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# Doctoral thesis

# Research on the development of business models for additive manufacturing companies in the context of the circular economy

**Scientific supervisor,**

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**Andreea-Cristina N. COSTACHE (MOCANU)**

# SUMMARY
# DOCTORAL THESIS

Cercetări privind dezvoltarea unor modele de business pentru companii din domeniul fabricației aditive în contextul economiei circulare
/
Research on the development of business models for additive manufacturing companies in the context of the circular economy

**COMISIA DE DOCTORAT**

| | | |
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**- 2024 –**

# Contents

# Foreword

Research and development in the field of additive manufacturing have evolved from a fascinating technological curiosity and rapid prototyping processes to mature technologies that produce industrial-use parts, which also inspired the direction of the doctoral studies culminating in this thesis.

The advantages of additive manufacturing technologies, with applications in the automotive, aerospace, defense, and medical industries, have become increasingly complex, leading to their growing industrial use.

The doctoral program consisted of preparing, presenting, and defending exams and scientific reports, deepening the study, proposing and developing a business model in the field of additive manufacturing, conducting experimental research on the decontamination of nylon powder (PA2200), creating and publishing scientific papers, and drafting this doctoral thesis on "Research on the development of business models for companies in the additive manufacturing field in the context of the circular economy."

During the doctoral program, five papers were produced and published, of which 4 as the first author and one as a co-author. Two papers are published in ISI-indexed conference volumes, and one in an ISI-indexed journal. I participated in three international conferences, two of which were in the poster section, and one paper was summarized in the form of a Book of Abstracts.

During my doctoral studies, I participated as a member of the target group in the project "Scholarships for Entrepreneurial Education among Doctoral Students and Postdoctoral Researchers (BeAntreprenor!)", conducted within UPB.

The execution of experimental research and the drafting of scientific papers led to the writing of the doctoral thesis.

I express my gratitude and thanks to my scientific advisor, Prof. Dr. Eng. Cristian Vasile DOICIN - Dean of IIR, for his constant guidance, moral and scientific support throughout the preparation of my doctoral thesis.

I extend special thanks to the advisory committee composed of: Prof. Dr. Habil. Eng. Nicolae IONESCU, Assoc. Prof. Dr. Eng. Mihaela Elena ULMEANU, Prof. Dr. Habil. Eng. Alexandra BANU, Senior Researcher II Dr. Phys. Gabriel MOAGĂR-POLADIAN, Prof. Dr. Eng. Gheorghe MILITARU, for their involvement and professional guidance throughout the development of the doctoral thesis.

I also extend my thanks to Dr. Carmen CURUȚIU from the Faculty of Biology, University of Bucharest, for her competent guidance and support in conducting the experimental research within the faculty.

Part of the research was conducted at the National Institute for Research and Development in Microtechnologies – IMT Bucharest (IMT), where I always found understanding and support.

I extend my special thanks to the management and colleagues at the National Institute for Research and Development in Microtechnologies – IMT Bucharest (IMT), without whose support I would not have been able to conduct the specific research and complete this work.

Thanks to my colleagues: Dr. Cosmin Alexandru OBREJA, Eng. Phys. Victor MOAGĂR-POLADIAN, Dr. Eng. Roxana-Maria MARINESCU, Dr. Eng. Bianca ȚÎNCU, Dr. Phys. Oana BRÎNCOVEANU, Dr. Phys. Cosmin ROMANIȚAN, Dr. Antonio RĂDOI.

I thank my husband and my parents for their moral support, understanding, and trust.

Andreea-Cristina Costache (Mocanu)

# Introduction

UAVs (Unmanned Aerial Vehicles) are becoming increasingly used in applications they were not originally designed for, which in turn leads to the need for research and development of new accessories that can meet the growing demands of customers. Initially, UAVs were used strictly in the military industry, with the term "drones" emerging as a reference to UAVs that carried weapons.

Recently, there has been an increase in the diversity of applications for which UAVs are used, in various fields such as military, agricultural, and environmental protection, and there is a noticeable upward trend in sales. In recent years, the market demand for the acquisition of small UAVs (microdrones) has expanded. Currently, they are widely used for both personal and professional purposes.

According to the report presented by Drone Industry Insights in June 2020, shown in Figure 1, the market trends in the drone industry are continuously rising. At the end of 2019, global drone sales were recorded at 17.6 billion. By 2025, sales are expected to exceed 42.8 billion (Schroth, 2020).

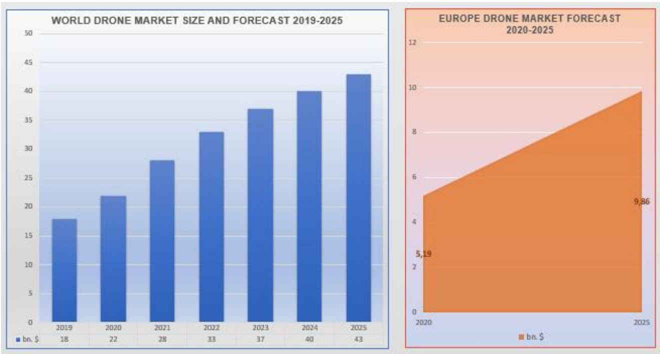



Figure 1 - The Drone Market and Forecast for the Years 2020-2025 (Schroth, 2020)

Depending on the field of UAV usage, certain specifications are required for their increasingly complex accessories, which can no longer be produced through traditional manufacturing methods. This has led to the necessity of establishing an SME that operates in the field of additive manufacturing, specifically in the production of UAV accessories through additive technologies in a sustainable manner.

The importance of the doctoral thesis topic is shaped by the current identified requirements and needs.

* * *

The doctoral thesis focuses on the main types of additive manufacturing (AM) technologies in the category of Powder Bed Fusion (PBF) processes.

After 40 years of history, Selective Laser Sintering (SLS) technology is a mature and suitable alternative for diverse and profitable applications (Chua C.K., 2014).

SLS technology, as part of the Powder Bed Fusion process, allows great flexibility in part design, along with the possibility of producing topologically and mechanically optimized objects. While these characteristics are specific to any AM technology, SLS technology offers an additional advantage: it does not require support structures, thus minimizing post-production time and the costs of manufactured objects.

SLS technology can be applied in many fields, with active commercial applications already in the automotive and aerospace sectors. Business models are continuously developing, and a specific area of interest where this technology is being used is UAVs (J. Savolainen, 2020), (W. Liu, 2019) (D. Strong, 2018). These represent an important market ranging from the most advanced and largest drones used for military purposes to the smallest UAVs used for goods delivery, land inspection (e.g., crop condition, high-voltage power lines, forest condition, or local pollution), and photo-video recording.

