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QUALITY ENGINEERING CHALLENGES ON THE WAY TO SUSTAINABILITY

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Abstract
The goal of this paper is to present the author's thoughts on the possible contribution of quality engineering to sustainable development. It is indicated that in the product life cycle designers have the greatest potential to support this challenge. Arguments have been presented to abandon the commonly accepted paradigm, according to which the overriding goal of the designer is to achieve the highest market value possible measured by the prospected level of demand for the products designed. It is postulated to include the minimization of the risks brought to the natural environment and social relations as a criterion of product design quality. To this goal, it is necessary for designers to pursue both environmentally friendly materials and technologies and design concepts reducing consumers' pressure on continuously increasing demand. Such an approach will allow for more effective control of consumption, the main cause of the negative effects of economic growth.

Keywords
Quality engineering, sustainability, product life cycle, product design, customization.

Introduction

It is believed that economic growth is essential for humanity to improve living conditions, economic development, and civilization advancement. Lack of growth is associated with crisis, recession and even depression.

However, recent decades have made people realize that there are processes accompanying economic growth, having a negative impact on the natural environment and social relations, including increasing economic inequalities [1]. Therefore, thinking about growth in terms of sustainable growth begins to predominate, where human needs are met in such a way as not to diminish the chances of realizing the needs of future generations [2].

Economic growth is stimulated by consumption and by supply, which is a response to emerging demand. This is one of the fundamental economic rights. Many factors influence the shaping of supply and demand, and as a result, economic growth. They are primarily associated with technological development, the wealth and level of education of the society, as well as the state financial and credit policy of banks [3]. Depending on who is speaking about economic growth, these factors are assigned a different weight. However, there is a consensus that the primary factor in stimulating demand is people's needs and expectations satisfied by purchasing consumer goods.

The creators of consumer goods, especially durable goods, are mainly engineers, e.g. designers, technologists, material scientists, IT specialists, and many others. It depends on them whether the designed products meet consumer expectations well. They are also largely responsible how far the production and use of these products influence the natural environment.

Today, the threat to the natural environment is the most serious civilization challenge for humanity [4]. The growing avalanche of consumption is indicated as its perpetrator. Its negative impact is visible in

two particularly spectacular aspects: the production of greenhouse gases and the emission of plastic waste.

Industrial production accounts for almost 20% of greenhouse gas emissions. It is related directly or indirectly (through the manufacture of the means of production) with the making of consumer products. The functioning of households is the source of the next portion, almost 10% of greenhouse gas emissions. Durable goods used in households have a significant share of this. Energy production, accounting for more than 20% of emissions, is needed to generate and maintain them. Greenhouse gases resulting from fuel combustion by means of transport (11% of emissions) result from the movement of people and the transport of consumer goods [5].

The main source of plastic waste is packaging used to transport and store consumer goods. They represent 55% of plastic waste. Plastics alone account for approximately 10% by weight and 40% by volume of household waste [6].

The unstoppable growth in consumption also contributes to the progressive economic and social stratification. The means of production and distribution are increasingly concentrated in the hands of a small group of their owners. The rest of humanity becomes only a passive and docile producer, distributor and consumer of the goods provided.

Fortunately, climate and social threats are becoming more and more recognized and there is a common belief that mankind should definitely tame its aspirations and dreams that are satisfied by simple consumption. It is emphasized that different paths lead to the achievement of well-being. They don't have to be related to growing consumption. There are many examples that economically underdeveloped societies may perceive their well-being higher than those belonging to the wealthy, at a high level of civilization development [7].

However, it is not easy for a man to voluntarily limit his needs and the amount of goods he consumes in order to satisfy them. This is due to the variety of motivations that make people buy products [8, 9]. In most cases, motivation is related to the satisfaction of basic needs, the need for comfort, entertainment, learning, etc. But to a large extent the impulse to buy goods is triggered not by the vital importance of need, but simply by the opportunities that arise due to the appearance of new products on the market, not necessarily needed by a human being. Since it is difficult for a man to limit his "drive" to consume, it is necessary to impose on his needs and expectations some external limitation. Otherwise, an imminent climatic, environmental and social disaster is very likely.

