Digital Transformation and Industry 4.0 as a Complex and Eclectic Change

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***Abstract*—New technologies and possibilities summarized under the keyword Digital Transformation induce massive changes in the organizations' processes and will lead to tremendous challenges for almost all businesses. Existing business models will be expanded or replaced by digitally driven services. The Industry 4.0 with its autonomous cyber physical production systems and its intelligent products require holistic approaches for and will lead to sustainable changes in the industrial manufacturing. This paper addresses the main fields of Industry 4.0 and Digital Transformation as well as their core concepts. Further the paper describes the key success factors: interoperability and the organizations' ability for innovations. These key success factors are illustrated by three case studies regarding the fields of information supply in Facility Management, digital logistics and intrapreneurial behavior as an important source for intra-organizational innovations.**

Keywords—Digitalization; Digital Transformation; industry 4.0; interoperability; semantic database; quality assurance; innovation

I. Context of Digitalization, Digital Transformation and Industry 4.0

Digitization has an impact on all systems of the global world and on the recent forms of society. There are different ways in which digitization becomes effective. Digital transformation and presentation of information and communication are the classic kind in the core processes of ICT. In addition to it, it includes the digital description and modification of objects, functions, processes, services, applications, etc. as components of the digitalized world. The most complex view of digitization is the digital change of systems and subsystems in the whole society (Fig. 1).

The change from the analogue to the digitalized world will already include transformations. Transformation is a process of continuous changes initiated by internal or external factors leading to significant quantitative and resulting qualitative new kinds of systems by substitution, elimination or turnaround of whole or parts of former systems or subsystems. Digitization is such a comprehensive key factor inducing transformations so called digital transformations. Different models based on stage theory divide the process of digital transformation into a number of steps (Fig. 2).

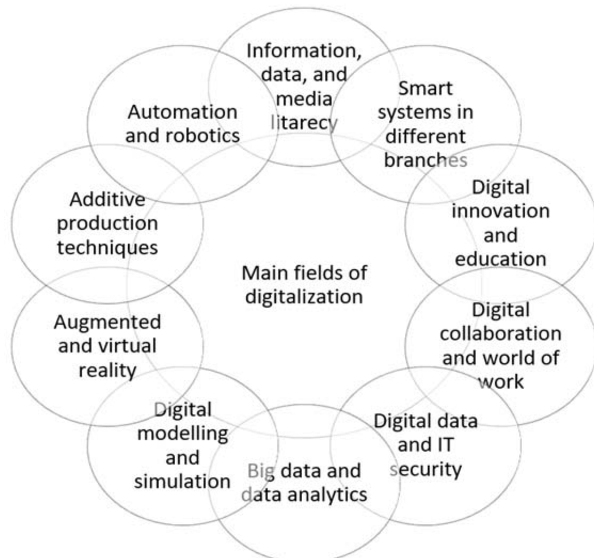

Fig. 1. Selected mainstreams of digitalization.

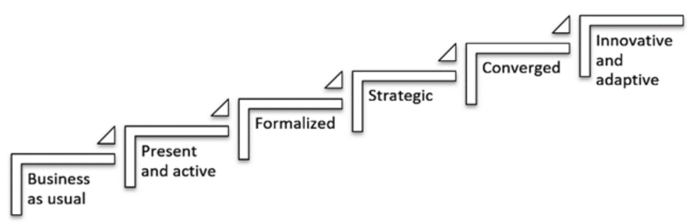

Fig. 2. Six stage model for digital transformation [1].

The digital transformation has a huge impact on the further development of industry as one of the main fields of application, especially:

- Digital transformation offers enormous chances and will place great challenges on industry.
- Digital transformation of industry will confront the national economies with tremendous change of structures.
- Because of the huge complexity digital transformation requires common and concerted concepts and actions.

Four levers for the digital transformation in industry are accentuated and prioritized: Digital data, automation, networking, and digital access to the customers [2]. This transformation is also announced as Industry 4.0.

