Enterprise Architecture Requirements for Digital Transformation Projects in an Automotive Industry

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Abstract. The adoption of Industry 4.0 technologies and it's concepts are helping develop more collaborative, connected, and intelligent production systems. In particular, IT projects have used a digital transformation approach to deploy such technologies in different types of companies, including the automotive sector. The digital transformation literature has extensively focused on the required technical knowledge for the implementation of new technologies and associated concepts. However, the literature does not present an approach that focuses on the integration of these technologies and concepts with other business elements such as strategy and processes, leading to a more interoperable organizational environment. By definition, this is the realm of enterprise architecture (EA), whose main concern is to align IT strategies with business strategies, considering the resources and processes necessary to implement those strategies, and allowing the required integration of the elements that can act together in a dynamic business environment. This paper helps bridge the gap between the alignment of technology and business in digital transformation projects by proposing an extended list of EA requirements or attributes based on existing frameworks. A content analysis of the literature for the extraction of the main characteristics of digital transformation projects was performed, considering aspects of Industry 4.0 and EA frameworks as background. As a result, the characteristics that best fit within the EA frameworks are grouped, deriving an extended list of EA attributes oriented for digital transformation projects.

Keywords: Enterprise architecture · Digital transformation · Industry 4.0

1 Introduction

The concepts and technologies associated with Industry 4.0 are experiencing exponential growth in the application to the development of more collaborative, connected and intelligent production systems. Although digital transformation has been much discussed in both literature and industry, the theme encompasses several new concepts tied to new technologies, which require technical knowledge for implementation.

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According [1], conceptually I4.0 is a view of a fully interoperable system where highly automated and connected machines communicate with each other and with all sorts of components they process, pre-produce and provision through the supply chain. In the Industry 4.0 era, manufacturing systems are able to monitor physical processes, create a so-called "digital twin" (or "cyber twin") of the physical world, and make smart decisions through real-time communication and cooperation with humans, machines, sensors, and so forth [2]. Industry 4.0 combines embedded production system technologies with intelligent production processes to pave the way for a new technological age that will fundamentally transform industry value chains, production value chains, and business models [3]. Many organizations find it difficult to understand the concepts of Industry 4.0 and how to relate them to their organizational architecture, leading to failure in identifying possible new projects. One of the main goals of building an enterprise architecture is to align the business perspective with enterprise IT [4].

The objective of this work is to identify an extended list of enterprise architecture (EA) qualifying attributes oriented for digital transformation projects. More specifically, this paper aims to: (i) provide a background, literature and theoretical review, gathering main concepts, models, and frameworks; (ii) define the attributes based on the literature and in a knowledge extraction process.

The identification of the preliminary attributes occurs with a quantitative and qualitative approach. Initially a literature review of the subject was carried out, addressing elements of Industry 4.0, Digital Transformation and Enterprise Architecture. The papers were then analysed, and a list of extended EA attributes were extracted based on existing frameworks.

In the next section, we review background knowledge about digital transformation and enterprise architecture. In Sect. 3, the methodology of this study is introduced. Section 4 lists the EA attributes extracted and grouped into the four EA domains. Section 5 concludes the paper.

2 Background

2.1 Digital Transformation

Digital transformation is defined as "the use of technology to radically improve performance or reach of enterprises" [5]. Another well-known definition of the term is that it "is achieved when the digital usages which have been developed enable innovation and creativity and stimulate significant change within the professional or knowledge domain" [6].

The term Industry 4.0 (I4.0), also known as smart manufacturing, was first mentioned at the Hannover fair in 2011. [7] summarizes industry 4.0 as an integrated, adapted, optimized, service-oriented, and interoperable manufacturing process which is correlate with algorithms, big data, and high technologies. It facilitates inter-connection and computerization into the traditional industry. According to [8] the modelling and virtualization/visualization technologies have been the two most frequent enabling technologies applied to support the realization of Industry 4.0. The goals of Industry 4.0 are to provide IT-enabled customization of manufactured products; to make

automatic and flexible adaptation of the production chain; to track parts and products; to facilitate communication among parts, products, and machines; to apply human-machine interaction (HMI) paradigms; to achieve IoT-enabled production optimization in smart factories; and to provide new types of services and business models of interaction in the value chain. Regarding the features, Industry 4.0 can provide more flexibility, reduce lead times, customize with small batch sizes, and reduce costs [9].

