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Alternative security of the combat readiness recovery using 3D printing and reverse engineering

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Abstract

Disrupting spare parts supply chains can harm the smooth running of an organization. In the case of military vehicles, weapons or other types of equipment used on the battlefield, this is a serious threat that may result in the inability to continue some tactical operations. An ad hoc way to maintain the ability to take action while the appropriate spare parts are delivered and to improve damaged devices may be to produce the damaged components locally. Such a temporary solution is possible for relatively simple elements whose structure, mechanical properties and principle of operation can be determined on a reverse engineering basis. This article describes the concept of alternative solutions for temporarily repairing damaged devices by producing spare parts in mobile specialized production subunits. This paper characterizes the types of 3D printing, contemporary examples of use in foreign armies, priorities of international alliances related to 3D printing, and a case study of repairing an unmanned aircraft by means of 3D printing. Using the experience and knowledge of foreign armies, adapting the possibilities of 3D printing applications to one's own needs, defining legal regulations and creating properly equipped subunits makes it possible to implement the presented concept. Creating conditions for implementing the described concept facilitates the production of a suitable product range in peace, crisis or conflict situations, which may significantly contribute to increasing the level of readiness of the national defense systems.

Keywords: 3D and 4D printing, defense system, production subunits, reverse engineering, supply chains.

1. Introduction

Additive manufacturing technologies, also called 3D printing, together with reverse engineering, are widely used in civil life sectors. These relatively young technologies are still in the development and research phase. The invasion of the Russian Federation into Ukraine on February 24, 2022, displayed the need for research in the field of new concepts, engineering and logistics solutions to increase defense capabilities. The requirements of the modern battlefield, such as sensor filling, the use of a large number of unmanned aerial vehicles, often implemented from the civil market, or disruptions in conventional supply chains, prompt the search for new solutions.

Although 3D printing is a relatively new technology, its applications are present in armies worldwide. The vast possibilities of using 3D printing can be beneficial for the production or reconstruction of military hardware spare parts, tools and instruments, parts of individual soldiers' equipment, including medical equipment, structural elements of military machinery and also buildings (Ali et al., 2022), bridges, runways and other infrastructure. 3D printing technology is becoming one of the priorities of innovative

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technological development trends in defense. This trend has been taken into account in the defense prospective directions of development established by members of the North Atlantic Alliance.

The allied countries' unification of weapon systems, military equipment and types of ammunition has a positive influence on the mutual support possibilities in the event of conflicts. Supply chains and logistical security disturbances may adversely affect the troops' operational ability in the conflict zone. Internal competencies, which require combat readiness, quick restoration and improvement of military equipment that has been put out of action, prompt searching for new solutions. One of the counteracting supply disruption concepts is to produce the necessary assortment locally using 3D printing laboratories. This type of subunit would be able to collect military equipment construction information in the form of its three-dimensional elements models and devices, enabling the production of these elements from appropriate materials. Such operational capabilities will contribute to securing the ability to restore combat readiness.

2. Possibilities of using 3D, 4D and 5D printing technology in military equipment operation securing

3D printing relies on the production of three-dimensional elements or objects by adding successive material layers, usually one after another. In the initial phase, a three-dimensional model of the object is created in Computer Aided Design (CAD). It is easy to make changes to the digital product model. In addition, the same model can be printed from various materials and using different methods, affecting the printed product characteristics. Considering the production's ecological aspect, it is worth emphasizing that additive production is a non-loss production, therefore only the necessary amount of material is used and is easy to recycle (Kordowska et al., 2015).

The ASTM F2792 standard presents accepted terminology related to additive manufacturing technology and defines and distinguishes seven groups of 3D printing. Each group of printing methods has its specific advantages and applications. In their paper, Fiał and Pieknik (2020) describe the characteristics of individual groups and their principles of operation in accordance with the following classification:

1. BJ – Binder Jetting;
2. VP – Vat Photopolymerization (Skrzek, 2020);
3. SL – Sheet Lamination;
4. ME – Materials Extrusion;
5. DED – Directed Energy Deposition;
6. PBF – Powder Bed Fusion (Piszko, 2022);
7. MJ – Materials Jetting.

