SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2025
ORGANIZATION AND MANAGEMENT SERIES NO. 221

CONDITIONS AND CONSEQUENCES OF QUALITY DEVELOPMENT – FROM QUALITY 4.0 TO 5.0

Elżbieta SKRZYPEK[1], Piotr GRUDOWSKI[2*]

[1] University of Kalisz; elzbieta.skrzypek@mail.umcs.pl, ORCID: 0000-0001-9020-1671
[2] Gdansk University of Technology; pgrudows@pg.edu.pl, ORCID: 0000-0003-0283-7544
* Corresponding author

Purpose: To present the essence, advantages and threats of Quality 4.0 and Quality 5.0 and to indicate further development directions of quality management concepts.
Design/methodology/approach: The research methods used are a thematic review of literature on research on Quality 4.0 and 5.0 and surveys conducted among companies with certified quality management systems in the region of southeastern Poland.
Findings: The challenges and drivers of Quality 4.0 development are closely related to Industry 4.0 and are based on IT revolutionizing the business world. The implementation of Quality 4.0 solutions leads to the integrated and intelligent automation of quality standards. The research results show a growing interest in the implementation of Quality 4.0 and TQM 4.0 solutions. The increased focus on social satisfaction through an environmentally sustainable approach has been reflected in Quality 5.0 related to Industry 5.0 and Society 5.0.
Research limitations/implications: The main limitations of the conclusions presented in this article and the reflections described by the authors and other researchers include: the study does not offer long-term data on the outcomes of Quality 4.0 and 5.0 implementations, making it difficult to assess their sustained impact; the concepts of Quality 4.0 and 5.0 are still evolving, and the article does not provide universally accepted interpretation. The authors acknowledge a need to develop research on Quality 5.0 in the following directions: investigate the role of organizational culture, leadership styles, and employee training in successfully adopting Quality 4.0 and 5.0; explore how Quality 4.0 and 5.0 can be tailored to specific sectors (e.g., healthcare, education, manufacturing) to address unique challenges and opportunities; examine the balance between automation and human involvement in Quality 5.0, particularly in industries where human judgment and creativity are critical.
Originality/value: The article identifies the challenges related to contemporary approaches to pro-quality management of organizations and systematizes the concept of quality in the conditions of Industry 4.0 and 5.0, indicating its key aspects. It is addressed to researchers of quality management issues.
Keywords: Quality Management; Industry 4.0; Society 5.0; Quality 4.0; Quality 5.0.
Category of the paper: General review; conceptual paper.

1. Introduction

The approach to quality has changed over the centuries and has been the subject of interest of philosophers, economists, sociologists and psychologists. Quality is omnipresent in all processes accompanying the activity of economic entities. It is defined as a state to strive for, a dynamic goal, the basis of existence and competitiveness of companies, a determinant of success, a tool for improving products, services, data, knowledge, information, skills, communication, management, relationships and life. It shapes the trust and satisfaction of customers and their loyalty and contentment. Quality is a measure of the maturity of the actions taken. The quality approaches shaped by Americans, Japanese, and Europeans, including Poles, create a base that enables quality development in response to the emerging needs of entities operating in conditions of change, uncertainty and risk (Hamrol, 2023; Souza et al., 2020). Quality development cannot occur without reference to already proven solutions. However, the points of gravity in the approach to quality problems may change.

More than the "classic" understanding of quality is required today. The conditions in which Deming, Juran, Feigenbaum, Crosby, and Ishikawa lived and created were not burdened with such significant variability as today. Today, the quality category must be expanded to include references to globalisation and innovation. Digitisation, networking, and social media force a broader view of quality. Work is being undertaken in standardisation, integration of quality systems, Quality 4.0, environment, social responsibility, sustainable development, digitisation and artificial intelligence (Skrzypek, 2021a). Evolutionary changes in the approach to quality generate the basis for integration, supported by economic, social and organisational premises and the development of digital technologies, enabling real-time decision-making based on data of appropriate quantity and quality, available, collected and coming from various sources. The development of new digital technologies creates conditions for integration. It enables work to be done faster, better, with greater efficiency and at lower costs, leading to business process optimisation. Quality in the Industry 4.0 era is estimated to drive improvements in the entire value chain of organisations, enterprises, corporations and countries (All-about-quality 4.0, 2024).

Quality determines the level of maturity of the actions taken and enables the improvement of organisational processes. The solutions of the fourth industrial revolution are closely linked to quality in a feedback loop. It is estimated that 23% of digitalisation initiatives are quality improvements. Jacobs emphasises that "the arrival of the fourth revolution will affect everything we do. It connects people, machines and data in new ways, democratises technologies previously available only to a few and introduces transformational possibilities such as those in analytics, materials science and connectivity. These technologies are important for quality because they transform culture, leadership, cooperation and compliance" (Jacob, 2017a).

Product quality remains a key social and economic factor. Customers expect innovative technological solutions, high durability, safety, and ecological responsibility of the product, which puts quality at the forefront of the factors determining the organisation's success. Personalisation and sustainable development are essential here. Products are expected to meet customer expectations and be created with the environment in mind.

