The impact of additive manufacturing used in the Russo-Ukrainian conflict on decentralized manufacturing[1]

Az orosz-ukrán konfliktusban alkalmazott additív gyártás hatása a decentralizált gyártásra

3D printing is one of the most widespread disruptive technologies today. It also plays a significant role in wartime, especially when the appropriate background and system are available. By combining this technology with digital warehousing and decentralized manufacturing, we can identify the most important cornerstones in the operational environment and challenges of the Russo-Ukrainian conflict. Since we conducted our analysis using data obtained from an active war environment that can be considered reliable, we can state that we have successfully identified the most important elements and categories of decentralized manufacturing associated with this technology.
Keywords: decentralized manufacturing, 3D printing, additive manufacturing, digital warehouse

A 3D-nyomtatás napjainkban az egyik leginkább elterjedt diszruptív technológia. A háborús környezetben is jelentős szerepet kap, kifejezetten akkor, ha megfelelő háttér és rendszer áll rendelkezésre hozzá. A technológiát összevontan vizsgálva a digitális raktározással és a decentralizált gyártással az orosz-ukrán konfliktus műveleti környezetében és kihívásai között sikerül azonosítani a legfontosabb sarokpontokat. Mivel egy aktív háborús környezetből kinyert, valósnak tekinthető adatokból folytattunk elemzést kijelenthető, hogy sikerült megbízhatóan megállapítani a technológiához köthető decentralizált gyártás legfontosabb elemeit és kategóriáit.
Kulcsszavak: decentralizált gyártás, 3D-nyomtatás, additív gyártás, digitális raktár

Introduction

Today, armed forces face a series of challenges that pose significant challenges. These can be global problems, such as ongoing environmental and climate change,[2] the appropriate and secure integration of artificial intelligence into current systems,[3] or local problems, such as an armed conflict that pits two or more nations against each other.

No matter how we look at these issues, one thing is certain. There are disruptive technologies available that play a significant role in these processes or can help manage negative developments. Additive manufacturing is such a technology. It is developing rapidly, has become part of everyday life, and is gaining an increasingly large share of the industrial segment.

This technology is capable of processing both simple polymers and specialized raw materials [4] for the production of customized items. It can be used to produce both simple components and complex structures, and in the event of an armed conflict, it can ensure part of

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[2] PADÁNYI 2022.; PADÁNYI 2024.
[3] NÉGYESI – FAZEKAS 2022.; FAZEKAS 2023.
[4] HALINKA et al. 2023.; VÉG 2023: 86.

our supply of spare parts,[5] or parts of offensive weapons can be manufactured using it. This segment may include drones that simply collect and transmit data[6] but versions designed to destroy the enemy also belong here.

The Russo-Ukrainian war provides us with a picture of the real-world application of 3D printing and the unique circumstances surrounding it, which are linked to digital warehousing and decentralized manufacturing. The aim of this publication is to identify the cornerstones of this symbiosis, analyse the way it works, and categorize its elements in order to obtain a comprehensive and detailed picture of the situation that has developed.

3D printing in the Russo-Ukrainian war

One of the most decisive weapons in the Russo-Ukrainian war are unmanned aerial vehicles (hereinafter: UAVs). Both sides use this technology thousands of times a day on the eastern front. One of the key weapons in Russia's deep strikes is the Geran–2 (a clone of the Iranian-developed Shahed–136), of which, according to some sources, thousands have already been manufactured and used in deep distance strikes. This is a situation that could not go unanswered, so the Ukrainian side naturally stepped up the production of interceptor drones. All this is already happening on a mass production scale, which could reach as many as 10,000 units.[7]

In the case of drone warfare, a war competition between so-called3D printing farms equipped with 3D printers is unfolding. These units are capable of producing a significant number of plastic parts for these UAVs, such as frames (Figure 1), covers, control surfaces, propellers, mechanical parts, etc. This method is fast and efficient, but not necessarily cheap. In the case of One-Way Attack (hereinafter: OWA) UAVs, it is not necessary to manufacture them to a high standard of durability, as these First Person View (hereinafter: FPV) devices usually only carry out a single combat mission during their lifetime. This means that even lower-quality devices and components may be acceptable, although this is a sensitive issue when human lives may depend on it.

