EDITORIAL

SPECIAL SECTION

Sustainability in production in the aspect of Industry 4.0

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Industry 4.0 and related new technologies have a negative impact on air pollution, waste generation and the intensive use of raw materials, information and energy [1, 2]. Consequently, efforts have been made to integrate sustainability into the operations of companies. In the countries of the European Union, there is a need to look for solutions dedicated to Industry 4.0, which will reduce the negative impact of new technologies on the environment. Manufacturing technologies (e.g. 3D printing) are also gaining importance. New production technologies must minimise waste and eliminate the use of hazardous materials [3]. Waste recovery and treatment technologies also need to be developed and implemented. These must be energy-efficient technologies. Pro-environmental measures should be analysed and refined throughout the product development process, as they can only produce the best results. Within organic production, companies can already plan and realise resource consumption through digital simulations in the aspect of the Circular Economy [4, 5]. Another aspect we want to consider is new production technologies in Agriculture 4.0, which is starting to actively use Industry 4.0 solutions [6].

The aim of the Special Section *Sustainability in production in the aspect of Industry 4.0* is to present the latest developments and applications in the following topics:

- New and innovative techniques in design and manufacturing in the aspect of sustainability.
- Impact of new and innovative techniques on the environment.
- Computer tools supporting environmental analysis.
- Computerisation of production and environment in the aspect of Industry 4.0.
- Eco-design.
- Ecological awareness of companies.
- "Green practices" in companies.

- Circular Economy.
- New production technologies in Agriculture 4.0.
- Maturity Model Levels for smart agriculture.
- Product life cycle analysis.
- Digital twins as a solution towards sustainability.
- IoT solutions supporting sustainable development.
- Programming supporting the sustainability concept.
- Artificial intelligence in sustainability on production.

The guest editors invited some of the researchers to present their contributions based on a selection of the best papers from the Special Session Sustainable Manufacturing in Aspects of Industry 4.0 of the 7th International MANUFACTURING Science and Technology Conference (http://manufacturing.put.poznan.pl/).

Rojek *et al.* [7] reviewed the current state of knowledge on sustainable manufacturing. Embodying a vision of the future manufacturing (production) system, the fourth industrial revolution (Industry 4.0) focuses on how to use modern methods (i.e. computerisation, robotisation, automation, new business models, etc.) to integrate all manufacturing industry systems to achieve sustainability. The idea was introduced in 2011 by the German government to promote automation in manufacturing. The authors review the past and present state of the art in this field and describe the known limitations, directions for further research and industrial applications of the most promising ideas and technologies.

Today's production processes are increasingly complex. A company that wants to be competitive in the market must take many factors into account. Batako *et al.* [8] analysed the issue of scheduling production for different types of workers in a large manufacturing company, where the decision-making process was based on the human factor and the foreman's knowledge, which was subject to error. Relying only on the human factor is not efficient, hence the work of Batako *et al.* aims to develop a new worker scheduling system, which can be considered a special case of the job shop problem from the set

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of worker scheduling problems. The Neuro-Tab Search algorithm and data collected by production sensors and process control systems were used to build production schedules, remotely monitor machine condition and durability, and for preventive maintenance. In addition, the work considers sustainability using Industry 4.0, which would minimise employee labour costs and the cost of the entire production process. The solution to the optimisation problem offered by the Neuro-Tabu Search algorithm and real-time data demonstrated a new way of managing production.

Patalas-Maliszewska *et al.* [9] showed the increasing role of sustainable production benefits in transforming production towards a sustainable organisation. The model proposed by this team integrates the sustainable business model (SBM) and the enterprise resource planning (ERP) system in the form of SBM-ERP. This proprietary approach allows a company's sustainable production activities to be organised and monitored, based on real-time data and information updated and contained in the ERP system. For managers, it provides a way to ensure parallel, sustainable production activities using information technologies that are already in use.

A different approach to sustainable production was presented by Trojanowska *et al.* [10]. The publication reflects the current situation in the field of possibilities of using augmented reality technology in the field of production technologies with the main intention of creating a tool to increase production efficiency. It is a set of individual steps that respond in a targeted manner to the possible need for assisted service intervention on a specific device.

Another aspect of sustainable development in the production process was shown in [11]. The article presents how to effectively reduce the environmental impact of the battery production process by stabilizing it. In the presented example, the proposed changes in the battery assembly process allowed the minimization of material losses from 0.33% to 0.05%, contributing to the reduction of the negative impact on the environment.

In another article, Krawczyk-Dembicka *et al.* [12] considered the co-design concept, which needs to be more widely studied in the manufacturing industry. This study presented an investigation of literature views on co-design in manufacturing operations. In addition, the influence of Industry 4.0 technologies and their coexistence with the concept of sustainability was also strongly considered in this study's empirical part. The process of the individualized production of the industrial line for animal food packing and cardboard packaging production has been studied. The study proves that co-design is better, more effective, and much more accurate for the final users' requirements regarding the new product development process. The study implies that the technologies of Industry 4.0 could support wider and more effective co-design exploitation by manufacturing entities.

Rucki *et al.* [13] presented the results of a metrological analysis of additively produced copies of a complex geometrical object: the fossil skull of *Madygenerpetonpustulatum*. Twelve different copies were surface scanned and 3D printed using a variety of AM equipment, materials and techniques. The same digitised model was used as a reference for comparison with the surfaces obtained by the Mitutoyo Coordinate Measuring Machine (CMM) CRYSTA-Apex S 9166 for each copy. The fidelity of the copies was assessed by statistical analysis of the distances between the compared surfaces, allowing the most accurate copies to be selected and less accurate copies to be eliminated. This provides a model-based approach for assessing the accuracy of the reproduction of any object with complex geometry.

Smart grids are becoming increasingly important during the energy crisis. Baba *et al.* [14] reviewed phase measurement units (PMUs), advanced metering devices that provide an accurate real-time synchronized measurement of voltage and current waveforms on buses to which PMUs are directly connected in a grid substation. Despite the development of many optimization approaches related to the placement of PMUs so as to ensure full observability of the electrical network with a minimum number of PMUs, further research is still needed: from power system control and monitoring, distribution network control, load shedding control and analysis to state estimation.

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