EASA (European Union Aviation Safety Agency) has developed common regulations across all EU member states regarding UAV flights. As of January 1, 2021, the new EU Regulation No. 2019/947 on the free movement of UAVs came into effect. Thus, in Romania, this current information has been published on the website of the Romanian Civil Aeronautical Authority (AACR). UAVs are classified into three categories based on their weight, as follows: <250 g; between 250 g and 2 kg; and between 2 kg and 25 kg. Another classification is based on the nature of the flight and the associated risks: Open, Specific, or Certified (AACR, 2020).

As of January 1, 2021, drone registration (90 EUR + VAT) and in-person visits to the AACR headquarters are no longer mandatory. Only the online registration of the pilot on the platform is required. For UAVs equipped with photo-video cameras (regardless of weight), users must register each device they own on the AACR platform and will receive a unique identification code. Additionally, for devices weighing more than 250 g, a remote pilot certificate must be obtained. This certificate is obtained through an online exam consisting of 40 questions for A1/3 certification (for flights outside cities) and 30 questions for A2 certification (flights in cities). To pass the exam, at least 75% of the questions must be answered correctly (for A1/3, 30/40 questions; for A2, 23/30). The platform was activated on January 22, 2021 (AACR, 2021).

The main objective of the doctoral thesis is to develop a business model for an SME operating in the field of additive manufacturing, using an industrial 3D printing system, the Formiga P 100 from EOS, with the capability to produce small and medium series objects, quickly change their size or geometry, and reduce costs compared to traditional methods for plastic parts - molding or manufacturing in a mold. The SME produces accessories with applications in the aerospace industry, developing specific parts for UAVs, starting from identifying customer needs and customizing various accessories for different types of devices. The objects are made from Nylon 12 (PA2200), which offers several important advantages: rapid part construction, minimal post-processing time, good material reliability and strength, and reduced costs. The decision to manufacture these products required a detailed cost-benefit analysis and a new direction for commercial activities.

One of the most significant human impacts on the environment is the presence of polymeric microparticles. These microparticles are found in almost every corner of the Earth and have dramatic consequences for the biosphere. Solving this problem requires the development of new management models regarding the manufacturing, use, and disposal of polymers.

The secondary objective of the doctoral thesis focused on reducing the environmental impact of polymers by recovering waste, purifying, and reusing powders as raw materials in other industries. This results in a new business model developed from the main model. Experimental research on the cleaning and decontamination of nylon powders (PA12) resulting from additive manufacturing activities was conducted by monitoring the presence of various types of aerobic bacteria, yeasts, and filamentous fungi, and different microorganisms. Morphological and spectral characterization was performed to determine how the reagents used for powder decontamination affect the polymer structure and its subsequent use. All results are presented in the personal contributions section.

# Part I. The Current State of Research on the Development of SMEs in the Field of Additive Manufacturing

## *Chapter 1*. Additive manufacturing technologies

Additive manufacturing technologies date back to the early 1980s, initially known as rapid prototyping technologies (Print 3D Bucuresti, n.d.) (Ulmeanu, 2015).

Initially, these additive manufacturing technologies advanced in small steps, but they have now seen industrial expansion, both in software and hardware.

In 1986, Charles Hull obtained the patent for stereolithography devices. The object is constructed in a vat of resin, upon which a laser or another light source acts to solidify each layer until it is completed. This manufacturing process is known as photopolymerization.

Carl Deckard obtained the patent for Selective Laser Sintering (SLS) technology in 1989. Initially, this technology was used on a small scale due to high costs and limited application in various industries (Additive-X, 2016).

Currently, sales of 3D printers have seen a significant increase due to the growing demand for 3D printed objects (James A. Gopsill, 2017).

The increase in the number of manufacturers has led to a reduction in printing costs, making it competitive even compared to traditional manufacturing methods (James A. Gopsill, 2017) (Ulmeanu, 2015).

**Standardization in the Field of Additive Manufacturing**

Since 2008, standardization associations in Europe have begun developing standards in the field of additive manufacturing, such as DIN (German Institute of Standardization): NA 145-04 and AFNOR (Association Française de Normalisation/French Standardization Association): UNM 920 (Popescu, 2016 ). The NA 145-04 standard, developed by DIN, refers to "Additive Manufacturing - Interdisciplinary Topics/Digitalization," while the UNM 920 standard, developed by AFNOR, refers to "Additive Manufacturing – Industrial Engineering, Equipment, and Materials."

By the end of 2011, ISO (International Organization for Standardization) and ASTM (American Society for Testing and Materials) had already jointly developed the following standards for additive manufacturing:

1. ISO/ASTM 52915:2013 Standard Specification for Additive Manufacturing File Format AMF Version 1.1
2. ISO/ASTM 52921:2013 Standard Terminology for Additive Manufacturing – Coordinate Systems and Test Methodologies.

The main stages of object construction are illustrated in Figure 2.

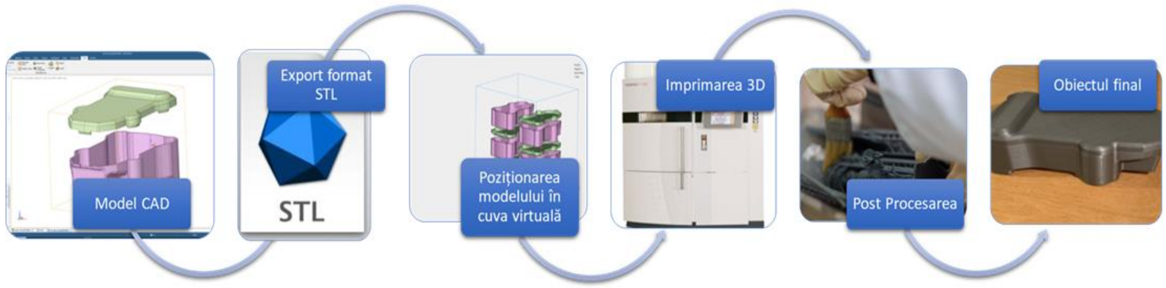



Figure 2 – The main stages of 3D construction

**Types of Additive Manufacturing Technologies**

The classification of the main additive manufacturing technologies within the Powder Bed Fusion (PBF) process is as follows (Casini, 2022):

- Selective Laser Sintering (SLS);
- Selective Laser Melting (SLM);
- Direct Metal Laser Sintering (DMLS);
- Electron Beam Melting (EBM).

***Selective Laser Sintering (SLS)***

In the process of fabrication 3D objects using the SLS method, materials such as polymers, ceramics, and metals are used. These materials are in powder form.

