Electrical Engineering Enterprise's Architecture Modeling as a Basis for its Transformation into Industry 4.0

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***Abstract*—The technology of current electrical engineering enterprise 's architecture modeling is studied in a form which is convenient for analyzing the architecture's state and determining its break with the target architecture which must be possessed by the enterprise during transformation into Industry 4.0. Instruments that are necessary for enterprise architecture designing and analyzing are still in status of development. Analyzing of current enterprise architecture demands methods of complex description of its layers and single elements. In this context enterprise architecture includes following: enterprise business architecture, application, data architecture, and technical system architecture. Aiming to find the best architectural solution, limits of resources, which will be available for building the enterprise architecture, as well as a set of metrics for evaluating and comparing project decisions, must be identified at each level. At the business architecture level, the business processes parameters and their relationship with other elements of this layer - organizational structure, management models, conceptual data model, as well as with elements of other layers of architecture are being analyzed. The applied methodologies will make it possible to objectify and concretize the concepts of enterprise architecture building, which will allow us to formulate a set of functional requirements for the software module for the analysis and evaluation of the optimal architecture. ArchiMate language allows to model an architecture in the most full and comprehensive way. An approach to the search for the optimal architectural solution based on significant criterion, which affects the architecture of the enterprise as a whole, is suggested. The proposed it contributes to the effective achievement of the goals of the enterprise within the framework of the adopted strategies. The set of enterprise business architecture has been developed with the use of the ArchiMate language. This approach is applicable to modeling the architecture of an electrical engeneeting enterprise, which provides support for modern technologies as the basis for its transformation into Industry 4.0.**

Keywords*—Industry 4.0, Enterprise Architecture (EA), design Enterprise Architecture, Enterprise Architecture elements, business system, design space for EA, ArchiMate.

I. Introduction

Currently, most of enterprises deal with different changes in their activity, for example such as development of information technology, globalization, changes in customers' requirements and etc. All of these things make impact on business development and on emergence of new business models. In the era of cloud, mobile and digital information technology there are important changes in digital transformation of enterprises, which are connected with the last creations in the sphere of cloud computing and mobile IT. There is active development in the sphere of big data, internet of things and blockchain technology that define trend development in the area of digitalization which is currently taking place. In the era of digital transformation the need to build and analyze enterprises architecture becomes actual.

Some time ago, information technology was just like a support tool, which served main business processes of the enterprise. However, nowadays they are becoming a key tool of their realization. In 2011, the creator and president of International economy forum in Geneva K. Shvab, made the concept of fourth industrial revolution, leading to the industrial order of Industry 4.0. As defining its main characteristics and technologies, the following are distinguished: widespread using of internet technology, artificial intelligence, internet of things [1,2]. The implementing of the technologies is taking place at high speed and is accompanied by an intense competition.

Its main characteristics are the widespread use of Internet technologies, artificial intelligence, and the Internet of Things. The features of the enterprises of the electrical engineering industry are: complexity and knowledge intensity of the final product; long technological cycle of its manufacture; high degree of automation of technological operations. In this regard, it becomes relevant to use digital counterparts of electromechanical systems, additive technologies, and systems to support the full life cycle of products. The implementation of integrated corporate production systems that can respond in real time to changing production conditions, supply chain requirements and customer needs is becoming relevant.

The Russian Union of machine builders formulated the main tasks in the field of industrial development: the creation of a competitive, dynamic, diversified and innovative economy in Russia. This needs to be solved such tasks as ensuring the

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implementation of investment projects on modernization and creation of new industries, high-performance workplaces, development of the technology transfer system, stimulation of the introduction of advanced managerial, organizational and technological solutions to increase productivity. Implementation of the tasks supported by the government of various government programs, such as programs of the Russian Federation "Economic development and innovative economy", "The Development of industry and increasing its competitiveness", "Development of science and technology", the Bashkir technology initiative concept, approved in the Government of the Republic of Bashkortostan dated July 21, 2017 No. 689-R, involving the reorientation of scientific and technical developments on the introduction of innovative technologies of the new generation.