There are many reasons to justify the development towards Quality 4.0 and 5.0, and we live in the conditions of Society 4.0, which is currently transforming into Society 5.0.

Quality 4.0 is becoming a priority in organisations, fulfilling the promise of a future filled with seamless connectivity, evolving technological innovations, and the associated reduction of process variability. This affects organisations as new insights emerge and industry efficiency increases (Jacob, 2017b).

The article aims to present the essence, advantages and threats of Quality 4.0 and Quality 5.0 and to indicate further development directions of quality management concepts. The research methods used are a thematic review of literature on research on Quality 4.0 and 5.0 and surveys conducted among companies with certified quality management systems in the region of southeastern Poland.

2. The essence of Quality 4.0

Armani et al. (2021) emphasise that Quality 4.0 aims to strengthen existing approaches to quality, expand the scale of application of new technologies, and find ways to improve processes. It means digitalising quality management to integrate technological structures, processes and people.

Quality 4.0 is a concept that refers to promoting the implementation of modern management methods that are based on (Wawak, 2022a):

- co-creation of value through the integration of departments, processes and entire enterprises,
- a systemic approach to management, ensuring trust, transparency and cooperation,
- physical integration of organisational infrastructure with the network and databases, collecting and analysing live data on the functioning of the infrastructure,
- fast, adaptive learning and introducing changes before problems occur,
- using machine learning and artificial intelligence for monitoring, analysis and decision-making.

As a result of research conducted by Armani et al. (2021), the following stages of the evolution of Quality 4.0 were identified:

- Absent quality - lack of knowledge in the field of quality management, lack of activities aimed at quality planning.
- Elementary quality - basic knowledge of the traditional approach to quality, lack of knowledge relating to new practices, technologies, systems and tools.
- Traditional quality - basic knowledge of Quality 4.0 and Industry 4.0, no investment planning in this direction.
- Advanced quality - the organisation has average knowledge of Quality 4.0, does not practice it, but plans to implement technologies, tools and processes that will enable the growth of its potential in this direction.

Quality 4.0 - the organisation has advanced knowledge of Quality 4.0 and uses techniques, tools and processes that enable quality management to be linked with Industry 4.0.

Table 1 shows the evolution of quality towards its fourth generation.

Table 1.
Evolution of quality towards Quality 4.0

Phase	Quality control	Quality assurance	TQM	Quality 4.0
Range	Product	Processes	Organisation, people	TQM, systems, stakeholders
The importance of quality	Checking	Projects	Strengthening	Innovations
Functions	Technical characteristics, statistical control of processes and deviations, corrections	Built-in process quality. Process and certification efficiency. Prevention	Organisational objectives related to certification. Quality as a strategic imperative. Continuous improvement	Suppliers, customers and society are integrated. Focus on data and digital tools providing new and up-to-date information.

Source: Sader et al., 2019.

2. Definitions of Quality 4.0

Gunasekaren et al. (2019) indicate that the first publications on Quality 4.0 appeared after introducing the term Industry 4.0. Watson (1998) predicted the concepts that comprise "Quality 4.0" more than 20 years ago. He drew attention to the availability of telecommunications technologies, the Internet, personal computers, networks, and machines with built-in intelligence. He believed these solutions could improve individual quality functions concerning data, processes, and products and improve quality analyses in an automated manner. The directions for the development of quality management research are expanding. A review of the database of journals analysed in terms of interest in Industry 4.0 and Quality 4.0 showed

the research is at an early stage (Wawak, 2022a). Quality 4.0 has not yet been defined in one widely accepted way. Researchers are trying to describe it by indicating its characteristic features. They point out that it is a concept that refers to the implementation of modern quality management methods, which are based on, among others (Skrzypek E., Skrzypek A., 2023; Wawak, 2022a), the co-creation of value through the integration of departments, processes and entire enterprises, system departure to management, cybernetics, ensuring trust, transparency and cooperation, integration of the organisation's physical infrastructure with the network and databases, collecting and analysing live data on the functioning of the infrastructure, fast, adaptive learning and introducing changes before problems appear (prediction), using machine learning and artificial intelligence for monitoring, analysis and decision-making.

Aldag and Eker (2018) defined Quality 4.0 as combining traditional quality management practices and techniques with new technologies. Such integration has resulted in an advanced collaborative environment where management activities are based on better connectivity in the value chain from supplier to end customer.

Schönreiter (2017) defined Quality 4.0 as integrating and synchronising data-related technologies to production processes and activities with quality management in real time. Quality 4.0 has to be connected with real-time analysis systems that can monitor, analyse, and control the entire value chain to take all necessary countermeasures to prevent production downtime or product rejection.

Hamrol (2023) believes that Industry 4.0, Technology 4.0, Products 4.0, and Society 4.0 create the construct of Reality 4.0, indicating that the processes and phenomena of the fourth industrial revolution somewhat inspire every person's life. Reality 4.0 includes Economy 4.0, Education 4.0, Medicine 4.0, Quality 4.0, etc.

