Enterprise Architecture Concept for Digital Manufacturing

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Abstract. The purpose of the research is to study and analyze the impact of technologies of Industry 4.0 on the development of manufacturing companies and its effect on enterprise architecture within the companies. The justification of the necessity or making changes in enterprise architecture with the implementation of the technologies of Industry 4.0 in the manufacturing processes of the company is given. The Reference Architecture Model for Industry 4.0 as well as Service-Oriented Architecture are analyzed as proper frameworks for manufacturing industry digital transformation. The results obtained in this work can be used by companies in order to create for themselves plans for development of manufacturing processes in order to reach higher level of development of the Industry 4.0.

1. Introduction
The success in technological developments and innovations in manufacturing processes has changed industrial environment. The concept of Industry 4.0 (I4.0) brings together digital and physical sphere into new technological dimension that impacts economy and markets by increasing productivity, improving production processes, affecting product lifecycle, developing new business models and affecting the business environment and creating new labor skills requirements. I4.0 stands for new organizational structure in production value chain over product life-cycle. Increase in production performance follows implementation on I4.0 technologies, due to connected, intelligent and decentralized way of production. The main aspect of I4.0 is interconnectedness of humans, machines and finished products. Integration between them is achieved during a production process that is enabled by cyber physical production systems (CPPS) which is one of the main attributes of fourth industrial revolution. In order to present new developed systems, interfaces, interdependences and parameters within the system, a comprehensive and well descriptive model should be developed [19]. With introduction of new technologies in new digital era of doing business, demand for deeper analysis is needed. The possibility of implementing various technologies, and making a right business model that will align with your business strategy, values and goals is essential.

Fast developing market demands that business are developing and implementing innovative projects within their business models. That is why many companies are simultaneously implementing I4.0 projects. The need arises from achieving competitive advantage in running digital innovation projects. These project leaves impact on business and operating model of a company. This is why companies are changing their business model to more service oriented which consequently affects all business
processes. Therefore, in effective digital transformation of business it is important to implement simple enterprise architecture (EA). However, frequently used methodology The Open Group Architecture Framework (TOGAF) and enterprise architecture are facing a problem because business and IT leaders sometimes forgetting following issues:

- The enterprise architecture & TOGAF is not practical, too complete and difficult to explain.
- The EA terminology is difficult to understand and not aligned with operational departments.
- The EA governance methodology and EA models are difficult to understand and to maintain.
- Too much focus of project deliverables and IT solution architecture.

These are the issues that impact the quality of enterprise architecture. These issues are impacted even more because business and IT leaders do not cooperate with enterprise architects or do not always agree with the vision of architects while making digital transformations of a company. The aim of aligning with enterprise architect is to present more simple and practical enterprise architect vision. Few EA frameworks are proposed to solve business to enterprise architecture problem.

2. Literature Review

The term Industry 4.0 is according to Pereira and Romero only different term for new industrial revolution which implies technologies such as Internet of Things, Big data and analytics, Cloud computing, Simulations, Robotics, Additive manufacturing, Augmented and virtual reality, Cybersecurity and Horizontal and vertical system integration.

I4.0 is fourth industrial revolution that focuses on the global customization or more personalized production where previous three industrial revolutions were more oriented towards mass production. That is why I4.0 is characterized as socio-technical revolution [21]. German government has proposed that information technology is introduced to manufacturing industry, and that is a moment in economic development where I4.0 was introduced. Smart manufacturing was a concept of I4.0 proposed by German government. The integration of information, communication and manufacturing technologies had led towards integration of products, equipment, employees and organization.

On the other side of the world, China has presented new industrial revolution - Made in China 2025 strategy, whose aim was to develop manufacturing industry through innovations, coordination and green, open and shared development. Chinese government stated that new industrial revolution creates new business models which are followed with new industrial, supply and value chains. Furthermore, the goal of newly proposed change in manufacturing industry, followed with modern network-based technologies, was to drive production, management and marketing processes with the accent on making improvements in effectiveness and quality of production. United States come up with the name of new fourth industrial revolution Smart Process Manufacturing, the rest of the Europe introduced the concept of Factories of the Future, India names fourth industrial revolution: Make in India Campaign and Japan developed i-Japan Strategy. The purpose of developing special model of fourth industrial revolution in developed countries was to emphasize transformation development in manufacturing industries and show economic strength of fulfilling customer needs [4].