In addition to the enterprises of the electrical engineering industry, such key development priorities are technologies for monitoring and managing complex technical and technological objects at enterprises, systems of automating production processes and CALS-technologies. The complexity of the final products of electrical engineering, its orientation to the requirements of a particular consumer, requires improvements in the processes of design, production and testing of products. The model of digital development of enterprises in the industry should take into account the requirements of the modern market: reduction of decision-making time, project implementation time and product launch time. This is possible with the transformation of existing business processes of production, and, consequently, the transformation of the enterprise architecture, including its IT infrastructure.

For supplying the competitiveness on the market and for successful development, the enterprise has to constantly improve the IT infrastructure and implement new technologies. In so doing, there is a problem: how to implement these innovations effectively? How to connect them with the existing IT-infrastructure of the enterprise as well as with the system of business processes and with the policy in the management area. The concept of enterprise architecture appeared, namely, at the interface of information technology and management. The enterprise architecture (EA) defines the business structure and the requirements for business processes, necessary data and technology which will supply business processes, transitional processes, that are necessary for implementation of a new technology. Each of enterprise architecture has to adapt and change with new trends and has to make correct reaction on changes of business conditions. The most important characteristic of enterprise architecture is to give overall picture of the enterprise.

II. Problems of Enterprise Architecture Formation

Nowadays, EA is mainly formed spontaneously or with the usage of existing architectural models, which despite of systematic approach for EA building, do not allow to quantify it’s building variety based on metrics description of its components. Hence, there is often optimal architecture formation and implementation problem, which will help to conduct active implementation and use advanced information technology, also, using enterprise capacity that was gained through many years. Enterprise architecture’s components have to comply with the set of functional requirements, which are defined by the business processes and users. So, creation of target EA and enterprise planning transition of the Industry 4.0 are an important issue of research. For solving this task, it is necessary to systematize the structure of EA that has to comply with the way of advanced area of digital technology development based on analysis result of EA structure and thematic research of the enterprise.

Considering the process of modeling the architecture of an electrical engeneering enterprise, it is possible to make a conclusion that the union way or algorithm that will be able to define IT infrastructure does not exist. However, for different architecture levels of EA it is possible to use some of created rules rendering possible to make analysis of the considering object by the metrics. Each level has specific method of description: text, graphic, informal or certain description. In accordance with above mentioned, in general, for enterprise architecture analysis it is necessary to have models that were built taking into account methods and tools created on each level.

In order to comply with the strategic goals of the electrical engeneering enterprises, when building the architecture of the enterprise, the goals set in documents such as the national program should be taken into account "Digital Economy of the Russian Federation" and "Strategy of socio-economic development of the Republic of Bashkortostan for the period up to 2030" [2]. The technical policy of enterprises is aimed at fulfilling the functions and tasks of society and solving problems in accordance with the Concept "Digital Transformation 2030".

The optimal architecture solution enables emphasizing the border between components of EA that should not be changed and components that have to be optimized and changed with requirements of the process. That makes high requirements for architecture quality. The quality means that IT architecture helps to achieve main business aims of the enterprise. In so doing, the choice has to be connected with the business aims during building and supplying of the enterprise architecture. It means that they have to be rational.

Each of organization wins and the reason is right understanding of its structure, products, operations, technology and network of relationships that bind them with the environment. Moreover, there are external factors should be taken into account from customers side and also from regulatory authorities. If the company becomes larger and its organizational structure and management processes become harder, the architectural decisions start to play very important role. The coherence of business and information technology is the most important tool for achieving efficiency of the organization. The efficiency is defined not only by detailed description of the specifications of each separated component but by relationships between components, as well.

Tools for optimal enterprise architecture creation are still on the improvement stage. Most of famous methodologies of EA building have declarative character and they are the union of successful projects. Besides all of brilliant advantages, using of existing methodologies is mostly subjective and based on personal experience of system analytics and creators, their preference of methodologies and modelling tools. None of them mean mathematical formalization of the process of enterprise architecture building [3]. That's why created solutions can't be even named rational. During the creation, it is necessary to form a number of clear quality criteria, and, also, metrics rate that will make an ability to assess variants of EA building and find the most optimal one.

The EA design is a process, and the result of this process is a product. Namely, the optimal EA is the base for design of business processes and for creation or implementation IS in a way which will be suitable for business aims, and IT policy of organization [4].

