The evolution of Enterprise Architecture in scopes of digital transformation

A I Levina[1], **A D Borremans**[1], **A A Lepekhin**[1], **S E Kalyazina**[1], **K M Schröder**[2]

[1]Graduate School of Business and Management, Peter the Great St. Petersburg Polytechnic University, Russia
[2] Zuyd University of Applied Sciences, Netherlands

Abstract. Nowadays the business has to develop in a rapidly changing environment. Globalization, digitalization and emerging information technologies affect not only the business processes of organizations, but they change the enterprise architecture in a complex way. The purpose of this research is to consider standard existing approaches to the Enterprise Architecture description and modeling. Moreover, the aim of this paper is to point out modern modeling frameworks that display such technologies as the Internet of Things, the Industrial Internet of Things and others, for a complete description of the enterprise model within the framework of Industry 4.0 and digital transformation.

1. Introduction

Designing and creating a business is a more complex challenge than designing a production. There is still no single recognized standard for designing and creating a business. To solve these problems, modern organizational technologies called business engineering are actively used. The core idea of business engineering is the usage of technological engineering achievements to design business systems that successfully work in the field of design and management of technical objects. This allows to make management more accurate and efficient. Business engineering is a set of theories, methodologies and methods of enterprise design based on a combination of knowledge and best practices. In accordance with the postulates of systems theory, a systematic perspective in the design of enterprises declares the need for a holistic view of the enterprise with an emphasis on the relationship between its components [1].

Creating an enterprise from scratch is, on the one hand, a serious challenge, and on the other, a unique opportunity to create an effective, sustainable system. Many approaches of modern management appeal to an already established business and work with existing enterprises in the direction of improving and optimizing performance indicators. It seems advisable to lay the foundations of effective functioning and sustainable development at the design and creation stages of a business, rather than correcting the imperfections that were laid down at the project stage during the system's functioning [2]. Correction of imperfections identified at later stages requires significantly more resources (financial, material, time) than the cost of creating effective management mechanisms at the beginning of the journey [3].

Creating an enterprise requires a comprehensive interdisciplinary approach that allows to take into account design and mutually integrate the diverse components of the business into a single system. Ideally, such an approach should be developed and fixed in the format of the standard recommended for use during the establishment of the enterprise, and be the basis for further examination of the conformity and quality of the created enterprise.

The purpose of this study is to analyze how the approach to modeling and development of an enterprise is changing in the conditions of digital transformation of the economy based on the standard for modeling Enterprise Architecture.

2. Materials and methods

It is difficult to overestimate the role of the design stage when creating any object. It is at this stage that all the principles of the functioning of the created system are laid down, at this stage it is possible to make the required corrections with minimal costs compared to the subsequent stages. The cost of fixing errors inherent in the project increases with each new stage of the creation of the object [4].

The central concept of business engineering is the concept of Enterprise Architecture. The concept of "architecture" initially appeals to the understanding and definition of the relationship between users of a system and the system itself. Understanding these relationships, and, consequently, the requirements for the system, allows to specify the essence of the system, i.e., structure, behavior and other properties. This “core”, often referred to as system architecture, is the basis for analysis, evaluation and optimization and serves as a starting point for the design, creation and implementation of the system. The Enterprise Architecture model is designed to combine management technologies of various aspects of the business together in order to create an integrated management system [5].

The Enterprise Architecture in its modern sense appeared as an answer to the problems of alignment of business requirements and IT infrastructure. The history of the issue is as follows. The development of technologies for the implementation of various types of economic activity, the tightening of customer requirements for goods and services in a competitive market environment, the complication of economic relations between market agents in the modern world and the associated increase in the amount of information operated by business entities, has led to the need to automate enterprise processes. The corresponding development of ICT has made IT systems an integral part of almost any enterprise. The use of ICT in business reduces the time it takes to complete operations, increases the efficiency of operations, provides for the collection, processing, storage, transmission, analysis of data, which increases the effectiveness decision support systems. It quickly came to an understanding that the implementation of information systems without adequate consideration of the requirements of the management system is not effective: the business requirements for IT support for its processes are the driver for the implementation of IT systems in enterprises [6]. As a result, a need arose for approaches to the formation of an integrated enterprise management system, including ICT as an integral part. The answer to the problems of aligning business requirements and ICT capabilities was the concept of Enterprise Architecture and its broader interpretation - corporate architecture. The Enterprise Architecture philosophy was quickly accepted by the largest players in the global IT market (SAP, Microsoft, Oracle) and formed the basis of their approach to the development and reengineering of information systems [7].

