Quality 4.0 in Enterprise Architecture Development

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Abstract

This study explores the current understanding of Quality 4.0 through literature survey. Beyond that, this paper covers a case study on Higher Education Institution (HEI) Quality 4.0 oriented Enterprise Architecture (EA). This study emphasizes Quality 4.0 as an integral part of holistic development of EA. In this approach focus is not only on technologies, but also on business organization strategic management and capabilities development.

Keywords: Quality 4.0, Enterprise Architecture, ArchiMate, Business Capability, Higher Education Institution

1. Introduction

Information Communication Technology (ICT), e.g., Big Data, Artificial Intelligence (AI), or Cloud Computing (CC) have changed manufacturing. Current patterns of quality, productivity, and innovation management in industrial manufacturing have an impact on further machine learning algorithms' development as well as on new methodologies of quality control. Quality 4.0 (Q4.0) is a way to pursuit performance excellence of business organizations. This approach is based on empirical investigation, practical knowledge discovery, real-time data gathering and analysis to support controlling and decision-making. Escobar et al. [10] argue that the development and application of Q4.0 in manufacturing companies enables implementation of defect-free processes, faster analysis of weaknesses, and mitigation of human-based inspection risks. The Q4.0 includes tools, techniques, and methods that allow to continuously monitor resources and people, to generate empirical data, discover patterns and discrepancies, and optimize the available resource usage. However, beyond appropriate software and computer infrastructure, the business architecture is crucial for the adoption of Q4.0 practices. This study aims to present that Q4.0 implementation should be considered at the EA development level as an indispensable part of EA planning, modelling and management. This paper consists of three sections. The first section includes the definitions of Q4.0 and the results of literature survey on Q4.0. In the second section, the Q4.0 concepts are considered in EA modelling context. The last part includes case study discussion on opportunities of Q4.0 application at Higher Education Institution (HEI).

2. Quality Notion vs. Quality 4.0 Idea

Quality can be recognized through an opinion that products or services meet the requirements of these who use them. According to ISO9000:2015 [13], quality is the degree to which a set of characteristics of an object fulfils requirements. Taking into account this definition, quality requires checking if the requirements are fulfilled or a verification if there is a gap between expected service and perceived service. Technical views of quality are included in the quality attributes, e.g., usefulness, access, reliability, security, or tangibles, which are physical evidence of service [15]. Reliability is identified with credibility, trustworthiness, believability, and honesty. Access means approvability and ease of usage, while security is understood as freedom from danger and risks. Alzahrani et al. [1] have summarized quality practices in the following types: inspection, design, empowerment, and discovery. The quality control methods and tools are used to inspect failures and weaknesses of produced items. More holistic methods for product

designing incorporate quality into design processes to prevent problems.

Quality has a pragmatic interpretation and as such is expected to satisfy stated needs. Quality is a perceptual, conditional and subjective attribute and it is defined and understood differently by people. Customers may focus on the quality of a product or service as they compare them to offers of competitors in the market. Producers might measure the conformance quality, the degree to which the product or service was produced correctly. In literature survey, Quality 4.0 is defined as usage of technology as well as a company-wide strategy with its performance measurement [1, 3, 11, 17]. In Quality 4.0, information technology is used "to design, operate and maintain adaptive, predictive, self-corrective, automated quality systems along with improved human interaction through quality planning, quality assurance, quality control, and control improvement to achieve new optimums in performance, operational excellence, and innovation to meet the vision, mission and goals of an organization" [2, p. 9].

Quality 4.0 means quality shift from the process operators to the process designers and involvement of employees in critical thinking [5]. Also Baran and Korkusuz Polat [7] argued that Industry 4.0 in contemporary organization of production results in its transformation into autopoietic organization, which is self-configured, self-monitoring, and self-developing. Quality 4.0 management includes human and technical aspects. Human resources management concepts and principles are related to social and behavioural dimensions. Cultural elements such as team work, leadership, employee ownership, customer sensitivity, and ethics are elements of Q4.0. Leadership is a key element of Q4.0 as leaders are responsible not only for the right technology selection, but also for preparation of managers and technical people to deal with technologies. Technical aspects cover technology development strategies, tools, practices, and information systems to deal with the design, implementation and improvement of products, services, and business processes as well as the elimination of operational risk.