II. Core Concepts and Models

Innovations are inherent for the digital transformation as well as Industry 4.0 because innovation means initiating something new building on the existing and creating a difference to the established ones [3]. The approach is based on the eclecticism because it is not limited to one paradigm or selected assumptions but uses multiple theories and views in order to get complementary insights into a system. Therefore, the digital transformation as complex change should be eclectic, innovative and at the end adaptive and sustainable. Digital transformation is directly related to smart systems, internet of things, industry 4.0 and digital ecosystems lately. Smart Systems are self-sufficient intelligent technical (sub-) systems with advanced functionality, enabled by underlying systems and components, providing heightened functionalities for upgraded and new industrial and consumer products and services [4]. The internet of things is the consistent continuation of the internet of data and information. Because the human-beings are physical and enter information of the physical world into the digital form of communication and computation the internet is primarily a reflection of the world of things more than of ideas [5]. Industry 4.0 will be a new digital stage of organization and control of the whole value chain over the entire product life cycle [6]. The concept of digital ecosystems was based on the idea that ecological, economic and social aspects of collaboration are important for the system development in the real world connected to the virtual world by digitalization. The architecture is swarm-based [7]. There are several approaches which are more or less related to these main themes.

There are two leading reference architectures besides many other approaches. The first one is the reference architecture model for Industry 4.0, the so called RAMI4.0 (Fig. 3) [8]. The second one is the Industrial Internet Reference Architecture (II RA) generated by the Industrial Internet Consortium which is characterized by similar reflections of the digital transformation in industry compared to the RAMI4.0 approach and which is focused on the viewpoints of business, usage, functionality and implementation [9], [10]. The agreement of the Plattform Industrie 4.0, with its strong roots in the manufacturing industry, and the Industrial Internet Consortium, with its more cross-domain oriented approach, is important for the further development of digital transformation in the field of industrial internet and industry 4.0. Especially, the comparability of the layer structure and contents will improve the common understanding of the fourth revolution by digitization in industry and services. The key issue will be the realization of the regular technical exchange, the identifying of mappings, differences and enhancements, and the discussion about common testing, focused on the benefit of interoperability of systems from different domains [11]. Interoperability of systems and components will be one of the most important innovations, challenges and chances of digital transformations in different fields of R&D as well as domains of applications.

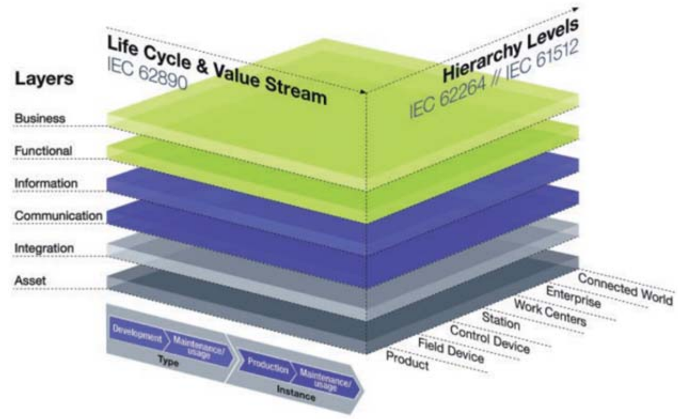

Fig. 3. Reference architecture model for Industry 4.0 (RAMI4.0).

III. Pivotal Role of Interoperability as a Key Success Factor

In daily business and especially in production and logistics more and more different information and communication systems are used. In many cases these heterogeneous systems either have to be connected to each other or at least it has to be ensured that data exchange is possible in some defined way. Therefore compatibility, integration and interoperability are substantial to realize digital transformation successfully. When different systems are combined into a major overall system, this is called integration [12]. "[...] integration means that various architectures can be intertwined, or plugged together, into a single logical and physical representation [13]". However, there is no statement about the type of connection of these systems. If the systems are compatible with each other they can interact with a basis of limited functions or features.

Interoperability, in contrast to compatibility and integration, is a pivotal factor for supporting and enhancing the digital transformation. Interoperability thereby is the ability of (distributed) independent and heterogeneous systems to collaborate seamlessly and to exchange information efficiently and applicably. Therefore, interoperability also means that information will be provided to the user without having separate arrangements between the systems [12]. The IEEE Standard Dictionary defines interoperability as follows: "Interoperability: The ability of two or more systems or components to exchange information and to use the information that has been exchanged" [14]. In addition, interoperability can be defined as a relationship between various tools in life cycle phases in a particular level of communication. Due to this, the challenge is that all components and systems have to be able to work together barrier-freely [15].

Interoperability on the one hand can be divided in five "levels of information systems interoperability": isolated systems, connected interoperability in a peer-to-peer environment, functional interoperability in a distributed environment, domain-based interoperability in an integrated environment and enterprise-based interoperability in a universal environment (Fig. 4) [16]. On the other hand interoperability can also be divided in technical, semantic and organizational structures [17].