Although organizations realize the opportunities they can derive from the digital transformation, they are finding it difficult to put it into practice and succeed it [10]. They face the complex realities of implementation ranging from introducing new CPS and smart factories technologies and applications to adapting or replacing core enterprise architectures (EA), ICT infrastructures and processes. As the digital wave is hitting, adopting a standardized approach to frame and execute digital transformation initiatives is important to be fruitful. Companies need to establish frameworks, methods and management practices to govern the IS evolution. The horizontal, vertical and end-to-end integration in industry 4.0 [11] requires changes in enterprise architecture, ICT integration and processes [12].

Since 2013, many consultancies specialized in the theme have disclosed Industry 4.0 frameworks. In the present paper we will use the Acatech Maturity Index which has been widely applied to implement digital transformation in organizations. This Maturity Index helps companies to determine which stage they are currently at in their transformation into a learning, agile company. It assesses them from a technological, organisational and cultural perspective, focusing on the business processes of manufacturing companies. The road towards Industry 4.0 will be different for every company. It is therefore necessary to begin by analysing each company's current situation and goals. Questions concerning the company's current situation include what its strategic objectives are for the next few years, what technologies and systems are already implemented and how they operate within the company. The answers to these questions can be used to determine which capabilities the company still needs to acquire in order to successfully introduce Industry 4.0 [13].

This method results in the formulation of a digital roadmap for all the relevant areas with a step-by-step approach to achieving the benefits that reduces the investment and implementation risks for the company. The roadmap helps companies to understand the importance of developing a common digital strategy for the whole business. The maturity index is divided into organisational areas and functional areas. These organisational areas outline the key organisational capabilities required by an agile company in Industry 4.0. The framework also illustrates potential development goals for current corporate functions in the form of visions [13]. The Acatech Industry 4.0 Maturity Index has been used to help many organizations master the digital transformation across all the involved relevant business units. For that matter, a study regarding this framework was conducted. The main characteristics were analysed, and a list of digital transformation attributes was extracted.

2.2 Enterprise Architecture

An enterprise architecture (EA) presents the structure of an enterprise and consists of the main enterprise components such as a company's goals, organisational structures,

information infrastructure and business process. It helps the organization determining how it can effectively achieve its current and future goals. The performance of an enterprise, such as innovations generated within the company, the re-engineering of business processes, and the quality and timeliness of information flow, can be improved if the EA system faithfully represents the characteristics and the nature of the organisation [14]. Enterprise architecture is the organizing logic for business processes and IT infrastructure reflecting the integration and standardization requirements of the company's operating model. Moreover, it is the backbone for enterprise and IS evolution [15]. According to [16], EA has been suggested as a discipline to ensure coherent structure, to make visible the underlying organizational system, and to facilitate change.

TOGAF is a comprehensive open EA standard which contains several components, amongst which, the Architecture Development Method (ADM) stands at its core. The ADM describes an iterative process for developing EA with the help of several phases (Preliminary phase, Architecture Vision, Business, Information systems, Technology, Opportunities and solutions, Migration planning, Implementation governance, Architecture change management, Requirements management).

Four architecture domains are covered by TOGAF:

- Business architecture,
- Data architecture,
- Application architecture and
- Technology architecture.

These are commonly accepted as subsets of an overall enterprise architecture. Business architecture focuses on the business strategy, governance, organization, and key business processes. While Data architecture approaches the structure of an organization's logical and physical data assets and data management resources. Application architecture creates a blueprint for the individual application systems to be deployed, their interactions, and their relationships to the core business processes of the organization. The Technology architecture works with software and hardware capabilities that are required to support the deployment of business, data, and application services. This includes IT infrastructure, middleware, networks, communications, processing, and standards [17].