Jacob (2017b) defined Quality 4.0 as leveraging traditional quality management techniques acquired by modern technologies to achieve a new level of excellence at the functional and operational levels. He argues that Quality 4.0 technologies lead to effective and efficient quality management, which increases market share, stimulates innovation, improves the ability to cope with value chain challenges and improves brand recognition (Jacob, 2017a). Business leaders should strive to achieve Quality 4.0. Otherwise, their company will be marginalised and be on their industries' sidelines (Jacob, 2017b). Allcock (2018) emphasised the difference between Quality 4.0 and traditional quality as a shift from manual measurements, recording results on quality charts and re-tuning the production process to fully automated operations, where sensors measure, applications analyse, and control the auto-tuning process (regulation, tuning). Chiarini and Kumar (2021) indicate that Quality 4.0 is associated with a shift towards total customer satisfaction and experience, innovation and sustainability; it refers not only to functions but also means exceeding customer expectations. It includes the overall customer experience, user convenience, after-sales service and environmental impact. Koc (2007) indicates that Quality 4.0 means that products provide positive customer experiences and are consistent with ethical and sustainable practices. An integral part of the perception of quality is information

transparency, which enables access to the Internet and the development of e-commerce. He emphasises the role of prosumers. Quality 4.0 requires the development of quality standards in the form of ISO 9001 standards, Six Sigma and Lean Manufacturing practices, which are proven tools for quality improvement and enable the elimination of waste. Skrzypek and Skrzypek (2023) indicate that Quality 4.0 requires developed organisational knowledge and access to the latest data, information, and technological solutions operating in this area. Training, new competencies, and care for up-to-date knowledge are necessary. Applying acquired knowledge in action is a condition for improving the quality of products and services and implementing projects that lead to the organisation's improvement, maturity, and competitiveness in operating in conditions of change, risk, and uncertainty.

The relationship between knowledge and the optimisation of the communication process, as well as the development of quality, are also highlighted by Gomes, Oliveira, and Chaves (2016). It is important to note that Zonnenshain and Kennett (2020) indicated that in the 21st century, quality serves as the foundation for the integration of various fields and characterized it as a discipline grounded in source data. Employing modelling and simulation for evidence-based quality engineering, utilising non-conformity monitoring alongside quality prediction, and embracing integrated quality management enable the merging innovation quality with innovation management. Furthermore, one cannot overlook the impact of advancing automation and artificial intelligence on predictive data analysis, the integration of reliability engineering with quality engineering, and the enhancement of information quality.

Taking into account the presented views, the authors believe that Quality 4.0 integrates digital technologies such as AI, IoT, and real-time analytics with traditional quality management to enhance decision-making, customer experience, and operational efficiency.

3. Quality 4.0 and Industry 4.0

Quality 4.0 refers to Industry 4.0 (Sony et al., 2020; Wawak, 2022b), which combines technical, information, communication and material models with traditional management models related to quality and closely related categories of excellence. At the same time, assigning decisive importance to technology in Industry 4.0 may be a source of problems in the quality area. The tools, techniques, and methods used so far, as well as the principles of quality management, will still be applicable in the conditions of Industry 4.0 in quality management. Still, solutions are needed to enable more effective collection, storage, processing and analysis of large data sets to make accurate real-time decisions (Jarvis, 2018). This is possible, for example, by using sensors, laptops, artificial intelligence algorithms, the Internet of Things or cloud computing. These changes must be introduced while maintaining the principles of quality management, which put people, their involvement, creativity, innovation and openness

to learning at the centre of attention (Hamilton, 2020; Hong et al., 2021). The components of Quality 4.0 include:

- Data and analytics - data plays a key role in making people informed and accurate decisions, while analytics enables the disclosure of information about raw data.
- Links between business information and operational technology.
- Scalability - processes and best practices must be scalable to ensure quality and uniformity.
- Application development - the role of interactive devices in augmented and virtual reality is rapidly growing (Abou-Zahra et al., 2018).
- Active leadership that has a significant role in promoting and implementing Quality 4.0 initiatives.
- Compliance - modern tools enable the assessment of the organisation's compliance systems and strategies.
- Management systems and system connectivity are essential operational elements of Quality 4.0. Quality management systems and other management systems integrate quality processes and provide data throughout the product life cycle, which can improve the organisation's ability to manage errors and delays effectively.

Digital transformation requires appropriate technologies that are also used in the area of quality management (Jacob, 2017a; Liboni et al., 2019; Reagan, Singh, 2020):

- AI technology: chatbots, robotics, computer vision, personal assistants.
- ML (Machine Learning) based technologies for fraud detection, object categorisation and prediction.
- Blockchain-based approaches to increase transparency and trustworthiness of information and asset transactions.
- Big Data and tools for handling and evaluating large amounts of data- using data to combine different data sets, categorise them, find helpful information and reduce large amounts of observational data to the most important factors.
- Deep Learning, including complex pattern recognition, sound and art creation, time series prediction and image adaptation.
- supporting technologies, e.g. Cloud Computing, Augmented Reality, Virtual Reality, sensors, Internet of Things, and Data Streaming.

