Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 104 (2021) 1571–1576

www.elsevier.com/locate/procedia

54th CIRP Conference on Manufacturing Systems

Intelligent waste management system for metalwork-copper industry

P. Aivaliotis[a], I. Anagiannis[a], N. Nikolakis[a], K. Alexopoulos[a,*], S. Makris[a]

[a]*Laboratory for Manufacturing Systems & Automation, University of Patras, Rion Patras, 26504, Greece*

* Corresponding author. Tel.: +30 2610 910160; fax: +30 2610 997744. *E-mail address:* alexokos@lms.mech.upatras.gr

Abstract

The circular economy paradigm requires new methods to design and operate manufacturing processes. In a production facility, reducing waste as well as optimizing waste management is of fundamental importance for companies aiming at adopting circular economy practices. This paper presents the concept of an intelligent waste management system for the efficient collection and recycling of industrial wastes, focusing on the metalwork-copper industry. The proposed approach facilitates the optimization of resource management in the waste collection process through the elimination of waste and the minimization of process variation, while, along with waste monitoring, consists of steps towards the creation of circular economy ecosystems. A software platform is proposed for receiving and storing waste data from the production, comparing them with expected statistical values and identifying abnormalities and/or deviations from pre-defined thresholds.

Keywords: Waste management; Circular economy; Platform; Sustainable production; Industry 4.0; Circular economy ecosystems;

1. Introduction

Manufacturing companies are investigating and investing in novel technologies, processes, and materials to achieve environment-conscious production [1,2]. In the context of Industry 4.0, manufacturing companies can benefit greatly by making a shift from a linear economy model to a circular one. The concept of Circular Economy (CE) is considered as a prominent approach for harmonizing ambitions for economic growth with environmental production [2] and sustainability [3].

CE can be perceived, with regards to manufacturing wastes, as a closed-loop business model targeting waste minimization, reuse, reduction of primary resources, remanufacturing, and recycling [4-6]. In manufacturing industries, CE is directly connected with waste management and product lifecycle assessment. The adoption of CE strategies can lead to sustainable production while decoupling economic growth from environmental impact [5].

The idea of transitioning to a CE has received increased attention worldwide within the last few years [7,8], but its adoption is still limited [9]. Although the benefits of the CE paradigm are fairly understood, there are few examples of industrial companies (e.g. in business-to-business settings) that have implemented a CE paradigm [4]. This comes even though an increasing number of firms are raising awareness about the practices and benefits of circular economy [10]. High upfront investments costs for circular business models can be a significant barrier to implementing a CE solution in the industry, especially when the benefits cannot be securely justified.

In this paper, the concept of an intelligent waste management system for scrap metal and plastic recycling in a metalwork-copper industry is presented. The development of such a system will contribute to increasing the capability of collecting, recycling, and reducing waste, with direct benefits for the industry itself as well as the environment, society and economy as part of a greater ecosystem. The work enhances the currently limited knowledge on how emerging Industry 4.0 technologies can be combined towards enabling CE strategies.

The remaining of the paper is organized as follows: Section 2 provides the main principles of CE in the context of

2212-8271 © 2021 The Authors. Published by Elsevier B.V.

10.1016/j.procir.2021.11.265

manufacturing systems, whereas Section 3 describes the concept of the proposed intelligent waste management system. Finally, Section 4 outlines the conclusions as well as the next steps of the work.

2. Circular Economy and Manufacturing Systems

2.1 Circular Economy

Climate change and the continuous environmental deterioration have forced world leaders to configure new strategic plans towards a resource-efficient economy. The European Union aims at an economy whose growth will be uncorrelated with the use of natural resources and with zero greenhouse gasses emissions until 2050, through the European Green Deal initiative [11]. In that direction, biological and technical materials should continuously flow through the value cycle in a way that keeps products, materials, and components at their highest value. This requires shifting from the linear economic model to a circular one, the so-called "Circular Economy" (CE). The Ellen McArthur Foundation illustrates the concept of CE in the "Butterfly Diagram" (Fig. 1). The Circular Economy model is based upon three main initiatives: 1) conservation and enhancement of the natural capital; 2) optimization of resource yields, and 3) minimization of leakage and negative externalities [12].