The TOGAF framework, a standard of The Open Group, is a proven Enterprise Architecture methodology and framework used by the world's leading organizations to improve business efficiency [18]. Including the automotive industry where this study was conducted. For that reason, the framework was closely analysed and requirements regarding enterprise architecture were extracted.

3 Research Design

To establish the attributes orienting digital transformation projects, first a literature review of the subject was carried out, addressing elements of Industry 4.0, Digital Transformation and Enterprise Architecture. With the data obtained, a preliminary list of attributes was extracted. These were submitted for a relational analysis, resulting in a

final list of enterprise architecture requirements oriented for digital transformation projects. The three stages of the research approach are represented by an IDEF0 in Fig. 1.

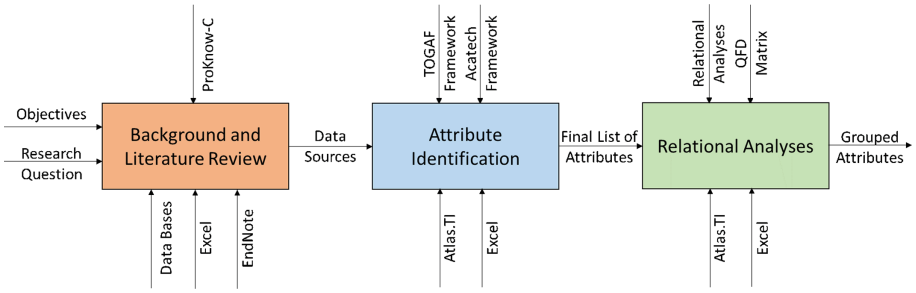

Fig. 1. IDEF0 of the research methodology (2019).

3.1 Systematic Literature Review (ProKnow-C Method)

This study follows the ProKnow-C method to conduct an efficient and well-structured systematic literature review [19]. The method was applied to investigate Enterprise Architecture requirements in the context of Digital Transformation. It consists of three main phases: (i) Initial investigation, (ii) Scientific Recognition of the Articles and (iii) Bibliometric Analysis. In this work, two research axes were selected, the first axe was represented by the keywords "Enterprise Architecture", "TOGAF" or "Zachman" and the second axe contained the following keywords: "Digital Transformation", "Industry 4.0", "Industrie 4.0", "Smart Factory" or "Fourth Industrial Revolution".

In the first phase, these keywords were used to search within the published papers titles, keywords, and abstracts, collected from Scopus, Web of Science and Science Direct data bases, the search returned 260 results. After removing the duplicated articles, 199 results remained. All the titles were analysed, and all the unrelated papers were dropped, remaining 51 articles. For the second phase, composed of the scientific recognition of the articles analysis, a search on Google Scholar was conducted, and based on the results, the representativity of each article in the set of 51 papers was calculated. It was defined, as a threshold for the article to remain in the current portfolio, a representativity of at least 95%, which resulted in an amount of 19 articles.

These 19 articles were submitted to an abstract analysis, 13 of them presented a closer connection to the topic and raised a list of established authors, these were designated as "Group A". In addition, 32 articles with less than 5 citations, were submitted to reanalysis for the period of the publications and by the relevance of the authors. Among the 32 articles under 5 citations, 27 articles of recent publication (2017 and later) were considered suitable for reading their abstracts. In addition, the authors of the 5 articles published prior to 2017 were correlated with established authors

present in "Group A". From this last analysis, 2 articles were separated for abstract analyses. A total of 15 papers were selected to composed "Group B". These 15 articles together with the 13 articles included in "Group A", formed "Group C", which, after reading the full text, checking availability and alignment with the theme of the research, 28 papers were kept, becoming part of the bibliographic portfolio.