People's creativity is the condition for developing the full potential in the automation of production processes. Automated production using conventional industrial robots is related to tedious programming. At the same time, robots cooperate directly and flexibly with employees; this causes production to gain new dynamics and releases new potential because robots take over standard processes while humans are involved in other activities that create added value. An employee using a robot, a so-called Cobot, as a multifunctional tool, e.g. a packaging machine, a palletiser, etc., feels significant relief and can focus on other, more important types

of work. A robot cannot replace human work but can supplement it by performing difficult, routine and even dangerous tasks. Artificial intelligence is also important because it performs tasks within assigned structures and develops its solutions through independent analyses. This, in turn, saves time for employees, who can continue to work more efficiently with specific results (Krill, 2024; Mills, 2020; Nahavandi, 2019; Omar, Nehdi, 2017).

Taking into account the developing research in the field of Quality 4.0 and their results presented in publications, selected characteristics of Quality 4.0 as an aspect of Industry 4.0 can be indicated:

- A priority in organisations that fulfils the promise of a future filled with seamless connectivity, evolving and innovative technologies and the associated reduction of process variability.
- A motive and test of efficiency and effectiveness of action.
- A factor shaping organisational maturity.
- A tool for improving management, products, services, knowledge, information, competencies, relationships, life.
- A determinant of success in conditions of variability and risk, uncertainty, lack of continuity of operations, a dynamic goal in conditions of environmental variability.
- An instrument shaping interpersonal relations.
- A signal in the process of shaping intellectual capital.
- A tool for integrating engineering with the concept of value and human satisfaction in the process of striving for perfection of all kinds.
- A set of tools for building trust.
- A concept that defines technologies, practices and processes aimed at quality management, which enable manufacturers to develop and maintain appropriate standards throughout the supply chain from research and development through procurement, production, logistics, sales, after-sales services and other corporate functions to administration and management.
- Complementing the concept of Industry 4.0, including machine learning, predictive analytics, Internet of Things, big data, and cloud computing, which, combined with traditional quality management systems such as QMS software, enable continuous improvement and improvement of overall business performance.

Skrzypek (2019, 2020, 2021b, 2023), based on the conducted research, indicated that Quality 4.0 is defined as a multi-aspect approach to quality, a platform enabling the use of digital tools in the process of optimising business processes, an approach creating broad opportunities for the development of quality management practices based on ISO 9000 standards, a tool for improving business efficiency, technology and a new way of quality management, a dynamic concept, an instrument for improving comprehensively understood efficiency, productivity and organisational maturity, solutions improving processes, solutions

improving processes, tools for intelligent quality management, a concept justifying standardisation 4.0, a platform for real-time process control and a chance for success.

The approach to Quality 4.0 is combined with the concept of promoting the implementation of modern management methods, which refer to prediction, wider use of machine learning and artificial intelligence solutions, efficient data collection and analysis, creating conditions for the integration of the organisation's physical infrastructure with the network and databases, co-creation of value and a systemic approach to ensuring transparency, trust and cooperation (Skrzypek, E., 2021a, 2021b; Souza et al., 2022). The keys to the development of Quality 4.0 are strong leadership for quality, quality measurement, training in the area of quality, developed quality culture, ongoing data acquisition and processing, analysis of large data sets, real-time decision-making, strong integration, developed competencies of the future, including digital ones, development of multidisciplinary teams, support and development of innovation and the use of the "Open-Quality" concept, which allows for the connection of quality experts with data analysts, which should support the adoption of solutions brought by the fourth industrial revolution.

There is a need to invest in Quality 4.0, which requires investment in technologies. Digital technologies are revolutionising the business world, and innovation is the key to the success of every organisation. So far, attention to quality issues has been focused on products and services, including the quality of products (What is Quality 4.0, 2021). In the conditions of Quality 4.0, more attention must be paid to the quality and security of data-related services. In addition, a significant part of the tasks performed by quality specialists are taken over by IT systems that can analyse data, interpret it, and propose solutions. At the same time, not all problems in quality management can be computerised and automated; it is necessary to develop the so-called competencies of the future (Skrzypek, 2023).

Quality 4.0 aims to strengthen existing approaches to quality, expand the scale of application of new technologies, and find ways to improve processes, which means digitalisation of quality management to integrate technological structures, processes and people (Arsovski, 2019). Assessment of the need for technological progress should consider aspects of feasibility and profitability, and it is also necessary to answer the question: Why are we developing technology? Here, business, science, government and society should clash.

Management must be subordinated to quality, which has become the central point of modern management of production and service organisations.

Quality 4.0 refers to the digitalisation of the total quality approach (TQM), in which effective ways of influencing the quality of technology, processes and people are sought (Chiarini, 2020). According to Chiarini (2020), this phenomenon combines intelligence and automation to increase efficiency and create conditions for real-time decision-making involving stakeholders to ensure greater transparency. The digitalisation of management methods also concerns quality management methods because the amount of available data is increasing, IT systems are being integrated, the Internet of Things and Services are being used on a wider

scale, and it is expected that the time needed to make decisions will continue to shorten (Sony et al., 2020). TQM involves coordinating decisions to achieve optimal quality, i.e., the quality expected by the customer and the organisation.