Fig. 4. Levels of Interoperability ([18] adapted from [12]).

Nowadays, for the modern industry it is important to have interoperable ICT. Thereby, adaptability, real-time capability and network capability are key success factors to enable innovative production processes. Interoperability is a basic prerequisite for getting continuous support with information technology among all levels of business processes [19].

IV. Case Study I: Total Information Supply for Facility Managers

Like in many other branches digitalization is one of the upcoming challenges in the Facility Management domain. Mobile devices like smartphones, tablet computers or wearables like smart glasses and smart watches enable Facility Managers to do their daily tasks in a paperless way. But although today most information is stored in a digital way – and therefore should be available easily – there are still a lot of obstacles to overcome. Over the long facility's lifetime several partners work on special parts of the facility. Some of the partners are only involved in the facility's planning, others only for special tasks – e.g. different companies that execute electronic and mechanical maintenance tasks – during its runtime. Each of the companies involved in the lifecycle use their own information systems with their own way to store the data. So, during the facility's lifetime it happens that information get lost when companies no longer have to deal with the facility. But even if the information is available entirely, in many cases it cannot be accessed easily by all the partners because of different file formats used by the various applications utilized by the partners. More problems in the daily FM-work arise from the increasing number of electronic components and the increasing availability of software used in the facilities, which lead to a higher facility's and thereby FM-tasks complexity. In the end all these problems lead to a time-consuming search for the needed correct and up-to-date information, high dependency on the experience of the FM-technician and a lack of repeatability at the same quality level.

One promising approach for optimizing FM-processes therefore is to improve the Facility Manager's information supply, which means having all the information stored by several partners in several IT systems on several media available in one point. Due to the fact that not all the possible information systems have the same interfaces by which the stored information could be exchanged, it is necessary to create a central database, which can provide these possibilities. Therefor a semantic database is applicable. This database must contain all keywords and their relationships in form of triples consisting of subject, predicate and object from a specific domain – in this case the Facility Management. The developed semantic web, the so called ontology, is then able to connect to the different used IT systems and thereby to link the contained information.

But, having all the available information from many facilities in one place leads to another problem. The Facility Manager has to find out which piece of information is necessary to him in order to fulfill a certain task. So to provide only the needed amount of information it is necessary to filter out the correct one. This can be done by automatically detecting the Facility Manager's context, quasi any information that can be used to characterize the user's situation [20]. To describe the user's context various context factors can be used. To reduce the provided information amount it is necessary to know at least the characteristics for the context factors

- current user and his role,
- his current task or activity,
- his location and viewing direction, and
- current time.

Besides these context factors the IT-environment and devices, information and information sources, the physical environment and the social environment are specified as important context factors in literature [21].

When having filtered out the needed amount of information by adapting the user's context it is necessary to represent this amount to the user in an intuitive way. This is where modern mobile devices can provide benefits to Facility Managers. Smart devices are able to show up the requested digital information right in place by superimposing these on the device's screen over the device's camera field of view (showing the real facility) as an Augmented Reality (AR) representation. This AR representation bases on the exact matching of the real world and an existing corresponding 3D model of the currently viewed facility. For this it is necessary to calculate the user's position and viewing direction as exact as possible. The described approaches for semantic linking, context adaption and Augmented Reality are represented in Fig. 5.

The underlying research project for the described concepts addressed the problems described above and intended to solve them by supporting a Facility manager with the needed information on a tablet PC. The project resulted in the development of a small semantic database containing basic FM-related keywords and their relationships in the Web Ontology Language format. Nonetheless this basic ontology was able to connect to the IT systems the research project's partners were using, but only after mapping the systems manually. An entire ontology would have needed more manpower and time, but would have been able to connect the IT systems automatically.

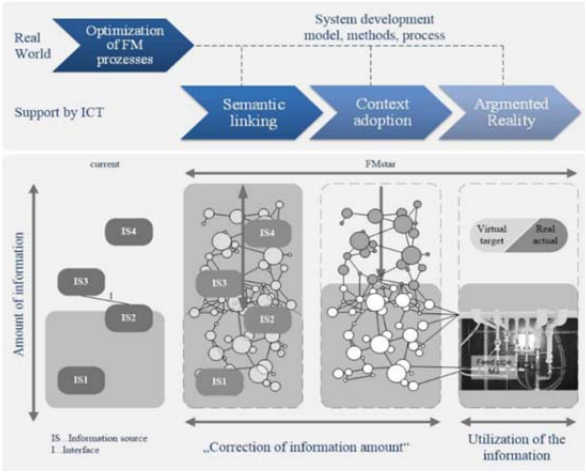

Fig. 5. The approaches of the research project [22].