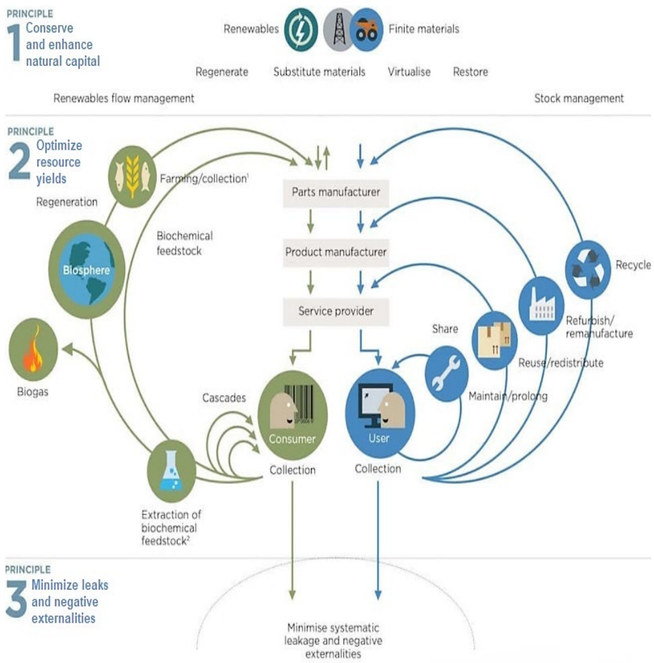

Fig. 1. Outline of a Circular Economy – the "Butterfly" Diagram. (Ellen MacArthur Foundation, 2019) [12].

The "Butterfly Diagram" contains the biological (left part) and the technical (right part) cycles, representing the flows of biological materials and technical materials (metals, plastic and synthetic chemicals) that should not re-enter the environment and must be continuously cycled. In the technical cycle, which is the one that concerns manufacturing industries, the product user interacts with its manufacturers by expanding the product's useful life and, finally, returning the product or some of its parts to the original manufacturer/s, with a view to its/their reuse, redistribution, reassembly and remanufacturing as well as the recycling of stock material.

The practices of CE occur in three different scales: 1) Micro (e.g., enterprise or consumer); 2) meso (e.g., eco-industrial parks [13]); and macro (regional, cities) [9]. At industrial level, circular manufacturing is a core mechanism for realizing a CE [14]. The CE approach aims to bring industrial sustainability to a new level by implementing Circular Manufacturing Systems (CMS), which aim to value recovery through long-lasting design, repair, reusing, remanufacturing, refurbishing and recycling in a systematic way [6,15]. The end of the lifecycle of a product may introduce a new lifecycle for some of its components, creating added value. In addition, a CE also includes novel maintenance approaches [16] and a systematic change, which requires extensive collaboration between institutions, academia, industries, and societies.

2.2 Transition to Circular Manufacturing Systems (CMS)

The shift of an industry to a circular business model requires severe modifications in a) the production process, b) the management of the supply chain, as well as in c) product design. The adoption of circular production models, in terms of reconfiguration, is more feasible for Small and Medium Enterprises (SMEs), due to their higher flexibility. However, SMEs may lack the adequate investment funds to push such changes. Converting conventional manufacturing systems to CMS may require the establishment of new equipment, such as recycling bins or waste detection sensors, as well as the purchase of waste transport vehicles, recruiting extra personnel for carrying out recycling and waste collection tasks, and redesign of production processes which is costly in many cases.

A step forward to CE for manufacturing industries is sustainable product design, or eco-design [17]. This strategy aims at minimizing the environmental impact of a product and waste, selecting low-impact resources, and enabling disassembling so that any of its parts can be recycled and reused. Several tools, such as Life Cycle Assessments (LCAs) [18], are employed to assess the environmental footprint of the product design, thus the overall impact that the production of a product has on the environment. Additionally, parts and raw resources recycling is directly linked with the creation of an ecosystem, containing recycling stations at country/state-wide level, waste transport networks and eco-efficient resources.

