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Small-lot Production with Additive Production Using Reverse Logistics and IT Solutions in COVID-19 Era*

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Abstract:

Purpose: *The objective of this paper is to present the possibilities of using reverse logistics and IT solutions in the area of remote cooperation in small-lot production based on additive technology in COVID-19 conditions.*

Design/Methodology/Approach: *Critical review and analysis of the literature on 3D printing, reverse logistics and ICT solutions case study.*

Findings: *Identification and compilation of problems related to 3D printing in crisis conditions presentation of preventive measures using additive technologies with the use of reverse logistics in conditions such as COVID-19.*

Practical Implications: *The presented research results show the possibility of using reverse logistics in 3D printing in crisis conditions.*

Originality/value: *Indication of future research directions: improving the functionality of IT solutions; increasing the effectiveness of the management of activities necessary in crisis conditions.*

Keywords: *Additive manufacturing, management, reverse logistics, IT solutions, innovation, Covid-19 pandemic.*

JEL classification: *H12, O14, Q01.*

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1. Introduction

The COVID-19 pandemic has caused major economic turmoil globally. It has disrupted the existing globalised supply chains, and thus the interdependencies between countries and economies. Large corporations as well as smaller producers sourcing inputs from remote locations are facing shortages of raw materials and goods due to pandemic lockdowns. The last months have been a time of changes and adaptation to new living conditions. Every crisis is conducive to the development of new technologies. In difficult times, we always intensify our search for new solutions, especially ones that will help us recover. Owing to Information and Communication Technology (ICT) solutions, we have been able to work and communicate remotely. This time of global crisis has also forced most businesses to review their existing processes and to consider using secondary raw materials in manufacturing.

In difficult and unpredictable times, such as the pandemic, the flexibility of business and manufacturing, understood as the ability to adapt to new conditions as quickly as possible, is paramount. The pandemic has also accelerated innovation in 3D printing. The main advantage of using 3D printers is the ability to start production quickly. With 3D printing, the time from designing to prototyping for a tool or spare part can be reduced to a few hours. Owing to this, despite the SARS-CoV-2 restrictions, in many cases it was possible to temporarily maintain the existing supply chain, which proved to be particularly important in the case of the medical industry.

The objective of this paper is to discuss the possibilities of using reverse logistics and IT solutions for remote cooperation in small-lot production based on additive manufacturing in COVID-19 conditions. The paper is structured as follows. Section 2 provides an overview of the study materials and methods. In section 3, the authors discuss the state of the art of 3D printing application in medicine and the use of secondary raw materials in filament production and the use of IT tools for communication and information sharing between stakeholders. Section 4 presents case study for 3D printing with the use of secondary raw materials in conditions such as an epidemic and its consequences: disrupted supply chains and lockdowns. The paper ends section 5 with final conclusions.

2. Materials and Methods

The main goal of the article is to present the possibilities of using reverse logistics and IT solutions in the field of additive manufacturing technology in COVID19 conditions. In order to achieve the assumed goal, a research procedure was designed consisting of 4 steps as shown in Figure 1. In the first step reverse logistics, and Information and Communication Technology (ICT) is used. This step also included a review and analysis of activities described in the literature in the conditions of the COVID-19 pandemic.