Automatic mapping only worked for documents which could be assigned to their respective facility's components via the component's ID, which was part of the document's name. The context based information supply worked as intended, having some issues regarding the recognition of the user's location. The originated approach was to recognize the location by using the tablet's GPS sensor, but this wasn't accurate enough to match the facility's 3D model and the camera view in the AR representation exactly. This issue was solved by using QR-Codes to calculate the user's position and viewing direction. After having solved the location issue the developed AR representation worked as intended.

V. Case Study II: Digital Logistics

Digital Transformation and the developing Industry 4.0 have an increasing impact, especially in the logistic sector. Due to a high level of automation and technology as well as its interdisciplinary approach the logistic sector is suitable for researching in and developing of innovative industry 4.0 applications. Therefore an innovative research laboratory was built up at a Saxon University – the so-called "Experimental and Digital Factory" (EDF). The EDF is a fully equipped mini-factory. It contains all relevant components for production, logistic, automation, information and communication technologies as well as innovative human-machine-interfaces and process digitalization. In addition, it also includes all necessary components for planning and controlling purposes. A selection of different systems being used within the EDF is shown in Fig. 6. Among others the laboratory is equipped with:

- an automated high-rack warehouse,
- different in-house transportation technologies,
- several production cells (build up as a modular system),
- a driverless transportation system,
- tracking, location and positioning technologies,
- possibilities for augmented and virtual reality representations,
- flexible and adaptable processing centres.

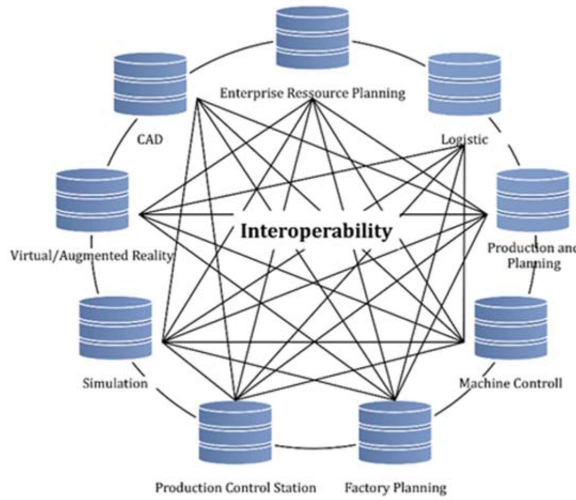

Fig. 6. Various systems and applications used in the Experimental and Digital Factory.

The principal aim of the industry 4.0 related researches is to examine and develop smart and interoperable environments. In the EDF, complexity and interdisciplinarity of the logistical processes ensure a high quality research environment for this topic. The research is also supported by the high automation level and the existence of heterogeneous and independent information systems.

At the EDF, in a first step of interoperability-related research, possibilities for its application within selected main systems in the logistics sector are going to be explored. After that the levels of interoperability will be analysed. Parallelly, preferences and modes of action of smart systems will be examined. Afterwards, the opportunities and potentials of interoperability – and in detail level 3: semantic interoperability – will be considered. In the last step the two issues (interoperability and smart systems) will be connected to a smart interoperable environment which will partly be adapted in the EDF as a prototype. Finally, it is planned to abstract the prototype to a general logistics environment.

VI. Recent and Future Innovations

Industry 4.0 is widely recognized to embrace opportunities of digitization, cyber-physical systems and smart factories [23]. Especially the opportunities related to new approaches for increasing organizations' innovative capacity are of particular interest. For example, the interaction of humans, machines and digital systems enables new possibilities for open innovation approaches [24] where consumers can directly influence the production process, choose configuration options provided by the producer or even suggest features they would like the product or service to have in the future [25], [26].

But cyber-physical systems and humans' interaction with these systems also provide new strategic opportunities for organizations to reveal their employees' full potential, encouraging them to provide suggestions for improving products, services and processes or even to act as intrapreneurs seeking new business ventures within their organization and to its benefit [27]. Employees' interaction with systems in new ways, e.g. through Augmented Reality solutions, enables a direct communication and processing of their ideas and specific suggestions through integrated IT systems. Recent research indicates that particularly the concept of intrapreneurship has a huge potential to be an incubator for innovation and to increase organizations' innovative capacity [28], [29].

