing:/": {
                    "grant": [
                        "READ","WRITE"
                    ],
                    "revoke": []
                },
                "policy:/": {
                    "grant": [
                        "READ","WRITE"
                    ],
                    "revoke": []
                },
                "message:/": {
                    "grant": [
                        "READ","WRITE"
                    ],
                    "revoke": []
                }
            }
        }
    }
}'
```

7.7.1 Un-interrupted scenario

Our first use case is going to study a scenario that all the machines are working with ideal values. We created and uploaded our digital twins with the best scenario values. The digital twins that we created, refers to the main machines. The printing machine, the cutting machine, the folding, and the binding machine. As we explained in previous chapter these machines are connected to tasks. The printing machine is the main and we will be based on this mainly.
The printing machine’s Digital Twin is:

```
curl -X PUT http://localhost:8085/api/2/things/printing:ditto'
  -u 'ditto:ditto' -H 'Content-Type: application/json' -d '{
    "policyId": "one:policy",
    "attributes": {
        "name": "thesis_ditto",
        "type": "industry 4.0"
    },
    "features": {
        "paper_sensor_capacity": {
            "properties": {
                "value": 8000
            }
        },
        "lithographoic-plates_sensor": {
            "properties": {
                "value": 1
            }
        },
        "ink_capacity_sensor1": {
            "properties": {
                "value": 8
            }
        },"ink_capacity_sensor2": {
            "properties": {
                "value": 7
            }
        },"ink_capacity_sensor3": {
            "properties": {
                "value": 6
            }
        },"ink_capacity_sensor4": {
            "properties": {
                "value": 8
            }
        },"ink_capacity_sensor5": {
            "properties": {
                "value": 5
            }
        },"ink_capacity_sensor6": {
            "properties": {
                "value": 6
            }
```

```
        },"ink_capacity_sensor7": {
            "properties": {
                "value": 7
            }
        },"ink_capacity_sensor8": {
            "properties": {
                "value": 9
            }
        },
        "enviroment_sensor": {
            "properties": {
                "value": 22
            }
        },
        "temprature_sensor": {
            "properties": {
                "value": 60
            }
        },
        "humidity_sensor": {
            "properties": {
                "value": 60
            }
        },
        "water_temprature_sensor": {
            "properties": {
                "value": 10
            }
        },
        "water_PH_sensor": {
            "properties": {
                "value": 5
            }
        },
        "water_hardness_sensor": {
            "properties": {
                "value": 12
            }
        },
        "alcohol_sensor": {
            "properties": {
                "value": 13
            }
        }
    }
}'
```

For the post press tasks', the Digital Twins are the following:

```
curl -X PUT 'http://localhost:8085/api/2/things/cutting:ditto'
   -u 'ditto:ditto' -H 'Content-Type: application/json' -d '{
     "policyId": "one:policy",
     "attributes": {
         "name": "thesis_ditto",
         "type": "industry 4.0"
     },
     "features": {
         "on-off_sensor": {
             "properties": {
                 "value": 1
             }
         },
         "blade_temp_sensor": {
             "properties": {
                 "value": 150
             }
         },
         "blade_pressure_sensor": {
             "properties": {
                 "value": 0.5
             }
         },
         "cutting_process_sensor": {
             "properties": {
                 "value": 1
             }
         }
     }
}'
```

```
curl -X PUT 'http://localhost:8085/api/2/things/folding:ditto'
   -u 'ditto:ditto' -H 'Content-Type: application/json' -d '{
     "policyId": "one:policy",
     "attributes": {
         "name": "thesis_ditto",
         "type": "industry 4.0"
     },
     "features": {
         "on-off_sensor": {
             "properties": {
                 "value": 1
             }
         },
         "knife_folding_temp_sensor": {
             "properties": {
                 "value": 200
             }
```

```
        },
        "folding_pressure_sensor": {
            "properties": {
                "value": 5
            }
        }
    }
}'
```