There are four main methodologies of building that are often considered in Zachman [5], D. Sowa [6], S. Spywak [7,8], I.Ilin [9], D. Greefhorst [10], G. Kalianov [11]. Some methodologies are reminded rarely, for example Microsoft, MDA. GRAI- GIM, SAM, E2AF and etc. Let's consider a comparison of the EA key construction methodologies.

Mission, strategy, functions, organizational chart, business processes, projects, infrastructure and information systems (IS) are related to general components. It is notable, that the most changeable component is business process, because the project's success in EA building is based on business processes optimization [11]. If the implementation of the innovation technologies will be carried on chaotic, non-optimized in time and costs business processes, these projects will be doomed to failure. That's why each project connected with EA improvement is started with analysis and optimization of business processes.

It often happens that the enterprise works many years and makes the decision about structure optimization to make it more efficient in the stiff competition conditions on the market. In that case, some of the existing business processes can be modernized and optimized. A part of business processes can be fluently stopped, and at the same time there are new business processes that can be created. The approach to building the architecture of electrical engeneering enterprises as a whole is built using traditional methodologies. The availability of optimal EA will help the enterprise to implement new innovation approaches in its activity and adapt to external environment changes that will provide flexibility and stability of the enterprise work.

III. The Mathematical Model of Enterprise Architecture

For the analysis of current enterprise architecture, it is necessary to use methods of complex layers description and other separated elements. Let's consider the sequence of actions when modeling the EA, which can also be used for electrical engeneering enterprises enterprises.

From the point of view of system analysis, the AP is a complex system, the structure of which is considered at three levels: the business layer, the application and data layer, the technological layer. For the components of each layer, you can select a set of quantitative metrics, as well as define a set of resource constraints. Their formation is the initial stage of development the EA. Their forming is the initial stage of the EA development.

To analyze the current EA, methods of complex description of its layers and individual elements are needed. There should be determined limits in sources that are available for building enterprise architecture and, also, set of metrics to assess and compare project solutions with the purpose to find an optimal architectural solution at each level. The task of building an optimal EA is to optimize the composition of its elements according to the criteria of resource efficiency.

Each of architecture presentation is considered to be a subset of the same project solution. The parameters of business processes, as well as their connection with other elements of this layer: organizational chart, management modes, and other layer elements of the architecture should be analyzed on the business architecture level [7].

The building of the general enterprise architecture and its IT infrastructure are an expensive, hard and long process. Not each of the enterprise has enough financial/administrative ability. It is the reason to use EA formalized methods based on mathematical models and metrics, which will describe all of the elements in the most fluent way.

In some approach the Zahman's model was taken as a basic, because this model is the most universal one [5]. The model is presented in the matric view and reflects formalized presentation of the enterprise. The participants' architectural presentations of EA process of building are presented in the lines in the cells set form. For example, from the system administrator view (functioning system) - it is the project of functioning and supplying information systems. To achieve such an EA presentation, it is necessary for the information, which has been taken from earlier not connected levels, to be intergrated using an approach that is understandable for all participants.

Let's consider five main architectural presentation:

- the type of business process architecture;
- the type of business system architecture;
- the type of data architecture;
- the type of applications architecture;
- the technological type of architecture.

These five architectural presentations take into account a variety of business processes, business system, data models and etc. It is possible to define EA in a mathematical way like a system of sets [12]:

- $R = (r_1, r_2, \dots r_n)$ – set of system requirements;
- $B = (b_1, b_2 \dots b_p)$ – set of business processes;
- $S = (s_1, s_2 \dots s_q)$ – set of business systems;
- $D = (d_1, d_2 \dots ,d_g)$ – the set of data elements;
- $A = (a_1, a_2 \dots a_k)$ – the set of applications;
- $T = (t_1, t_2 \dots t_w)$ – the set of technologies;
- $C = (c_1, c_2 \dots ,c_h)$ – the set of limited sources, metadata and business rules.