In Q4.0, two groups of technologies should be valuable, i.e., automation and integration. In terms of integration, technologies supporting connectivity among equipment, people, and software functionalities allow quality related data to be shared. Q4.0 approach requires an implementation of a user-centric perspective where all internal and external (e.g., customers) stakeholders are interconnected for collaboration and quality risks mitigation. In terms of automation, sensors, robots, blockchain system, and other IoT solutions support production and quality control of products and services [8]. In Q4.0 oriented manufacturing companies, the stage of product design, testing, and prototyping is supported by technologies, e.g., augmented reality (AR) and virtual reality (VR) systems, digital twins and simulation systems, and 3D printing. Q4.0 oriented managers should understand the usefulness of connecting data, analytics and processes to improve visibility and benefits. Quality concerning data plays critical role in management and should be stored in secured and scalable clouds in Big Data repositories. Application of analytical tools and Business Intelligence systems is important to measure the quality. Machine learning (ML) and Artificial Intelligence (AI) solutions enable descriptive and prescriptive analytics, simulations and predictions [22]. Quality of performance can be monitored by analysing product usage data in an automated way using AI. At the control stage, quality of conformance is monitored through sensors, smart glasses and smart gloves [24]. RFID (radio frequency identification), barcodes, QR codes, drones, autonomous vehicles, collaborative robots, and 3D printing and simulation by virtual reality are used in manufacturing and quality control [9]. The usefulness of technology is also evaluated individually. Some companies pursue the opportunities, other are not interested in them. For example, blockchain technology has lately gained much recognition. The blockchain applications are argued to be suitable for supply chain tracking, auditing, and security. The automotive sector is inclined to introduce blockchain technologies, as that sector's supply chains operate in many industries and many countries, therefore the blockchain application reduces transaction costs, support control and security, eliminate repetitive work, ensure the evidence of possession of resources, and enrich self-sustaining operations. The Quality 4.0 technologies enable direct data collection, analysis, and decision-making or have indirect impact on the quality of production, through automation and supporting

communication, monitoring, and security.

Sony et al. [25] have highlighted motivation, organizational readiness and risk mitigation as important for Q4.0 implementation. Santos et al. [23] have emphasized creative thinking, leadership, internal stakeholders' communicativeness, and long-life learning competencies as critical factors. Nguyen et al. [20] argue that leadership, strategic planning, people management; customer focus, information system analysis, and supplier management have impact on quality oriented business organization. Implementation and usage of Q4.0 technologies require appropriate business capabilities. They include, among others, employees' competencies. Social media platforms, as well as AI and ML systems create new skills that enhance the employees' expertise. The new knowledge concerns risk management, compliances, internal integration of EA components as well as organizational proactiveness. Araujo and Gave [4] have discussed two types of proactiveness, i.e., responsive and creative. Responsive proactiveness needs the usage of market signals that are true symptoms of future change, while creative requires brainstorming, creative thinking, new ideas comparisons, or conceptualization of new products. Introduction of a new product to the market causes changes in the competitive dynamics, changes in the supply chains or in the behaviours of stakeholders. Similar results may arrive when a company conceives a new business model that causes changes in rules on the market. Q4.0 business environment requires connecting the design and production environments to enable data acquisition and analysis.

3. Business Capabilities in Enterprise Architecture

Enterprise architecture modelling is followed by defining the enterprise. In information science, the notion of enterprise is connected with organizational structure, processes, procedures, data, information, software and hardware. Business architecture should identify the main stakeholders, business plans and business strategy goals, available assets, competencies, drivers and constraints. The category of capability is crucial for business processes development and further determining values for customers. Business capability is a high-level concept, which is linked to the business strategy. The development of business capabilities, as well as their deployment to develop Quality 4.0 and to produce value can be impacted by business strategy. The decision to implement Q4.0 is individual for each enterprise, as well as the decisions on which technologies will support Q4.0 result from the business capabilities. Capabilities provide high-level view of the current and desired abilities of a business organization in relation to its strategy and its environment. Business capabilities are applied in a variety of business scenarios and value generation contexts, making them a useful notion across the firm. Through the line of sight from business strategy to business capabilities, and then to Quality 4.0 and next to business processes and software functionalities, the impact of strategy on value for customers becomes explained. When the value stream focuses on delivering value, business capabilities are used in the business architecture to align on what is needed in processes.