The concept of "Enterprise Architecture" was first introduced by J. Zachman in his publication "Structure of the architecture of information systems" in 1987 [8]. Zachman’s methodology is based on the discipline of classical architecture and provides a set of perspectives or structures for describing modern complex corporate systems. The basic idea is that each individual aspect of the system can be described in order and coordination with everyone else. The architecture model is a table consisting of five rows and six columns. As a result, the specialist has an integrated enterprise model, independent of its design tools, which is easy to understand by specialists in any field.

Currently, there are various methods for the formation and evaluation of Enterprise Architecture, in addition to the Zachman model. They determine the classification of the main areas of architecture, a description of the rules (policies) used, standards, processes and models:

- TOGAF (The Open Group Architectural Framework) [9];
- Methods of designing the architecture of state-owned companies FEAF (Federal Enterprise Architecture Framework), DoDAF (Department of Defense Architecture Framework) [10];
- Methodologies of analytical companies: Gartner, META, etc.[11].

Currently, Enterprise Architecture is widely used as a systematic management approach, meaning by this term a combination of various elements of the management structure and the relationship between them. According to one of the definitions, Enterprise Architecture is a single whole of principles, methods and models that are used to design and form an organizational structure, business processes, information system and infrastructure. An important characteristic of Enterprise Architecture is that it is a single whole: individual components of the architecture can be locally optimized, but this does not mean that the system consisting of them will be optimal.

Despite the growing popularity of the architectural approach, currently the lack of a common language and unstable communications between business and IT professionals still pose serious obstacles to the design, modeling and implementation of balanced architectural solutions. In this regard, an important component of the effectiveness of implementing organizational changes is the alignment (coordination) of various architectural components, in particular, business and IT components. Alignment here means ensuring that the mutual requirements of the various components correspond to each other. Aligning the components allows you to create a balanced architecture of the enterprise, which ensures the effective functioning of the company not only in the present, but also lays the foundation for future sustainable development. Efficiency in this case cannot be achieved through local optimization - an integrated approach is required that takes into account the interconnectedness and interdependence of business and IT components.

Enterprise Architecture is a comprehensive management tool designed to provide effective management solutions in response to the challenges of the business environment. The heterogeneous structure of the Enterprise Architecture requires constant alignment of all its elements, which are grouped into layers. At the same time, the need to constantly adapt to the realities of modern business necessitates a constant change and development of Enterprise Architecture. In the framework of Enterprise Architecture as an integrated model of enterprise management, a number of individual elements are united into layers. Layers and their elements are interconnected and interdependent: some define requirements for others and provide feedback. The multi-level structure of the Enterprise Architecture model determines the relationship between the main components of the system. Layers of Enterprise Architecture combine elements that are uniform in nature. The number and names of layers, as well as the assignment of an element to a particular layer vary in different sources, but the leading researchers have similar approaches to the elemental composition of Enterprise Architecture [12]. In the framework of this study, the TOGAF standard was chosen as the basis for analyzing the design of the enterprise.

The TOGAF approach, which has become the de facto standard for architectural design, offers the following layers of Enterprise Architecture:

- Business architecture: defines a business strategy, management, key business processes and organizational structure;
- Data architecture: describes the structure of the logical and physical structure of enterprise data and data management resources;
- Application architecture: provides a plan for the deployment of individual applications, their interaction and their relationships with the main business processes of the enterprise.