Furthermore, some points need to be explained. The technology and data are tools used in projects and digital activities which are driven by strategy for boasting company’s full performance. One more significance is given on recognizing the area of influence (just operational or across the enterprise) where I4.0 technology will bring value. The starting point for boasting I4.0 standards is mapping performance drivers and value objectives or in other words understanding the needs of a company and preferences of targeted market segments. Further questions have to be taken in consideration before making decision on implementation I4.0 technologies [20]:

- Performance: What is the challenge of company’s performance?
- Interventions: What company’s layers need to be influenced in order to change overall performance?
• Organization: Who are the people that operates and make decisions of company's performance?
• Need for help: What would facilitate them in process change?
• Data and Technology: What are the use case applications of digital technology would affect performance?
• Agile smart sequence: Development of plan that has biggest performance and economic impact

Due to the high growing research on I4.0, many theoretical and practical understanding of digitally connected manufacturing technologies have been studied. However, implementation of such technologies, transforms not only manufacturing processes but also society as a whole, economic, social and ecological models are digital transformation accomplishments. Each of these three dimensions must be fulfilled as an independent esteem in order to achieve sustainable and successful technology adaptation. According to [17], the Triple Bottom Line or economic, social and eco-logical models require holistic balance to accomplish challenges of sustainable benefits achievements. There are many dimensions of sustainable benefits that I4.0 provides and some of them are ecological which means reduces negative environmental impacts. Among ecological sustainable benefits, what authors emphasize the most is a development of new production technologies such as additive manufacturing which significantly diminishes production and logistics processes waste. When talking about social benefits, few employees benefits are listed. For example, employee satisfaction is achieved through well developed and designed HMI (Human Machine Interfaces) so as through a continuous professional education with help of intelligent assistance systems. Furthermore, new IT skills are going to be required whereas training, monitoring and collaboration will still be expected. So, some processes such as planning, monitoring and decision-making are going to be done autonomously which shows that digital transformations is meaningful and challengeable. Finally, I4.0 demands research in following eight areas before adopting its principles in any industry [17]:

• Standardization and reference architecture
• Managing complex systems
• A comprehensive broadband infrastructure for industry
• Safety and security
• Work organization and design
• Training and continuing professional development
• Regulatory framework
• Resource efficiency

IT transformation projects are often considered risky and expensive due to the lack of research on the practice of planning IT transformations as a tool support in the I4.0 implementation. The goal of I4.0 transformation planning is the achievement of full automation of the value chain and production individualization which is achieved through the integration of cyber physical systems with the existing enterprise IT system. The process of integration leads to the new level of enterprise IT complexity and companies are obliged to apply holistic management approach [24]. Holistic management approach is defined as a process of decision-making and planning which results in more accurate management decision which balances social, environmental and financial performance [25]. Enterprise Architecture (EA) is viewed as an integrated and holistic approach on designing system's fundamental order that has incorporated all elements of an organization and its relationships in well-designed logic [8]. The main focus of EA is the infrastructure of an organization, following processes, information and applications and technology. Principles and guidelines of EA are derived from the strategy of an organization and they guide the to-be design of organization’s infrastructure [10]. The EA observes the company's operating model's standardization and integration requirements in organizing business processes
and IT infrastructure logic. The requirements must be written for achieving business agility and profitability [1]. Furthermore, models are constructed in order to provide a roadmap for the implementation of the architecture within an organization. That is how EA assists to an organization in right business planning and quality improvements. Additionally, EA approach helps businesses in aligning business and IT resources in one information system, whereas EA framework supports methods in governing development processes [2]. In order to achieve full value realization, a project needs to be entirely planned and conducted. In conducting successful planning of any digital transformation projects, methods of enterprise architecture management (EAM) need to be exercised. EAM primary goal is the optimization of IT support and the reduction of IT costs in the project execution, and EA provides enterprise management with a strategic view of company's business and IT perspective [11].

One of the IT management tools in building EA planning is the EA framework TOGAF. The Open Group Architecture Framework (TOGAF) is an enterprise architecture methodology that provides companies with high-level framework in software development. The benefits of its implementation are reduction in errors, maintenance of time, following budget plan expenditure and alignment of IT with business units. TOGAF is an IT management framework that helps business to align IT goals with business goals and also serves as a help in the cross-department IT organization.

The overall goal of EA planning is to align the IT transformation plan with the overall strategy of an organization. The EA planning is first managed with as-is architecture (current) model and then transformed into to-be architecture model. The to-be architecture modelling referers to the scenarios that can be possible with specified architecture. Whereas, the modelling process demands a sequence of phases that will meet current and future requirements of a business. The EA planning phase is a phase where the transformation steps are documented, executed and evaluated [22]. EA planning requests planning, requirements management, release and synchronization management and integration systems management.