3.2 Attribute Identification and Relational Analysis

The preliminary list of attributes were derivatives of the three main data sources considered. Various requirements were identified from both frameworks, as well as from the systematic literature review. Among the 28 articles, four were identified as more adherent to the theme of this research. These four articles approached characteristics, requirements, capabilities and attributes for enterprise architecture frameworks for digital transformation [15, 16, 20, 21]. To extract the attributes from these four articles, the ATLAS-TI software was used. The papers were imported in the software and codes were created to categorize and identify the main requirements, characteristics, capabilities and attributes. As a preliminary result, 53 attributes were identified from the three data sources. All the attributes were analysed, and the requirements that had similar approaches were grouped together, resulting in a final list of 21 attributes. Lastly, a relational analysis between the attributes was carried out.

4 Results

The change from a closed-world modelling world to a more flexible open-world composition and evolution of enterprise architectures defines the moving context for adaptable and high distributed systems, which are essential to enable the digital transformation [22]. This work identified 21 EA attributes oriented for digital transformation projects. To organize the twenty-one attributes within the four EA domains, a relational matrix inspired in the QFD tool was constructed. The QFD (Quality Function Deployment) matrix was used to define the correlation between the attributes and the four EA domains. This tool was first used successfully by Japanese manufacturers of consumer electronics, home appliances, clothing, integrated circuits, synthetic rubber, construction equipment and agricultural engines, before American and European manufacturers started to use it within product development projects [23]. However, in practice, the QFD becomes widely applicable, since this matrix makes explicit the relations between the elements analysed [24]. The degree of correlation between attributes (attributes vs. EA domains) was evaluated by means of weights (1, 3, 6 and 9) assigned to each attribute, 1 being considered the correlation weak and 9 very strong. Then, the attributes with the highest weights in the considered aspect were allocated in each domain. The relational analyses between the 21 attributes and the four EA domains is represented in Table 1.

Table 1. Relational Matrix between the list of attributes and EA domains.

Attributes	Business architecture	Data architecture	Technology architecture	Application architecture
Application integration	1	3	6	9
End-to-end process integration and automation	3	6	6	9
Structured communication	3	6	6	9
Business modeling innovation	9	3	1	1
Flexible, robust and responsive services	9	6	6	6
Flexible communities	9	1	3	1
Stakeholder management	9	3	1	1
Agile management	9	3	3	3
Business principles, goals, drivers, and Key Performance Indicators (KPIs) validation	9	1	1	1
Organizational governance	9	1	1	1
Data integration	1	9	3	6
Architecture repository	6	9	1	1
Dynamic collaboration in value networks	3	9	1	1
Data migration	1	9	1	3
Data governance	1	9	1	3
Real-time data processing	1	9	6	6
Data-driven sensing and decision making	6	9	1	1
IT security	1	6	9	6
Digital capability	1	6	9	3
Hardware, software, and communications technology	1	3	9	3
Technology integration	1	6	9	6

With a total of seven attributes each, the Business architecture and Data architecture domains have the most attributes. The Business architecture domain is composed of the following attributes: “Business Modelling Innovation”, “Flexible, robust and responsive services”, “Flexible communities”, “Stakeholder Management”, “Agile Management”, “Business principles goals, drivers, and Key Performance Indicators (KPIs) validation” and “Organizational Governance”. The requirements “Data integration”, “Architecture repository”, “Dynamic collaboration in value networks”, “Data Migration”, “Data Governance”, “Real-time data processing” and “Data-Driven Sensing and Decision Making” were grouped in the Data Architecture domain.

The Technology Architecture is composed of the following four attributes: “IT Security”, “Digital capability”, “Hardware, software, and communications technology” and “Technology Integration”. Finally, the three attributes “Application Integration”, “End-to-end process integration and automation” and “Structured communication” were grouped into in the Application Architecture domain.

5 Conclusion

In conclusion, twenty-one enterprise architecture characteristics oriented for digital transformation projects were acquired. By performing a relational analysis inspired on the QFD tool, the main requirements each enterprise architecture domain is responsible for while implementing digital transformation projects were identified.

The research work in the next stage will focus on envisioning a framework that will assist enterprise architecture to approach digital transformation projects. To do so, the next step is to use the extended list of attributes to conduct a maturity assessment using multicriteria decision making methods (MCDM), under enterprise interoperability framework that will be carried out in the automotive company.

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