The working process is illustrated in Figure 3. Thin layers of powder material are deposited in the working tank of the 3D printer. The laser beam (with a power of 30 – 400 W) acts on the material until it reaches the melting temperature, allowing the fusion of the powder grains to transform them into a solid mass. The intensity of the laser beam is adjusted to melt and shape the object only in the area of interest. When the layer is completely built, the piston lowers, allowing the deposition of a new layer of powder. This process is repeated until the object is fully constructed. The deposition system is also equipped with a blade that gently presses the material to make the object denser. After the complete fabrication of the 3D object, post-processing is necessary. Post-processing involves removing the remaining powder grains, removing support structures (mandatory in the case of metals), and optional sanding or painting (Chua C.K., 2014).

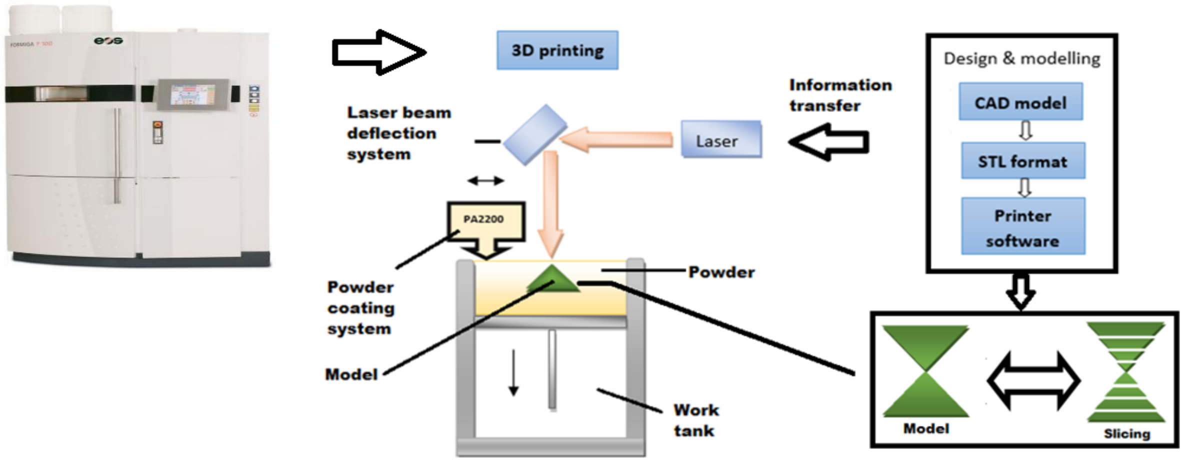



Figure 3 – SLS Working model (A.C. Mocanu (Costache), 2023)

**Applications of 3D Printing**

3D printing is applied in various industries such as the automotive and aerospace industries, where the relevant aspects are: reducing the weight of components, reducing the number of components by redesigning them as a complex unitary assembly, and creating complex geometries. In the military industry, weapons and spare parts for ships are produced, while in the medical industry, 3D printing is used for constructing objects analogous to natural bone structures and dental implants with porous characteristics for better surface fixation. Among the objects made for the medical industry such as: prostheses, hip implants, knee implants, hearing aids, blood vessels, and organs. 3D printed products improve the patient's comfort level by allowing interaction with products specifically designed for their needs. The input data is taken directly from CT or MRI scans (3DHubs, n.d.).

# *Chapter* 2. The current state of business models in the field of additive manufacturing

In specialized literature, a business model is a system of interconnected activities that describes how a company will generate revenue and profit. The business model includes details about the products or services offered, the channels and resources needed to deliver and provide the products or services. It also details the costs necessary for the products or services offered (Carlos M. DaSilva, 2014).

**Globally companies data in the field of additive manufacturing**

The business models adopted by global companies in the field of additive manufacturing have been analyzed.

Companies such as Stratasys (an American company founded in Israel), General Electric Additive, Arcam, EOS GmBh, 3D Systems (an American company), Ultimaker (a Dutch company), Voxel Jet, and Materialise (a Belgian company) have opted for the Business to Business (B2B) model. These companies rely on the sale of 3D printers, consumables, related accessories, software packages, additive manufacturing services, design services, consulting services, and on-demand production services for companies.

RepRap is an open-source 3D printing project from the UK that has become very popular in the Do It Yourself (DIY) community. The project's goal is to create a 3D printer that can print most or even all of the components needed to build a copy of itself (RepRap Company, n.d.) (John L Irwin, 2014).

The business model of companies like 3D Hubs and ShapeWays is platform-based and Business to Consumer (B2C). The platform offers a flexible and accessible solution for accessing additive manufacturing technology. The business model is based on an online 3D printing platform that provides additive manufacturing services to customers worldwide. The platform allows users to connect with 3D printer owners around the world. It offers customers the ability to upload 3D models and select from a variety of material options and 3D printing technologies to obtain production quotes (TINGJIE LI, 2017).

**Statistics on Romanian companies in the field of additive manufacturing**

The main codes, according to the statistical classification of national economic activities (CAEN), for companies whose activity is 3D printing are as follows:

- 1812 Other printing activities n.e.c. This class includes relief printing machines, including rapid printing machines.
- 2229 Manufacture of other plastic products.
- 7410 Specialized design activities. This CAEN code includes industrial design.

A detailed analysis shows that there are currently 58 companies in Romania operating in the field of 3D printing and design. The classification of these companies according to the CAEN code is illustrated in Figure 4.

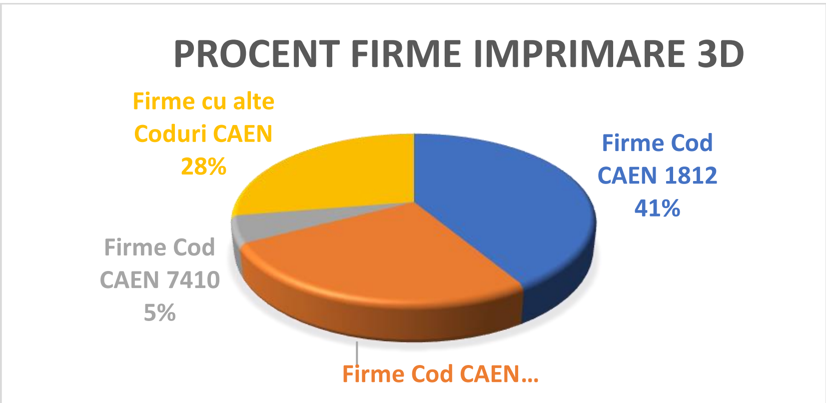



Figure 4 - Classification of companies according to the CAEN code

Out of all the analyzed companies, totaling 58, only 42 are relevant for this study. 24 of the companies have the primary CAEN code 1812, 15 have the code 2229, and 3 have the CAEN code 7410.

The manufacturing technologies used are FDM (predominantly with materials such as PLA and ABS), one company uses SLS, and one uses FDM, SLA, and SLS.