In the TOGAF ADM Enterprise Architecture development method, the authors of this approach mention the data architecture and application architecture as part of a single layer “Information Systems Architecture” [13]. In the following, the term “IT architecture” will be used in relation to this single layer. Technological architecture describes the software and hardware capabilities needed to support the deployment of business services and application services. This includes IT infrastructure, middleware (software), networks, communications, processing, standards, etc. Enterprise Architecture is nowadays one of the leading management concepts. The architecture of the enterprise is the foundation of the business: it is the business goals that the company’s activity is aimed at that set the requirements for the architecture of the enterprise. The architecture should be quite stable, but at the same time, it should have built-in flexibility and adaptability to changing business environment conditions, developing technologies, and new business tasks. Thus, all the components of the Enterprise Architecture, no matter how fundamental they are, are somehow temporary.

3. Results

Along with traditional representations of Enterprise Architecture, under the influence of the ongoing digital transformation of business in general and industry in particular, concepts and models have been actively developed in recent years that describe the integration of digital technologies in Enterprise Architecture [14]. In the professional world community, the reference models of two different consortiums are most famous: Reference Architecture Model Industry 4.0 (RAMI 4.0) [15] and the Industrial Internet Reference Architecture (IIRA) [16].

The three-dimensional model of RAMI 4.0 architecture distinguishes layers (business, functions, information, communications, integration, assets), hierarchical levels (unified environment (literally - connected world), enterprise, work center, station, control devices (instrumentation), field devices, product), the stream of value creation throughout the life cycle (development and support of the type of product or system, development and support of a specific instance of the product or system).

IIRA is a standards-based, open architecture for the Industrial Internet of Things (IIoT) [17]. The value of IIRA, according to developers, is its broad applicability in industries to ensure interoperability of the systems and technologies used, as well as for technology management and standards development. The architectural representations of IIRA are determined by analyzing the various uses of IIoT, identifying the relevant stakeholders (stakeholders) of the IIoT systems and correctly identifying the specific interests of the stakeholders [18].

The IIRA model uses 4 views: a business view, a user view, a functional view, an implementation view. A business presentation provides identification of stakeholders and their business vision, values and goals when creating an IIoT system in a business and regulatory context. The user view considers options for the intended use of the system. As a rule, it is presented in the form of a sequence of actions involving people or logical (for example, a system or system components) users who provide their intended functionality to achieve the basic capabilities of the system. The functional presentation focuses on the functional components in the IIoT system, their structure and interconnection, the interfaces and interactions between them, as well as the interconnection and interactions of the system with external elements in the environment to ensure the life of the entire system. The introduction is about the technologies needed to implement functional components, their communication schemes and their life cycle procedures [19].

The IIRA reference architecture begins with a general structure of a high degree of abstraction and offers common architectural patterns to ensure the widespread use of industrial Internet applications in all industries. Applying this common architecture for real-world use cases transforms and extends abstract architectural concepts and models into specific, detailed architectures that take into account the specifics of industrial Internet use cases. Thus, the application of the reference model occurs throughout all processes of the system's life cycle - from concept, collection of requirements and design to the need for modernization and abandonment of the current model.

The described models of Enterprise Architecture in a digital transformation are similar in ideology - both offer a format for integrating information and operational technologies [20].

The analysis showed that the RAMI 4.0 model is mainly intended for use in industrial enterprises, the IIRA model focuses on the use of industrial Internet in various industries. As an alternative, the use of the TOGAF standard, namely the ADM cycle for analyzing the development of enterprises, is proposed. ADM TOGAF is iterative, throughout the process, between phases and within phases. ADM is considered the core of TOGAF and consists of a phased cyclic approach to developing a common Enterprise Architecture (Figure 1).