Despite the great advantages Industry 4.0 involves, however, it is also acknowledged that it contributes to more complex, fast-changing and disruptive business environments [30], [31]. This consequently requires organizations to be particularly innovative and to increase efforts of proper planning, controlling and measuring. Specifically, the difficulty to measure innovation and to build an efficient and effective controlling environment has been pointed out recently [32]-[35].

VII. Case Study III: 3D Measurement and its Application in Intrapreneurial QM Processes

The quality assurance for metalworking value creation processes, for example in forming processes in car-body manufacturing in the automotive sector, is characterized by a multitude of measurements. These ensure that the produced work pieces meet the specified quality requirements in terms of dimensional accuracy and geometric features. Quality assurance is mostly carried out by sampling methods, where a defined number of work pieces is measured in order to have an overview on the overall quality within the examined production lot.

Even though sampling methods are usually reliable, their application within fully automated fast-paced production facilities might not be feasible, as work pieces have to be removed from the production process. Additionally, there will only be quality related data for a smaller number of work pieces, which implies that there are still chances for faulty parts to remain undetected.

One promising possibility to ensure high quality levels for each produced work piece, is the introduction of quality checks of each individual part. Modern optical measurement systems can be built in a modular way, which allows their integration within the production process. Especially optical systems are able to carry out three-dimensional measurements with high speed and accuracy, which enables them to perform an automated quality assurance of each produced part within the process and if necessary, even after each sub-process. This allows a reduction of time and labor for quality assurance processes and further increases production performance as no work piece has to be removed from the process for tasks related to quality assurance.

An automated measuring process allows not only a documentation of the gained measurement values along with other production data as a digital twin, it also allows an automated failure detection, as most modern products have corresponding digital reference data, such as CAD models. The requirements stored within these digital models can be compared to the physical object's real world implementation, via the utilization of three-dimensional measurement data. To achieve this, the measured values can be compared to the reference values within the CAD-dataset. Deviations that reach beyond the permitted tolerance values imply the presence of faulty work pieces and thus allows an automated failure detection. Due to the automated detection of failures, the amount of scrap can be reduced, as faults can be detected upon their occurrence and the production of further faulty parts and possible scrap could be prevented.

In a research project the authors and their partners were using a scalable and modular system of stereo camera units to obtain three-dimensional measurement data by using photogrammetry methods. The system was able to detect failures with an accuracy of 40µm. The measuring time thereby lasted around 4 to 5 seconds to create 3D models with dimensions of up to 500x500x200 mm.

Additionally, the detection of faulty parts can be used as a fundamental part for an automated root-cause analysis. Based on knowledge from a predefined failure catalogue, as well as knowledge on the production process, an information system can be enabled to identify a faults cause and its origin within the value chain. The information on a faults cause and origin can be used to inform the relevant positions within the supply chain as well as the personnel responsible for maintenance activities. In case of maintenance it is also possible to supply information on the required maintenance tasks and materials, which allows a swift removal of possible defects and thus allows the reduction of downtimes within the production facility to a minimum. With an additional feedback and suggestion loop within the maintenance assistance part, maintenance workers could also be enabled to return newly gained information on the maintenance or repair process. Exemplary this returned information could consist of feedback on the materials used or general ideas to improve the overall process in terms of time, efficiency or cost. The application of this feedback loop would allow and encourage employees to act as intrapreneurs, as they would be able to develop improvements and even innovations for their own workplace and thus the whole corporation.

VIII. Conclusion

Digital Transformation will confront organizations and society with immense challenges. To stay successful in a changing market it is important for these organizations and their employees to utilize modern digital technologies and to improve their ability to create new innovations.

Interoperable systems represent an important aspect in the field of new technologies, because these systems are able to integrate new components ad-hoc and without the need of pre-installing or pre-customizing them first. In the field of innovation management organizations will have to work towards the improvement of the employees' sense of responsibility. Employees will have to develop and improve their role within the organization in an active and intrapreneurial way, according to the organization's transformation.

The three illustrated case studies represent some examples for the eclectic extent of Digital Transformation and Industry 4.0. Especially the creation of ontologies as one basic concept for interoperability has to be intensified within the next years.

Additionally the opportunities of mobile devices will lead to eclectic changes in many business processes. Therefore it is necessary that employees are highly qualified regarding the handling of those devices and the underlying technologies. Knowing the corporations business processes will be a key factor to be able to use the innovative possibilities coming from the Digital Transformation and to be innovative by themselves.

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