For these companies, financial data such as turnover, net profit, and the average number of employees for the period 2020-2022 were analyzed. The largest share of businesses is in the range of 0-50.000 RON. At the end of 2022, only 19 reported a profit of the analyzed companies.

**Cirular Economy**

The circular economy has become a topic of interest in the last decade. The main principles of the circular economy are the elimination of waste and pollution, keeping products and materials in use, and regenerating natural systems. The circular economy brings benefits to the environment. Reduced the negative impact of pollution by eliminating waste, which harms human health and natural systems such as air, water, and soil pollution. (European Parliament, 2023).

The main elements that describe the circular economy are presented in Figure 5.

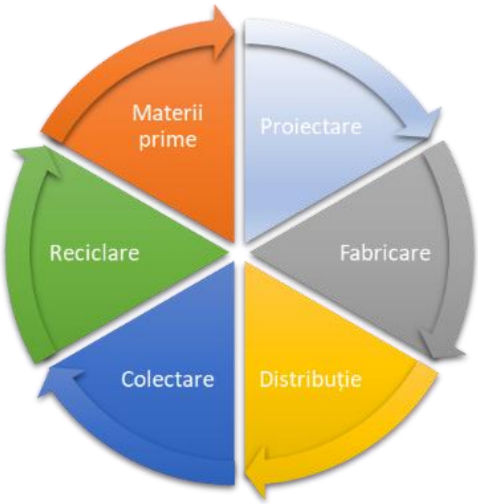



Figure 5 – Circular economy

In September 2022, the National Strategy on the Circular Economy was published in the Official Monitor of Romania. The main goal of this strategy is to create a long-term vision and strategic direction (Guvernul României, 2022).

The transition from a traditional economy to a circular economy must be made progressively so as not to affect quality, competitiveness, and performance, considering that the business environment in Romania is predominantly characterized by SMEs. The transition to a circular economy challenges businesses to rethink their business models to use resources and materials for as long as possible, gradually eliminate waste, and reduce pollution, thereby eliminating negative effects on the environment (Guvernul României, 2022).

# *Chapter* 3. Conclusions of the current state of SME development in the field of additive manufacturing

From current state analysis of additive manufacturing technologies and the statistics on companies in the field of additive manufacturing, important conclusions can be drawn as follows:

Selective Laser Sintering is a mature technology, competitive with traditional methods in terms of more complex geometries, reducing the weight of components, creating a complex unitary assembly. The products made have applications in fields such as the automotive, aerospace, military, and medical industries.

Due to the increasing volume of three-dimensional object manufacturing and the rising sales of 3D printers, the cost of 3D printing has decreased. Additive manufacturing technologies have become competitive with traditional methods in terms of time, more complex geometries, reducing the amount of material waste, and the costs involved.

The analyzed business models are of the B2B type (selling 3D printers and CAD design or printing preparation software to other companies), B2C (selling 3D printers to end users, individuals), and platform type (offering a wide range of production services).

In Romania, the first companies in the field of additive manufacturing were established in 2014. In 2017, there was an increase in the number of newly established companies. The year 2019 recorded the highest number of newly established companies. The pandemic also affected this field of activity, with the number of newly established companies decreasing during this period. In 2022, there was a recovery. The analyzed companies in the field of additive manufacturing in Romania approach the traditional economy. For this reason, the opportunity to establish an SME with the primary activity of additive manufacturing and the secondary activity of polymer recycling was identified, to fit into the context of the circular economy.

The circular economy is an alternative solution to the traditional economy. In practice, the circular economy differs from the traditional economic model. This circular economy approach promotes reuse and recycling activities to keep products and materials in circulation in the economy, thus reducing the negative impact of pollution.

# Part II. Contributions to the development of business models in the field of additive manufacturing in the context of the circular economy

## *Chapter 4. Directions, main objective, and methodology of research-development*

Based on the data from the current state analysis, the following research-development directions are considered relevant for the establishment of an SME in the field of additive manufacturing:

- Developing an original structure for generating business models with activities in the field of additive technologies.
- Research on the use of 3D printing technologies for prototyping and creating complex end-use parts.
- Developing sustainable technologies for manufacturing with rapid modification of characteristics and dimensions of components for UAVs.
- Experimental research on the decontamination of Nylon powder, microbial contamination control, and morphological and spectral characterization of the powder.

The main objective of the thesis is to develop a business model with activities in the field of additive manufacturing. As a case study, a business dedicated to manufacturing components for small UAVs using Selective Laser Sintering (SLS) technology, utilizing Nylon 12 powder (PA12/PA2200), will be analyzed.

The secondary objective of the thesis is to develop a method for recovering, recycling, and reusing Nylon powder so that the company can transition to a circular economy.

The methodology of research-development is designed as a reference system for the actions to be undertaken to achieve the main objective of the doctoral activity, as well as for future developments.

- Identifying the opportunity for producing UAV components in Romania.
- Developing specific business models for establishing an SME in the field of additive manufacturing with the potential to integrate into the circular economy.
- Applying the AHP method to determine the optimal variant for establishing the SME.
- Developing scenarios for establishing the business and analyzing the financing structure for implementation.
- Manufacturing complex accessories for UAVs. The process consists of design, CAD modeling, and 3D printing.
- Recovering, decontaminating, and recycling Nylon 12 powder.
- Determining microbial contamination.
- Studying the effect of the decontamination process on the structure and composition of Nylon 12 powder.

# *Chapter* 5. Contributions regarding the development of innovative business models in the field of SLS technologies

In the context of establishing an SME in the field of additive manufacturing, threats must be managed in detail, and an appropriate strategy must be created for future challenges by detecting potential business risks. Any small company, at the beginning of its journey, must maintain flexibility and adapt its strategy to cope with the constantly changing business environment.

Given that the trend for UAVs is continuously growing and the demand for related accessories is increasing, the company aims to adapt to market requirements and produce customized accessories on demand according to customer specifications. The company offers on-demand design services.

