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The SWOT Analysis of 3D Printing Capability in the Hungarian Defence Forces[6]

Abstract

The purpose of the research presented in the article is to conduct a SWOT analysis of additive manufacturing technology, with a special focus on 3D printing capabilities within the Hungarian Defence Forces. In the first part of the paper, we introduce the most dynamically evolving type of additive manufacturing processes today, 3D printing technology, along with its properties and potential applications. Following this, we outline the strategic goals and the advantages that enhance supply security, which support the legitimacy of 3D printing as a manufacturing process in the execution of military tasks. In the main part of the paper, we present the SWOT analysis of 3D printing technology used in logistical tasks, which, among other things, provides an opportunity to explore further applications of the manufacturing process, as well as to address and minimise potential risks associated with the manufacturing technology.

Keywords: additive manufacturing, 3D printing, 3D printing capability, SWOT analysis

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Introduction

One of the revolutionary manufacturing technologies of the 21st century, 3D printing, can be used effectively, efficiently, and economically in various industrial production processes as well as in the defence industry. It has numerous advantages over traditional manufacturing technologies – many of which have been presented in publications[7] we have shared – making it increasingly popular, accepted, and applied.

It has become a part of our everyday lives, and given that the technology is continuously evolving to meet the expanding needs of users, it will undoubtedly play an increasingly significant role among the technological solutions shaping the future.

Our research conducted in the field of additive manufacturing technology, particularly in 3D printing, along with the results we have achieved so far, motivated us to carry out a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis of the application of 3D printing technology in the Hungarian Defence Forces (HDF). Our primary goal with this was to demonstrate that 3D printing has an important place and role in military manufacturing and supply tasks. Through the information gathered, analysed, and evaluated during the research, including the benefits and drawbacks of the manufacturing process, we sought to answer the question of which areas of defence could effectively and appropriately utilise this manufacturing solution. Based on our years of experience in design, manufacturing, usage, and quality control, we identified opportunities where the application of 3D printing processes can shorten and make military supply chains safer.

Due to the known and yet untapped advantages of manufacturing technology, Hungary's National Military Strategy[8] also places a special emphasis on 3D printing. It states that, for example, the gradual spread of disruptive technologies[9] further increases our country's security risks. Therefore, the Hungarian Defence Forces must become a modern, well-equipped military force that meets the demands of the times. This requires the development of existing capabilities, the creation of new ones, and the implementation of necessary military technology advancements. The establishment and operation of the domestic national defence industry provide the independence and supply security needed to achieve the objectives set out by the military strategy. The published results of our research in additive manufacturing technology confirm that 3D printing capabilities have a place in the domestic defence industry, including in a military force equipped with modern military technology.

The realisation of the expectations outlined in the military strategy, including the possibilities for the development of military and technical equipment and the reduction of potential risks in military supply chains was another important reason for SWOT analysis of 3D printing technology. Optimising military logistics processes (including manufacturing activities) is a key pillar of the sustainability of military supply chains, making it logical to conduct a detailed analysis of 3D manufacturing processes in order to make informed decisions about their application.

[7] Daruka et al. 2024a.
[8] Government Decree 1393/2021 (VI. 24.).
[9] Disruptive technology: Innovative technological changes, services, or solutions (e.g. the steam engine, the automobile, email, mobile phones, etc.) that fundamentally reshape market dynamics.