Politicians have theoretically effective tools. They can apply, for example, the introduction of appropriate tax and legal regulations. So that, for example, high fines have to be paid for improper use of plastic packaging. So that, traveling by public transport is made much more profitable than by car. Admittedly, such measures are taken in some countries, but they are definitely ineffective. Thus, the possibilities offered by science and technology remain. Fortunately, both of these spheres have great opportunities, above all – unlike politicians – with a long-term impact. A lot is already happening in switching energy production to renewable sources or in the use of car engines that do not emit carbon dioxide and other pollutants. There is much to be gained in this regard, and the prospects are promising.

Objective of research

The goal of this paper is to present the author's point of view on the potential contribution of quality engineering to sustainable development. It was assumed that quality engineering is oriented on implementation and creative development of the achievements and methods of various scientific disciplines in the design of products, their production, delivery and operation, with the intention of making these products best meet the needs and expectations of consumers, and to ensure their fair profit for producers and suppliers. In order to more clearly notice the tasks of quality engineering that could support sustainable economic development, and then define these tasks more closely, the process of creating quality in subsequent stages of a product's life has been analysed, Fig. 1 [10].

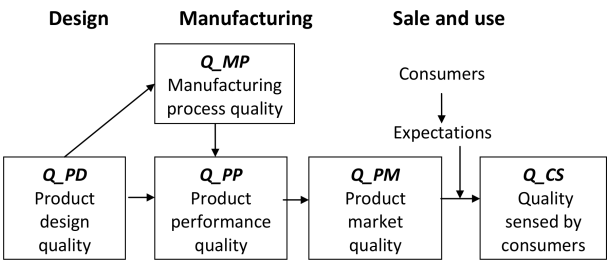

Fig. 1. Quality chain of a product.

The deductive method was used in the considerations presented in the article. Based on the life cycle of the a product, as well as on the basis of literature studies and the author's own thoughts, a hypothesis was formulated that quality deficit experienced by consumers is an important factor regulating demand and consumption. This hypothesis is the basis for putting forward a suggestion that quality engi-

neering can play an important role in efforts taken to achieve sustainable development.

A proposal was presented for designers to adopt a new design paradigm aimed at sustainable consumption. Additionally, the tasks of quality engineering in the design and implementation phases of the manufacturing processes were identified.

Deficit in consumer satisfaction as a driver of the growth in demand

Each of a product's life cycle stages, from concept and design, through production and sales, to use and disposal, adds or strengthens the quality of the product, preserves or protects it [11]. A kind of quality chain is created this way, Fig. 1.

The design stage includes the development of the general concept of the product functioning, computer simulations, and finally saving the design concept in a form that allows for the construction and technological preparation of the production process. Conceptual work is usually carried out in R&D departments, in cooperation with sales and marketing specialists. The result of these activities is the creation of the product design quality (Q_PD). The more accurately designers are able to predict and take into account the current and future needs and expectations of the target consumer group in the design, the higher the design quality of the product.

The design quality of the product includes its eco-friendliness, which means that the product does not have a negative impact on the environment and can be partially or completely recycled or is biodegradable [12]. It is the designer who determines what materials the product is made of, how the various materials used in it are connected with each other (detachable, inseparable connections), and what consumables are used in the process of its use.

Design quality has a decisive influence on all stages of a product's life after the design phase. Errors and omissions made in the project result in the emergence of problems both during the production and use of the product, and the later their effects are noticed and eliminated, the greater they are [13].

The properties retained in the design are transferred to the product during the production processes. Manufacturing processes quality (Q-MP) is transferred into the product performance quality (Q-PP). Its measure is the compliance of the properties of the manufactured product with the properties recorded in its design specification.

The resultant quality of product design and quality of manufacturing performance determines the quality of the product delivered to the consumer. It can be called the product market quality (Q_PM). It means what the buyer can expect from the product offered to him. But the consumer, as a buyer and then user of a specific product, notices in it only those properties that he needs to satisfy his needs and evaluates them through the filter of his expectations [14]. Quality understood in this way can be called the quality sensed by the customer (Q_CS).