Business capability describes what ability is needed to deliver a specific value via data, processes, organization, and technology (Figure 1). Different types of capabilities are used in the business organization and enable collaboration among various EA elements. Business capabilities are "hidden" in:

- People, e.g., internal and external stakeholders' skills and competencies, organizational structures, or decision making frameworks;
- Processes, e.g., process agility, process self-organization; data analytics algorithms implementation;
- Information and data, e.g., information actuality for decision making, data governance;
- Technology, e.g., intelligent objects' functionalities for monitoring and communication, technology support of information management.

The capabilities' choice and development relate to the range of activities and quality management that will enable an enterprise to win on the market. Capabilities are the map of functionalities, activities and competencies that are critical to determine how-to-win and where-to-act strategies. Including Quality 4.0 in EA modelling is a challenge, as in general,

the question on EA quality is relatively new topic. As concept of value is quite different from the notion of quality, the last one may be placed in the EA assessment field.

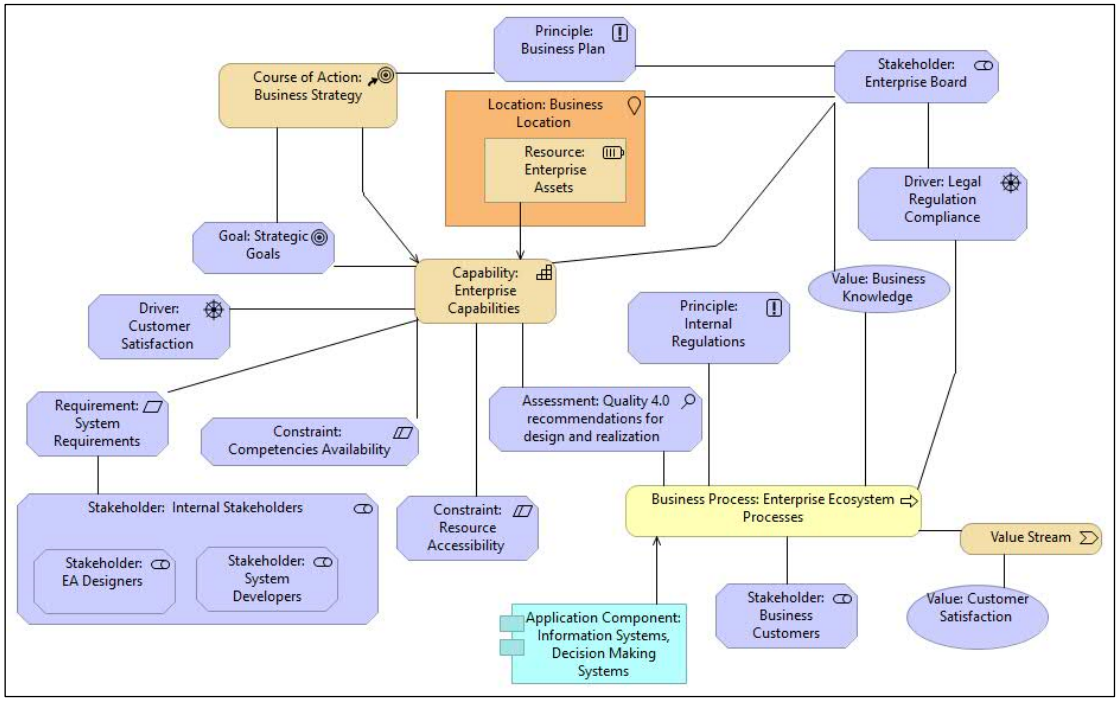

Fig. 1. Business Architecture Conceptualization for Quality 4.0 implementation.

Enterprise architecture quality has already been included in standards and models, such as maturity models. The EA quality assessment covers systematic processes undertaken to make decisions on the quality of artefacts and relations among them. Hence, the assessment concerns semantic models. The EA assessment means also decisions on the quality of EA goals, development activities, information resources, processes, actors, products, requirements, capabilities, and relationships among these elements. The EA models provide a holistic view of the enterprise's key strategies and their impact on business functions and processes, software and hardware implementation. Useful criteria of EA assessment are as follows: process flexibility and agility; enhancement of organizational productivity through the usage of less expensive and carefully selected resources; process simplification oriented towards an increase of effectiveness and efficiency of business transactions. Various EA stakeholders have different perception and opinions on EA quality. As EA quality may have many interpretations and its assessment is a multi-criteria decision-making process, the quality features are classified according to criteria identified and important for a particular quality assessment application. Therefore, assuming that product or service relevance means satisfying the environmental needs, while rigour means the usage of adequate methods, the EA quality attributes can be classified as in Figure 2. Specification of these attributes is based on [16, 18].