Despite of the fact that theoretical presentation of EA is so easy, the volume of details, which is embedded in each of eight sets, presents itself a large number of artifacts. Firstly, at the phase of conceptual designing, the choice of project variables in five architectural sets: $\{b_1, b_2, b_3, \ldots, b_p\}$, $\{s_1, s_2, s_3, \ldots, s_q\}$, $\{d_1, d_2, d_3, \ldots, d_m\}$, $\{a_1, a_2, a_3, \ldots, a_k\}$ and $\{t_1, t_2, \ldots, t_w\}$ } is very large, has no clarity and it is limited by five multiples $C = \{ c_1, c_2, c_3, \ldots, c_h \}$ and $R = (r_1, r_2, r_3, \ldots, r_n)$. As the creation of EA develops into the phase of logical and physical projecting, the space of projecting is becoming smaller, and projecting components are becoming more definite (Fig. 1).

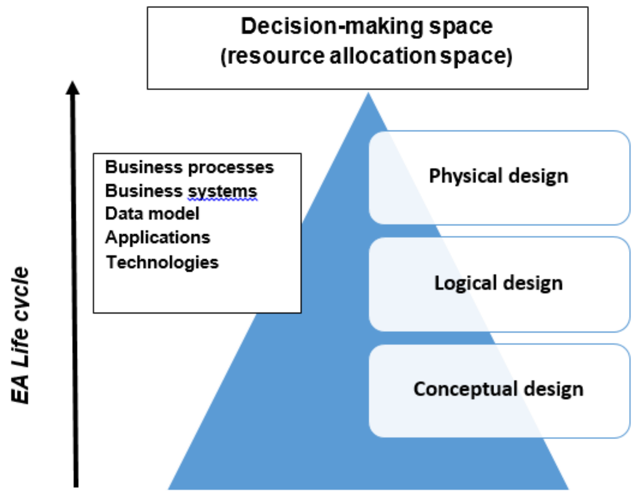

Fig. 1. Architectural presentations and the space of decision-making during the life cycle

The quantity of project variable in each set is big enough during the large enterprise architecture building in the economical digitization conditions and Industry 4.0. For example, in the C block it is possible to emphasize such limits like capital costs for corporate database, the productivity (the number of transactions processed simultaneously, the speed of require process, the time of server recovery etc.), the cost for users study, costs for supplying, scalability etc. Wherein, it is often possible to have a criteria conflict. The solution for such tasks is described in theory of Multiple-criteria decision-making – MCDM [13,14].

MCDM studies the problem of choosing the best alternative among a number of competing alternatives. The following basic principles are used: each alternative is described by a set of evaluation criteria; some of the criteria are contradictory; the criteria can be evaluated by different units of measurement. After forming a set of design spaces, the problem of their Pareto optimization is solved in order to find the optimal design space that best meets the efficiency criteria.

Let's define the set of sources X_i, for $i = 1, 2, 3, \ldots, n$ (project space X) the set of attributes $S = \{(A_1, A_2, A_3, \ldots, A_J)\}$, hence each of the attribute A_j is a function of X_i. According to the Pareto principle, there is the solution $S_P \in S$ and in the case of the one attribute value increasing is only possible when the meaning of one or several other attribute decreases [15]. In our case, established attributes correspond to the set of system requirements. It means that R is specified in EA perception form with 8 multiples.

Real tasks by projective EA are processed by several project groups. Each of them consider the specific aspect of EA and keep a hundred of design variables.

Let's consider the projective task, which is characterized by the set of sources X_i for $i = 1,2,3,\ldots,n$, such as $X = \{X_1, X_2, X_3, \ldots X_n\}$ - this is the design space. The set of attributes $A = \{ A_1, A_2, A_3, \ldots A_J\}$ is arranged that each of the attribute A_j is a function of design variable X_i and for this function there is exists the Pareto solution S.

Next, let's say that this project space is split into M subspaces $Q = \{Q_1, Q_2, Q_3, \ldots Q_m\}$, so that the crossing area of each couple of these subspaces is not empty and each of subspace has the individual Pareto solution T_m. And it is necessary to make an answer: what's the connection between these separated Pareto solutions? And one more question is: what if such relation is famous, is it possible to use them for achieving of global solution S? The formulation of the design task and optimization by Pareto will have such limits like:

- the existing set of functions for optimization is separated on n subsets, large space of the limit is separated on n subspaces of solutions, and the space of variable limits – on n subspaces limits;
- there is the set of n tasks of Pareto optimization, each of them consists of one function subspace, one solution subspace and one limit subspace, for example: $\{POP_i$, for $i = 1,2,3 \ldots,n\}$;
- each of the optimization tasks is able to create her own individual Pareto solution S_{POPi};
- the intersection of a pair subspaces of solutions cannot be empty and has at least one variable is a common in the couple;
- the intersection of a pair constraint subspaces cannot be empty and has at least one limit which is common in the couple.