Additive technologies use a wide range of materials, such as polymers and plastics, composites, ceramics, metals, gradient materials, and hybrid and special materials (Fiał & Pieknik, 2020). Polymers are most commonly used of 3D printing technology. 3D printer users often use thermoplastic fibers, such as polypropylene, polylactide, polypropylene and thermoplastic filaments with higher melting points, such as polymethyl methacrylate. The most common metals in 3D printing are alloys based on cobalt, nickel, aluminum, titanium and stainless metals. 3D printing technology is advanced enough to be used in aviation, where nickel-based alloys are used. These types of metals are resistant to high temperatures (1200°C and higher) and have very good corrosion resistance. Titanium alloys are also commonly used in aerospace components. The application of these metals facilitates the creation of components that are resistant to high temperatures and presure. The group of ceramic materials and concrete are characterized by very good mechanical properties and a lack of pores in the structure of an object. They are used in conditions where they can be affected by chemical factors and high temperatures. Due to the liquid state before curing, ceramic materials can be used when obtaining a specific shape and geometry is required. A separate group consists of materials consisting of at least two phases – composite materials. Composites are used in high-efficiency industry sectors. The most commonly used include polymer composites reinforced with glass fibers and polymer composites reinforced with carbon fibers. They are characterized by good fatigue properties, corrosion resistance and high strength.

Progressively additive manufacturing is more commonly used in the defense sectors of various states worldwide. Military powers, such as the United States and Great Britain, work closely with scientists from around the world to search for and put new technologies into service. The US army spends billions of dollars implementing additive manufacturing technologies into its defense industry, recognizing their great potential (Clemens, 2022). In 2019, it was announced that a printer for military applications would be created and tested by the US Armed Forces in the area of its mission. Experts would then evaluate the results of its use (Boissonneault, 2019). It is important that the USA ordered a 3D printer that will be able to print vehicle hulls and other components of military equipment with maximum dimensions 9 meters in length, 6 meters in width and 3.7 meters in height. As a result of the project, the largest metal additive printer for military applications will be created. Construction is another area where the US has noticed the benefits of 3D printing. A 3D printer from ICON has created a barracks at Camp Swift Training in Texas for US troops.

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The 3D building, with an area of approximately 350 m²' is able to accommodate 72 soldiers. The United States Air Force (USAF) in cooperation with Indiana Technology and Manufacturing Companies, designed and implemented runway mats that are used to secure EAF – Expeditionary Airfields. This solution enables military aircraft to take off and land on ground that is not suitable for this purpose. The new runway mats have replaced their aluminum predecessor due to their lighter and more durable construction (Clemens, 2022). The United States Air Force uses additive manufacturing to produce spare parts for aircraft such as the C-5 Super Galaxy, B-52 Stratofortress, B-2 Spirit, Black Hawk helicopters, and other aircraft that are no longer in production. The resumption of serial or job-lot production generates huge costs related to adapting production lines to the production of missing elements. The use of additive printing minimizes the cost of obtaining spare parts and positively affects the aircraft service extension life. Another example of a part printed for the USAF is the component found in the cockpit of the United States Air Force's pride and most expensive fighter, the F-22 Raptor. During the preservation of the aircraft, in 80% of the cases, this aluminium element did not meet the standards for further operation. Additive manufacturing technology facilitated the production of a titanium replacement that did not corrode. The component has been certified and approved for use, significantly shortening the waiting time for a spare part. Certification allowed for the use of the element and improved the safety of pilots (Maciążek, 2021). In contrast, the United States Navy (US Navy) uses additive manufacturing to produce maintenance tools and replacement components. These items are obtained in a much shorter time than in the case of a classic supply chain, increasing the readiness to use individual subunits. The French army prints propellers for mine-finding ships, reducing construction time. It is worth emphasizing that such propellers are of large size and weight; one of the five propeller blades can weigh up to 200 kg. Another European country using additive manufacturing is Spain. This country improves the functioning of the defense sector and, in particular, aviation technology through the production, e.g., special wrenches for the main rotor of helicopters and measuring instruments used to check the tightness of the aircraft landing gear. Additive printing technologies are widely used in the Australian army. Previously developed structures were tested and then certified. The effect of implementing additive technologies is, e.g. minimizing the cost of obtaining missing parts. An example of the 3D printing application in the Australian defense sector is the production of wheel covers for vehicles, which are produced in just 29 minutes, with a financial outlay of just 100 Australian dollars. Tests are underway in the UK using additive manufacturing to develop new explosives (Clemens, 2022).