Quality 4.0 reduces defects, enables personalization, improves efficiency, and fosters data-driven transparency. When pointing out the effects of Quality 4.0, it should be emphasised that:

- Digital transformation leads towards integrated and intelligent automation of quality standards, which should translate into profitability and success of the organisation as well as increased efficiency and competitiveness (Wawak, 2022a).
- Quality 4.0 is reflected in research and development, which should be reflected in the quality of projects because comprehensive integration in Industry 4.0 will enable designers to access data and analyse it, which should translate into increased adaptability through faster response to changes in demand and shorter information processing time (Seon et al., 2018).
- Digitalisation and automation improve the quality of processes, automated systems facilitate machine learning, and there will be quick access to data from production processes and customers, which will enable better mapping of customer needs and production of products that better meet their needs and expectations (Liboni et al., 2019).
- Digitalisation of quality management enables real-time data telemetry, and advanced machine learning algorithms are emerging (Jarvis, 2018).

Quality and effective quality management in all management areas are good platforms for integrating management systems because they facilitate access to data, more efficient management, and real-time decision-making. In the conditions of the fourth industrial revolution, this is a desirable solution. Methods, techniques, and quality management tools must be adapted to the requirements of the digital revolution and integrated with IT systems.

The benefits of Quality 4.0 resulting from the research include (Liboni, 2019; Seon et al., 2018): improving process management in the organisation, gaining long-term competitive advantage resulting from quality, effective risk and opportunity management, optimising the quality cost structure, reliable quality assurance of all processes, faster and more complete identification of customer or other stakeholder requirements.

In addition, the following are indicated (Wawak, 2022b): improving the prevention of quality problems already in the design and development phase, broader involvement of employees in decision-making processes at various management levels, shortening the time of current order fulfilment, and increasing the flexibility of response to product and process deviations from specifications. Researchers also point to the possibility of achieving compliance at the 6 sigma level, the possibility of mass personalisation of products. Thanks to Quality 4.0, leaders receive data needed for monitoring, efficiency, quality, and estimating the real costs of good and bad quality.

The following barriers to the implementation of Quality 4.0 are identified (Wawak, 2022b): too high investment and time requirements, lack of a long-term quality management strategy in the organisation and the need to acquire completely new knowledge by many employees of the organisation, often passive approach and reluctance of top management or the owner, current lack of financial resources and difficult communication and cooperation between quality management staff and IT specialists.

In 2020, at the Maria Curie-Skłodowska University in Lublin, in the Department of Intellectual Capital and Quality, research was conducted on Industry 4.0 and Quality 4.0. The online survey was addressed to 300 enterprises with a certified QMS; the enterprises are located in Poland. The statistical analyses were based on the responses from 100 surveys. A tag cloud indicated the respondents' definition of Quality 4.0. The most frequently mentioned definitions were: comprehensive definition of quality (43.1%), technology and a new way of quality management (42.2%), a new way of quality management (42.2 %), a tool for improving the management of an organisation supported by IT technologies, an opportunity to increase productivity (30.4%) (Skrzypek, E., 2021b).

The links between quality and important problems from the point of view of the functioning of quality-oriented enterprises were also indicated. These studies show that Quality 4.0 is associated with (Skrzypek, E., 2021b):

- Reducing costs by avoiding failures and eliminating downtime.
- Supporting business through rapid response, anticipation and taking proactive actions with less employee involvement.
- Its use on production lines, warehouses, retail and remote offices, i.e. in the entire lifecycles of goods and services.
- Correlating current data from various sensors (5G) with historical data, which opens up new business opportunities.
- The Internet of Things and progress in the fourth industrial revolution.

The following directions of research are indicated as related to TQM and Industry 4.0 (Wawak, 2022a):

- Technology-related area: how to manage quality through digitalisation and automation of processes while ensuring security, privacy and data protection.
- Area related to quality: is it possible to assess the maturity (stage of development) in terms of the organisation's adaptation to TQM 4.0.
- The area related to people management: how to prepare quality management specialists to acquire the skills necessary to cope with the challenges related to Industry 4.0 (e.g. the use of big data), how to help employees who have been involved in quality management for a long time to adapt to emerging changes (e.g. quality monitoring), using online platforms in real-time.

TQM 4.0 is focused on creating and designing analogue and digital measurement systems, saving the collected data for analysis, and, based on the obtained results, improving the production process in terms of quality (Sader et al., 2019).