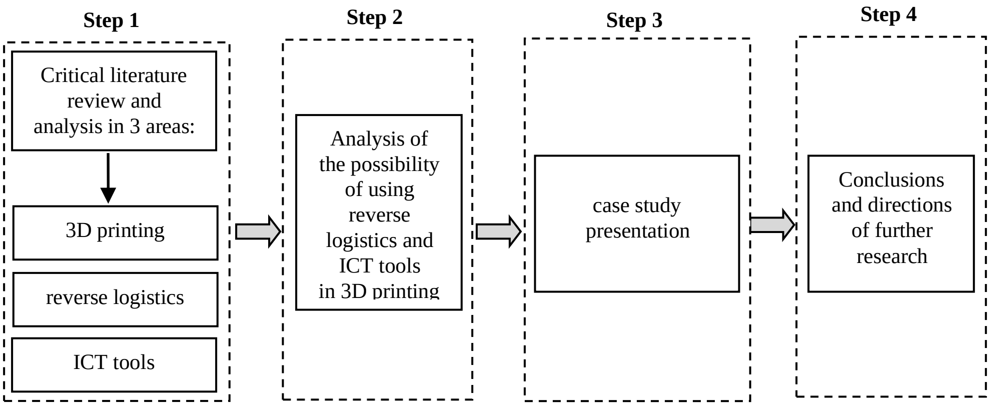

Figure 1. *Research framework*

The second step includes the analysis of the possibilities of using reverse logistics solutions and ICT tools in 3D printing in crisis conditions related to the pandemic - resulting from the literature review. In the third step, a case study was presented related to the outbreak of the pandemic in Poland and the printing of elements of protective helmets, which were transferred to medical units and public institutions. Due to the prevailing global logistics problems and difficulties with the procurement of many products, including very important personal protective equipment - 3D printing made it possible to meet the needs in this area. The case study presents the application of recycling through the use of PET bottles for the production of filament. An analysis of the printing of helmet bands was carried out at the 3D Printing Center of the Koszalin University of Technology.

3. Theoretical Background

3.1 Additive Manufacturing

The additive manufacturing technology, also known as 3D printing, has been developed for over 30 years. The first 3D printing technique was invented by Charles Hull, in 1986 the production of the first 3D printers began. After the FDM technology patents expired, there was an explosion in the production of printers in this technology. A significant increase in the dynamics of its development can be noticed after 2010. FDM printing technologies went to universities and private homes. At present, a variety of printing materials are used, ranging from plastics through metal to concrete. Depending on the materials, different printing technologies are used.

The most common material in additive manufacturing is plastics in the form of filaments. In crisis situations, when the supply chains of production materials are broken, filaments can be obtained from waste, e.g. PET bottles. Filaments that can be used in 3D printers working in FDM/FFF technology are the so-called thermoplastics. They liquefy under the influence of temperature and are applied layer by layer using a nozzle. While PET filaments include such artificial materials as ABS or PLA, PET-G combines their most desirable features: strength, flexibility, low material shrinkage, very good dimensional accuracy of prints. PET-G filaments are characterized by high elasticity. In addition, they are available in a transparent (light transmitting) version. The common feature of these filaments is that they are recyclable. The recycling of plastics allows them to be reused, which reduces printing costs.

The beginning of 2020 is the beginning of the covid -19 pandemic in Europe and in the world. Lockdown was announced in many countries in March. Since March 2020 in whole word 3d printers have been working 24 hours a day to protect against covid-19 (Yu Ying and Clarrisa Choong *et al.*, 2020; Manero *et al.*, 2020). Actions were taken to alleviate the shortage of medical resources much needed during the pandemic (Mueller *et al.*, 2020; Tarfaoui *et al.*, 2020). Diving mask adapters were designed and printed, converted into medical oxygen masks, protective visors, film adapters (Imbrie-Moore *et al.*, 2020), and training phantoms for paramedics who took DNA swabs for COVID-19 tests were designed and printed.

3.2 Reverse Logistics in Waste Management

Scientific literature presents a wide choice of different terms, synonyms and definitions for ‘reverse logistics’. In Polish publications, reverse logistics is often termed as *opposite logistics*, *ecologistics*, *disposal logistics*, *waste logistics*, *reserved logistics* and *reuse logistics*, while foreign sources refer to *aftermarket logistics, retrogistics,* or *aftermarket supply chain* (Szołtysek and Twaróg, 2017; Kaup *et al.*, 2019).

Reverse logistics (RL) is a relatively new term, it was first mentioned in scientific literature in the 1980s. Lambert and Stock (Lambert and Stock, 1981) defined reverse logistics as a reverse material flow opposite to supply chain. In the 1980s, Murphy and Poist (Murphy and Poist, 1989), inspired by reverse product flow, defined reverse logistics as a material flow of products from consumers to producers in the supply chain. This definition was accepted by Pohlen and Farris (Pohlen and Farris, 1992), who named the final consumer and emphasised that the product flow was reverse in the supply chain, however without identifying the main activities within reverse logistics.