The emerging Industry 4.0 technologies can positively influence sustainable manufacturing, management, and the integration of CMS [19]. Also, computerized assets such as Design Support Systems (DSS) can integrate the concept of CE in the design phase of parts [20]. The Ellen McArthur Foundation acknowledges the role of intelligent assets and connectivity in the proliferation of CE [21]. Manufacturing companies have begun to realize that Industry 4.0 technologies can be used to address contemporary needs such as optimal resources and sustainable production. Intelligent waste management systems can be deployed, containing sensors, databases and platforms running management and scheduling algorithms, automating the whole procedure, and accelerating the transition to CE. In this context, the innovations of the

Internet of Things (IoT) [22] and Big Data [19], as well as neural networks, deep learning, simulation, and forecasting support the transition and automate decision-making, scheduling, storage and waste tracking. In addition, Cloud Computing combined with IoT offers proper data storage and information exchange between the shop floor workers, waste producers and partners with waste transporters and related services. Despite the existence of many commercial CE software solutions nowadays, there is still limited knowledge on how to combine and build upon those technologies a systematic approach to enable CE strategies [9].

2.3 Sustainable Waste Management

Sustainable waste management plays a key part in CMS. Solid waste management in the steel industry is broadly classified in the literature in “4Rs” i.e., reduce, reuse, recycle and restore the materials (Fig. 2.) [23] and can be defined as systematic inspection, collection, storage, transport, processing, recovery, and disposal of solid waste. Adopting an efficient waste management strategy is a strong challenge for metalwork industries today. Nowadays, waste management and waste transportation scheduling can be carried out using appropriate commercial software solutions. Most of the existing applications are cloud-based solutions, offering interfaces for real-time monitoring, online mapping, data analytics, tracking and optimal route design.

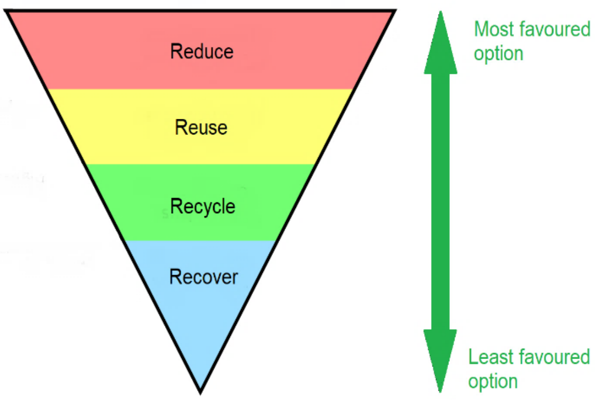

Fig. 2. Hierarchy of the “4 Rs” of solid waste management.

2.4 Circular Economy-Related Key Performance Indicators (KPIs) for CMS

The shift to CMS should not only be driven or based on typical cost, quality, and time KPIs, but also consider CE-related ones. Life Cycle Assessment can be very useful for evaluating the environmental impact of products through various sets of KPIs. Traditionally, LCA methodologies include four stages: scope definition, Life Cycle Inventory, Life Cycle Impact Assessment, and interpretation of results, as shown in Fig. 3. [18]. LCA is the most common approach for evaluating the design of a product or a manufacturing process from an ecological point of view. Several environmental effects considered in LCA include energy consumption, gas emissions (CO_2, Methane, laughing gas etc.), transportation effects, use of water and land use. Other important CE related KPIs are the Material Circularity Indicator, the Environmental Cost Indicator, the Raw Material Yield Index, and the Recycling Efficiency. Nowadays, circularity efficiency evaluation based on such KPIs can be carried out at industrial level through several commercial software tools.

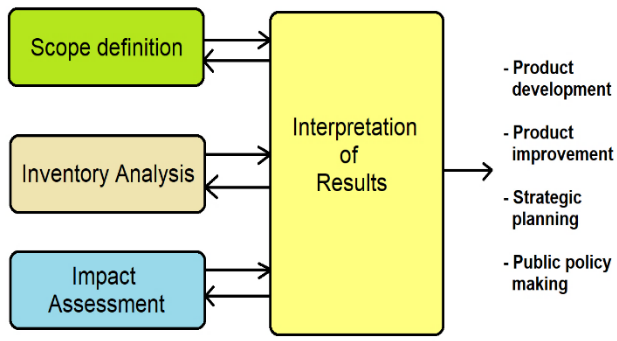

Fig. 3. Flow chart of Life Cycle Assessment.

2.5 Expectations and barriers towards CMS

CE is seen to reduce conflicts between the competitive and environmental priorities within a company, making it more competitive, while at the same time reducing its environmental footprint [24]. In a broad context, the expectations towards CMS are:

- Increased resource efficiency.
- Resource recycling and recovery.
- Reduction of waste and pollutants.
- Eco-design.
- Cleaner production
- Increase of the added value.
- Increase of the competitiveness of businesses.
- Improvement of environmental quality.