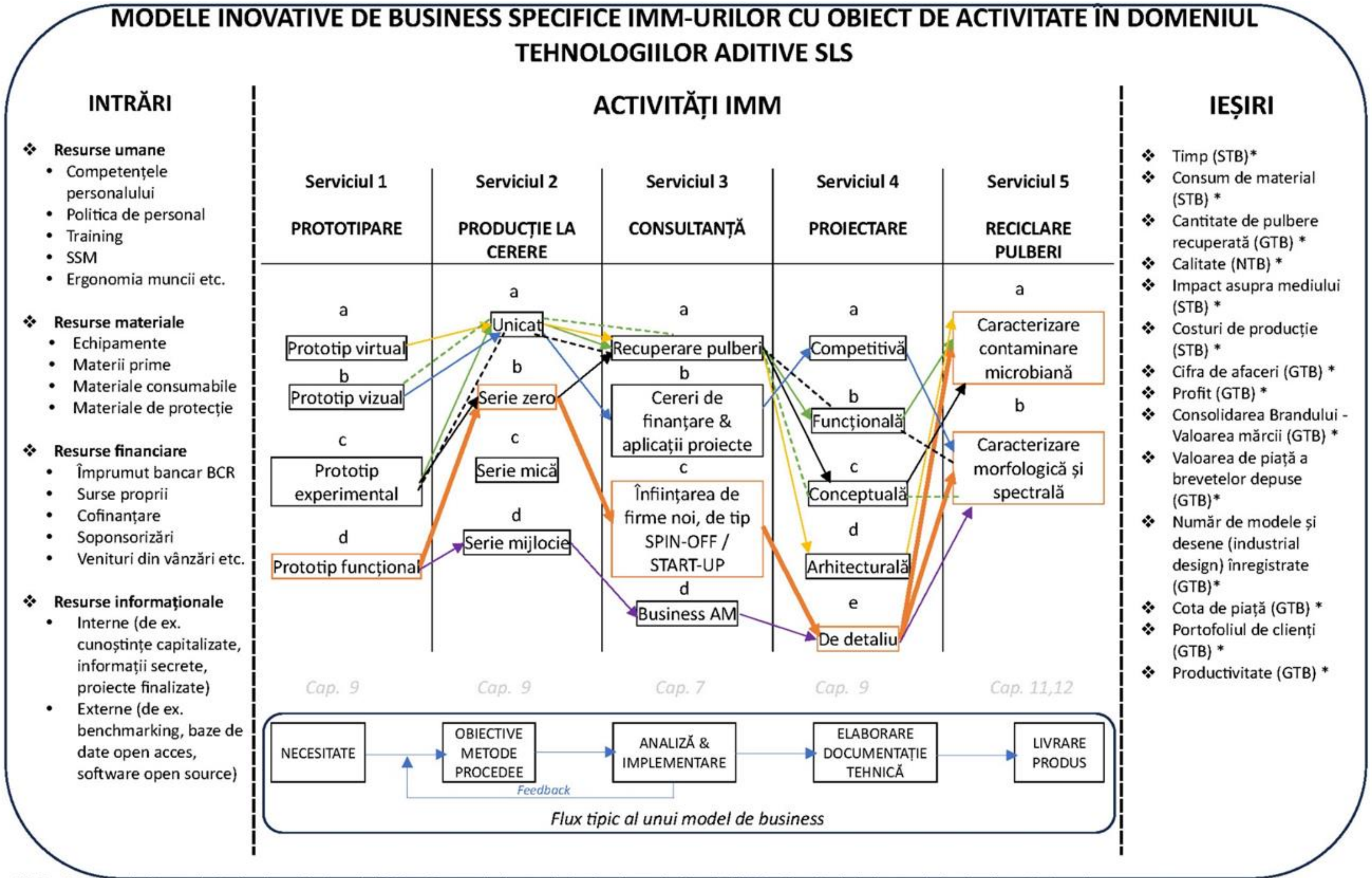
The possibility of establishing a Spin-Off business has been identified, which offers the opportunity to strengthen relationships with the industrial environment and the possibility of using the workspace and equipment of the collaborator.

**Developing innovative business models in the field of additive manufacturing**

In the diagram presented in Figure 6, based on the SWOT analysis and the current state, an original structure is proposed for generating business models with activities in the area of SLS additive technologies. By combining the services within the SME's activities, 640 theoretically possible business models emerge. A client can choose any combination of services from the SME's activities.

Regarding the SME's activity, the following services are outlined:

1. **Prototyping:** In terms of prototypes, virtual, visual, experimental, or functional prototypes can be created. Virtual prototypes represent design in specialized software programs, visual prototypes look like the desired object but do not fulfill its functions, being just a model, the experimental prototype, and the functional prototype fulfills the desired functions but does not have an optimized design.
2. **Production on-demand** is done according to the client's needs. Products can be produced in unique series (a single product or a few copies according to a client's requirements), zero series (less than 50 pieces), small series, or medium series.
3. **Consultancy** in powder recovery, funding applications, establishing new spin-off and start-up companies, and Business AM.
4. **Design on-demand** at different levels: competitive design - benchmarking, functional design - determining the product's functions, conceptual design - establishing concepts, architectural design - determining the product's architecture, and detailed design.
5. **Powder recycling**, which can include two analyses. This service includes microbial contamination characterization and morphological and spectral characterization.




*STB – Smaller the better (criteriu de minimizare) / GTB – Grater the better (criteriu de maximizare) / NTB – Nominal the better (criteriu de optimizare)

Figure 6 – General diagram of innovative business models

Among the 640 models, were selected eight business models, identified in Figure 6 by arrows of different colors. The business models are outlined based on the combination of the SME's activity services. The choices of business models are based on the analysis presented in the current state. The current state of business models refers to services 1, 2, 3, and 4 from the diagram presented in Figure 6.

**Choosing the optimal business model**

According to the general diagram of innovative business models, shown in Figure 6, regarding the characteristics of a business model, it is considered that the most important criteria by which the eight business models can be analyzed multicriterial are: profit, turnover, recovered powder, market share, and client portfolio.

To select the optimal model among the eight models, was used the AHP method because it is recognized as one of the most efficient multicriteria analysis methods (Saaty & Peniwati, 2008) (Forman & Gass, 2001) (Dincă LL., 2018). The AHP method is applied in two stages. The first stage consists of determining the weight of the criteria, and the second stage consists of determining the optimal business model (Saaty & Peniwati, 2008).

For the calculation of weights, the BPMSG platform was used (Goepel, 2018) In the evaluation of criteria according to the AHP priorities analysis, importance was assigned as shown in Figure 7.

The highest score given is 5. The criteria were considered quite close in terms of importance. The first two most important criteria that form the basis of any business are Profit and Turnover. The next criterion in order of importance is the amount of recovered powder because the SME aims to adopt a circular economy approach.