In the 1990s, the concept of reverse logistics was still evolving. Stock devised a definition (Stock, 1992), which stressed the role of recycling in the logistics of waste disposal and reuse. This approach was summarised by Kopicky (Kopicky *et al.*, 1993), who built on the reverse logistics chain, adding information flow supporting the functioning of the chain. M. Thierry et al. observed that “*The objective of product recovery management is to recover as much of the economic (and* *ecological) value as reasonably possible, thereby reducing the ultimate quantities of waste*" (Thierry *et al.*, 1995). Fuller and Allen highlighted the role of the distinct driving forces for reverse logistics, i.e. economics, government, corporate responsibility, technology and logistics (Fuller and Allen, 1995).

In late 1990s, Rogers and Tibben-Lembke (Rogers and Tibben-Lembke, 1998) defined reverse logistics as the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. In 1999, Caldwell noted when meeting executives in a number of companies that it was appropriate to invest in reverse logistics management, as it could result in savings for the business. It was identified as one of the few remaining possibilities of reducing business costs (Daher *et al.*, 2006).

Based on the applicable EU legislation, it is necessary to hold manufacturers liable for their products in the context of environmental impacts. Undertakings should be obligated to engage in reverse logistics activities (Hajna and Ovesny, 2011; Balic *et al.*, 2019). Reverse logistics should rely on building of distribution networks as well as on the collection and proper disposal of end-of-life products which can be reused by reselling or reprocessing them within the system. Pokharel Mutha states that the reverse logistics literature is based on three main building blocks: inputs, structure and processes and outputs (Pokharel and Mutha, 2009).

Reverse logistics involves waste flows and related information. They should be designed with a view to optimising the detrimental impact of waste on the natural environment. It is particularly important to reduce the amount of landfilled waste. It should be emphasised that in this context, it is important to integrate waste flows in time and space, while optimising the costs and developing the best possible solutions for the environment (Szołtysek and Twaróg, 2017).

The end point of traditional material flows (end of life) marks the starting point for reverse logistics, which is aimed at adding value to waste generated at each stage of the value chain. The core element of the flows are end-of-life materials, which are appropriately managed in this way. Processes in reverse supply chains are executed by other entities and involve other activities than processes in traditional chains. There are two complementary dimensions to reverse logistics: ecology and economics (Sadowski, 2006).

In 2018, the global output of plastics reached 360 million tonnes (of which 62 tonnes in Europe) (Plastics – the Facts 2019). New Directive (EU) (EC, 2018) on packaging and packaging waste obliges EU member states to recycle a minimum of 65% by weight of all waste by 31 December 2025 and at least 70% by 31 December 2030. Literature indicates that plastics (Kojnoková *et al.*, 2020), such as PET (Kuczenski and Geyer, 2012, Coelho, Castro, and Gobbo, 2011), can be processed by means of closed-loop recycling based on a small-lot production (3D) (Yuen, 2016) system, where waste can be reused to create a new product. Importantly, this reverse logistics process sets the direction for optimum PET waste management (raising the environmental awareness of the younger generation), and above all, it can be used to manufacture life-saving medical supplies in emergency situations.

3.3 ICT Tools in the Times of COVID-19

The COVID-19 threat, school closures and social distancing recommendations have necessitated a shift in ways and styles of working, a modification of action plans and strategies, a change in people management and implementation of new solutions (Arshad, 2020; Grima *et al.*, 2020; Khan *et al.*, 2020). The COVID-19 pandemic has caused many business processes and human interactions to migrate from real to telecommunications space (Dwivedi *et al.*, 2020). All industries have seen an increased interest in digital tools that facilitate remote work and help maintain business continuity without the need for physical meetings or presence in office, unless they are necessary (Pan and Zhang, 2020). Information and Communication Technology (ICT) solutions have enabled remote work and communication (Sarkis *et al.*, 2020).