Although CMS are associated with innovative business models, yet the adoption of such models is limited [25]. According to Korhonen et al., 2018 [26], the main limitations and challenges over the concepts of circular manufacturing and economy may be classified into the following categories:

- Thermodynamical limits: cyclical systems consume resources and create waste emissions.
- Spatial and Temporal System Boundary Limitations: problems are shifted along the product life cycle.
- Path dependencies and Lock-in: First technologies retain their market position despite in-efficiency.
- Intra-organizational vs. Inter-organizational Strategies and Management.
- Limits of social and cultural definitions: The concept of waste is always constructed in a certain cultural, social, and temporal context and this context is dynamic and changing.

The aforementioned barriers are not the only ones that hinder the wider adoption of CE practices in manufacturing. Currently, no general framework has been introduced for the transition of an industrial company to CMS. The shift depends on the individual needs of each industry. Proper decision-making for waste management can be hard to apply at the industrial level, due to several economic, political, and social criteria that must be considered and may be in conflict with each other [27]. In addition, there are large knowledge gaps that

This is a resupply of March 2023 as the template used in the publication of the original article contained errors. The content of the article has remained unaffected.

challenge the optimization and digitalization of the CE [28]. Several CE-related initiatives are constrained by a lack of regulation, incentive(s) and infrastructure required for resource exchange [29]. However, since Industry 4.0 emerging technologies spread, it may now be feasible to overcome barriers by shifting production processes towards smart manufacturing [30].

3. Concept for Intelligent Waste Management System in Copper Industry

The implementation of intelligent waste management in the metalwork-copper industry in the context of CE will execute practices aimed at the maximum efficient use of raw material, including copper scrap, since the reuse of scrap offers significant benefits, such as the reduction of energy consumption, gas emissions and water use. Copper scrap is an extremely useful secondary raw material with great environmental value. The concept of this paper refers to a copper-tube manufacturing industry case study.

3.1 Gaps Identification and Proposed Solution

The lack of interconnection and automation within the running production and the predetermined implementation frequencies of the management processes of the generated wastes leads to high waste management costs, temporary occupation of the shop floor by large quantities of scrap, and above all, inability to timely inform head-engineers in cases that waste production is higher than expected. Ex-post knowledge of these cases leads to delayed scheduling of corrective actions and prevents systematic waste reduction. To deal with these issues, a cloud-based platform is proposed, able to receive real-time data for the generated waste straight from the manufacturing processes and:

- compare them through statistical decision-making processes with baseline/expected data.
- provide warnings about declinations that require corrective actions.
- monitor the fill level of the scrap/waste bins and provide alerts when a waste bin is full or when a wrong type of waste is placed in the bin.
- receive feedback from the users – waste producers in case of emergencies in the Shop Floors.
- provide information of consumable resources' performance.
- schedule waste management activities, such as waste collection and transportation to recycling centers or foundries, in an optimal way and,
- provide customized reports to its end-users about waste generation, recycling performance and detected events.

The primary objectives of the proposed waste management framework mainly include:

- the increase of reuse degree of raw material and
- the reduction of diesel consumption in the subprocess of waste collecting per ton of produced products, which will subsequently reduce CO_2 emissions.

Additionally, CE-related KPIs which are expected to be improved through the development of the proposed intelligent waste management process and could be used by the suggested platform for evaluating the performance of the implemented waste management strategies are the:

- Raw Material Yield Index.
- Scrap Collection Efficiency.
- Material Circularity Indicator.
- Renewable Energy Sources (RES) Ratio.
- Net cost savings due to circular activities.

3.2 Structure of the Proposed Intelligent Waste Management System

The system will consist of three discrete levels and particularly: 1) the sensor and data acquisition level; 2) the set of management algorithms; and 3) the integrated platform. The approach towards the implementation of such a proposed waste management system is illustrated in Fig. 4.