Introduction to 3D printing technology

The manufacturing process is the sum of activities during which a material is transformed in a planned manner, changing its shape and properties to produce a product that meets the customer's requirements. In traditional manufacturing methods, excess material is typically removed from the raw material using some kind of machining process (such as planning, turning, milling, etc.) until the desired shape, as per the product design, is achieved. In contrast, during the additive manufacturing process – of which the most well-known type, and the one discussed in this article, is 3D printing – the object is built layer by layer by adding material, based on a (usually) digital 3D model. The CAD (Computer-Aided Design) files required for printing can be created by:

- designing, e.g., using CAD software
- 3D scanning

The increasingly popular 3D printing technology is continuously and rapidly evolving, which means that newer and newer printing processes and printing materials are becoming available to users. As a result, this additive manufacturing process can be applied more widely, efficiently, and at lower costs. One of the outcomes of these developments is, for example, an innovative printing method in which a single print head can generate hierarchical structures[10] from ultrafine fibres and solid layered material. The classification of the currently available printing methods is not only essential for our research but can also significantly help users navigate the continuously expanding range of options and assist them in selecting the type of printer that best suits their needs. 3D printing processes can be grouped based on their application area (e.g. education,[11] research, prototype manufacturing, etc.), the printing process itself (e.g. extrusion-based, powder bed, etc.), and the printing material used (e.g. plastics, metals, composites, etc.).

Despite the advantages of 3D printing, it is important to remember that the technology is still in a phase where we are developing manufacturing and procedural details that best meet the requirements of its application areas, aiming to partially or fully replace existing solutions. This revolutionary additive manufacturing process, despite the advantages discovered so far, still requires significant improvements in many of its details. Reducing printer defects,[12] as well as addressing the quality issues of materials and improving their mechanical properties,[13] strengthens both manufacturer and user satisfaction and trust. Effective contributions to this can be made through the adoption and application of existing manufacturing standards, as well as the standardisation of quality control procedures for finished products.

The 3D printing technology is being increasingly adopted by various industry players, as continuous developments provide additional benefits such as cost reduction and efficiency improvements. Notable advancements include the increase in printable size, the expansion of material types and improvements in their quality, and the reduction of supply chain risks. Due to these advantages and favourable

10 Kara et al. 2023.
11 Daruka et al. 2024b.
12 Zentay et al. 2023a.
13 Zentay et al. 2023b.

opportunities, the defence industry also uses this manufacturing process, including in various areas such as military supply tasks.

Application of 3D printing technology in the Hungarian Defence Forces

Similar to profit-oriented economic actors, but driven by different intentions, the defence industry, including the Hungarian Defence Forces, eagerly adopts modern and innovative technologies that offer some form of competitive advantage. Among the objectives of applying advanced solutions in military tasks are increasing efficiency, achieving faster response times, reducing risks, and enhancing security, all of which collectively serve the success of mission execution and the safety of personnel. To achieve these goals, the modern military force being developed in alignment with military strategic objectives heavily relies on technological advancements.[14] Consequently, 3D printing is present in various areas, such as defence-related educational, research, and supply replenishment systems.

Recent geopolitical tensions and the increasing security risks caused by the Russian–Ukrainian war in our neighbouring region continuously challenge NATO, and by extension, our country as well. Therefore, the Hungarian Defence Forces must become a modern, well-equipped military force capable of responding to contemporary requirements and changes. During modernisation, significant attention must be given to solutions that have proven effective and successful in current conflicts. The events of the Russian–Ukrainian war and the Israeli–Palestinian conflict in the Gaza Strip demonstrate that, among other factors, the widespread use of inexpensive drones, AI-driven advanced weapon systems, and the military application of 3D printing have significantly altered the previously established methods of warfare. Today, 3D printers optimised specifically for military use offer a reliable and predictable solution for handling logistical tasks on-site, while also reducing the risks associated with supply chains. The following list includes military application areas where 3D printing technology has already proven its advantage over traditional manufacturing methods:

- production of prototypes and samples
- manufacturing of components with complex geometries
- production of custom or personalised equipment
- manufacture of shell casings[15] for explosive and ordnance disposal tasks
- production of drones[16]
- manufacture of weapon parts and spare parts
- on-site, including battlefield, manufacturing capability
- printing of tactical maps[17]
- application of artificial intelligence in 3D printing
- production of educational aids

[14] Hegedűs–Gyarmati 2022.
[15] Ember–Ádám 2022.
[16] Hegedűs et al. 2023.
[17] Kállai 2023.