To sum up, additive printing technologies are used in the defense sectors of countries around the world. Countries using these methods of production implement them in various types of armed forces. Due to its numerous advantages, additive manufacturing is very popular. It can be said that it will be implemented even more widely in the near future due to its dynamic development and benefits.

Technological progress, the development of new methods, and the use of modern additive printing materials in the 21st century initiated the development of a new 4D printing technology. This type of 3D printing has its origins in 2012, when the American IT specialist, Skylar Tibbits, presented a printed object at the TED – Technology, Entertainment and Design conference. The object changed its shape under the influence of water (Tribbts et al., 2016). The object changed its properties over time. Thus, time was considered the fourth dimension in the concept of 4D printing. Under the influence of external factors, other than electromechanical devices, the manufactured elements change their properties in a predictable way. In this concept, the materials used for printing are often called programmable or intelligent. As a result of the susceptibility of these materials to stimuli, which include temperature, water, electrical impulses, light, pressure, magnetic field, gravity and others, reversible or permanent changes occur in printed objects. Among the materials used for 4D printing, the so-called intelligent materials with shape memory effect (SME) and materials that change their shape – the shape change effect (SCE). The first group of materials is characterized by the fact that the printer operator/technologist programs the shape he wants to obtain, then when using the printed object, it changes its shape to the predetermined form as a result of external factors acting on the element. SCE materials act under the influence

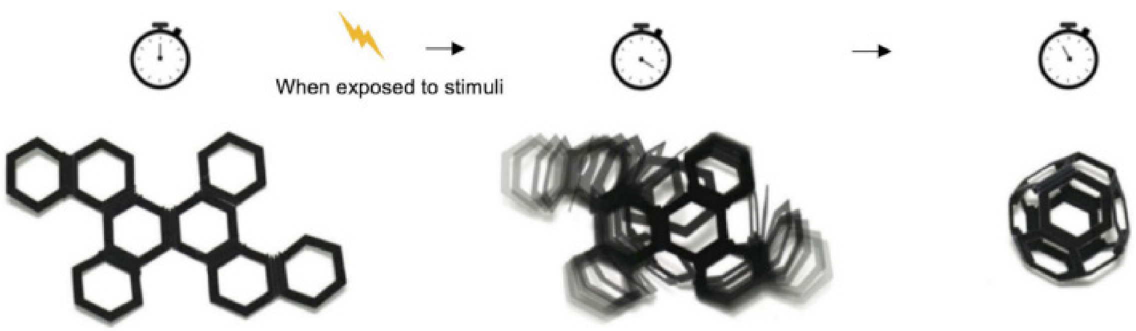

Figure 1. The concept of 4D printing. An example of a printed object that has been immersed in water. Adopted from: "Druk 4D czym różni się od druku 3D" by P. Szczygieł & I. Rajzer. Copyright 2020 by Publisher.

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of a given stimulus, change their shape and return to the state before reacting to a given impulse as soon as the given stimulus stops affecting them (Figure 1) (Szczygieł & Rajzer, 2020).

The advantage of using intelligent materials is the fact that the initial form of the printout can be in the form of a flat element that is easy to store and transport, while in the final phase the object will assume a spatial, complex form.