Once the design tasks have been presented according to the structure as described above, each problem is assigned to a single command. The following groups should be formed within this command for the development of business processes, business systems, applications and databases, as well as an architectural and design team. Respectively, the variable solutions in the solution subspace of the business-process development group are variables such as: X_A - the number of type A processes, X_B - the number of type B processes, X_C - the number of type C processes, etc. Similarly, the variable solution in the application development group, are variables such as: Y_A is the number of type A software applications, Y_B is the number of type B software applications, Y_C is the number of type C software applications, etc. In addition, the subspace for each POP_J problem contains preset values for decision variables in other POP_Q problems, where $Q \neq J$.

The set of individual Pareto solutions obtained at each iteration $\{SPOP_i$, для $i = 1,2,3,\ldots, n\}$ is used to replace the preset values, and the new iteration of the Pareto solutions is obtained,

$\{POP_i$, для $i = 1,2,3,\dots, n\}$. This Pareto iteration process is repeated 4-6 times until the difference in values between two successive $SPOP_i$ iterations is less than the required threshold $\Delta SPOP$.

Let's consider this method using on the example of designing a database architecture for an enterprise application. Let's define the design attributes: A_1 - response time to a request (performance), A_2 - solution cost, A_3 - number of requests processed. The initial target is the maximum values of A_1 and A_2. Suppose that during the design process, a solution A is obtained, characterized by the following vector of values of design attributes: $A_1 = 20$ seconds, $A_2 = 450$ thousand rubles and $A_3 = 500$ requests/day).

Additional design efforts ultimately lead to solution B with different values of design attributes: ($A_1 = 20$ seconds, $A_2 =$ 350thousand rubles and $A_3 = 500$ requests / day, which is better than solution A.

Further, as the design continues within the framework of a specific technology, it becomes obvious that it is no longer possible to lower the value of the A_2 attribute below 350 thousand rubles, which will also give 20 seconds and 500 queries per day. In fact, the only way that an engineer can get a lower design cost is to make a technical solution C with a criteria vector (50 seconds, 200K RUB, 500 requests/day). At this stage, the design effort has reached the frontier of Pareto efficient design, where designs B and C are Pareto efficient designs.

Test the architecture for various test cases, baselines, and workload scenarios so that each test produces a single point in the Pareto frontier of interest. Together, these test points define the actual frontier of effective Pareto design. For example, design point P entails a specific base configuration, and design point Q implies a different base configuration. These two configurations should differ in a number of parameters: the number of processors available for processing, the type of DBMS used, the transaction monitoring system, etc.

The decision point arises when it is possible to choose an optimal subset of n data sources that meets the following criteria:

- all desired data items are represented in this subset;
- the subset contains the smallest number of data sources needed to provide all required items;
- the subset belongs to the set of effective decisions on its Pareto design boundary, obtained by considering a set of criteria (for example, minimizing design costs, cumulative response time for a request, etc.) within the framework of the multi-criteria decision making method (MCDM).

The database developer does not immediately see how the characteristics of his projects are located in relation to the Pareto frontier; he needs to obtain and compare several design solutions. For example, solution B is less expensive than solution C, although both provide the same performance. Solution D is cheaper than C, but technologically impossible. As the designer maintains a fixed level of performance and continues to make design changes, eventually there will come a point when he cannot. It was at this point that he reached the frontier of Pareto design. Each technology has its own Pareto design frontier.

IV. Presentation of the Enterprise Architecture Model Using the ArchiMate Modeling Language

In the course of developing an optimal EA, the following main tasks should be solved:

- development of an enterprise architecture model;
- determination of the composition of significant criteria for each element of the model;
- creation on its basis of a new model of the process of restructuring the architecture of an enterprise taking into account significant criteria, as well as a means of assessing this process;
- development of technology for building a promising enterprise architecture associated with its IT strategy and production specifics.