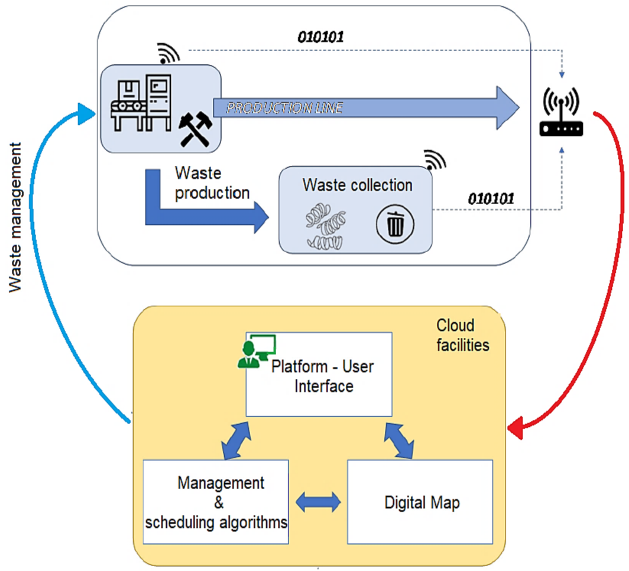

Fig. 4. Implementation diagram of the proposed intelligent waste management system.

The proper and effective operation of the proposed system will be achieved via the development of individual subsystems, algorithms, and facilities. More specifically, the proposed approach includes:

- all the necessary equipment enabling maximum copper-waste collection ability per Shop Floor.
- all the required sensor systems for monitoring the state of the waste bins (scrap type, fill level, position, movement, weight etc.).
- the creation of specifications (with upper and lower control limits) for the proper/expected waste collection and the expected / standardized filling rate of the waste bins per waste type.
- all the required interfaces for data acquisition through the Manufacturing Execution System (MES), as well as directly from the machines, when required.
- real-time monitoring and state detection algorithms of the collected waste, such as image processing algorithms and machine vision algorithms.
- a factory digital map as a kind of Digital Twin.
- Digital Twins of processes and/or process steps.
- infrastructure material of the platform.

- a management platform, with the development of Waste Producers and Administrator interfaces. Through waste monitoring processes, alongside the use of historical data and scheduling algorithms, the platform will be able to make prognostics about waste generation and schedule waste collection and resource management activities optimally. The Administrator will be able to detect declinations from the control thresholds through Statistical Process Control, and then inform the Head Managers to define precautionary corrective actions.

3.3 Architecture for the Industrial Internet of Things (IIoT) Platform

In order to meet the needs of the described waste management system, a platform of the so-called paradigm of IoT enabled Context-Aware Manufacturing Information System (CA-MIS) [31] is proposed. The architecture of the platform (Fig. 5) may

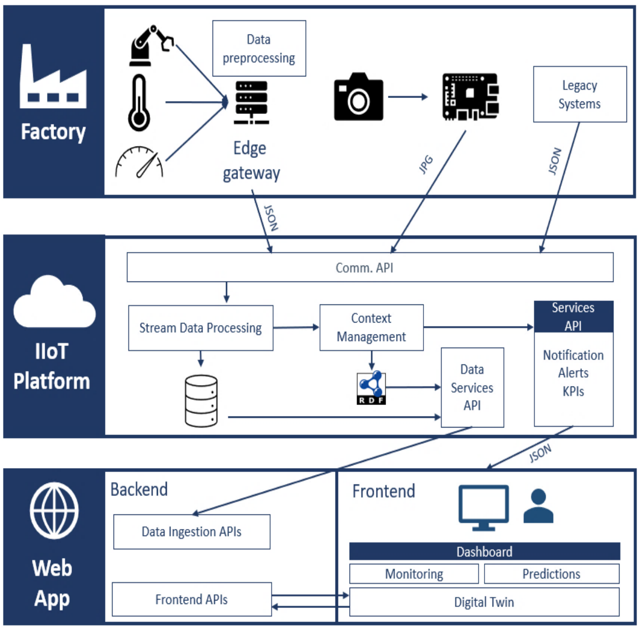

Fig. 5. Proposed IIoT platform architecture

be distinguished in three tiers: i) the Factory Tier, which includes the shop floor, the data acquisition systems and the proxy unification services; ii) the Platform Tier, thus the Context Engine and the context-aware services; and iii) the Application (or Enterprise) Tier, that concerns all the applications that run real-time and provide the appropriate mockups for assisting user workflow operations [32]. The CA-MIS design enables the integration of different data and sensor sources and the deployment of different end-user applications.