```
curl -X PUT 'http://localhost:8085/api/2/things/binding:ditto'
  -u 'ditto:ditto' -H 'Content-Type: application/json' -d '{
    "policyId": "one:policy",
    "attributes": {
        "name": "thesis_ditto",
        "type": "industry 4.0"
    },
    "features": {
        "on-off_sensor": {
            "properties": {
                "value": 1
            }
        },
        "cover_sensor": {
            "properties": {
                "value": 1
            }
        },
        "melt_glue_temp_sensor": {
            "properties": {
                "value": 190
            }
        },
        "book_cover_availability": {
            "properties": {
                "value": 1
            }
        }
    }
}'
```

The policy is uploaded, with the same way we make a PUT request with curl command and the data is passed with the -d parameter to the localhost.
By running the program the results of the set processes are visualized.

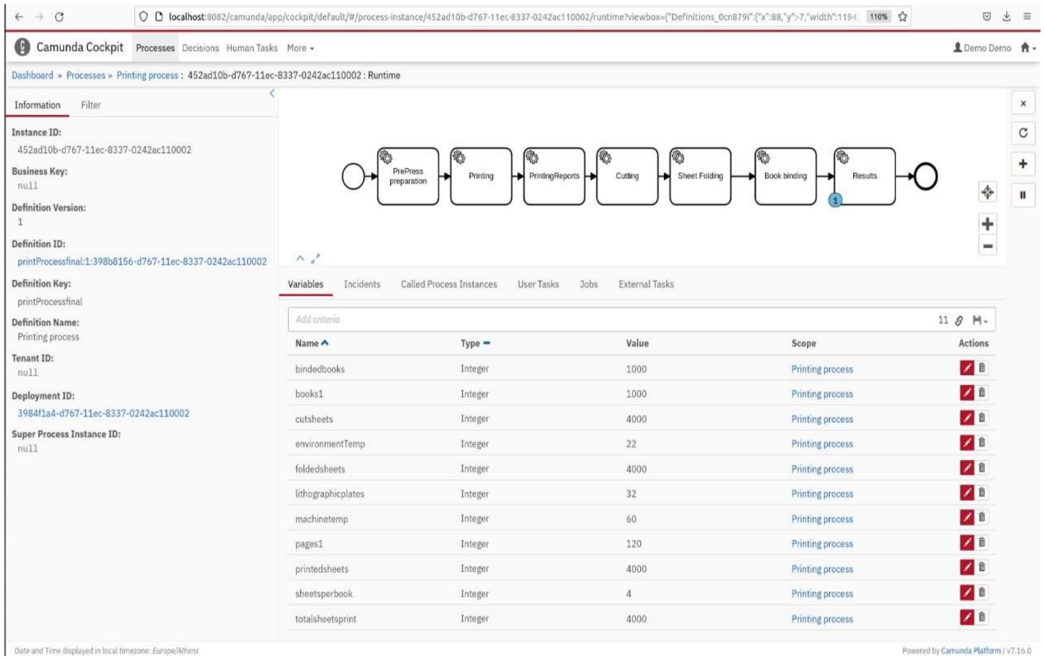


Fig.31 Un-interrupted scenario's results In Camunda

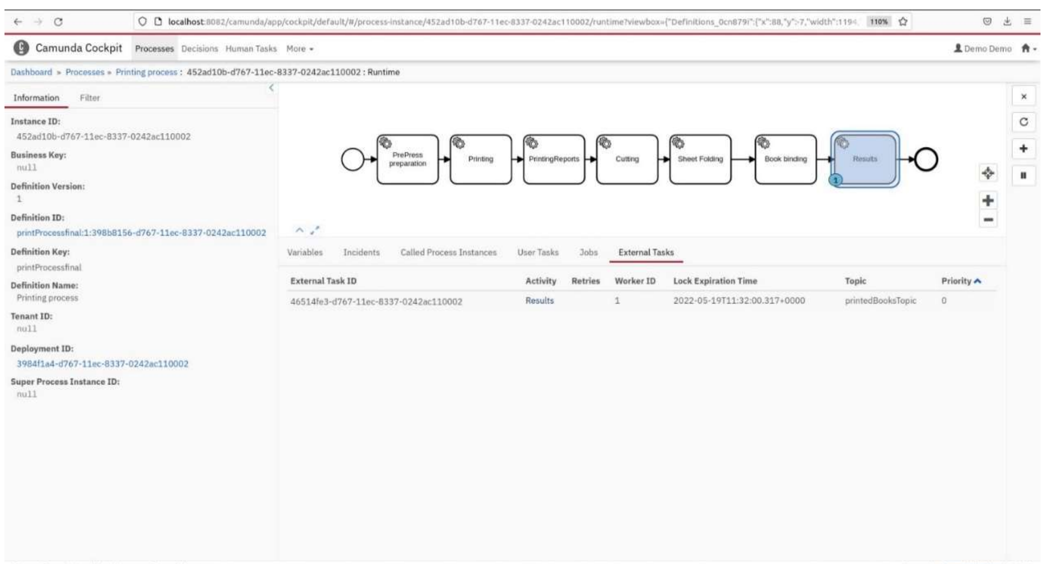


Fig.32 Un-interrupted scenario's external task results In Camunda

From the above results it is concluded that when ideal values are given by our Digital Twins to the system, the process is completed without disturbances or errors. Meaning that the represented state of the digitally translated sensors, return the desired value to successfully implement the workflow of the production line.
Additionally, the Camunda process instance reaches and completes the final task, which prints the overall results of every previous successfully completed task.

7.7.2 Machinery error scenario

In this use case the machinery error scenario will be approached. This error could be anything that could affect the production and cause problem of the product or create delays at the deliverables.

A common error could be the temperature of the machine. The limits of the machine temperature are specific, and these are very important for the function of the machine and the safety. If the temperature exceeds the limits the damage may be in a small impact such us to stop the machine or very critical issue such to destroy the machine.

In order to implement the aforementioned scenario, the Digital Twin representing the machine attributes, the respective value is being altered and again uploaded to Ditto API with the new value below:

```
"temprature_sensor": {
            "properties": {
                "value": 90
            }
        }
```

By re-running the relevant process, the returned results are the following:

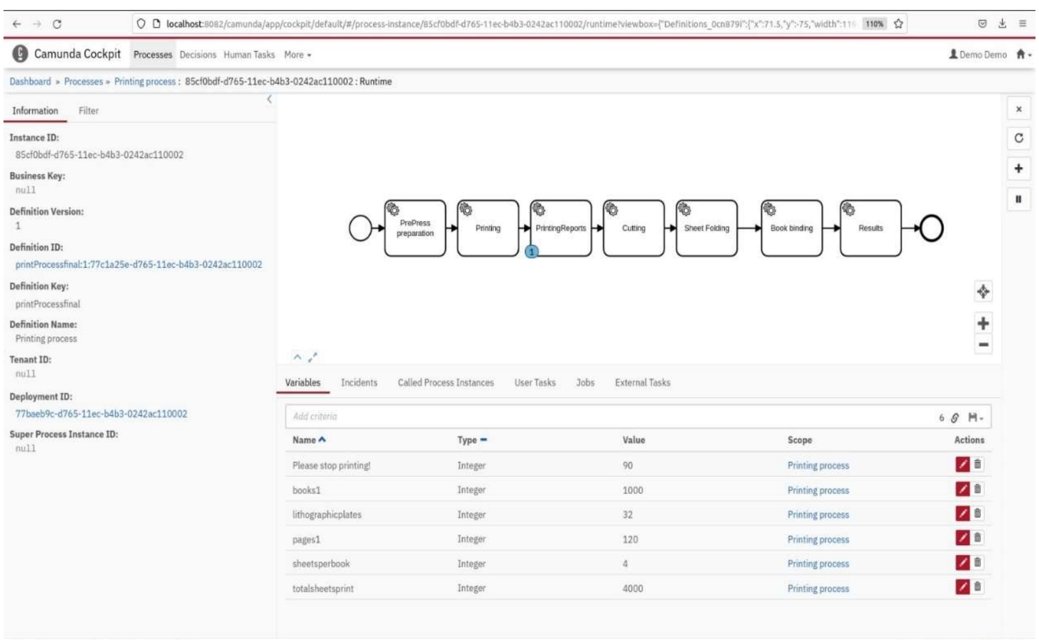


Fig.33 Machinery Error scenario's results In Camunda

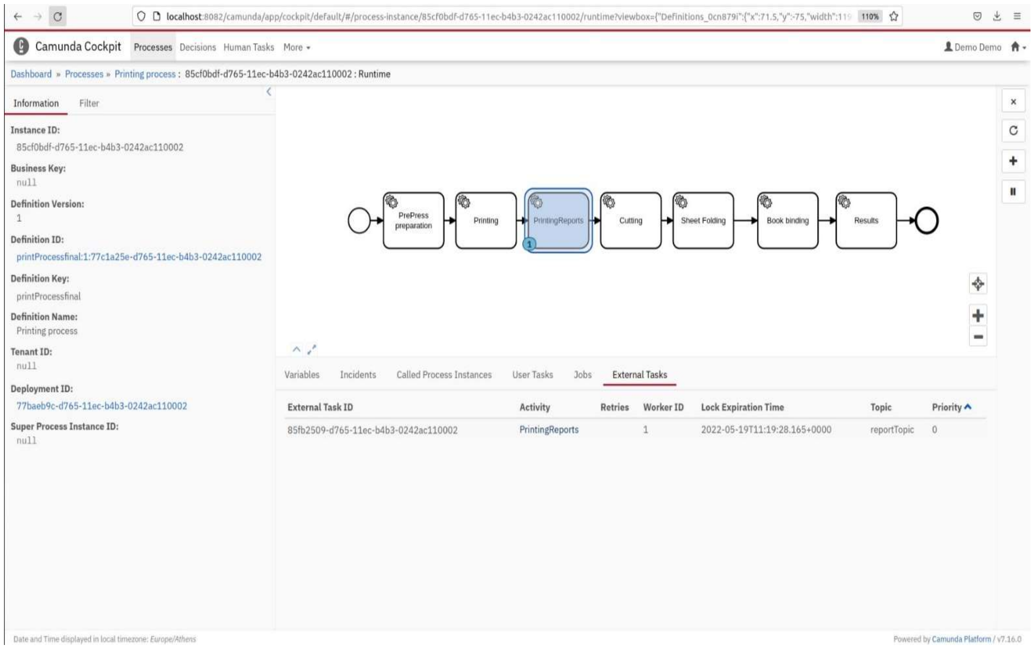


Fig.34 Machinery Error scenario's external task results In Camunda

As a result of the above process and approach, the process instance token has stopped on the PrintingReports task, which indicates that there was an error value leading to the termination of our process. The Name of the attribute returned as "Please stop printing" with Value 90, that represents the temperature of the printing machine that has risen above the preset limits.
The overview of the process instance in this scenario assists on indicating possible errors and providing an addition to the failure handling of the production line. Two actions can be taken to ensure the continuity of the production aiming to resolve possible repetitive issues delaying the workflow:

1. Technical check of the sensor for faulty functionality and temperature reporting
2. Technical check of the printing machine for malfunctioning

7.7.3 Environmental error scenario

In this use case the environmental error scenario will be approached. This error could be the external factors that could affect the production and cause problems with the quality of the end-product and increase the costs for the production of the appropriate and final deliverables.

A common error could be the temperature of the printing area as it needs to be in a controllable environment to be able to ensure the paper, as well as the printed sheets quality. The limits of the printing environment are strict as presented in the previous sections. If the temperature exceeds the limits the damage may cause delays and defect end-product which impacts the profits calculated as well as the damage costs.

In order to implement the aforementioned scenario, the Digital Twin representing the environmental attributes, the respective value is being altered and again uploaded to Ditto API with the new value below:

```
"enviroment_sensor": {
        "properties": {
            "value": 30
        }
    }
```

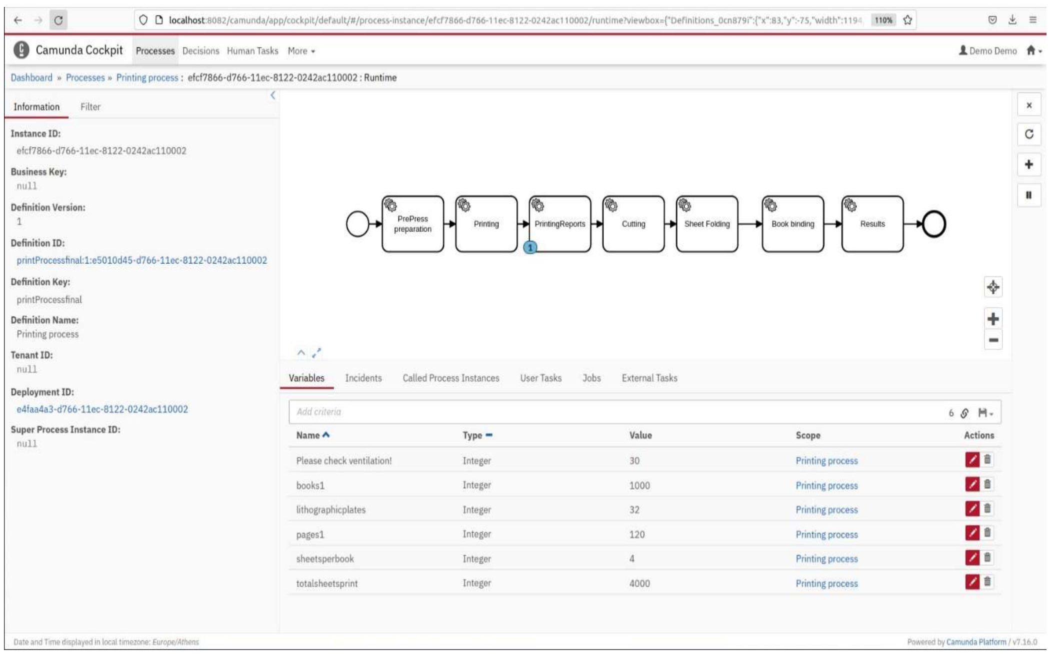


Fig.35 Environmental Error scenario's results In Camunda

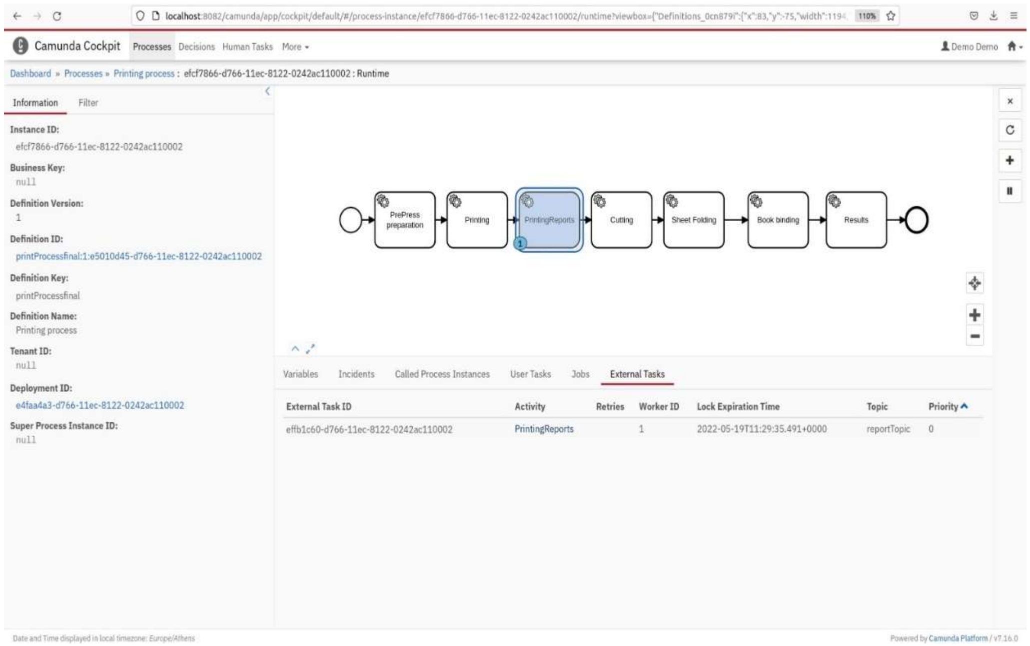


Fig.36 Environmental Error scenario's external task results In Camunda

Once again, our process instance token stops in the PrintingReports task, which indicates that there was an error value leading to the non-completion of our workflow. The attribute returned by Name "Please check ventilation!" with Value 30, indicates the temperature of the printing room which exceed the limits mentioned above.

The overview of the process instance in this scenario assists on indicating possible errors and providing an addition to quality discrepancy on the end-product (printed paper sheets). Three actions can be taken to ensure the continuity of the production with the desired quality aiming to resolve possible repetitive issues directly impacting the costs and the profit of the total production:

1. Technical check of the sensor for faulty functionality and temperature reporting
2. Check for malfunctioning ventilation
3. Possible user errors (for example: not properly closed doors leading to overheating)

8. Conclusions

As the previous industrial revolutions impacted humanity with new approaches and benefits so is the 4^{th} doing the last decade. The progress towards a new present, a both digital and physical controllable environment is inevitable. Smarter and decentralized tools are already and will effectively continue contributing to the challenging days worldwide.

The technologies that are the backbone of Industry 4.0, not only provide big advantages to today's industrialized era, but also to people's everyday life. On the restless environment of evolution and updates, the continuous progress of these technologies needs to be followed up, in order to guarantee a successful and sustainable business future. The optimization offered is adding to the business automation a value that cannot be disregarded.

The decentralized decisions with remote access based on cloud environments save time and effort for all the different parts included in the life cycle of a business product. While the customer needs change in a fast pace, business reactions have to be decisive, flexible, dynamic and agile to cover the demand and remain profitable through the innovations implemented. From the producer to the consumer, the benefits are vast.

The Big Data produced from all the machine and human actions as well as interactions, add value to the research of means that aim to improve the current status of everyday processes and create new ways for businesses and people to become more productive with less effort.