4. Quality 5.0 as a new concept of quality and social satisfaction

The idea of Industry 4.0 is already represented in many industries and companies. However, its human-centric and pro-ecological reorientation and integration with technological achievements are being observed, referred to as Industry 5.0. Therefore, the definition of Quality 5.0, referring to the concept of Industry 5.0, assumes that it is the satisfaction of all stakeholder groups while meeting social needs through a sustainable approach to environmental issues. Organisations' future strategies must focus on all groups of stakeholders, including competitors. All social and environmental problems must be included in the development strategy of enterprises within the fifth generation of quality management, Quality 5.0, towards social satisfaction. Therefore, there is a need to develop new approaches, methods, tools, and a new quality function to support organisations in sustainable business development. Adopting the Quality 5.0 concept is expected to create conditions for the dynamic, sustainable development of companies. Quality 5.0 from 2020 reflects a new era marked by digital transformation, growing automation and awareness of the impact on the environment and society (Deleryd, 2020). This approach is based on Industry 5.0 (Nahavandi, 2019). Defining the concept of Quality 5.0 is increasingly associated with innovation, technology and sustainable practices. It is noticeable that in this context, expectations arise that high-quality products and services will be able to provide users with exceptional experiences, enriched with digital interfaces and artificial intelligence, and at the same time, will be sustainable and will positively impact society. As part of quality 5.0, manufacturers will use advanced technologies, e.g. artificial intelligence or analysis of large data sets, to accurately predict customer needs and personalise the experience, improving the quality of the market offer. In a closed-loop economy, quality is redefined, and principles related to waste reduction, recycling and manufacturing products that do not harm the environment are important. Quality 5.0 considers customer satisfaction, innovation, social impact and sustainable development.

Quality 5.0 is, according to J. Frick and P. Grudowski, the fifth evolution of quality management principles, which reflects the transformational impact of new technologies and holistic quality concepts on industrial processes. It emphasises the quality of the product and service and a holistic view encompassing sustainable development, customer satisfaction, employee involvement and social responsibility. They formulated the principles of Quality 5.0, indicating its components (Frick, Grudowski, 2023):

- Design: Design software solutions enable the creation of virtual product prototypes and appropriate testing before a physical prototype is created. This leads to more precise quality control during the design phase.
- Production: Monitoring production and identifying and correcting errors in real time are enabled by advanced technologies, such as the Internet of Things, automation, robotics, and artificial intelligence. This leads to minimising waste, reducing machine downtime and creating the basis for the final product to meet the highest quality standards.
- Inspection: Technology solutions enable computer vision systems to use artificial intelligence in automatic inspections, which helps identify defects with greater accuracy. Machine learning algorithms constantly learn, allowing for increased quality control accuracy and reliability.
- Data analysis: data analysis and machine learning are used to analyse large data sets generated during production. As a result, patterns and trends related to quality issues can be identified, allowing for further quality improvement through proactive quality control.

The concept of Quality 5.0 is consistent with the concept of Society 5.0. The Japanese government's 5th Science and Technology Basic Plan 2020 proposed Society 5.0. There is a need to incorporate new CSR and environmental care solutions into the principles of quality management. Japan has developed a plan to move from Industry 4.0 to Society 5.0. The Japanese government has adopted a plan in which all aspects of society, including industrial work, are shaped by the latest techniques and technologies. Economic growth will occur through artificial intelligence, further robotisation of society, automation of industry and faster communication. Revitalising management models using new measures of social satisfaction is the first step towards achieving future profitability, a sustainable future and lasting organisational success. Referring to the conditions for developing Quality 5.0, it should be pointed out that new solutions, concepts, methods, techniques and tools will be necessary to support Quality Management 4.0 and 5.0 and enable real-time decision-making in quality (Deleryd, 2020). Scientific research must be conducted to establish the theoretical foundations for Quality 4.0 and 5.0 and to provide guidelines for their implementation within the realm of Quality Management 5.0 in enterprises. In the context of Industry 5.0, understood as a technological transformation, emphasis is placed on collaboration between human beings and advanced technologies to achieve high and sustainable production quality (Liboni, 2019). Quality 5.0 creates a platform for integrating quality control with the production process, focusing on proactive measures to prevent defects and inefficiencies. There are two approaches to product quality control: one is the direct testing of product quality, while the other is testing process quality. Quality 4.0 engages in both approaches, addressing challenges identified by manufacturers. Quality 5.0, in the area of control, represents a proactive approach to replacing the traditional control model, which concerns itself with identifying and removing defects after

production. This shift includes continuous monitoring, predictive analytics, and real-time corrections to prevent defects before they occur (Nahavandi, 2019).

However, the following problems associated with Quality 5.0 should be addressed (Frick, Grudowski, 2023):

- Shaping new roles of quality managers in integrating economic, environmental and social aspects for sustainable development.
- The growing role and importance of management teams working with co-producers, collaborators and business competitors, exploring the role and scope of decision-making through artificial intelligence and machine learning.
- Measurement adaptation: moving from previously used customer satisfaction measures to society's satisfaction based on existing and new ones, including social, environmental and economic factors in the fifth generation of quality.
- Searching for tools enabling efficient management of the transition from the fourth to the fifth generation of quality implies a change in the main values of external stakeholders.
- Solving the problem of how a company's internal core values can be aligned with the external core values desired by society.

Summary

The approach to quality has changed over the centuries. In the conditions of the fourth industrial revolution, Quality 4.0 appeared, and its components included data and analytics, connections between business information and operational technology, scalability, application development, leadership, compliance, and management systems. It is a concept defining technologies, practices and processes aimed at quality management. The challenges and keys to developing Quality 4.0 are strongly related to Industry 4.0 and are based on information technologies that revolutionise the business world. Implementing Quality 4.0 solutions leads to the integrated and intelligent automation of quality standards. The research results prove the growing interest in implementing Quality 4.0 and TQM 4.0 solutions. Paying more attention to social satisfaction through an environmentally sustainable approach was reflected in Quality 5.0 associated with Industry 5.0 and Society 5.0.