It is proposed to use the ArchiMate language, a specially developed language for representing architectural models, as a means for building an object-oriented AP model. The ArchiMate language uses the detailed description of model elements and using rules for them in modeling. The TOGAF methodology and the ArchiMate language are The Open Group standards that are directly related to enterprise architecture development. Each of them has its own specifications, they can be used independently of each other, or together with other standards [16,17].

The representation of the EA model in ArchiMate is given at the following levels: strategy, business, applications, technology architecture, implementation and migration (Fig. 2). This division is in good agreement with the methodologies of Zachman, TOGAF, Gartner.

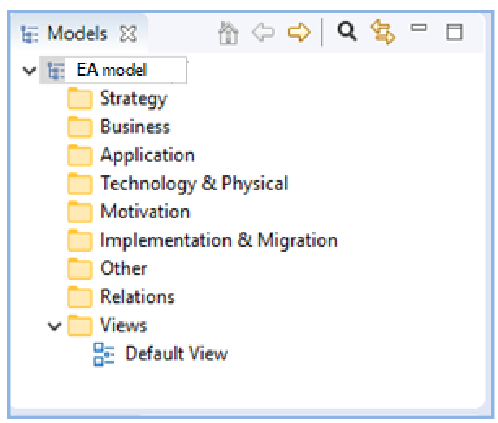

Fig. 2. The structure of EA in ARCHI project

At the same time, the structure, logic of the EA model building and the set of elements in ArchiMate have much in common with object-oriented methods and the UML language. Therefore, the development of an object-oriented enterprise architecture model is possible using this language and the

ARCHI tool (v. 4.6.0). At the metamodel level, EA is represented as a combination of the following components [18]:

- active structural elements that can perform actions;
- elements of behavior: units of actions that are performed by active elements;
- passive structural elements: objects on which actions are performed;
- services: represent a unit of functionality that the system provides to the external environment through interfaces;
- interfaces: access point for services.

Active building blocks can be defined on several layers of the EA: the business layer, the application layer, and the technology layer [18]. These can be business performers (defined as elements of the organizational structure of an enterprise), application components (modules, procedures), devices (Fig. 3).

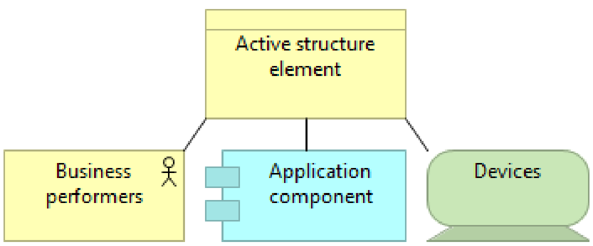

Fig. 3. Active structural elements

Behavior elements are associated with active structural elements and determine their actions. One element of behavior can be associated with several structural elements. They are formed mainly at the level of the business layer and are closely related to the business processes of the enterprise (Fig. 4).

Passive structural elements are represented by data, over which active structural elements are performed certain actions in accordance with business rules (Fig. 5).

Services are also defined on several layers of the EA and in each case represent one or another aspect of the functionality:

- from the point of view of business executives, these are business functions;
- from the point of view of applications, these are functional application services;
- from a technological point of view, these are technological services implemented by devices.

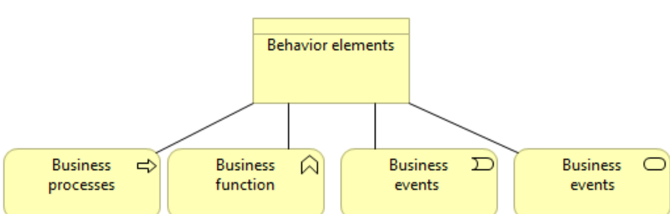

Fig. 4. Behavior elements

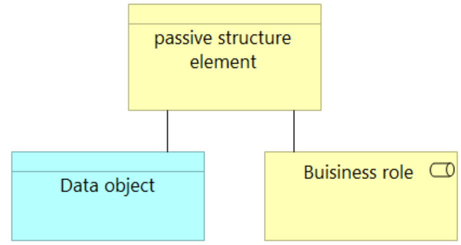

Fig. 5. Passive structural elements

At the same time, services are a connecting element between layers, since for their implementation they require the definition of components at all levels. The division into internal and external services (Fig. 6) determines the relationship between the layers: internal ones are available only at their own level, external ones can be accessed outside their own layer.