Over the past few years, 3D printing has demonstrated its growing presence across various fields compared to traditional manufacturing methods, which is why it has rightfully entered the portfolios of economic players. With the increase in user demands, further development of the technology is expected, and, together with the continuous expansion of printing materials, it is anticipated that it will enable applications in additional areas. A part of our investigation, as presented in this article, focuses on identifying which new military areas might emerge in the future. As highlighted in the previous list, 3D printing currently contributes to the success of military operations by providing in-house manufacturing capabilities, enhancing the efficiency of manufacturing processes, and making supply chains safer. We anticipate that 3D printing capabilities will be integrated into the Hungarian Defence Forces in the near future, for which the necessary conditions have been detailed in a previous article of ours.[18]

SWOT analysis of 3D printing

A SWOT analysis is a strategic planning tool that helps organisational leaders in decision-making by identifying and evaluating strengths, weaknesses, opportunities, and threats related to the subject under examination. In our paper, we conducted a SWOT analysis of the military application of 3D printing to identify areas and tasks where the 3D manufacturing process can be applied more effectively and efficiently than current solutions. The analysis particularly focused on the organisational changes needed for the implementation of the technology and the necessary development of the printing process to best meet military requirements, as well as the legitimate needs and expectations of users.

We deliberately did not examine whether the military application of 3D printing is justified, as the technology has convincingly proven its military relevance in recent armed conflicts and wars. Furthermore, military strategy is largely based on the experiences of current wars and sets out expectations for the modernisation and development of the Hungarian Defence Forces to which 3D printing technology can also contribute.

During the implementation, we first conducted an organisational analysis of the HDF, examining the internal factors, specifically the strengths and weaknesses. We focused on whether the current organisational structure is suitable for integrating the technology and whether the application of the technology and the necessary organisational changes are justified. In the second part of our analysis, we examined the external factors that the Defence Forces cannot significantly influence or control, yet which could have a substantial impact on the military and its operations. Based on our design and printing experiences with 3D printing technology, we prepared a SWOT analysis of the procedure:

[18] Daruka et al. 2024a.

Strengths:

- Customisability: Enables the easy production of custom products, including those tailored to the users' body measurements.
- Rapid prototyping: Allows for the immediate and quick creation and testing of prototypes, followed by necessary design adjustments. This facilitates accelerated product development processes and cost reductions.
- Manufacture of complex geometries: Enables the production of parts with complex geometries that would be difficult or costly to achieve with traditional manufacturing methods.
- On-demand manufacturing: Reduces inventory costs and increases flexibility by allowing products to be produced as needed, quickly responding to user demands.
- Environmentally friendly application: Produces less waste compared to traditional subtractive manufacturing processes and requires less energy, contributing to environmental protection.
- Manufacture of unique and specialised products and tools: Allows for the creation of custom, specialised tools, such as those used in explosive ordnance disposal, enhancing the safety of the personnel involved.
- Expanding material options: Supports a variety of materials with optimised properties for specific tasks, such as plastics, metals, and ceramics.
- Decentralised or on-site manufacturing: Enables the production of necessary parts at the point of use, even on the battlefield, without relying on risky supply chains.
- Simplification and safety improvement of logistical tasks: Allows for on-site, demand-based production of products, avoiding complex and risky supply chains. This reduces logistical tasks, saving time and energy for logistics units. The application of this technology can be a good alternative for reducing supply chain risks, as discussed in a previous publication.[19]
- Creation of a digital database: The efficiency of 3D printing tasks can be actively supported by a centralised, non-public digital database established at the national level.
- Optimised design processes: The use of artificial intelligence-based generative design (a collaboration between the designer and the computer) allows algorithms to generate thousands of possible solutions based on design parameters and requirements from which the designer can choose. This helps in optimising material usage, strength, and costs.
- Centralised 3D Printing Capability: A centralised printing facility at the military level offers several advantages, including cost savings, secure data management (e.g. for weapon parts), optimisation of manufacturing processes, and maximisation of utilisation.
- Creation of training and development centres: Establishing a training centre ensures the transfer of both theoretical and practical knowledge required for 3D printing.