With respect to *AHP priorities*, which criterion is more important, and how much more on a scale 1 to 9?

| | A - wrt **AHP priorities** - or B? | | Equal | How much more? |
|---|---|---|---|---|
| 1 | ◉ Profitul | ○ Cifra de afaceri | ○ 1 | ◉ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 2 | ◉ Profitul | ○ Cantitatea de pulbere recuperata | ○ 1 | ○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 3 | ◉ Profitul | ○ Cota de piata | ○ 1 | ○ 2 ○ 3 ◉ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 4 | ◉ Profitul | ○ Portofoliul de clienti | ○ 1 | ○ 2 ○ 3 ○ 4 ◉ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 5 | ◉ Cifra de afaceri | ○ Cantitatea de pulbere recuperata | ○ 1 | ◉ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 6 | ◉ Cifra de afaceri | ○ Cota de piata | ○ 1 | ○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 7 | ◉ Cifra de afaceri | ○ Portofoliul de clienti | ○ 1 | ○ 2 ○ 3 ◉ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 8 | ◉ Cantitatea de pulbere recuperata | ○ Cota de piata | ○ 1 | ◉ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 9 | ◉ Cantitatea de pulbere recuperata | ○ Portofoliul de clienti | ○ 1 | ○ 2 ◉ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |
| 10 | ◉ Cota de piata | ○ Portofoliul de clienti | ○ 1 | ○ 2 ○ 3 ◉ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 |

CR = 0% Please start pairwise comparison

Calculate

AHP Scale: 1- Equal Importance, 3- Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance (2,4,6,8 values in-between).

Figure 7 – The importance of criteria according AHP priorities analysis

In Figure 8, the comparison matrix of the criteria and the weights for the criteria are presented, according to the principles previously stated, generated by the BPMSG online application (Goepel, 2018) based on the entered data.

The resulting weights are based on the principal eigenvector of the decision matrix:

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 1 | 2.00 | 3.00 | 4.00 | 5.00 |
| 2 | 0.50 | 1 | 2.00 | 3.00 | 4.00 |
| 3 | 0.33 | 0.50 | 1 | 2.00 | 3.00 |
| 4 | 0.25 | 0.33 | 0.50 | 1 | 4.00 |
| 5 | 0.20 | 0.25 | 0.33 | 0.25 | 1 |

Principal eigen value = 5.196
Eigenvector solution: 5 iterations, delta = 3.7E-8

a. The comparison matrix of the criteria

These are the resulting weights for the criteria based on your pairwise comparisons:

| Cat | | Priority | Rank | (+) | (-) |
|---|---|---|---|---|---|
| 1 | Profitul | 41.2% | 1 | 9.1% | 9.1% |
| 2 | Cifra de afaceri | 25.9% | 2 | 5.9% | 5.9% |
| 3 | Cantitatea de pulbere recuperata | 15.8% | 3 | 3.9% | 3.9% |
| 4 | Cota de piata | 11.6% | 4 | 5.4% | 5.4% |
| 5 | Portofoliul de clienti | 5.5% | 5 | 1.9% | 1.9% |

Number of comparisons = 10
Consistency Ratio CR = 4.4%

b. The weights for the criteria

Figure 8 – Establishing the weights for the criteria

The BPMSG platform generated the weights for the five analyzed criteria. Profit is the most important parameter of the business model, with a weight of 41.2%. The next criterion in order of importance, with a weight of 25.9%, is turnover. This parameter is important because it shows the scale of the business. The third criterion is the amount of recovered powder, with a weight of 15.8%. The last two criteria are market share with a weight of 11.6% and client portfolio with a weight of 5.5%.

The next steps for identifying the optimal business model consist of creating the ranking matrix (Table 1) and preparing the decision matrix (Table 2). In the ranking matrix, business model 6 was considered as the reference.

Table 1 – The comparison of business models based on the five criteria

| Modele / Criterii | Model 1 *1a2a3a4d5a* | | Model 2 *1b2a3a4c5b* | | Model 3 *1b2a3b4a5b* | | Model 4 *1c2a3a4b5a* | | Model 5 *1c2a3a4b5b* | | Model 6 *1c2b3a4c5a* (Ref) | | Model 7 *1d2b3c4e5ab* | | Model 8 *1d2d3d4e5b* | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ierarhizare | Fracțiune din total | Ierarhizare | Fracțiune din total | Ierarhizare | Fracțiune din total | Ierarhizare | Fracțiune din total | Ierarhizare | Fracțiune din total | Ierarhizare | Fracțiune din total | Ierarhizare | Fracțiune din total | Ierarhizare | Fracțiune din total | | |
| Profitul | 1 | 0.045 | 2 | 0.091 | 2 | 0.091 | 3 | 0.136 | 3 | 0.136 | 3 | 0.136 | 4 | 0.182 | 4 | 0.182 | 22 | 1,000 |
| Cifra de afaceri | 1 | 0.045 | 2 | 0.091 | 2 | 0.091 | 3 | 0.136 | 3 | 0.136 | 3 | 0.136 | 4 | 0.182 | 4 | 0.182 | 22 | 1,000 |
| Cantitatea de pulberi recuperată | 2 | 0.091 | 2 | 0.091 | 2 | 0.091 | 2 | 0.091 | 2 | 0.091 | 3 | 0.136 | 5 | 0.227 | 4 | 0.182 | 22 | 1,000 |
| Cota de piață | 3 | 0.103 | 3 | 0.103 | 4 | 0.138 | 3 | 0.103 | 3 | 0.103 | 3 | 0.103 | 5 | 0.172 | 5 | 0.172 | 29 | 1,000 |
| Portofoliul de clienți | 3 | 0.103 | 3 | 0.103 | 4 | 0.138 | 3 | 0.103 | 3 | 0.103 | 3 | 0.103 | 5 | 0.172 | 5 | 0.172 | 29 | 1,000 |

* Business model 6 (***1c2b3a4c5a)*** was considered as the reference

To determine the optimal option, each business model is compared with the reference, and scores from 1 to 5 are given, where 1 is evaluated much worse than the reference model and 5 is evaluated much better than the reference model. To normalize the values (so that their sum equals 1), each given score was divided by the total for the row, resulting in fractions of the total.

In Table 2, the decision matrix was created. The first column lists the five analyzed criteria, the second column lists the weights obtained in Figure 8 for each criterion, and columns 3-10 list the fractions of the total for each business model.

Table 2 – Decision matrix

| Criterii | Pondere | Modelul 1 | Modelul 2 | Modelul 3 | Modelul 4 | Modelul 5 | Modelul 6 | **Modelul 7** | Modelul 8 |
|---|---|---|---|---|---|---|---|---|---|
| Profitul | 0.412 | 0.045 | 0.091 | 0.091 | 0.136 | 0.136 | 0.136 | **0.182** | 0.182 |
| Cifra de afaceri | 0.259 | 0.045 | 0.091 | 0.091 | 0.136 | 0.136 | 0.136 | **0.182** | 0.182 |
| Cantitatea de pulberi recuperată | 0.158 | 0.091 | 0.091 | 0.091 | 0.091 | 0.091 | 0.136 | **0.227** | 0.182 |
| Cota de piață | 0.116 | 0.103 | 0.103 | 0.138 | 0.103 | 0.103 | 0.103 | **0.172** | 0.172 |
| Portofoliul de clienți | 0.055 | 0.103 | 0.103 | 0.138 | 0.103 | 0.103 | 0.103 | **0.172** | 0.172 |
| TOTAL | 1.000 | 0.063 | 0.093 | 0.099 | 0.124 | 0.124 | 0.131 | **0.187** | 0.180 |

The total for each business model is obtained by multiplying each criterion's weight by the corresponding fraction of the total and summing all the results from the multiplication.