The main limitations of the conclusions presented in this article and the reflections described by the authors and other researchers include:

- The article primarily relies on literature reviews and theoretical discussions, providing limited empirical data or case studies to substantiate claims regarding the effectiveness of Quality 4.0 and 5.0 implementations.

- The study does not offer long-term data on the outcomes of Quality 4.0 and 5.0 implementations, making it difficult to assess their sustained impact.
- The concepts of Quality 4.0 and 5.0 are still evolving, and the article does not provide universally accepted definitions, which may lead to interpretation issues.

The authors acknowledge a need to develop research on Quality 5.0 in the following directions:

- Investigate the role of organizational culture, leadership styles, and employee training in successfully adopting Quality 4.0 and 5.0.
- Track the implementation of Quality 4.0 and 5.0 over time to assess long-term effects on organizational performance, sustainability, and stakeholder satisfaction.
- Explore how Quality 4.0 and 5.0 can be tailored to specific sectors (e.g., healthcare, education, manufacturing) to address unique challenges and opportunities. - Develop and test metrics for evaluating the environmental and social impact of Quality 5.0, aligning with its focus on sustainability and societal satisfaction.
- Examine the balance between automation and human involvement in Quality 5.0, particularly in industries where human judgment and creativity are critical.
- Investigate the ethical implications and data privacy challenges associated with the use of advanced technologies (e.g., AI, IoT) in Quality 4.0 and 5.0.

By addressing these limitations and exploring these future research directions, scholars and practitioners can deepen their understanding of Quality 4.0 and 5.0, paving the way for more effective and sustainable quality management practices.

References

1. Abou-Zahra, S., Brewer, J., Cooper, M. (2018). Artificial intelligence (AI) for web accessibility: Is conformance evaluation a way forward? *Proceedings of the Internet of Accessible Things*, pp. 1-4.
2. Aldag, M.C, Eker, B. (2018). *What is quality 4.0 in the era of Industry 4.0?* 3rd International Conference on quality of life. University of Kragujevac. Retrieved from: https://strudocu.com.en-gb, 24.11.2024.
3. *All About Quality 4.0 - Components, Challenges & Benefits.* Retrieved from: https://www.habilelabs.io/blog/all-about-quality-components-challenges-Benefits, 1.02.2025.
4. Allcock, A. (2018). Nikon talks quality 4.0. *Machinery, 176(4276*), pp. 49-50. Retrieved from: https://www.machinery.co.uk/machinery-features/nikon-talks-quality-4-0-industry-4-0, 30.09.2019.

5. Armani, C.G., Oliveira, K.F., Munhoz, I.P., Akkari, A.C. (2021). Proposal and application of a framework to measure the degree of maturity in Quality 4.0: a multiple case study. In: M. Ram (ed.). *Advances in Mathematics for Industry 4.0* (pp. 131-163). Academic Press.
6. Arsovski, S. (2019). Social oriented quality: from quality 4.0 towards quality 5.0. *13th International Quality Conference*, *Vol. 13*, pp. 397-404.
7. Chang, R., Hong, J., Varley, K. (2020). *The COVID resilience ranking: The best and worst places to be in the Coronavirus era*. Retrieved from: https://www.bloomberg.com/graphics/covid-resilience-ranking/, 25.05.2022.
8. Chiarini, A. (2020). Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research. *The TQM Journal, Vol. 32, No. 4*, pp. 603-616.
9. Chiarini, A., Kumar, M. (2021) What is Quality 4.0? An exploratory sequential mixed methods study of Italian manufacturing companies. *International Journal of Production Research, 60(16)*, pp. 4890-4910. https://doi.org/10.1080/00207543.2021.1942285.
10. Deleryd, M., Fundin, A. (2020). Towards societal satisfaction in a fifth generation of quality – the sustainability model. *Total Quality Management & Business Excellence*, *36*(3-4), pp. 292-308. https://doi.org/10.1080/14783363.2020.1864214.
11. Frick, J., Grudowski, P. (2023) Quality 5.0: A Paradigm Shift Towards Proactive Quality Control in Industry 5.0. *International Journal of Business Administration, Vol. 14, No. 2*, pp. 51-56.
12. Gomes, F., Oliveira, M., Chaves, M.S. 2016). Knowledge sharing in project management process groups. *Proceedings of the European Conference on Knowledge Management, ECKM 2016, January*, pp. 307-315.
13. Gunasekaren, A., Subramanian, N., Ngai, W.T. (2019). Quality management in the 21st-century enterprises. Research pathway towards Industry 4.0. *International Journal of Production Economics, Vol. 207.*
14. Hamilton, R.H, Sodeman, W.A. (2020). The questions we ask: Opportunities and challenges for using big data analytics to strategically manage human capital resources. *Business Horizons, 63(1)*, pp. 85-95. https://doi.org/10.1016/j.bushor.2019.10.001.
15. Hamrol, A. (2023). *Zarządzanie i inżynieria jakości ze spojrzeniem w rzeczywistość 4.0.* Warszawa: PWN, p. 20.
16. Jacob, D. (2017). *Quality 4.0 impact and strategy handbook*. LNS Research, MasterControl.
17. Jacob, D. (2017). *What is quality 4.0?* LNS Research, MasterControl. Retrieved from: https://blog.lnsresearch.com/quality40, 16.09.2024.
18. Jarvis, A., Morales, I., Jose, J. (2018) *Quality Experience Telemetry: How to Effectively Use Telemetry for Improved Customer Success*. Quality Press.
19. Koc, T. (2007). The impact of ISO 9000 quality management systems on manufacturing. *Journal of Materials Processing Technology, 186(1-3)*, pp. 207-213. https://doi.org/10.1016/j.matprotec.2006.12.034.