In the case of 4D printing, special attention should be paid to the development of intelligent materials and the search for new alloys with shape memory, thus expanding the areas of potential application. Smart materials include nano and micro-materials, materials with the ability to adapt to external factors, and the so-called metamaterials, which are materials with controlled physical properties.

In 2016, the North American company Mitsubishi Electric Research Laboratories (MERL) presented a new concept of additive printing. Two more dimensions were added to traditional 3D printing, thus creating 5D printing technology (Figure 3). When printing objects, the printer head and the work table move (Pap, 2016). Elements are made in this way in five dimensions (XYZ –responsible for the length, height and depth of the printed object, and AB – for the axes of rotation of the work table) (Omega Team, 2020). In Figure 2, shows the directions of movement of the printer heads in 3D printing technology.

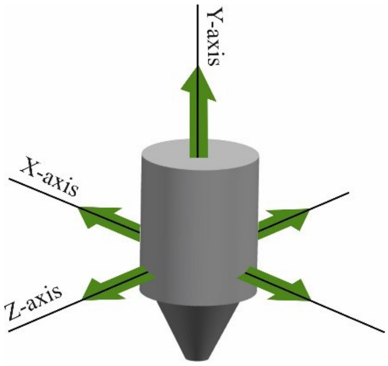

Figure 2. Directions of printer heads movement in 3D printing technology
Source: Authors' own work.

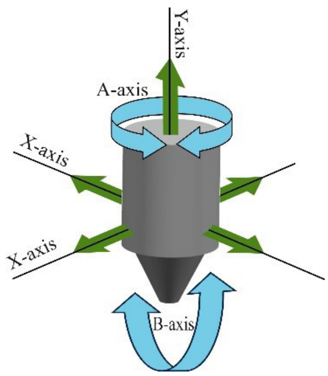

Figure 3. Directions of printer heads movement in 5D printing technology
Source: Authors' own work.

Mitsubishi Electric Research Laboratories scientists conducted a series of tests on 5D printed models using plastic, reaching the following conclusions (Pap, 2016):

- there is an opportunity to print models with complex internal structures;
- 5D printed models are much more durable than 3D printouts;
- the use of the new technology allowed for four times less material consumption than in the case of 3D printing;
- the number of redundant supports is minimized.

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Additive printing in five dimensions is in the early stages of development, but it is possible that it will replace traditional 3D printing in the near future. In the case of simple objects, the printing process can be achieved theoretically by any means. Economic, quality and strength factors are then taken into account (Leniowski et al., 2016).

3. Supporting the operation of military equipment through the use of 3D printing and reverse engineering

During the NATO summit in 2016, which took place in Warsaw, special attention was paid to the development of innovative technologies that will significantly affect the security and defense of member states. The result of the summit was an analysis performed by STO NATO (Science and Technology Organization NATO) entitled "Tech Trend Report 2017". This document defines innovative technological trends, the application of which in the future will contribute to gaining a military advantage over a potential adversary. The analysis was divided into three time periods in which the given technologies will be characterized by the highest intensity of technological development and the greatest impact on the fighting armies operations theater. Among the technologies that have a large influence on the development of military equipment and the improvement of the NATO members security in the short-term perspective, i.e., the next six years, additive manufacturing was distinguished. In the medium-term perspective, i.e., up to 20 years, there will be dynamic development of advanced materials, including smart materials (MON, 2019).

The November 2022 Subcommittee on Technology Trends and Security report pointed out that in many cases, analysss focus on the problems of the present day and fail to consider unexpected changes in society, technology or politics. NATO needs to anticipate and adapt to new security threats while focusing on deterrence, defense and cooperative security. At the same time, the report states that "Russia's war with Ukraine is primarily a conventional war in which traditional weapon systems, especially artillery, play a decisive role. (…) The future course of armed conflicts is difficult to predict, especially since warfare is shaped by geopolitical, social, technological, economic, environmental and military trends" (Fridbertsson, 2022). The section of the report on technological progress and the implementation of new and groundbreaking technologies describes the application of additive printing to improve prototyping development. It will also enable the rapid local production of various components and repairing military equipment. Therefore, the report's provisions suggest that it is justified to prepare for the challenges of the future battlefield, with particular emphasis on the use of modernized, conventional weapon systems.