In CA-MIS, the produced data coming from the shop-floor sensors are pre-processed through the proxies and then forwarded to the main/server system for storage and advanced processing. A database holding all the relevant information is maintained. The Context Engine is responsible for managing the context data and provide the running applications with relevant data services (i.e., data analytics), critical alerts and notifications. Finally, indications regarding event detection, monitoring, prognostics, and digital twin models as well, are displayed in Graphical User Interface (GUI) dashboard/s.

4. Conclusions

The concept of an intelligent waste management system in the copper-tube manufacturing industry has been proposed after introducing the state-of-the-art of CE and CMS. The approach proposes the adoption of a cloud-based platform for receiving and storing waste data from production. Furthermore, the implementation of management and scheduling algorithms, as well as neural networks and machine vision systems are proposed for comparing real-time received data with expected values and identifying abnormalities from pre-defined thresholds. Finally, a Factory Digital Map as a kind of Digital Twin will complete in a sufficient way the whole waste management framework.

The outlined concept validates the benefits that Industry 4.0 enabling technologies, such as IIoT, Big Data and Deep Learning, can have on the implementation of CMS as well as on the configuration of CE policies. The proposed system is expected to lead to “intelligent” and efficient monitoring of waste and finally to the reduction of copper and plastic waste generation. This system constitutes a transition, adaptation in an industrial environment and further development to the direction of zero-waste production and falls within the scope of the vision of creating the Factories of the Future and a CE.

Future activities will focus among others on the implementation and the prioritization of KPIs relevant to consumable resources management and waste collection efficiency. Moreover, one of the next steps will be the development of a predictive scrap management module, which will be integrated with the cloud-based platform. Finally, the proposed system will be tested in a real industrial application and updated based on the feedback collected during the validation phase.

Acknowledgements

This work was funded by the Greek General Secretariat for Research and Technology (GSRT), under the “IntWaste” project: Circular Economy - Intelligent Waste Management System.

References

[1] Chryssolouris G., Papakostas N., Mavrikios D. A perspective on manufacturing strategy: Produce more with less. CIRP Journal of Manufacturing Science and Technology, 2008; 1/1, 45-52.
[2] Lieder M., Rashid A. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. Journal of Cleaner Production, 2016; 115: 36-51.
[3] Ritzén S., Sandström G.Ö. Barriers to the Circular Economy – integration of perspectives and domains. Procedia CIRP 2017; 64: 7-12.
[4] Parida V., Burström T., Visnjic I., Wincent J. Orchestrating industrial ecosystem in circular economy: A two-stage transformation model for large manufacturing companies. Journal of Business Research, 2019; 101: 715-725.
[5] Morseletto P. Targets for a circular economy. Resources, Conservation & Recycling, 2020; 153: 104553.
[6] Asif F.M.A., Roci M., Lieder M., Rashid A., Štimulak M., Halvordsson E., de Bruijckere R. A practical ICT framework for transition to circular