20. Krill, M. (2019). *Industry 5.0 – networking między człowiekiem a maszyną*. Retrieved from: https://polskiprzemysl.com.pl/utrzymanie-ruchu/industry-5-0/, 20.10.2024.
21. Liboni, L.B., Cezarino, L.O., Jabbou, C.J., Oliveira, B.G., Stefanelli, N.O. (2019) Smart industry and the pathways to HRM 4.0: Implications for SCM. *Supply Chain Management, 24(1)*, pp. 124-146. https://doi.org/10.1108.SCM-03-2018-0150
22. Mills, M. (2020). From Reactive To Proactive. *Quality Progress*, *53(6)*, p. 56.
23. Nahavandi, S. (2019). Industry 5.0 - A Human Centric Solution. *Sustainability, 119160, 4371*. https://doi.org/10.3390/su111643712019.
24. Omar, T., Nehdi, L.M. (2017). Automated Data Collection for Progress Tracing Purposes: A Review of Related Techniques. In: H. Rodrigues, an Elnashai, G. Calvi (Eds.), *Facing the Challenges in Structural Engineering*, GeomEast: Sustainable Civil Infrastructures. Springer.
25. Reagan, R.J., Singh, M. (2020). *Management 4.0: Cases and Methods for the 4th Industrial Revolution. Blockchain technologies*. Singapore: Springer.
26. Sader, S., Husi, I., Daroczi, M. (2019). Industry 4.0 as a Key Enabler toward Successful Implementation of Total Quality Management Practices. *Periodica Polytechnica Social and Management Sciences, 27(2)*, pp.131-40. https://doi.org/10/gpwkcs.
27. Schonreiter, I. (2017). Significance of Quality 4.0 in Post-Merger Process Harmonization, *Innovations in Enterprise Information Systems Management and Engineering*, pp. 123-134. https://doi.org/10.1007/978-3-319-58801-8_11
28. Seon, S.W., Dahlgaard, J.J., Dahlgaard-Park, S.M., Kim, M.G. (2018). A Quality Scorecard for the Era of Industry 4.0. *Total Quality Management &Business Excellence, 29(9-10)*. https://doi.org/10.1080/14783363.2018.1486536.
29. Skrzypek, A. (2019). *Maturity and improvement of the organisation*. Toruń: TNOIK Publishing House.
30. Skrzypek, E. (2021). Digitalization along with 5G and 6G networks - Determinants and Consequences. *Annales Universitatis Mariae Curie- Skłodowska Lublin - Polonia Sectio H Vol. LV, 1*, pp. 52-66. https://doi.org/10.17951/h.2021.55.1.51-66.
31. Skrzypek, E. (2021). How to understand quality - towards quality 4.0. *Problemy Jakości, no. 3*, pp. 10-14.
32. Skrzypek, E. (2023). *Quality management*. Lublin: UMCS Publishing House.
33. Skrzypek, E. (ed.) (2020). *Quality as a hope for a better world.* Lublin: UMCS Publishing House.
34. Skrzypek, E., Skrzypek, A. (2023). *Quality 4.0 in the conditions of the fourth industrial revolution*. Lublin: UMCS Publishing House.
35. Sony, M., Antony, J., Douglas, J.A. (2020) Essential ingredients for the implementation of Quality 4.0: A narrative review of the literature and future directions for research. *The TQM Journal, vol. 32, no. 4,* pp. 779-793.

36. Souza, F.F., Corsi, A., Balbinotti, R.N., Kovaleski, J.J. (2022) Total quality management 4.0-adapting quality management to Industry 4.0. *The TQM Journal, vol. 34, no.4*, pp. 749-769.
37. Watson, G.H. (1998). Digital Hammers and Electronic Nails; Tools of the Next Generation. *Quality Progress, vol. 31, no.7*, pp. 21-26.
38. Wawak, S. (2022) Directions of development of quality management research. *Zarządzanie i Jakość, Vol. 4, no. 2*.
39. Wawak, S. (2022). Benefits and barriers of implementing quality 4.0 in Polish enterprises - preliminary research. *Problemy Jakości, no. 5*, p. 7. doi:10.15199/46.2022.5.1.
40. *What Is Quality 4.0*. The Oakland Group (2021). Retrieved from: https://www.theoaklandgroup.co.uk/what-is-quality-4-0/. 17.03.2025.
41. Zonnenshain, A., Kennett, P.S. (2020). Quality 4.0-the Challenging Future of Quality Engineering. *Quality Engineering, vol. 32, no.4.*