[19] Daruka et al. 2024c.

- Easy training for production: The process for a specific type of 3D printer can be taught within a few days.
- Generative design capability: Generative design for creating 3D models uses artificial intelligence-based software to generate thousands of design variants based on fundamental parameters (e.g. load, strength, size, material). Additive manufacturing allows for printing of complex generative design bodies.[20]

Weaknesses:

- Printing capacity limitations: For larger or higher quantities of products, the printing process can be time-consuming.
- Limited material selection: Current printers are only capable of using a limited range of materials, which restricts the scope of applications.
- Cost: high initial investment costs for setting up the necessary infrastructure, including printers and quality materials.
- Size restrictions: The technology currently has limitations on the maximum print size, which can restrict its use.
- Material quality issues: The quality of printed products, such as surface finish or strength, can be inconsistent and may not match that of products made with traditional methods. For example, in laser powder bed fusion of metals, surface quality often does not meet application requirements.[21]
- High start-up costs: Establishing 3D printing capabilities involves significant initial costs for infrastructure, equipment, and high-quality materials.
- Technological constraints: Current technological limitations affect manufacturing capabilities, including print speed, size, surface quality, and detail.
- Regulatory issues: The legal and regulatory environment for printed products is still developing and may not fully address all concerns.
- Accuracy: The dimensional and shape accuracy of printed products may not yet match that of products made using traditional manufacturing processes, especially mass-produced items.
- Quality control: The regulatory framework for quality control of finished products is still lacking. For example, fibre-reinforced polymer composites used in aviation and automotive industries face significant issues like catastrophic failure under overload and lack of ductility, necessitating non-destructive testing methods to assess structural integrity and predict the remaining properties of composite structures after partial damage.[22]
- Competitive technologies: Traditional manufacturing processes can often produce products more economically, quickly, and reliably, especially in higher quantities.
- Security risks: Easy access to 3D printing designs and technology could pose security risks if misused, such as for producing weapon parts.
- Technology maturity: The 3D printing process is still in the development phase, including printers, materials, and regulatory environments.

[20] Markovits et al. 2023.
[21] Markovits–Varga 2024.
[22] Hliva–Szebényi 2023.

Opportunities:

- Technological process optimisation and development: 3D printing offers opportunities to optimise design and manufacturing processes, enhancing efficiency. Further advancements can lead to increased printable sizes, new printer materials, and improved quality and mechanical properties of finished products.
- Growing user demand: Increasing demand for printing services drives manufacturers to innovate, leading to the development of more affordable, efficient, and versatile printers.
- Innovation and design freedom: 3D printing provides design freedom and innovative opportunities, allowing for the development of new products and procedures.
- Medical applications for military use: There is a possibility to create customised medical devices and prosthetics tailored for military needs.
- Research and development: The known advantages of 3D printing, such as immediate production of complex structures, facilitate overcoming challenges in research and development tasks.
- Education and training: Utilising 3D printing in education can aid instructors in explaining concepts through the creation of teaching aids and support students in realising innovative ideas.
- Increased technology acceptance: Demonstrating the benefits of 3D printing over traditional manufacturing methods helps to increase the technology's acceptance and widespread use.
- Decentralised 3D printing capabilities: Establishing printing capabilities at various military locations offers several benefits, including simplifying supply chains, enhancing logistical security, saving time, and enabling on-demand, localised manufacturing.