The report "Science & Technology Trends 2023-2043, Across the Physical, Biological, and Information Domains", prepared by the NATO Science & Technology Organization (Reding et al., 2023), emphasizes the acceleration of the development of 3D printing technology. It also draws attention to the decentralization of production, just-in-time production, and 3D/4D printing technologies. Additive printing technology has also been referred to in the context of the production of military equipment: boats, aircraft, autonomous submarines, missiles, logistics, and space technologies. It was noticed that the 3D printing technology makes it possible to maintain the efficiency of military equipment whose production is discontinued. An important aspect addressed in the report is the future of 3D printing in the context of biomedical applications (printing bones, skin, organs, drugs), such as biomedical robots, tissue engineering or bioscaffolds (Naniz et al., 2022). It is possible for these future-proof solutions to revolutionize the treatment and care of combat casualties, e.g., individual orthoses already available in the future (Figure 4). The scope of potential use of 3D printing technology in medicine seems to be very wide and future-proof (Aimar et al., 2019).

Figure 4. Examples of medical elements printed in 3D technology. Adopted from: "NASA Awards Copper #D Grant for 3D Printing Antibacterial Medical Devices in Space" by U. Iftikhar. Copyright 2019by Publisher. https://3dprintingindustry.com/news/nasa-awards-copper-3d-grant-for-3d-printing-antibacterial-medical-devices-in-space-148338/

In addition to the use of classic polymer materials for battlefield rescue applications, it is also worth mentioning materials with biocidal properties, used in 3D printing. Some materials with additives, e.g., copper or silver nanoparticles, show bactericidal, fungicidal and virucidal properties. These materials can be attractive in battlefield rescue, where maintaining the sterility of the tools used is difficult. They can also be used in everyday conditions, especially in public places (Figure 5).

Figure 5. Overlays made of flexible antibacterial filament MDFLEX by Copper3D. Source: Authors' own work.

The field of science related to additive printing technology is reverse engineering. This concept is defined as obtaining information about a physical object and analyzing this data to develop a technical specification for later use (Szelewski & Wieczorowski, 2015). Existing physical objects are examined to learn about their construction and functioning, assess the degree of wear of a given element, the correctness of design, or to recreate technical documentation (Lulkiewicz, 2017). Structural models of elements are created using contact, non-contact, or hybrid methods (Szelewski & Wieczorowski, 2015). The developed technical specification must be verified. At this stage, the previously prepared documents are checked in terms of their correctness and whether they meet the technical requirements and are sufficient to produce a new facility. Subtractive and additive technologies are most often used to produce a new element (Figure 6) (Szelewski & Wieczorowski, 2015). The use of reverse engineering significantly minimises the costs associated with the design of given facilities and significant time savings (Młody et al., 2023). In addition to the listed benefits, the reverse engineering method creates an opportunity to (Kachel et al., 2011):

- assess the interoperability and cooperation of components,
- reconstruct the technical specification and documentation of the facility, e.g., in the case of its loss,
- analyze the subject to determine the infringement of copyrights and patents and the composition of components,
- estimate production costs after a thorough analysis,
- control the state of wear and maintenance of geometrical dimensions of elements,
- create replicas and duplicates of physical objects,
- create digital models for strength and fatigue testing, etc.