manufacturing systems. Procedia CIRP 2018; 72: 598-602.
[7] Blunck E., Werthmann H. Industry 4.0 – an opportunity to realize sustainable manufacturing and its potential for a circular economy. In DIEM: Dubrovnik International Economic Meeting, Sveučilište u Dubrovniku, 2017; 644-666.
[8] Kerdlap P., Low J.S.C., Ramakrishna S. Zero waste manufacturing: A framework and review of technology, research, and implementation barriers for enabling a circular economy transition in Singapore. Resources, Conservation & Recycling 2019; 151: 104438.
[9] de Mattos C.A., de Albuquerque T.L.M. Enabling Factors and Strategies for the Transition Toward a Circular Economy (CE). Sustainability, 2018; 10/12: 4628.
[10] Liakos N., Kumar V., Pongsakornrungsilp S., Garza-Reyes J.A., Gupta B., Pongsakornrungsilp P. Understanding circular economy awareness and practices in manufacturing firms. Journal of Enterprise Information Management, 2019.
[11] European Commission. A European Green Deal, 2019. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.
[12] Ellen MacArthur Foundation. Circular economy systems diagram. Introduction to the Circular Economy, 2019; 9-11.
[13] Gómez A.M.M., González F.A., Bárcena M.M. Smart eco-industrial parks: A circular economy implementation based on industrial metabolism. Resources, Conservation & Recycling, 2018; 135: 58-69.
[14] Takata S., Suemasu K., Asai K. Life cycle simulation system as an evaluation platform for multitiered circular manufacturing systems. CIRP Annals – Manufacturing Technology, 2019; 68: 21-24.
[15] Geissdoerfer M., Savaget P., Bocken N.M.P., Hultink E.J. The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production, 2017; 143: 757-768.
[16] Takata S. Maintenance-centered Circular Manufacturing. Procedia CIRP, 2013; 11: 23-31.
[17] Garcia-Muiña F.E., González-Sánchez R., Ferrari A.M., Volpi L., Pini M., Siligardi C., Settembre-Blundo D. Identifying the Equilibrium Point between Sustainability Goals and Circular Economy Practices in an Industry 4.0 Manufacturing Context Using Eco-Design. Social Sciences, 2019; 8: 241.
[18] Zendoia J., Woy U., Ridgway N., Pajula T., Unamuno G., Olaizola A., Fysikopoulos A., Krain R. A specific method for the life cycle inventory of machine tools and its demonstration with two manufacturing case studies. Journal of Cleaner Production, 2014; 78: 139-151.
[19] Bag S., Pretorius J.H.C. Relationships between industry 4.0, sustainable manufacturing and circular economy: proposal of a research framework. International Journal of Organizational Analysis, 2020.
[20] Stavropoulos P., Spetsieris A., Papacharalampopoulos A. A Circular Economy based Decision Support System for the Assembly/Disassembly of Multi-Material Components. Procedia CIRP, 2019; 85: 49-54.
[21] Pagouropoulos A., Pigosso D.C.A., McAloone T.C. The emergent role of digital technologies in the Circular Economy: A review. Procedia CIRP, 2017; 64: 19-24.
[22] Garcia – Muiña F.E., González-Sánchez R., Ferrari A.M., Settembre-Blundo D. The Paradigms of Industry 4.0 and Circular Economy as Enabling Drivers for the Competitiveness of Businesses and Territories: The Case of an Italian Ceramic Tiles Manufacturing Company, Social Sciences, 2018; 7/12: 255.
[23] Sarkar S., Mazumder D. Solid Waste Management in Steel Industry – Challenges and Opportunities. International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering, 2015; 9/3: 978-981.
[24] Gusmerotti N.M., Testa F., Corsini F., Pretner G., Iraldo F. Drivers and approaches to the circular economy in manufacturing firms. Journal of Cleaner Production, 2019; 230: 314-327.
[25] Sousa-Zomer T.T., Magalhães L., Zancul E., Gauchick-Miguel P.A. Exploring the challenges for circular business implementation in manufacturing companies: An empirical investigation of a pay-per-use service provider. Resources, Conservation & Recycling, 2018; 135: 3-13.
[26] Korhonen J., Honkasalo A., Seppälä. Circular Economy: The Concept and its Limitations. Ecological Economics, 2018; 143: 37-46.
[27] de Sousa Melaré A.V., González S.M., Faceli K., Casadei V. Technologies and decision support systems to aid solid-waste management: a systematic review. Waste Management, 2017; 59: 567-584.
[28] van Schalkwyk R.F., Reuter M.A., Gutzmer J., Stelter M. Challenges of digitalizing the circular economy: Assessment of the state-of-the-art of metallurgical carrier metal platform for lead and its associated technology elements. Journal of Cleaner Production, 2018; 186: 585-601.
[29] Winans K., Kendall A., Deng H. The history and current applications of the circular economy concept. Renewable and Sustainable Energy Reviews, 2017; 68: 825-833.
[30] Jabbour C.J.C., Fiorini P.D.C., Wong C.W.Y., Jugend D., Jabbour A.B.L.D.S., Seles B.M.R.P., Pinheiro M.A.P., da Silva H.M.R. First-mover firms in the transition towards the sharing economy in metallic natural resource-intensive industries: Implications for the circular economy and emerging industry 4.0 technologies. Resources Policy, 2020; 66: 101596.
[31] Alexopoulos K., Makris S., Xanthakis V., Sipsas K., Chryssolouris G. A concept of context-aware computing in manufacturing: the white goods case. International Journal of Computer Integrated Manufacturing, 2016; 29/8: 839-849.
[32] Alexopoulos K., Sipsas K., Xanthakis E., Makris S., Mourtzis D. An industrial internet of things based platform for context-aware information services in manufacturing. International Journal of Computer Integrated Manufacturing, 2018; 31/11: 1111-1123.

This is a resupply of March 2023 as the template used in the publication of the original article contained errors. The content of the article has remained unaffected.