The inherent quality of products is, in historical and statistical terms, increasingly higher. However, this is not accompanied by a continuous increase in consumer satisfaction. The increase in satisfaction with the purchased and used products is somewhat limited. This is the result of a constant comparison, one might say, of balancing the quality perceived by the consumer Q_CS with the quality expected by the consumer (Q_CE), Fig. 2. Expected quality should be understood as an image of the consumer's perceptions of a possible, new, better product meeting similar needs as the "old" product.

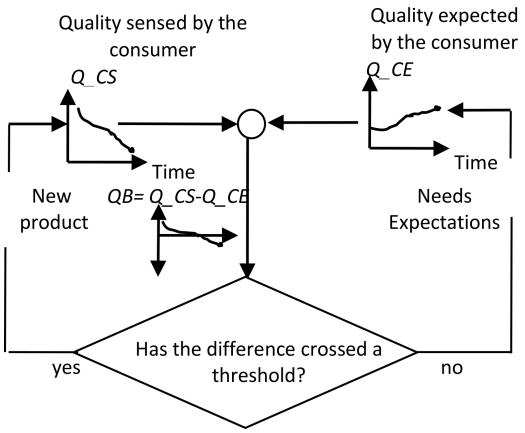

Fig. 2. An unsteady balance between expectations and quality sensed by consumers.

After purchasing a product, the consumer evaluates its quality (Q_CS) at a certain level. With the passage of time, he becomes weary of the product, notices somewhere similar products that seem better to him. The product itself wears out and begins to lose its original usefulness. As a result, the quality of the product is perceived as increasingly worse, and after exceeding a certain threshold, the difference between what is and what is expected is so great that a decision is made to buy a new product.

The difference between the level of perceived performance and the expected quality can be treated as a kind of quality balance (1):

$$QB = Q\_CS - Q\_CE. \tag{1}$$

The quality balance represented by the above equation applies to the entire product. It can also be determined separately for each (2):

$$QB_i = Q\_CS_i - Q\_CE_i. \tag{2}$$

The quality balance is a measure of consumer satisfaction. Balance for the entire product may be positive, although it is negative for some properties [15]. Conversely, the total balance is negative, while some properties are assessed positively. Someone likes something about the product and something does not suit them. A negative balance shows that the consumer perceives a quality deficit.

The balance of quality can be a criterion for distinguishing three "types" of consumers:

- usually satisfied, do not expect more than they have. They are not looking for new attractions at all costs, $QB > 0$,
- constantly looking for new impulses to feel satisfaction. They buy new products, and after some time they look for new emotions, ($QB \leq 0$ or $QB > 0$),
- constantly dissatisfied by nature. Whatever they have, they think could be better, ($QB < 0$).

It seems that there are large groups of people in the entire consumer population who can be classified as either seeking or still dissatisfied. In these groups, statistically speaking, the dominant feeling is the persistent satisfaction deficit from the products they own and use. People representing these groups are, on average, more dissatisfied than happy. It is this deficit that is the driving force behind economic growth, unfortunately with all its negative environmental and social consequences.

Quality engineering challenges

Analysis of the quality balance equation ($QB = Q\_CS - Q\_CE$) and the quality chain presented in Fig. 1, justify defining – in the context of sustainable development – some important challenges for quality engineering in the field of product design and product manufacturing. Three of them are presented below.

In the area of product design:

1) designing for maintaining a balance between consumer requirements and the need to protect the natural environment and maintain human-friendly social relations,
2) designing with special consideration for the environmental impacts of the product during its whole lifecycle (so called eco-design).

In the area of production process design and production process execution:

3) meeting the requirements set out in the design specifications of products with the simultaneous economical use of non-renewable resources and the minimum negative impact on the environment.

The possibilities of meeting the challenges 2 and 3 are well defined and widely used today. In eco-design, attention is focused, for example, on the selection of materials and methods of joining them, so that during the disassembly of the product, as many clean materials as possible can be recovered [16–18].