3. Using RAMI4.0 for Enterprise Architecture Modelling in Digital Manufacturing

The fundamental goal of Industry 4.0 is to facilitate cooperation and collaboration between technical elements. Industry 4.0 has introduced the ability of the communication capability between innovative production equipment and new products. The Reference Architecture Model Industry 4.0 (RAMI4.0) was developed by International Electrotechnical Commission [12] on the initiative of German public and private institutions for the purpose to provide the unique vocabulary and structure that is understandable to everyone in describing Smart Production or Industry 4.0 components. RAMI4.0 is officially adopted in March 2017 as a Publicly Available Specification for Smart manufacturing.

Furthermore, RAMI4.0 is defined as a structure that is helping to describe different assets from different presence. An asset in an organizational structure is defined as an item that has a value for the organization. An item that gives value for an organization can be tangible or intangible, so physical objects and software are both assets for an organization. The I4.0 components does not have to include all organizational assets, but only the one that have communication capabilities. One of the functions of RAMI4.0 is to analyze the asset by using three dimensions: architectural layers, value life cycle and hierarchy levels. RAMI4.0 has a goal to provide a complex analysis of an organizational asset with a holistic view of it and simplify its understanding. RAMI 4.0 is constructed from three dimensions such as Layers, Life Cycle & Value Steam and Hierarchy Levels as is it presented in the figure below.
The layers from the figure describe six layers with given properties and system structure with given functions and function-specific data of each layer. The Life Cycle and Value Stream gives explanation of assets in their value cycle. Meaning, the value of an asset is represented from idea, development and maintenance with the respect to the type and the production of the asset. The hierarchical layered structure describes functional hierarchy of a manufactory which has imposed value-added processes. When mapping RAMI 4.0 in functional way, following terms between layers and RAMI 4.0 are explained. The business layer in RAMI4.0 is explaining the whole business life cycle over all functional hierarchies, where the combination of data and functions can show new business opportunities within i4.0 with the use of RAMI 4.0. The assets in RAMI 4.0 are objects that hold a value for an enterprise (example: machines, personnel, raw material, software etc.) and participate in the business processes. Functional in RAMI 4.0 explains a viewpoint where a system is introduced in different functional domains. The example can be MES system that is integrated and then run. The RAMI 4.0 communication layer best presents the combined configuration of I4.0 communication format and data format. In this layer the communication across multiple levels is achieved. From the life cycle of an asset, which means from development to production to service the consolidation is achieved over the functional hierarchical levels which means from product to connected world. The RAMI 4.0 communication layer emphasizes the transmission mechanism where the network of Industry 4.0 components and their interconnection is described. Certain standards for implementing RAMI 4.0 communication layer are specified [6].

The layered structure is vertical and it represents various perspectives (data maps, functional descriptions, communications behavior, assets and business processes flow) of an I4.0 system or entity. This type of layered structure corresponds to IT thinking due to the complexity and manageability of the projects.

The function of layers in the horizontal lift axis have different purpose. The left-hand horizontal axis emphases important criterion in the product life cycle throughout the lava streams. The life cycle of the I 4.0 gives potential for companies’ assets improvements and with the help of RAMI 4.0 the relationships and links of different assets can be visualized and standardized with the representation of life cycle and the associated value streams. The RAMI 4.0 uses IEC 62890 standards as a guideline for the life cycle and value stream dimensions.

Furthermore, the value stream is also presented on the left side of the RAMI 4.0 model. Improvements of produced type, which is one of the main ideas of I4.0, are shown in the value stream of RAMI 4.0. The value stream in the digitalized production provides many benefits to a product life cycle. Examples are: data from the machines can be used in logistics, inventory and purchasing department have clearer information about parts from suppliers in real time, customers can check the completion status of the product in the time of production and etc. In the value stream and due to the
digitalization, the production enables linking of purchasing, order planning, assembly, logistic, maintenance, the linking of customers and suppliers and other paths to the improvements paths [3, 15].

The RAMI 4.0 is the three-dimensional architecture model which provide Service Oriented Architecture (SOA) framework that combines services and data in order to facilitate and follow the main paths of I4.0. The architecture model provides the horizontal integration through value networks which is one of the technologies of I4.0. Furthermore, vertical integration from products to the end user and with the Cloud computing is also consistent within the model. Additionally, lifecycle management and end-to-end engineering so as the human power contributing to the overall value stream is followed in the RAMI 4.0 model.