Barafort et al. [6] define relevance as an alignment of business activities and standards. Mohajeri and Leidner [19] discuss the pluralistic nature of relevance and present a typology of relevance according to four perspectives: applicability, knowledge production transfer, value, and empowerment. Relevance is relative and depends upon stakeholders' preferences and knowledge as well as upon business capabilities. An IT solution as EA element may be an original innovation, but not commonly acceptable; an applicable solution, however not feasible. Relevance is defined as the degree to which an object contributes to improve the outcomes of interest. On the other side, rigour is grounded in EA elements design and implementation practices. Gill and Gill [12] define rigour as criteria-based or compliance-based. Compliance-based perspective is related to the selection of an appropriate development methodology, accurate usage of methods and documenting that use. Rigour is identified with competent and systematic usage of

procedures, fostering the standardization and legal regulations, audits of reasoning. Rigour in practice is the strength of reasoning, discipline, order and obedience. Paine and Delmhorst [21] emphasize the necessity to maintain a balance between rigour and relevance.

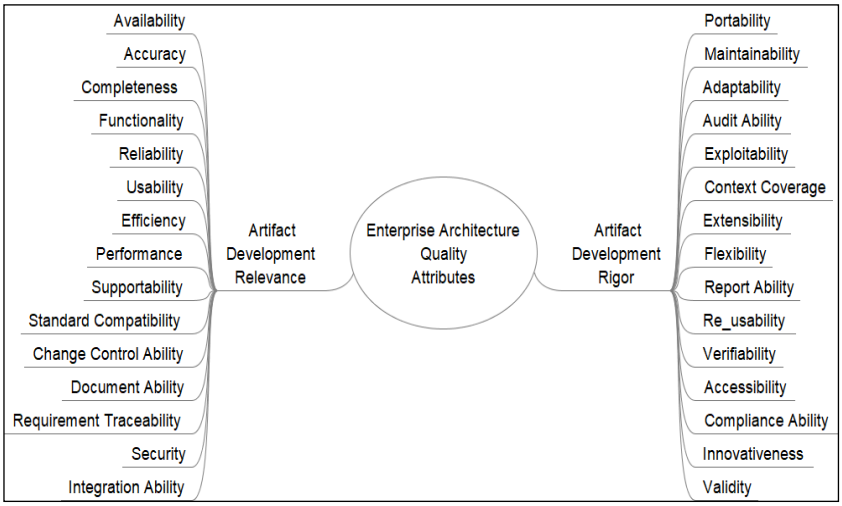

Fig. 2. Enterprise Architecture Quality Attributes.

The ISO/IEC/IEEE 42030:2019 [14] standard focuses on architecture evaluation, which is identified with the assessment of its effectiveness and suitability towards stakeholders' needs and expectations. According to this standard, architecture evaluation can be conducted to assess the quality of architecture entities, i.e., enterprise, business unit, solution, data, application, product, service, hardware item. The evaluation concerns various technologies, e.g., mobile, cloud, Big Data, robots, Internet of Things, sensors. In this standard, the value is subjective and relative to the value recipients, while quality of an object is something what the customer gets out and pays for.