The business model that the SME adopts in establishing the business in the field of additive manufacturing is illustrated by orange arrows in Figure 6. Thus, the newly established business model is based on creating a functional prototype, with zero series production (up to 50 pieces). The SME focuses on manufacturing parts according to customer needs, on demand. The aim is to establish a spin-off business, which is based on detailed design, and from the perspective of powder recycling, it involves microbial contamination characterization and morphological and spectral characterization.

# *Chapter* 6. Characterization of developed business model

The optimal business model previously presented involves establishing a business in the field of additive manufacturing, using Selective Laser Sintering (SLS) technology and developing in two directions: the main direction consists of additive manufacturing of parts, using 100% powder purchased from specialized suppliers or in a ratio of up to 1:1, recycled powder and fresh powder, and the secondary business direction, which offers novelty to this business model, consists of the fact that Nylon powder, which can no longer be reused in a new manufacturing cycle, will be recycled and sold for the manufacture of films used as packaging material, after undergoing recovery, filtration, and decontamination stages, thus allowing its reuse as raw material in another industry, protecting the environment, reducing costs and waste, in an effort associated with the concept of a circular economy.

The new business will be an SME, with a Limited Liability Company (LLC) chosen as the form of organization, due to several advantages: the company's associates are liable to creditors with the company's assets, the company can include multiple CAEN codes in its activity object, and the possibility of choosing the business taxation method. The company, UAV 3D Printing Lab SRL, has a share capital of 200 RON and a production activity domain. The company will be non-VAT paying. According to the law, in Romania, any newly established company is non-VAT paying. For a company to become VAT paying, it must exceed the threshold of 300,000 RON in turnover or submit a request to ANAF to change its status to a VAT-paying company.

The inputs into the SME's activities, according to the diagram presented in Figure 6, are human, material, financial, and informational resources.

The management of the company SC UAV 3D Printing Lab SRL is ensured by the legal representative of the company, Eng. Ec. MOCANU Andreea-Cristina.

The legal representative of the company graduated from the Faculty of Entrepreneurship, Engineering, and Business Management, in the field of Engineering and Management, with a master's degree in Economic Engineering and Business Management at the Faculty of Engineering and Management of Technological Systems (formerly IMST, currently FIIR) and is a PhD student in the field of Industrial Engineering.

Within the project, two new jobs will be created for design engineers. The employees will do training courses to correctly use the equipment and will also be trained in occupational health and safety and work ergonomics.

The working hours are Monday to Friday from 8:00 to 16:30 (30 min lunch break).

The registered office of the new company will be in Ilfov County, Voluntari locality, Erou Iancu Nicolae Street No. 126 A. The registered office is in a rural locality, where the number of SMEs at the county level per 100 inhabitants is greater than 4.

For the investment sizing, all tangible and intangible assets were considered, totaling a general amount of 831,005 RON.

# *Chapter* 7. Contributions according to the development of business scenario

Consulting services regarding business development scenarios are illustrated in service 3 of the innovative business model diagram (Figure 6).

The scenario method involves prospective analysis and probabilistic modeling of the possible implications of current and/or past events on the future (Popa, 2015).

To illustrate the costs, sources of financing, and business sustainability, were created three development scenarios. Each scenario is based on investment project evaluation indicators. The calculated indicators are: Net Present Value (NPV), Profitability Index (PI), and Internal Rate of Return (IRR) (Elena Valentina Ţilică, 2020), (Militaru, 2013).

Three different scenarios (unfavorable, probable, and favorable) were analyzed in terms of initial investment and sources of financing. In all three scenarios, the own contribution is 23,500 EUR, with differences being given by the value of the bank loan and obtaining a non-refundable financial allocation by submitting the business plan within the Start-Up Nation program. The revenue forecast is the same in all three scenarios and is reflected in the company's short and long-term objectives.

For all scenarios, the costs involved in the financial analysis include total investment costs, raw material costs, and operational costs. Raw material costs are the same for all scenarios (referring to the stocks of nylon powder used in the manufacturing process of objects). Nylon powder is sold in 20 kg plastic bags, at a price of 1,200 EUR/bag (60 EUR/Kg). Operational costs are expenses related to the company's main activity, such as administrative expenses (salaries, rent, and utilities for the first 3 months of activity) and marketing expenses.

Monthly costs are presented in Figure 9. For the company's production activity, the same operational costs will be considered for all three scenarios.

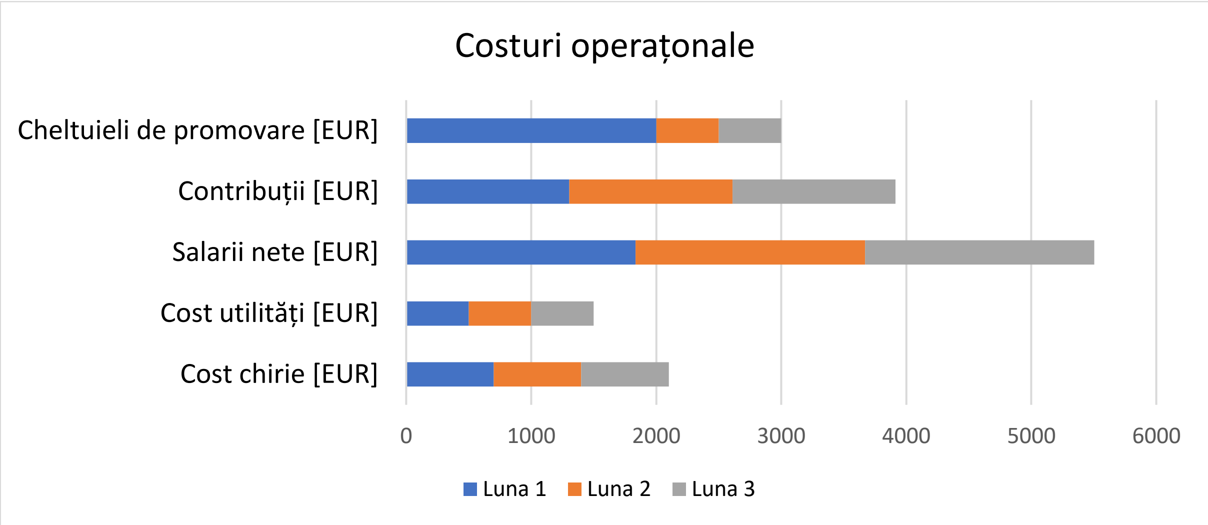



Figure 9 – Chart of administrative expenses for the first 3 months of activity

Investment costs refer to the cost of equipment and software applications necessary for the activity. For the establishment of the SME, investments are required for the following equipment and auxiliaries, depending on the chosen scenario: Formiga P100 3D printer, furniture (3 desks, 3 chairs, a shelf cabinet), computers and related accessories: mouse, keyboard, headphones, CAD design software (ANSYS SpaceClaim), and investments in stocks (consumables - Nylon 12).