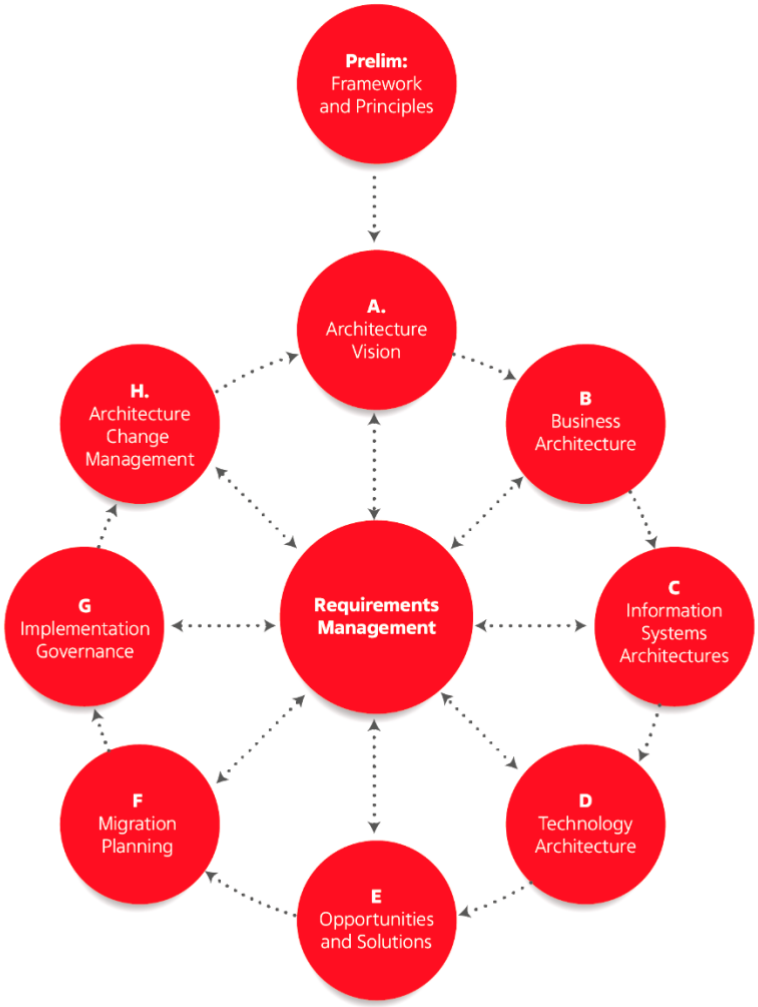

Figure 1 – TOGAF ADM

ADM provides the architecture development process and includes architecture structure creation, architecture content development, and architecture implementation management. One of the main domains of architecture is technology architecture. In the process of introducing additive technologies, a description of the corresponding hardware capabilities required to deploy a new type of production will be required. ADM TOGAF can be considered a description of the life cycle of a process that operates at several levels in an organization within a holistic management structure [21].
Architecture design is carried out at stages A-E, as a result of which a common vision of the required architecture is formed and a business architecture, application architecture, and technological architecture are created. Based on this, implementation and migration plan, which is a schedule for the implementation of the described solution and includes timelines, costs, resources, benefits and stages of implementation can be created. At the stage of implementation and migration, a general strategic approach to the implementation of solutions and the use of planned opportunities is determined, that is, the project is directly organized. The implementation and migration plan is consistent with the overall enterprise approach to managing and implementing change [22].

4. Discussion

The proposed models takes the current state of IT and production technologies into account and offers relevant domains for inclusion in the Enterprise Architecture. However, it can be noted, firstly, the great dimension and complexity for the perception of these models, as well as their focus precisely on the organization of information exchange using digital technologies. It can be noted that for large, traditional infrastructure-intensive enterprises, such methodologies do not provide a procedural approach to the design of Enterprise Architecture, allowing detailed design of its individual domains. Further research may be based on the ideology of the universally recognized TOGAF standard, which does not place special emphasis on the problems of digital transformation of enterprises, but at the same time allows this aspect to be included in the framework of the existing ideology, focusing on business engineering rather than on the implementation of individual technologies.

5. Conclusion

Thus, the introduction of new technology should be considered as a holistic project, affecting all levels of the organization. In order to optimally build a system of business processes, the formation of technology architecture, application architecture, it is advisable to use the TOGAF architecture development method, which considers enterprises as a system. The result will be a wider and more efficient use of the latest technologies that ensure the digital transformation of the enterprise.

Acknowledgments

The reported study was funded by RFBR according to the research project № 19-010-00579.