In the production phase, they consist of the continuous improvement of production techniques and technological processes, ensuring that the design requirements are met "the first time around", i.e. without the need for reworks (zero waste). In the distribution phase, they relate to logistic optimization so as to limit the movement and transport of products. In each of these areas, measures are taken to use energy-saving methods of production or transport.

The above-mentioned activities are often discussed in the extensive literature in the field of quality engineering and quality management [19, 20]. For example, in work [21] among the activities undertaken within the so-called 4.0 quality highlights include: improvement of quality standards, practices and methods, development of quality cost models, introduction of modern lean techniques, implementation of automation and IT technologies.

The activities related to the production and distribution processes have their limitations resulting from the necessity of using specific, necessary amounts of resources to produce the planned number of products. Therefore, even if the waste in production processes will be completely eliminated and the production technologies will become super energy-efficient, the mass of material goods "flooding" the world will continue to grow, and with it the amount of resources consumed. It is therefore necessary to limit the amount of produced goods, which means stopping the uncontrolled growth of consumption.

Designers' orientation towards sustainable demand

Such possibilities are in the hands of designers, who would like to follow a path of design oriented towards maintaining a balance between people's expectations and demands and the environment sensitivity to negative influence of production processes and product exploitation. Designers have the ability to reduce human pressure of consumption by reducing the permanent quality deficit, i.e. maintaining the balance $QB = Q\_CS - Q\_CE$ for as long as possible at a positive or only minimally negative level. They can influence – through their projects – a greater

stability of the Q_CS level and a slower increase in Q_CE expectations. For opportunities to turn into real actions, a design paradigm shift is necessary.

Today, designers predominately share an approach focused on the existing needs and expectations of consumers and on creating new needs, so that the designed products have the greatest possible market potential, giving the opportunity to obtain the highest profit from their sale. With this approach, the best companion to designers seem to be marketers who create or even search for consumer needs that consumers often have no idea about. Designers, at best, improve products through material and topological optimization of the structure, and upgrading of their technology.

It is necessary to propose a change of this approach, so that the design quality of the product is not determined in relation to the needs of consumers and the potential profit of the company, but in relation to the footprint left by the product – throughout its life – in the environment. Designers should also be guided by the principle of not creating needs that do not enrich a person, and when satisfied may have a negative impact on social relations. At the same time, they should design to optimize energy consumption over the entire product life cycle.

With regard to the environment, the proposed postulate follows the rules known as the 5 R's: refuse, reduce, reuse, repurpose and recycle [22]. All these actions should be undertaken, in the presented sequence, to minimize products' influence on environment contamination and pollution. The new design paradigm enhances the "refuse" rule. It says that necessity of launching a new product on the market, in the environmental and social context, should be considered before commencing design activities.

In other words, it is necessary to limit the uncontrolled flooding of the market with new products that people need only because they have been invented by someone. The point is that when designing products, designers should take into account not only stimulating demand for the products they design, but also the awareness of the need to "temper" the demand.

Designers should change their relationships with the marketing community. Marketing as it is performer today should be thoroughly overhauled. It should be oriented not only to promoting products, but also to honestly and fairly explaining to consumers the value of a given product in their lives. Marketing should stop telling people that they should buy something because they deserved it, and they'll get better. There should also be a limited role in promoting products by various types of celebrities who confuse people that think if someone famous on television or in a colorful magazine thinks something is good, it means that it is both good and valuable.

The above-mentioned postulates are not novel. Already in the 1970s, Papanek [23] noticed that since the industrial revolution, the basic design paradigm was a direct relationship with market needs, and any alternative design approaches did not attract much attention. In response to this observation, design schools focused on social issues, such as the needs of people in developing countries, the elderly, the poor and the disabled, were created. These efforts made people aware of the existence of an alternative to market-based product design, but did not develop a new model of social practice [24].

Sustainable customisation

Today, the possibilities of introducing new paradigms of design (pro-environmental and pro-social) on a large scale are greater than 50 years ago. Designers have a wide range of possibilities in this regard. High hopes can be placed, e.g. in the customisation of products. It should be mentioned that before the industrial era, most products were designed this way. Today, however, it takes on a mass character. Mass customisation represents a manufacturing paradigm which aims to provide a variety of customized products with cost, quality, and delivery performance comparable to that achieved by mass production [25, 26]. In this "release" it is also a way to fulfil the dream of many people, to be someone exceptional – unique. Not only through your personality, your creative contribution to life, e.g. social or cultural, but also through the purchase and use of unique products.