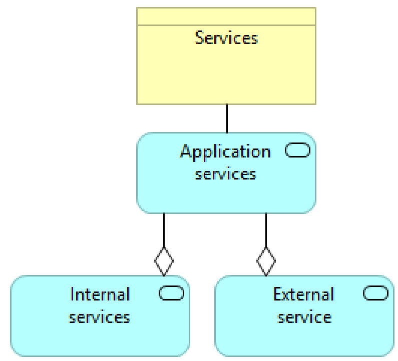

Fig. 6. Services in the ArchiMate model

Interfaces are a kind of active structural elements and a point of access to services from the side of users (Fig. 7).

The EA elements interaction of the ArchiMate model can be represented, for example, as follows: a business service is assigned to a business process which interacts with a business consumer through an interface. Business performers are elements of the organizational structure of an enterprise; there can be several of them within a business process. Roles are assigned to each business executive (Fig. 8).

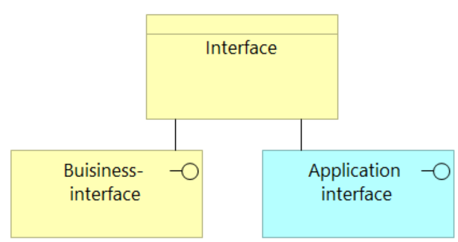

Fig. 7. Interfaces

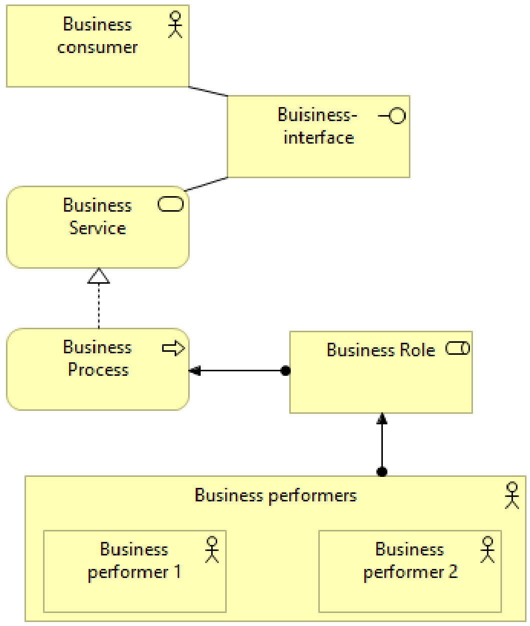

Fig. 8. Interaction of EA elements in the ArchiMate model

Thus, to build an object-oriented model of EA, it is necessary for each of the above structural elements to determine a set of components, their quantitative and qualitative characteristics, as well as the relationship between them. The proposed approach allows us to determine both the qualitative composition of the EA elements and their quantitative metrics.

I.Conclusion

The necessary tools for designing and analyzing corporate architectures are still under development. There are methods which are needed for a comprehensive description of its layers and individual elements to analyze the current architecture of the enterprise. In contrast to existing approaches, the possibility of optimizing the enterprise architecture based on formal methods that take into account the interaction of architectural layers.

The applied methodologies make it possible to objectify and concretize the concepts of constructing an optimal enterprise architecture, which makes it possible to formulate a set of functional requirements for the software module for analyzing and evaluating the optimal architecture.

The ArchiMate language is the concept based on a systematic approach to its construction, which allows the most complete and comprehensive modeling of the enterprise architecture. The language supports the description, analysis and visualization of architecture at the required level of detail through the main business domains, services and architectural frameworks, and also allows you to apply complex methodologies for building an enterprise architecture, such as TOGAF, reference models, etc.

The article proposes an approach to finding the optimal architectural solution based on significant criteria affecting the architecture of the enterprise as a whole, which contributes to the effective achievement of enterprise goals within the adopted strategies. A complex of models of enterprise business architecture using the ArchiMate language has been developed. These models can be the basis for the formation of a set of functional requirements for the interface of the software module for analysis and assessment of the optimal architecture of an enterprise of an electrical machine-building complex during its transformation into Industry 4.0.

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