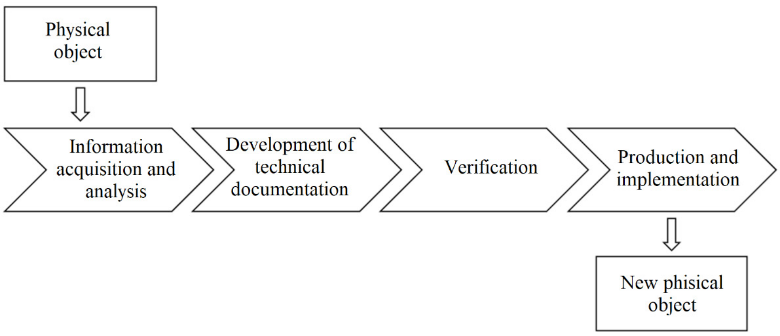

Figure 6. Flowchart of the reverse engineering process. Source: Authors' own work based on "Inżynieria odwrotna i metody dyskretyzacji obiektów fizycznych" by M. Szelewski and M. Wieczorowski. Copyright 2015 by Publisher.

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In reverse engineering, 3D scanners are commonly used to map physical objects into a form compatible with computer software. Creating digital models using these devices is an extension of the 2D scanning idea, which consists of using the principles of light reflection from the surface and its return to the optical elements located in the scanner head. Then, the reflected light is converted into a spatial digital form. Using 3D scanners, the image and the model of the scanned object are saved. The created point cloud is then used by computer software to create a discretized spatial model. This process significantly shortens the procedures related to the design. Using 3D scanners and appropriate software, it is possible to reconstruct objects with complex geometry and internal structure (Piłat et al., 2016).

4. An example of improving an unmanned aerial vehicle by a recreated element

One of the possibilities of using reverse engineering is the improvement of military equipment that has become inoperable due to damage to one of its elements. Having the technology to create a model of a damaged element, processing it in a way that allows for creating the element model before damage and then producing this elementbecomes possible to recreate the equipment (Zahorski, 2021). As an example of this repair method application, an unmanned aerial vehicle – the DJI MAVIC AIR 2 drone (Figure 7), will be used. As a result of damage – a fracture in one of the arms with an installed engine, the UAV was disabled.

Figure 7. Unmanned aerial vehicle and damaged arm for repair
Source: Authors' own work.

By using the idea of reverse engineering, an attempt to recreate it was made. For this purpose, a three-dimensional scan of the damaged part were used. A model of the undamaged element was created to process the information received about the damaged element. Depending on the size of the elements, stationary scanners (for small elements) and handheld scanners (for larger elements such as vehicles or buildings) can be used to create a spatial model. Models of the damaged UAV arm elements were made using the Shining Einscan-SE stationary scanner (Figure 8).

Figure 8. Shining 3D scanner station, model Einscan-SE
Source: Authors' own work.

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By using the Autodesk Netfabb Premium 2023 program, damaged arm elements models were connected. In the next step, the final processing and verification of the model was performed (Figure 9).