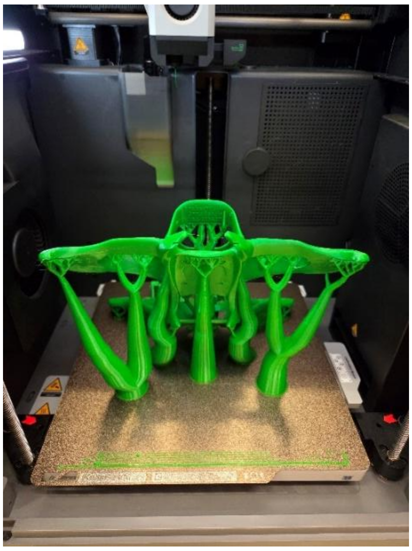

Figure 1: Drone frame during 3D printing.
Source: edited by the author.

[5] GÁVAI 2024.; GYARMATI – GÁVAY – HEGEDŰS 2025.
[6] SZILÁGYI et al. 2024.
[7] TYRER-JONES (2025).

3D printing is an effective method for manufacturing explosive components. It is important to note that the technology is not yet capable of producing shaped charge using explosives as printing materials, so plastic or liquid explosives must be used for their final production. . It is not necessary to manufacture all components, as the latest explosive devices are only partially improvised. The armed forces modify and supplement these otherwise standard devices to make them more effective or to enable them to be deployed from completely different weapon platforms, even UAVs.

Ukrainian forces are also using devices known as "Candy Bombs" against Russian troops. These consist of casings manufactured using additive manufacturing, which are filled with conventional plastic explosives and covered with fragments. These are mostly manufactured not by professional factories, but by volunteers, in close cooperation with users. Of course, there are no official data on their number, but the number of devices imported into Ukraine so far can be estimated at several tens of thousands. There are two other special features of this activity. Production is not carried out by professional specialists, but artificial intelligence (hereinafter: AI) based software is now used for design tasks. It is important to note that the components arrive in the recipient country as children's toys during customs clearance, thus concealing their original purpose. . Since they are made of plastic, the latter fact may not be apparent to the untrained eye.[8]

As a specific example, Ukrainian forctrainedes have converted RKG–3 anti-tank grenades in this way. The final result is an aerial bomb that can be effectively deployed using commercially available drones. According to some sources, the accuracy of the converted offensive weapons is within a 1-meter radius from a height of 300 meters. This successful development is underscored by the fact that today every Ukrainian brigade has some amount of additive manufacturing capacity.[9]

In addition to all this, Ukraine receives a great deal of support from Western countries, including 3D printers. Some of these are capable of operating reliably in operational areas. The device developed for the production of metal parts the size of shipping containers, for example, is unique in its kind and capable of producing parts weighing up to 40 kg.[10] Of course, spare parts supply is a key issue in wartime. One of the most important tools for relieving the burden on supply chains and becoming independent of them is 3D printing,[11] and there is perhaps no simpler solution for manufacturing spare parts or replacement parts, although there is a downside to everything. As We mentioned earlier, in the case of equipment and parts that are exposed to heavy loads, their service life may be significantly reduced, and maintenance cycles may be shortened. This can be compensated for with appropriate engineering expertise and material selection, and in some cases can even be improved compared to the original part

Of course, the Russian side also uses this disruptive technology, although significantly less information is available about it on the Internet and other sources. However, even in the absence of information, it can be strongly assumed that they also exploit the combat advantages inherent in additive manufacturing, which can even reach a strategic level.

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[8] DASS 2024.
[9] DASS 2024.
[10] Verdict 2024.; XSPEE3D.
[11] SABER et al. 2025: 52.

According to the available information, the Russian army also uses fixed farms where specially trained units manufacture drone components using additive manufacturing tools. Of course, based on what has been said, they are able to satisfy anyone's needs with their tools, including the manufacture of components for explosive devices.[12]

Digital warehouses

Digital repositories (databases or libraries) are structured data storage systems that are suitable for storing, managing, organizing, and searching large amounts of information (mainly design documentation). These interfaces do not function solely as information storage locations, but can also be dynamic platforms for information flow, knowledge sharing, learning, and collaboration. These digital interfaces are mostly accessible online, which can have numerous advantages if cybersecurity is also emphasized during their development.[13]

These advantages include, but are not limited to, the following:[14]

- Global, unlimited access. Online access without opening hours allows users to access digital materials stored in the database anytime, anywhere, provided they have the appropriate technical equipment and network access.
- Search and filter function. The registration, search, and filter functions in digital warehouses enable you to find the information you need quickly and efficiently.
- Significant storage capacity. Digital warehouses can store and manage huge amounts of information in digital form.
- Provision of interactive content. Digital databases offer access to interactive content (e.g., instructional videos, interactive maps, assembly instructions) and other multimedia elements.
- Easy management of changes. The content of digital warehouses can be easily updated, modified, and maintained, ensuring that users always have access to up-to-date data and information.