Personalization takes various forms. Typically four are distinguished [27–29]:

- cooperation – product features required by an individual consumer are given to him already at the design stage – at this stage, the designer collaborates with the consumer. For now, this form of personalization is used only in the case of ordered products, produced in large numbers, but exclusively (e.g. city buses designed for the needs of a specific city [30],
- cosmetic – changes to the product are introduced only at the final stages of the product's life: assembly or packaging and sales, According to this scheme, cars are personalized (e.g. by adjusting the shape of car seats to a specific consumer), as well as office furniture, etc.,
- adaptive – the consumer, by purchasing a product, has the option to adjust its functionality and appearance (aesthetics) features to his preferences. These possibilities are planned at the design stage,

but the consumer is only turned to at the use stage. Thanks to built-in solutions (often mechatronic and supported by artificial intelligence), the product can be adapted to a wide range to specific, individual requirements (e.g. a car seat),

- hidden – the consumer is offered products selected on the basis of the results of continuous, but hidden from the consumer, research on his preferences.

Today, customisation must seek to reconcile the personal preferences of consumers with the overarching goal of sustainable development, which is not to endanger the natural environment and social relations. Ultimately, it should put environmental issues in the first place, hence the term – sustainable customisation. Sustainable customisation should encourage designers to offer products tailored to the needs and expectations of consumers, while reducing their motivation to frequently replace products still in use and having full usability [31, 32].

This can be achieved, for example, by applying on an even larger scale than at present the principle of modular design which decomposes complex systems into simple modules. The product can be upgraded by adding new functions simply by plugging a new module so that the system can be augmented within a specific range [33]. In this way, it is possible to introduce solutions that have been thoroughly tested in terms of ecology and functionality. In the future, it may be possible to introduce self repair systems into products. Such products with an integral "healing mechanism" will be more "reliable" – will be able to maintain operation for a longer period of time [34].

Personalization raises the question of the durability of products, limited by technical wear (the product loses its usefulness) or the so-called moral wear and tear (the design solution used in the product is outdated). Having the opportunity to obtain a product that meets their current needs, consumers may want to exchange their products for new ones more often, with the conviction that they will better meet their expectations. Manufacturers may therefore find that it makes no sense to manufacture products with a shelf life that is too long. And this corresponds to the often used strategy of the so-called planned obsolescence [35]. It is achieved by designing products with a predetermined nominal service life (after this period of operation, damage occurs to the product, the repair of which is not profitable) or by placing on the market – after a certain period of time – new generations of more technically advanced products.

This strategy is used primarily with the benefit to the producer in mind. Its purpose is to encourage the consumer to buy new products as often as possible. To this end, producers engage in intensive marketing and influence consumers by using the latest technologies in their products, while at the same time (covertly) giving products a deliberately limited shelf life.

Such practices contradict the idea of sustainable economic growth. But it is hardly possible to eliminate them completely. Producers strive to achieve more profits, just as consumers strive to create opportunities to increase their consumption. In order to limit the use of such practices, consumers should be openly informed about their existence and encouraged to avoid them. This can be achieved by making people aware of the various roles (consumers, employees, employers, people interested in environmental protection) which a person can take on in social and economic life. He sees durability differently in each of these roles.

As a consumer supporting environmental measures, he is interested in ensuring that the products he uses cause as little damage to the environment as possible throughout his life. From this point of view, he expects products that, apart from being environmentally friendly, both in terms of design and operation, are durable and reliable. Durable and reliable products have to be exchanged or replaced less frequently, and therefore inadvertently consume less raw materials and energy and generate less waste. On the other hand, the consumer realizes that new products are more ecological, therefore the use of structurally outdated products may be "per balance" unfavorable for the environment.

As a consumer, you want your product not to break down, but as a service worker for these products, it is not necessarily in your best interest.