4. Quality 4.0 at a Higher Education Institution

The case study main research goal is to present the concept of Quality 4.0 from a Higher Education Institution (HEI) practitioner viewpoint. At HEI, Q4.0 managers manage and communicate with various stakeholders, i.e., HEI administrative staff, teachers and students. Hence, the Q4.0 managers are expected to have competencies of leadership and strategic thinking. They should know how to communicate with ICT, use IoT devices to monitor education process realization, and make decisions based on Big Data. They are expected to be creative in curricula development, problem-solving and they are able to learn. In these Quality 4.0 circumstances, HEI is developed into an autopoietic organization, which is a self-managed, self-controlling, and self-improving complex. The Q4.0 managers ought to understand high costs of quality management, and constantly compare them with benefits. They understand the necessity of cybersecurity, creation of reliable Internet connectivity, particularly in situation of virtual education. They perceive some employees' resistance to change, as well as they see the culture changes, as for example the impact of social media and informal education on formal processes at HEI. Higher education institutions have a particular group of stakeholders, i.e., the recipients of HEI educational services (Table 1). This group includes candidates, recruits, students, as well as alumni, who are also involved in strategic management of quality. At HEI, the main subject of evaluation covers educational processes, accompanied by supportive administrative staff activities. Therefore, the quality issues concern people involved in the educational process, i.e., teachers. The general model of HEI enterprise architecture oriented towards Q.4.0 is presented in Figure 3. The critical concepts cover HEI boards, administrative staff, teaching staff, business drivers, constraints, principles, assessments, and capabilities. These elements are included in business architecture. Particular attention should be given to HEI capabilities (Figure 3), which concern people, data, processes,

software and technology. Just capabilities determine the education level as well as Q4.0 implementation. Mainly, software and hardware tools are applied to monitor, and control the communication among teachers, students and administrative staff. For the HEI business excellence, the communication must be in real-time to ensure lecturing and examining continuity without breaks or errors. High volumes of teaching materials are accessible in clouds. Beyond that, students' examination work is also recorded for auditing of teaching.

Table 1. Recipients of HEI educational services.

Stakeholder	Candidate	Recruit	Student	Alumni
Key driver	Willingness to try	Willingness to attend	Willingness to learn	Willingness to learn and promote HEI
Stakeholder goals	Looking for recommendations on HEI	Access to HEI education	Learning, knowledge acquisition and development; being a student community member	Making money; encouraging other people to study
Success criteria	Preliminary events' experiences	Attending enrolment programmes	Knowledge as long-life capital	Being proud of participation in alumni community
Activities	Events and meetings; informal and non-formal education participation	Programmes, events; informal and non-formal education Participation	Learning, training, taking exams in formal education system; self-evaluation	HEI promotion; post-graduate education; non-formal education; self-development
Key metrics	Engagement; conversion rates	Engagement; conversion rates	Student performance; student retention rates	Post-graduates activities cost and participants numbers