4. Service Oriented Architecture for Digital Manufacturing

Service Oriented Architecture is defined as an architecture style where separate applications are provided in technologically self-dependent services. To emphasize the importance of the architecture style we should understand that nowadays an enterprise should be viewed as a collection of services [18]. Applications are defined as a providers of the IT support for business processes that should be built in short period of time. Whereas, service is defined as functionality that is repeatedly used and is offered to the user through an application interface. To understand how and why EA and SOA have similar goals following dependencies are stated by Greefhorst [7]:

1. SOA provides an EA with important principles on applications.
2. SOA depends on EA, its contents and governance, in order to succeed,
3. The service-oriented paradigm should be applied to other aspects of an EA.

These three dependencies explain how both EA and SOA have in goal to build application functionality within an organization in order to increase flexibility and reduce costs. Furthermore, EA depends on SOA because SOA provides principles and guidelines which are used in application of EA whereas SOA depends on EA in order to succeed in its application.

In order to optimize its overall business, companies should view their organizations as business components that provide services that pro-vides insights into the synergy within and outside of the organization. Also, the focus should be put on their core distinguishing capabilities and services of other organizations.

Nowadays, in the fast changing manufacturing environment, there is a constant demand for changes in enterprise’s processes and products while keeping the essential production environment managed and available to respond to changes [14]. In order to meet the challenges, the IT support and automation software systems are needed. As a factory is becoming automatized the integration of SOA architecture in the solutions of MES, ERP and EAM systems is crucial. Further findings are de-fined as the crucial one in engineering applications of SOA approach [13]:

- Provide integration between people and computers in well integrated working environment that follows various levels of the product life cycle with the real-time knowledge and information accessibility. The integration of various sources of information is essential in supporting the decision capabilities of the system and more efficient communication between humans and computers.
- Be heterogeneous in a way to reconcile software and hardware multi-vendor and multi-purpose in different environments.
- Be interoperable in a way that subsystems and system components that use different programming language and different data representation language and models and even operate in different computing platforms still operate in an efficient way.
- Be open and dynamic means that different subsystems such as software, hardware or factory devices are integrated and can be easily removed from the existing subsystem without stopping the existing working environment
Be agile takes into account agile manufacturing which has to adapt quickly to changes in product design. Newly manufacturing environment has to adapt fast on high competition. The industrial automation systems are expected to be complex systems of existing systems. The future systems will demand cross-domain integration and implementation of IT-drives solutions in the traditional automation systems. The future concept is going to be a large ecosystem of systems with collaboration of systems on large scale due to the distributed, autonomous, pro-active, intelligent, fault-tolerant systems that have capabilities, functionalities and structured characteristics of services as a "cloud services" [9].

![Figure 3. Future industrial system view of cloud-based composition of cyber-physical services.](image)

The figure "Future industrial system view of cloud-based composition of cyber-physical services" explains the creation of a production automation and control system that is being considered as more conventional technology nowadays [5]. The SOA based ecosystem is a combination of networked systems that offer their services as web services in one whole flexible and agile system within the EA of an enterprise. One of the key focuses in this system integration is the integration of aggregated device-level services with web services of higher-level and business processes that are on the business applications level (ERP), so that the functionalities of device level can be demonstrated on higher business application levels such as manufacturing, logistics, sales and marketing level. The benefit of such services is that no additional re-programming is required where applications can be re-configured. The SOA approach can also be applied to IoT support system [16]. Because the nature of IoT is that its architecture is decentralized and heterogeneous, the concept of SOA architecture is suitable in achieving interoperability between heterogeneous devices.

5. Conclusion
The business performance challenges show that businesses are facing organizational, technological and environmental challenges and that all the companies want to produce products with less costs and place product faster on the market. In successful adoption of I4.0 the manufacturing companies are changing their business models in becoming paperless companies. When companies reach predictive level of I4.0 development level, the business model of the company is changed.

In order to realize the projects of implementing I4.0 technologies in manufacturing companies, a holistic enterprise architecture approach can be used in order to plan transition activities and understand how different layers of organization will be changed. Existing and most popular TOGAF framework has been considered to be not enough for modelling enterprise architecture for digital manufacturing. The RAMI4.0 as well as Service-Oriented Architecture are seen as most proper frameworks for digital manufacturing enterprise architectures. The future studies will be devoted to developing reference EA models for different manufacturing industries based on RAMI4.0 and SOA frameworks.

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