For a person in the role of a producer, increasing durability makes it possible to obtain a higher price for a product. On the other hand, it increases, often significantly, the cost of production, and this may reduce the income from sales. For a person as an employee, a higher price may limit the demand for the products, which may entail the risk of losing his job.

Taking into account these opposing effects, the optimal design is one that allows one to obtain the greatest difference between the potential benefits and the potential costs and losses.

Personalization on a mass scale, supported by the postulated new paradigm of design, should be the basic challenge of Industry 4.0, and at the same time a sign of the level of technological development achieved today. However, it poses huge challenges for the industry, engineers and managers [36], namely to ensure an economically acceptable unit cost

of products. For personalized products to be competitive, they cannot be significantly more expensive than products with the same functionality and quality of workmanship offered in mass production. Customers do not want to pay for the personalization itself, they are only willing to pay for the extra value the product has for them. Fortunately, manufacturing techniques and forms of organization and production control are becoming more and more perfect. In the factory of the future, the processes will be fully supervised, operated by virtually infallible and fatigue-free robots, controlled by intelligent systems that make optimal decisions under given conditions. They provide an opportunity for effective leveling of unit costs in mass production and mass personalized production.

Conclusions

Sustainable development must gradually look for new ways to achieve a high quality of life, personal happiness and social well-being. One of them is limiting the part of consumption that destroys social relations and the natural environment of man.

Technical sciences, including quality engineering, especially product designers, have an important task to fulfill in this process. Designers should be increasingly guided by the paradigm of designing products that meet human needs, without awakening new needs, which are environmentally and socially harmful, leading to pressure for a continuous increase in consumption.

Introducing the postulated paradigm will not be an easy task. Its implementation will result in temporary losses for many, as it will slow down economic growth understood in a classic way as a process of increasing production capacities (on the scale of the national economy or on a wider scale, depending on the breadth of view), measured by the growth of real gross domestic product. It will require a change in the perception of the success of human civilization, a reevaluation of the perception of personal and social goals.

References

[1] Ulman S.R., Mihai C., Cautisanu C., *Peculiarities of the relation between human and environmental well-being in different stages of national development*, Sustainability, 12, 81061–26, 2020.

[2] Hwan-Joo S., HanSung K., Young Soo L., *The Dynamic relationship between inequality and sustainable economic growth*, Sustainability, 12, 5740, 1–16, 2020.

[3] Themba G., Nicholas M., *Macroeconomic determinants of economic growth: A review of international literature*, South East European Journal of Economics and Business, 11, 2, t33–47, 2016.

[4] Brad S., Mocan B., Brad E., Fulea M., *Environmentally sustainable economic growth*, Amfiteatru Economic, 446–460, 2016.

[5] https://ziemianarozdrozu.pl/encyklopedia/38/energia-i-emisje-co2.

[6] Cichy J., Sobczyk W., *Plastic waste and its recycling* [in Polish: *Odpady z tworzyw sztucznych i ich recykling*], AGH, Kraków, 11.11.100.482.

[7] Dominko M., Verbic M., *The economics of subjective well-being: A bibliometric analysis*, Journal of Happiness Studies, 20, 6, 1973–1994, 2019.

[8] Czapinski J., *Happiness psychology* [in Polish: *Psychologia szczęścia*], Scholar, Warszawa, 2017.

[9] Bohler S., *Le Bug Humain* [in Polish: *Zachłanny mózg*], Feeria Science, Łódź, 2020.

[10] Cesarotti V., Crevelli V., *The quality chain: a total quality approach to external and internal supply chain management*, In Total Quality Management, Springer Science+Business Media Dordrecht, 185–188, 1995.

[11] Sower V.E., *Essentials of quality*, John Willey & Sons, Inc, 2011.

[12] Kim H., Cluzel F., Leroy Y., Yannou B., Bris G., Gwenola Yannou-Le B., *Research perspectives in ecodesign*, Design Science, 6, Cambridge Univeristy Press, 2020 .

[13] Urlich K., Eppinger S.D., *Product design and development* (5th edition), McGraw-Hill, New York, 2012.