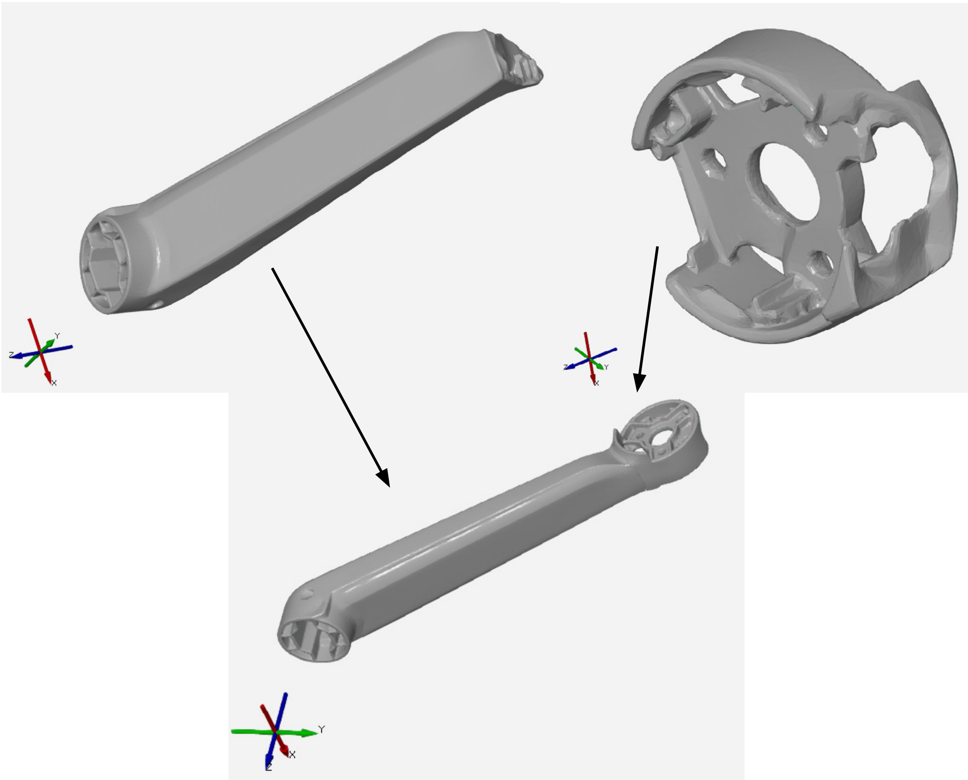

Figure 9. The process of creating a three-dimensional unmanned aerial vehicle arm model using a 3D scanner
Source: Authors' own work.

Based on the technical data analysis of the unmanned aircraft (Table 1), Polymax material from the Polymaker was selected to print the new spare part. The choice of material for the reconstruction of damaged parts depends on its mechanical and environmental strength properties, production technology and time and material costs. The selected material is easy to print, which makes it possible to produce on most FDM printers – Fused Deposition Modeling. Material properties: Young Modulus 1879 ± 109 Mpa, Tensile Strength 28.1 ± 1.3 Mpa, Bending Strength 48.0 ± 1.9 Mpa, Charpy Impact Strength 12.2 ± 1.03 kJ/m².

Table 1. *Specifications of the DJI MAVIC AIR 2 unmanned aerial vehicle*

No.	Parameter	Unit	Value
1.	maximum flight time	S	2040
2.	range	Km	18,5
3.	maximum flight altitude	M	5000
4.	maximum flight speed	km/h	69
5.	weight	G	900
6.	battery capacity	mAh	3500

Source: Authors' own study based on DJI Mavic Air 2 technical specification.

The total production time for the parts of the unmanned aerial vehicle (3D scans, development of an improved model, printing) lasted 6 hours 25 minutes, which is a significantly reduced time compared to a commercial purchase. Considering the possibility of scanning the undamaged counterpart of the damaged part, or having a spatial model of the part in the database,

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the working time could be further shortened (Zahorski, 2021). The cost of production (assuming having specialized equipment and software) turned out to be 60-100 times lower compared to a standard commercial purchase. Having information about the strength properties of the material from which the original element was made, the properties of the reproduced element can be significantly closer to the original.

Using the technical idea analyzed on the basis of an example, a similar method of operation can be used in many areas. The given method of operation can be applied in peacetime – if needed for immediate improvement, as well as during warfare – if needed for improvement in the event of supply chain disruptions. It should be stressed that the given method of operation is intended to enable the continuity of military operations. Such actions should not serve to deprive manufacturers of commercial sales of military equipment under any circumstances. It is also important that the use of the presented method of operation remains in accordance with applicable law.

A detailed discussion of materials selecting criteria for spare parts is a related but broad range of issues planned to be discussed in the subsequent stages of work. The choice of materials and production technology is determined by using strength properties and information about the original parts. In the case of parts requiring certification, the selection of materials also results from regulations and standards, e.g., the Guidelines for Development of Civil Aircraft and Systems ARP4754A in passenger aviation (SAE International, 2010). In the case of parts that do not require certification, good practices and designers' experience are also very valuable. Unmanned aircraft whose operation involves the lowest risk in the "open" category should not be subject to classic aviation compliance procedures (OJEU, 2019). The principle should be that the mechanical strength in terms of safety factors and resistance to all possible stresses during use allows the product to withstand them without damage or deformation. The publication assumed the concept of creating the possibility of producing simple structural elements for use in critical situations not intended for ordinary operation.