Given that there is no opportunity or possibility to gather or retrieve data by positioning sensors during the run of an actual production line, the machinery supporting the present approach on a printing company had to be digitally represented and implemented.

Hence, the creation of Digital Twins representing the actual machinery was based on datasheet limits, as this was the only way to simulate the real state of the machines and their functionality.

Upon simulating the production line, a point was reached where it was digitally duplicated successfully. This was followed by the workflow in the three use case scenarios checked which react identically and accordingly, as in the real-world scenarios.

By this application, alterations on the Digital Twins can be implemented without physically accessing or managing the actual machines. By recreating possible malfunctioning scenarios and ideal workflows, with the aim on reducing production costs as well as ensuring efficiency and quality, the results can be highly profitable.

With the aid of the successful integration of the Digital Twins' state within the business workflow, the flexibility to adjust and even add additional attributes and values are limitless, which can lead to business growth, without even having to physically invest in the implementation before the actual machine has proven its value to the business.

The conclusion reached is that by being able to identify, detect and predict the possible malfunctions affecting both the workflow and the costs, process improvements can take place on the actual production line, as well as optimizations on the quality and timeliness of the end-products.

Future research should consider gathering data from similar production line workflows, in order for the application to run independently, predicting the workload, offering solutions and their outcomes via a machine learning approach. Furthermore, possible errors or repetitive mistakes or issues would be foreseen, and actions would eventually be planned to ensure the overall non-interrupted scenarios, which all manufacturing businesses want to implement and work with in their production lines. To conclude, the impact of Industry 4.0 proves to be a major part in the future business planning and implementation. It is necessary to cite the importance of continuous research on the matter and the addition of the results to the solutions already in place, to reach the limits of the digitally enhanced smart manufacturing.

9. Appendix

Sample Code

The aforementioned processes and scenarios are based on the sample code added below. The definitions of the Python code are used mainly as the background for the implementation of the process tasks the worker fetches and locks. Each and every external task from the Camunda workflow representing the business processes runs with the value checks that are being parsed from the Digital Twins with the trigger by the input of the book order.