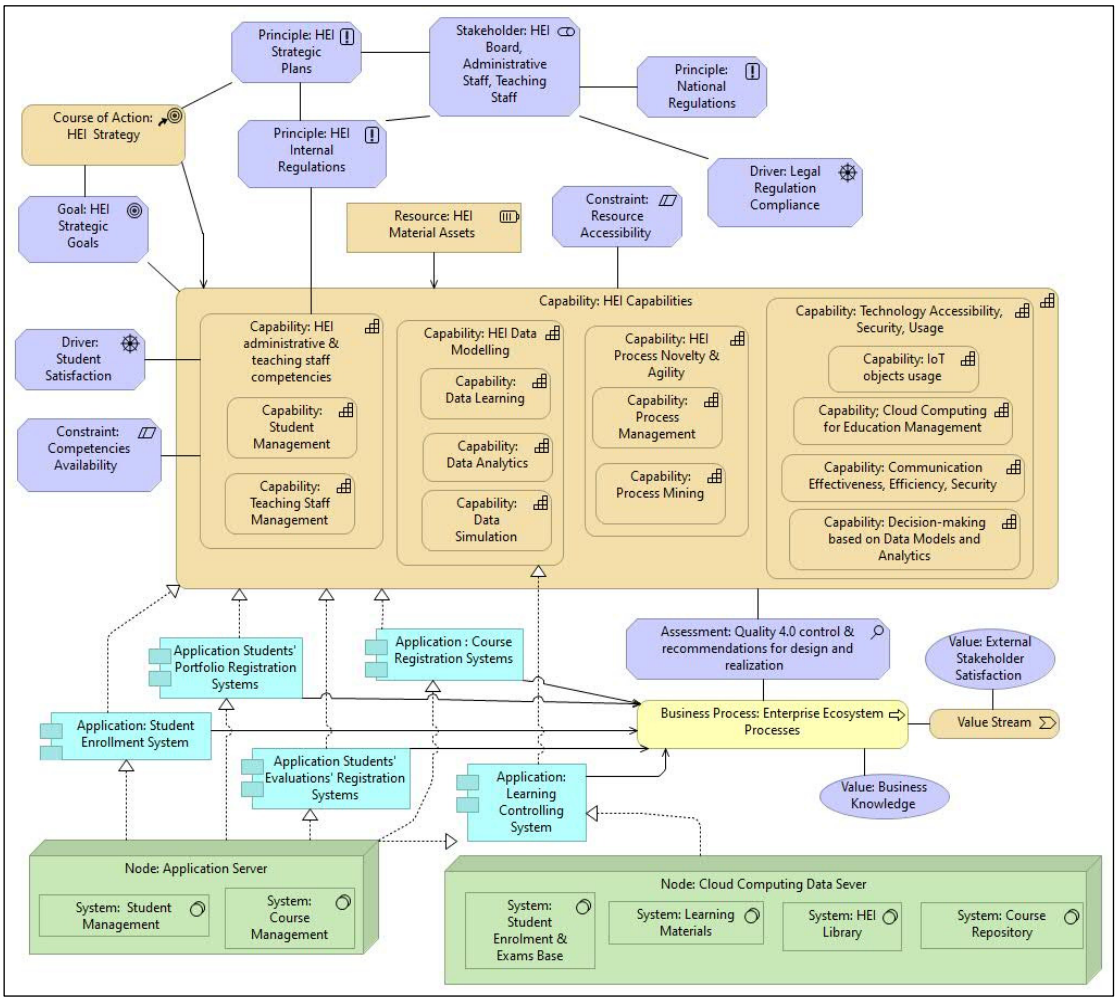

Fig. 3. Quality 4.0 oriented HEI Enterprise Architecture.

The educational processes are constantly monitored and Key Performance Indicators

(KPIs) values are recorded. The typical metrics may cover time of direct contact of the teacher with the students, numbers of students participating in classes, students' retention, students' satisfaction.

In the context of HEI Quality 4.0 management, the data modelling, analytics and educational process mining, benchmarking, and resource optimization are crucial for the organizational excellence. Beyond HEI accreditation processes, educational institutions are constantly working on self-improvement, predictive maintenance of actual activities, and proactive reduction of insufficiencies. Predictive analytics is based on understanding student preferences and behaviours. In this way, HEI may predict future capabilities and renew its strategy. The learning environment is expected to be safe and secured, therefore HEIs implement network abuse detection systems and cyber regulation compliance. Education controlling system may require access to teaching evidence in form of structured as well as unstructured data across different devices and applications, such as desktop applications, web and smartphones applications. New analytics methods are creating opportunities for HEIs to make decisions from formal education data as well as from freely available external information sources, such as social media. While traditional business intelligence has focused on structured data, advances in analytics methods permit the examination of various data types from NoSQL databases.

Prescriptive analytics may concern learning processes, competences of teaching staff, learning efficiency. Therefore, in this way HEU may improve teaching practices and recognize teaching staff strengths and weaknesses. As Quality 4.0 approach in HEI is strongly based on massive data, intelligent objects and Internet communication, it may be troublesome for business processes' actors, i.e., learners and teachers. Therefore, there is the question on motivations and business drivers. Student satisfaction and high retention rates, high rank in comparisons with other universities are important business drivers. However, beyond that, Quality 4.0 implementation requires strong support of top management for the implementation of quality practices. Their activities result from legal regulations compliance. Key issues of organizational culture, i.e., acceptance and transparency are needed for achieving Q4.0 success.

5. Conclusions

Actual literature on Quality 4.0 has revealed factors which characterize quality management in the Industry 4.0 context as well as provide the fundamentals for further studies. However, there is still no strategic directions, and lack of sufficient explanations of opportunities created by Quality 4.0. The technologies allow to supervise the whole production process, from conceptualization to the liquidation and removal of product or service from market. The Quality 4.0 technologies permit to involve external stakeholders, i.e., customers, students in the quality management process through real-time data management. Quality 4.0 is a part of quality management and organizational excellence, the decisions to what degree Industry 4.0 technologies will be used depends on top management and other employees preferences. This study emphasized the meaning of business capabilities for Q4.0 development and deployment in manufacturing companies as well as in service-oriented business organizations. In manufacturing companies, the production processes are automated, designed and controlled by technologies, while in services institutions the automation may cause humans alienations. Therefore, the Quality 4.0 motivations, barriers and readiness in service sector can be subject of further research.

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