5. The concept of the security area operation organization and alternatives to regular supply chains

An alternative method of securing the reconstruction of combat readiness through the use of 3D printing and reverse engineering technology requires having full-time subunits in the army structures, dealing with the collection of construction information, model processing and the proper selection of printing technology. In addition to possessing competences and devices enabling the production of elements (production laboratories), these subunits may also be able to perform functional tests of reconstructed elements (Stachaczyk, 2023). This would make it possible to improve the production process and to gather information about the possible needs for structural changes.

Recreating parts from damaged items is an imperfect solution because of the potential for design differences. It also should be considered that the element to be manufactured is impossible to reproduce due to wear or damage. In such case, it is crucial to have a database of three-dimensional models of elements that can be produced in the area of the military equipment used. Creating a database makes it possible to speed up the production process, minimize differences compared to original elements, and send encrypted data on the construction of elements between users.

Equipping military subunits with specialized equipment for the production of elements needed to ensure the ability to restore combat readiness shortens the supply chain for its critical needs. However, equipping all military units with sets of specialized equipment would be a demanding challenge. The concept of diversification of units dealing with the production of elements using incremental printing technology and reverse engineering encourages the creation of mobile, specialized production laboratories (Stachaczyk, 2023). This enables the transport of devices facilitating the production set just in time in order to meet the needs of units and subunits. There are already companies on the civil market that offer additive container printing houses (Figure 10). Recognizing the potential of mobile printing houses, the US Army, through the US Department of Defense, commissioned the company 'ExOne' in 2021 to develop and build portable additive manufacturing laboratories in order to deploy them to service in both the army and the navy. The concept of the printing house is to meet the requirements and needs of the defense potential. Moreover, the construction of the container additive manufacturing laboratory is to be designed to perform its functions in operating zones and places affected by natural disasters (Maciążek, 2021).

The creation of mobile production laboratories allows us to minimize the waiting time for parts to be recreated. It should be considered that the mere creation of military subunits at the disposal of the commands of the types of troops would significantly shorten the delivery time of a certain range of critical supplies. This way of preparing for alternative security of supply chains in the event of impediments to the smooth flow of parts is an almost inexhaustible warehouse of certain types of spare parts. The production of replacement elements that restore combat readiness and parts resulting from current critical needs is a definite added value for the possibility of continuous operation of troops in the face of unexpected problems (Figure 11).

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Figure 10. Container, mobile additive printing house designed by ExOne for the United States Department of Defense. Adopted from: “Wojskowe zastosowanie druku 3D” by M. Maciążek. Copyright 2021 by Publisher. https://3d.edu.pl/wojskowe-zastosowania-druku-3d/

Figure 11. An example of reproduce of specialist tool using 3D printing
Source: Authors’ own work.

6. Summary

Additive printing technology is increasingly used by the military. Using the experience of the allied forces with the application of the technology, developing competencies and implementing their own innovative solutions, it is possible to achieve significant benefits from shortening the supply chains of critical parts, especially during disruptions in the flow of supplies in conflict conditions.

The effective use of the discussed technologies requires the creation of sub-dealing with additive printing for tactical military applications. It is necessary to create databases of three-dimensional models of elements with the potential to recreate combat readiness. The development of the described concepts can be based on the cooperation of military units with military research institutes, universities, and civilian companies in coordinationwith operational level commanders.

Providing individual military units with equipment enabling the production of elements with additive printing technology and devices for the use of reverse engineering will shorten the waiting time for the delivery of critical replacement elements. A more effective solution may be to create mobile production laboratories. The same mobile laboratories may be used in land, air or sea units.

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A critical issue of the actual use of additive printing technology possibility in the army is the creation of regulations. The perspective of using elements created in this way for real-life applications should be specified in the documents governing the operation of military equipment. Making elements of soldiers' individual equipment, uncertified elements, or replacements for less crucial elements of military equipment seem not to be an issue. Determining the scope of using 3D printing and reverse engineering in the context of certified and potentially copyrighted parts requires some specific regulations.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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