With the advantages listed above, such a platform provides faster, more efficient, more flexible, and more convenient access to information online, far surpassing traditional methods (traditional libraries, education, reading, etc.). Even with the security risks threatening databases, they have proven their worth in manufacturing areas.[15]

In order to ensure that the physical conditions for 3D-printing are met in a well-organized infrastructure, the personnel operating the technical equipment, technicians, and engineers must have access to the relevant information, data, and files stored in the appropriate digital format. Such a platform ensures that staff do not need design expertise; excellent management of the manufacturing equipment is sufficient to produce parts of the required quality. There are currently several open-access websites where files suitable for 3D printing can be downloaded free of charge or for a fee. The files on these sites vary, ranging from simple household items to more complex structures. The biggest disadvantage of using these files is that special military components, parts, and structures cannot be found there, as in many cases they are protected

[12] Sputnik International 2024.
[13] DARUKA et al. 2024: 76.
[14] DARUKA et al. 2024: 76–77.
[15] DARUKA et al. 2024: 77.

and restricted from the public by law, and the professional design and material selection of the parts cannot be adequately verified.[16]

According to Ukrainian officials, they already have a digital warehouse filled with digital documentation for more than 170 domestically designed components and plan to expand it radically in the future. The platform not only provides access to personnel, but also offers manufacturing services, most of which are, of course, advanced additive manufacturing capabilities. This interface connects the defence industry more closely and helps reduce dependence on supply chains. In technical terms, the repository is an online database. Only verified Ukrainian manufacturers can upload their documentation and obtain designs produced by others. Currently available items include antennas, drone frames, propellers, and special modules. A significant advantage is that it provides access to 11 different services (casting, 3D printing, etc.). These options allow manufacturers to respond to emerging needs with advanced solutions.[17]

In parallel with the operational advantages of digital warehouses, cybersecurity and information assurance emerge as critical enabling factors. As these repositories contain sensitive design data, production parameters, and in some cases classified military components, they constitute high-value targets for cyber espionage and sabotage. Compromise of such systems may result not only in the loss of intellectual property but also in the deliberate manipulation of design files, potentially leading to the production of faulty or unsafe components. Consequently, the protection of digital warehouses must extend beyond traditional access control and encryption measures and include integrity verification mechanisms, version control, and secure authentication of uploaded files. In a decentralized manufacturing environment, trust in digital design data becomes a decisive operational factor.

Decentralized manufacturing

Centralized manufacturing capacity is not a strategy that is destined to succeed in today's warfare. . Of course, this can be nuanced if the production units are located in a country that is legally protected, not directly involved in the conflict, or if the company has significant defence and countermeasure capabilities. However, these are special situations. In general, it can be said that almost the entire territory of a country involved in an armed conflict can be attacked with advanced weapons, although only the major powers have the military capacity and technological background for this. However, even more accessible deep strike systems are capable of causing significant damage to these types of facilities. . However, even more accessible deep strike systems can cause significant destruction to such facilities.

An often-underestimated element of decentralized manufacturing is the human factor. The effectiveness of additive manufacturing in combat environments does not solely depend on technological availability but also on the rapid transfer of practical knowledge to operators with limited formal engineering backgrounds. The Russo-Ukrainian conflict demonstrates that short, task-oriented training modules, standardized workflows, and intuitive manufacturing interfaces can compensate for the lack of traditional industrial expertise. In this context, digital warehouses serve not only as repositories of design files but also as platforms for accelerated

[16] DARUKA et al. 2024: 77.
[17] K., Joseph 2025.

learning, enabling soldiers and volunteers to adapt manufacturing processes to rapidly changing operational requirements.

From a strategic perspective, decentralized additive manufacturing significantly enhances system-level resilience. By distributing production capabilities across multiple geographically separated nodes, armed forces reduce their vulnerability to single-point failures caused by kinetic strikes or supply chain disruptions. Even limited-capacity manufacturing cells can maintain operational continuity by producing mission-critical components locally. This resilience-oriented approach aligns with modern concepts of adaptive warfare, where survivability and flexibility are prioritized over economies of scale.

Decentralization, on the other hand, has a significant advantage. Crowdfunding manufacturing is a new trend in this segment, but it works surprisingly well. One outstanding example of manufacturing financed by donations and community support is WildHornets. This Ukrainian military company uses the revenue generated in the manner described above to manufacture, among other things, FPV drones carrying various weapons, drone-hunting FPV UAVs, batteries, and ground control units on a 3D printing farm. They do all this using Bambulab 3D printers (Figure 2) and produce 65% of the UAVs themselves. According to their public statistics, Ukrainian troops have destroyed 151 tanks, 613 vehicles, 448 UAVs, 220 armoured vehicles, 122 artillery or MLRS units, 4 air defence units, and killed 818 soldiers. This resulted in a total loss of USD 1.69 billion for the Russian Federation.[18]

Figure 2: Drone parts made with a Bambulab X1E 3D printer

Source: edited by the author.