[14] Liu R., *Application of data analytics for product design: Sentiment analysis of online product reviews*, CIRP Journal of Manufacturing Science and Technology, 23, 128–144, 2018.

[15] Kametani T., Nishina K., Suzuki K., *Attractive quality and must-be quality from the viewpoint of environmental lifestyle in Japan*, H.-J. Lenz et al. [Eds], Frontiers in Statistical Quality Control, Springer-Verlag Berlin Heidelberg, 315–327, 2010.

[16] Shu-Yang F., Freedman B., Cote R., *Principles and practice of ecological design*, Environmental Reviews, 12, 2, 97–112, 2004.

[17] Byggeth S., Broman G., Robert K., *A method for sustainable product development based on a modular system of guiding questions*, Journal of Cleaner Production, 15, 1–11, 2007.

[18] Dostatni E., Diakun J., Mazur W., Hamrol A., *Application of agent technology for recycling-oriented product assessment*, Industrial Management & Data Systems, 113, 6, 818–839, 2013.

[19] Devdas Shetty, *Developing a system for sustainable product design and manufacture*, Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Detroit, Michigan, 498–507, 2016.

[20] Shin W.S,. Dahlgaard J.J., Dahlgaard-Park S., Kim M.G., *A quality scorecard for the era of Industry 4.0*, Total Quality Management & Business Excellence, 29, 9, 959–976, 2018.

[21] Gunasekaran A., Subramanian N., Ngai W.T, *Quality management in the 21st century enterprises: Research pathway towards Industry 4.0*, International Journal of Production Economics, 125–129, 2019.

[22] Shalin S., *Zero waste can be achieved through 5R principles of waste management*, 5th World Convention on Recycling and Waste Management, 2017.

[23] Papanek V., *Design for the real world: human ecology and social change*, Pantheon Books, New York, 103–115, 1971.

[24] Margolin V., Margolin S., *Social design* [in Polish: *Projektowanie społeczne*], „2+3D", 7 (II), 56–65, 2003.

[25] Murat M., Huang X., Schroeder R.G., *The effect of quality management on mass customization capability*, International Journal of Operations & Production Management, 30, 9, 900–922, 2010.

[26] Salvador F., de Holan M., Piller F., *Cracking the code of mass customization*, MIT Sloan Management Review, 50, 3, 70–79, 2009.

[27] Gilmore J.H, Pine II B.J., *The four faces customization*, Harvard Business Review, 15, 2, 21–30, 1997.

[28] Fels A., Falk B., Schmitt R., *User-driven customization and customer loyalty: A survey, complex systems engineering and development*, Shehab E., Tomiyama T., Lockett H., Salonitis K., Roy R. [Eds], Procedia CIRP, 60, 410–415, 2017.

[29] MacCarthy B., Brabazon P., Bramham J., *Fundamental modes of operation for mass customization*, International Journal of Production Economics, 85, 3, 289–304, 2003.

[30] Górski F. et al., *Immersive city bus configuration system for marketing and sales education*, Procedia Computer Science, 75, 137–146, 2015.

[31] Umeda Y., Nonomura A., Tomiyama T., *Study on life-cycle design for the post mass production paradigm*, Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Cambridge University Press, 149–161, 2000.

[32] Lee H., Chang E., *Consumer attitudes toward online mass customization: an application of extended technology acceptance model*, Journal of Computer-Mediated Communication, 16, 2, 171–200, 2011.

[33] Tseng M., Yue Wang R., Jiao J., *Modular design*, [in:] Chatti S., Laperrière L., Reinhart G., Tolio T., The International Academy for Production (eds) CIRP Encyclopedia of Production Engineering, Springer, Berlin-Heidelberg, 2018.

[34] Bell C., McWilliam R., Purvis A., *Concepts of self-repairing systems*, Measurement and Control, 46, 6, 176–179, 2013.

[35] Aladeojebi T.V., *Planned obsolescence*, International Journal of Scientific & Engineering Research, 4, 6, 2013.

[36] Alcacer V., Cruz-Machado V., *Scanning the Industry 4.0, A literature review on technologies for manufacturing systems*, Engineering Science and Technology, and International Journal, 22, 899–919, 2019.