6. References

[1] Hepp M and Roman D 2007 An Ontology Framework for Semantic Business Process Management *Wirtschaftinformatik Proceedings* 27

[2] Kozlov A and Teslya A 2016 The corporate social projects: risks valuation method based on the fuzzy sets approach *Proceedings of the 3rd International Conference on Project Evaluation. Icopev* pp 189–193

[3] Bril A R, Kalinina O V, Ilin I V, Dubgorn A S and Iliashenko O Y 2017 Forecasting the turnover growth in the risk management system as management decisions support *2017 XX IEEE International Conference on Soft Computing and Measurements (SCM)* (IEEE) pp 692–693

[4] Ross J W 2003 Creating a strategic IT architecture competency: Learning in stages

[5] Ilin I V and Anisiforov A B 2014 Improving the efficiency of projects of industrial cluster innovative development based on enterprise architecture model *WSEAS Trans. Bus. Econ.* **11** 757–764

[6] Ilin I, Levina A, Abran A and Iliashenko O 2017 Measurement of enterprise architecture (EA) from an IT perspective: research gaps and measurement avenues *Proceedings of the 27th International Workshop on Software Measurement and 12th International Conference on Software Process and Product Measurement* (ACM) pp 232–243

[7] O'Leary D E 2000 *Enterprise resource planning systems: systems, life cycle, electronic commerce, and risk* (Cambridge university press)

[8] Zachman J A 1987 A framework for information systems architecture *IBM Syst. J.* **26** 276–292

[9] Haren V 2011 TOGAF Version 9.1 A Pocket Guide

[10] Urbaczewski L and Mrdalj S 2006 A comparison of enterprise architecture frameworks *Issues Inf. Syst.* **7** 18–23

[11] Sessions R 2007 A comparison of the top four enterprise-architecture methodologies *Houst. ObjectWatch Inc*

[12] Anisiforov A B and Dubgorn A S 2017 Organization of enterprise architecture information monitoring *Proc. of the 29th IBIMA Conf.-Education Excellence and Innovation Management through Vision* vol 2020 pp 2920–2930

[13] Blevins T J, Spencer J and Waskiewicz F 2004 TOGAF ADM and MDA *Open Group OMG*

[14] Zaychenko I, Smirnova A and Kriukova V 2018 Application of Digital Technologies in Human Resources Management at the Enterprises of Fuel and Energy Complex in the Far North *Energy Management of Municipal Transportation Facilities and Transport* (Springer) pp 321–328
[15] Zezulka F, Marcon P, Vesely I and Sajdl O 2016 Industry 4.0–An Introduction in the phenomenon *IFAC-Pap.* **49** 8–12
[16] Buchheit M 2017 The Industrial Internet of Things Volume G1: Reference Architecture 58
[17] Mumtaz S, Alsohaily A, Pang Z, Rayes A, Tsang K F and Rodriguez J 2017 Massive Internet of Things for industrial applications: Addressing wireless IIoT connectivity challenges and ecosystem fragmentation *IEEE Ind. Electron. Mag.* **11** 28–33
[18] Bolobonov D, Ilin I, Korolev I and Frolov A 2019 IoT in Smart Cities' Utility Systems: from prototype to production *International Conference on Digital Technologies in Logistics and Infrastructure (ICDTLI 2019)* (Atlantis Press)
[19] Jeschke S, Brecher C, Meisen T, Özdemir D and Eschert T 2017 Industrial internet of things and cyber manufacturing systems *Industrial Internet of Things* (Springer) pp 3–19
[20] Levina A, Kalyazina S, Iliashenko V M and Dubgorn A 2019 Digital Transformation Drivers of Russian Business *International Conference on Digital Technologies in Logistics and Infrastructure (ICDTLI 2019)* (Atlantis Press)
[21] Buckl S, Ernst A M, Matthes F, Ramacher R and Schweda C M 2009 Using enterprise architecture management patterns to complement TOGAF *2009 IEEE International Enterprise Distributed Object Computing Conference* (IEEE) pp 34–41
[22] Bril A R, Kalinina O V and Ilin I V 2017 Financial and economic assessment of investment and innovative projects on the improvement of personnel management system *Aktual. Probl. Ekon. Actual Probl. Econ.* 176