Threats:

- Competition from traditional manufacturing methods: Conventional manufacturing methods are often better known, more widely accepted, and more efficient than 3D printing. Traditional methods may not have limitations in terms of size or material availability, making them more suitable for certain applications.
- Cybersecurity risks: The risk of cyberattacks poses a threat to the integrity of the 3D printing process. There is a potential danger of producing defective, compromised, or weakened components without detecting the issues.
- Regulatory shortcomings: The ease of access to 3D printing technologies and the availability of printable designs (e.g. firearms) online necessitate stringent legal regulations to ensure public safety and prevent misuse.
- Standardisation issues: The lack of standardised practices for the elements and environmental conditions of 3D printing, as well as for quality assurance of printed products, can hinder the technology's adoption and effectiveness.
- Technological limitations: 3D printing faces several limitations compared to traditional manufacturing, such as restricted printable sizes, limited material

options, and inconsistent product quality. These issues need to be addressed or developed further.
- Security concerns: The ease and affordability of access to 3D printing, combined with inadequate regulatory oversight, heighten security risks. For instance, the ability to easily produce firearms poses a significant threat.
- Printing quality and reliability: There is a need for improvements in printer reliability and material quality to enhance the overall quality and mechanical properties of printed products. Ensuring consistent print quality is crucial for widespread adoption and reliability.

The SWOT analysis we conducted can assist the leaders of the Hungarian Defence Forces, or its individual units, in understanding the advantages and opportunities of 3D printing technology, as well as its limitations and risks, to make informed decisions about adopting or rejecting this manufacturing process. Should the decision be to implement 3D printing, our analysis provides essential background information for system setup and operation, as well as for developing the necessary organisational and equipment development strategies.

Summary

3D printing has been a part of the lives of businesses using additive manufacturing technology for decades. It has been used to some extent, but for a long time, it did not hold a significant place in the portfolios of companies producing various products. Since user demand did not increase significantly in this direction, printer manufacturers also did not invest more time, energy, or money into development. However, in recent years, developments have led to the rapid spread of the technology, now being used much more widely than before. Many of the previously unfavourable characteristics of the technology have been significantly improved, resulting in cheaper and more accurate printers. The variety and quality of usable materials have significantly increased, further boosting demand for printers.

Thanks to these advancements, 3D printing has increasingly overshadowed traditional manufacturing processes in various industrial sectors today, as it offers numerous advantages over them. Among other things, the ability to quickly produce prototypes for testing, material savings, and the potential to create complex structures all contribute to making 3D manufacturing more cost-effective, faster, and versatile compared to competitors. In addition to profit-oriented players in the economic sector – though with different objectives – the national defence industry, including military defence, is also eager to adopt innovative and modern solutions for more effective, successful, and rapid operations.

Due to the ongoing Russian–Ukrainian war and various geopolitical tensions, there is a need for a modern military that can quickly respond to changes and ensure the country's security and independence. Achieving a modern military requires not only the development of existing capabilities but also the creation and integration of new capabilities that enhance the achievement of military objectives.

The military application of 3D printing technology has demonstrated its effectiveness in many cases on the battlefield, such as in the production of weapon parts and drones, and in reducing supply chain risks. Accordingly, the Hungarian Defence Forces have started using 3D manufacturing technology initially for research purposes, and we are currently in the initial, exploratory phase. In our paper, we conducted a SWOT analysis of the military application of 3D printing to identify the advantages and disadvantages of the technology, as well as areas and tasks where the 3D manufacturing process could be applied more effectively and efficiently than the current methods. We paid special attention to the organisational changes and infrastructure development required for the technology's application, as well as the technological development needs to meet military requirements.

Following the analysis, we conclude that the establishment and integration of 3D printing technology as a manufacturing capability in the Hungarian Defence Forces could contribute to the creation of a modern military force with independent supply capabilities that meets contemporary requirements. The weaknesses and threats of the manufacturing process can be significantly mitigated through regulation and development.

Our SWOT analysis and subsequent evaluation, based on our experiences with the 3D printing process, are intended to provide decision-supporting information for the development of 3D printing capabilities in the Hungarian Defence Forces.

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