The home office concept relies mostly on teamwork. Employees need to communicate, hold teleconferences and customer meetings, collaborate on project implementation or use shared calendars. All those activities require an appropriate platform. Many of the solutions on the market are successfully used for remote work in the pandemic period. These include but are not limited to:

- Microsoft Teams (Buchal and Songsore, 2019);
- Team Viewer (Mukaino *et al.*, 2020),
- Slack (Leonardi, 2020),
- Skype (Gonzales-Zamora *et al.*, 2020),
- Zoom (Lowenthal *et al.*, 2020).

Project management is a particular type of group work. It involves scheduling, team building, assigning tasks and holding people accountable. In this area, there is also a range of solutions that support employees working on home office projects, such as:

- Asana (Kudyba, 2020).
- Basecamp (Rysavy and Michalak, 2020).
- Manage it (Ernst *et al.,* 2015).
- Trello (Carroll and Conboy, 2020; Kudyba, 2020; Rysavy and Michalak, 2020).

Despite the advanced ICT tools, the pandemic has caused extreme disruptions (Papadopoulos, Baltas and Balta, 2020) that have interrupted the regular flow of goods or services in the system (Blackhurst, Dunn, and Craighead, 2011). These situations have had a crushing impact on business activity and supply chain efficiency, and therefore on the performance, profitability and survival of many businesses. Their effects are multiplied and intensified when production, services and trade are globally interconnected (Hughes *et al.*, 2019).

However, COVID-19 has contributed to the emergence of new dimensions of cooperation. More and more businesses that used 3D printing admitted that they had established business relationships across sectors, boundaries or even competitors, with the aim to share ideas, build joint projects and drive customer value. Digital manufacturing is based on an ecosystem mentality, and cooperation has become critical to success. Owing to this approach, already in the initial weeks of the coronavirus outbreak, despite the global supply chain disruptions, it was possible to respond to the huge deficits in and even more immense demand for personal protective equipment (PPE) for healthcare facilities.

4. Production of Helmets from PET Bottles – A Case Study

Due to logistical problems, shortages of filaments to produce helmets appeared very quickly. So, the filament was made in-house from PET bottles. The number of bottles needed to obtain a ground kilogram of material to produce filament is 40 pieces. The filament manufacturing process is shown in Figure 2.

Initially, the waste was cleaned, and plastic or paper stickers were removed. In the next step, the bottles were thermally shrunk. The shrink bottles were fed to a milling machine (SHR3D IT) which ground them to the appropriate fraction. After gaining one kilogram, the fraction was dried and fed to a filament making machine (Composer 450). After obtaining the filament, test helmet bands were printed.

Figure 2. *The process of obtaining filament from PET bottles*

An important element in the distribution of the helmets was the communication between the helmet manufacturer and institutions where there was a demand. In a pandemic situation, communication via mobile phones and e-mail was primarily used. Communication with institutions in need was usually obtained through private contacts. A valuable solution for communication and collaboration would be the use of IT solutions as mentioned in section 3.3 of this article.

5. Conclusions

Many businesses struggle with disrupted supply chains in crisis times, but also on an everyday basis. Experts predict that in the near future, most businesses will tend to become independent of their suppliers and seek to safeguard the continuity of production processes on their own. In the light of such changes, 3D printing will become simply indispensable, considerably reducing the distance between design and manufacturing, from weeks to days or even hours.

Uninterrupted component deliveries have a decisive influence on the continuity of the production process for any business. Disruptions in the supply chain may hinder or even rule out the production of finished or intermediate goods. Preparedness goes beyond being prepared for what comes next. It entails flexibility and the resources required to address any contingency that may emerge. Hence the importance of the ability to leverage the resources available at a certain place and point in time. Reverse logistics and recycling could be an answer. 3D printing offers an excellent example of this flexibility in view of the immense demand for personal protective equipment during the COVID-19 pandemic. The use PET bottles in 3D printing enabled the rapid production of a large number of pandemic response supplies, such as helmets. Such measures are recommendable not only in crisis situations, when filament for 3D printing is in short supply, but also in business as usual situations, with a view to protecting the environment.

An important element for communication and cooperation for 3D printing in COVID-19 conditions would be the use of appropriate IT solutions. The problem presented in the article requires further research in the fields of improving the functionality of IT solutions and the effectiveness of the management of activities necessary in crisis conditions.

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