Of course, other manufacturers also operate such hidden factories, and as mentioned above, products are also supplied from outside Ukraine, and military units also have self-sufficient capacity.

Taking all this into account, we can comprehensively interpret decentralized manufacturing, which has both a state-organized and a voluntary branch. Both the organized and voluntary versions can be integrated into the digital warehousing system, thus facilitating the production of the tools needed for the tasks and known to the soldiers.

[18] TYRER-JONES (2025).; Wild Hornets (w. y.).

However, it is worth further dividing the elements of production according to location, because we can distinguish between plants operating in a protected environment and plants located in conflict zones, which are usually technically hidden. In the case of protected plants, the possibility of illegal, covert attacks or sabotage, even using secret service methods, must of course be taken into account.

It is also worth discussing state-organized manufacturing in order to get a complete picture of this ecosystem. This refers not only to the activities of players in the defence industry as part of traditional industry, but also to maintaining the army's self-sufficiency. Each component plays an important role, as it ensures that equipment and spare parts are available at all times. One of the keys to the success and efficiency of this system is its coordination with digital warehouses, so that all stakeholders can deliver fresh, high-quality products.

However, there are issues that need to be clarified. The right to manufacture spare parts is not unrestricted in all cases, although in the case of old equipment that is no longer supplied, this is not an issue. However, in the case of new, modern equipment, it is not always possible for the army to carry out repairs itself, and in some cases the manufacturing of replacement parts may result in serious industrial property rights infringements. A similar situation may arise if intellectual property (hereinafter: IP), designs, information, and know-how are transferred to partners via digital warehouses without the consent of the copyright holder. These legal challenges are currently the biggest known limitations of the decentralized manufacturing ecosystem,[19] and the simplest solution is a royalty-based compensation system. In principle, the number of manufactured devices can be tracked, and a fee agreed in advance between the parties is paid to the rights holder, unless they explicitly waive this right.

Beyond legal and industrial property concerns, the widespread use of additive manufacturing in armed conflicts raises ethical and international humanitarian law-related questions. The low entry threshold of 3D printing technologies blurs the traditional distinction between state and non-state actors involved in weapons production.[20] Volunteer-based manufacturing initiatives, while operationally effective, challenge established accountability frameworks. These developments necessitate a reassessment of existing regulatory approaches to weapon manufacturing and highlight the need for updated international norms addressing digitally enabled decentralized production.

Another challenge is the process of quality assurance and standardization. Military standards set high benchmarks that ensure reliable operation under difficult conditions. However, this is worth reconsidering, especially in the case of OWA devices, because in many cases the technological solutions used to manufacture the products result in unreasonably high prices.

Although this is just one example, it is definitely worth storing the documents necessary for quality assurance in a digital repository so that the organization can filter the finished products through self-checking.

This alone does not replace the importance of military acceptance. In the case of standardization, especially for UAVs, it is also worth considering the processes and defining technology circles rather than specific devices, and classifying the devices that fall within them

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[19] CHAN et al. 2018: 156–162.
[20] SUCKAU 2025: 25–26.

as applicable. Obviously, this is only if they meet the predefined parameters and the expected quality.

Summary

The Russo-Ukrainian conflict offers valuable lessons for future military planning regarding the integration of additive manufacturing, digital warehousing, and decentralized production. These practices are not limited to high-intensity conflicts but can be adapted to crisis response, peacekeeping operations, and disaster relief scenarios. The rapid scalability, flexibility, and cost-efficiency of such systems suggest that decentralized manufacturing will become a permanent element of modern military logistics rather than a temporary wartime solution.

Overall, we have managed to review and summarize – albeit not exhaustively – the practices used during the Russo-Ukrainian conflict in the context of 3D printing, digital warehousing, and decentralized manufacturing.

The results show that, technically, decentralized manufacturing could also become a possibility for proxy financing, where supporting states and market players could enter an armed conflict covertly or even openly as non-belligerents. Regardless, this system, which is often built on community funding and donations, can be an excellent foundation for a country's self-defence. It requires organization and preparation, but the benefits it provides become significantly more valuable as the intensity of operations increases.

There are still obstacles to overcome in order for this symbiosis between the three areas to function with maximum efficiency, but a solution is in sight. Moreover, once legal and quality assurance issues have been clarified, all parties can strive with increased intensity to achieve mutual success in such a system.

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