```
if __name__=="__main__":
    import pycamunda.processdef

    url = 'http://localhost:8082/engine-rest'
    worker_id = '1'

    #Get the book order to be printed
    print("Hello user, please enter the total amount of books
  ordered")
    books_input = order()
    books = int(books_input)
    #Get the total pages of the book to be printed
    print("Thank you! Please enter now the pages of the book")
    pages_input = totalpages()
    pages = int(pages_input)

    start_instance =
  pycamunda.processdef.StartInstance(url=url,
  key='printProcessfinal')
    start_instance.add_variable(name='pages1', value=pages)
    start_instance.add_variable(name='books1', value=books)

    for _ in range(1):
        start_instance()

    worker = worker.Worker(url=url, worker_id=worker_id)
    worker.subscribe(
        topic='calculationsTopic',
        func=calculations,
        variables=['pages1', 'books1']
    )
    worker.subscribe(
        topic='printingTopic',
        func=printingprocess,
        variables=['totalsheetsprint']
    )
    worker.subscribe(
        topic='reportTopic',
        func=reportingprocess,
        variables=['environmentTemp', 'machinetemp' ]
```

```
        )
        worker.subscribe(
            topic='cuttingTopic',
            func=cuttingprocess,
            variables=['printedsheets']
        )
        worker.subscribe(
            topic='foldingTopic',
            func=foldingprocess,
            variables=['cutsheets']
        )
        worker.subscribe(
            topic='bindingTopic',
            func=bindingprocess,
            variables=['books1']
        )
        worker.subscribe(
            topic='printedBooksTopic',
            func=printresults,
            variables=['bindedbooks']
        )
        worker.run()
```

The complete code and the relevant description of it can be found in the following link :

https://github.com/emil88lime/Industry-4.0---IoT

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Figures