**Scenario 1 – Unfavorable scenario**

The unfavorable scenario involves renting the workspace, purchasing the industrial 3D printer, purchase of furniture, workstations, and specialized software.

The investment costs required for project implementation consist of purchasing a Formiga P100 3D printer (142,600 EUR), three computers (3,000 EUR), two ANSYS SpaceClaim software licenses (5,000 EUR), one Materialise Magics software license (2,000 EUR), three desks, three chairs, a shelf cabinet (2,000 EUR), and setting up the workspace with a usable area of 80 sqm – industrial epoxy flooring (3,000 EUR) and ensuring a buffer amount of 5,000 EUR. The space is rented in the Pipera industrial area on Erou Iancu Nicolae Street 126 A and is distributed as follows – 30 sqm offices and 50 sqm production area.

The total costs are illustrated in Table 3.

Table 3 – Total Costs – Unfavorable Scenario

| Cost de investiție [EUR] | Costul cu stocurile de Nailon 12 [EUR] | Cost operațional Pentru primele 3 luni [EUR] | Cost total [EUR] |
|---|---|---|---|
| 162.600 | 2.400 | 16.000 | 181.000 |

Table 4 - Financing structure of the investment project – Unfavorable Scenario

| Sursa de finanțare | Scenariu nefavorabil | |
|---|---|---|
| | [EUR] | % |
| Aport propriu | 23.500 | 12,98 |
| Credite bancare | 157.500 | 87,02 |
| TOTAL valoare de investiție | 181.000 | 100 |

To implement the investment project, is required a bank loan of 157.500 EUR, equivalent to 779.625 RON for ten years (120 months), at an exchange rate of 1 EUR = 4,95 RON. The interest rate provided by the bank is 15% per year. The amount of money that will be paid at the end of the ten years is 227.482 EUR, equivalent to 1.126.036 RON. This amount was calculated using the online credit calculator for legal entities from BCR on September 8, 2022. The monthly debt for bank loans amounts to 2.539,60 EUR/month, equivalent to 12,571.07 RON/month.

$$RL = \frac{\frac{15\%}{12} \cdot 157.500}{1-(1+\frac{15\%}{12})^{-120}} = 2.539,60\ EUR \tag{1}$$

The profit and loss account for the first three years of the company's activity was made. In the first year of activity, a loss of 16.575 EUR is anticipated, while in the next two years, profit is expected as follows: in the second year of activity 80.010 EUR, and in the third year 186,820 EUR.

Additionally, a cash flow forecast for a period of three years was made. The cash flow is illustrated in the third column of Table 5.

Table 5 –The substantiation decision

| An | Element | Valoare Flux de numerar | VAN | RIR | IP |
|---|---|---|---|---|---|
| 0 | Investiția | 132.042 | | | |
| 1 | CF1 | -14.871 | 139.173,26 | 57% | 0,05 |
| 2 | CF2 | 57.917 | | | |
| 3 | CF3 | 164.727 | | | |

**Scenario 2 – Probable scenario**

The probable scenario differs from the unfavorable scenario by applying for a non-refundble grant of approximately 40,000 EUR within the Start-Up Nation program. This will reduce the amount obtained through a bank loan.

The total cost in the probable scenario, as in the unfavorable scenario, is 181.000 EUR. The financing structure is detailed in Table 6.

Table 6 - Financing structure – Probable scenario

| Sursa de finanţare | Scenariu probabil | |
|---|---|---|
| | [EUR] | % |
| Credite bancare | 117.500 | 64,92 |
| AFN – prin programul Start - Up Nation | 40.000 | 22,10 |
| Alte surse (aport propriu) | 23.500 | 12,98 |
| TOTAL valoare de investiție | 181.000 | 100 |

The SME requests a bank loan of 117.500 EUR, equivalent to 581.625 RON for 10 years. The interest rate is fixed at 15% per year. The monthly rate is calculated using the formula. The total monthly costs amount to approximately 8.095 EUR (of which 6.150 EUR/month represents operational and raw material costs and 1.895 EUR/month represents the monthly debt for bank loans, equivalent to 9.383,65 RON).

$$RL = \frac{\frac{15\%}{12} \cdot 117.500}{1-(1+\frac{15\%}{12})^{-120}} = 1.895\ EUR \tag{2}$$

A projected cash flow for the first three years of the company's activity was created as follows: in the first year, a negative cash flow of -7.131 EUR is recorded, in the second year of activity a positive cash flow of 65.657 EUR is recorded, and in the third year 172.467 EUR.

In Table 7, the investment evaluation indicators were calculated.

Table 7 – The substantiation decision – Probable scenario

| An | Element | Valoare | VAN | RIR | IP |
|---|---|---|---|---|---|
| 0 | Investiția | 132.042 | | | |
| 1 | CF1 | -7.131 | 156.845,42 | 75% | 0,19 |
| 2 | CF2 | 65.657 | | | |
| 3 | CF3 | 172.467 | | | |

**Scenario 3 – Favorable scenario**

The favorable scenario involves establishing a spin-off business with the National Institute for Research and Development in Microtechnologies – IMT Bucharest, in accordance with service 3 presented in the general scheme of innovative business models (Figure 6). In this way, the Institute provides the SME with the workspace and equipment. The rent for using the equipment and workspace is 700 EUR/month. Initially, two CAD design engineers will be employed, each with a fixed salary of 508 EUR/month. The third employee is the administrator, with a net monthly salary of 819 EUR. The total costs are reduced by 5,000 EUR, as the costs for setting up the workspace (3,000 EUR) and purchasing furniture (2,000 EUR) are eliminated. Investment costs consist of purchasing the three computers and design software.

To implement the business, the amount of 33,500 EUR is needed to cover investment costs (10,000 EUR), raw materials (2,400 EUR), operational costs (16,000 EUR), and a buffer amount

(5,000 EUR) for unforeseen expenses. Own funds amount to 23,500 EUR, and a loan of 10,000 EUR will be accessed to support the company in its first year of activity.

Figure 10 illustrates the cash flow diagram for the first year of the SME's activity. Time is represented by the horizontal line. Upward arrows represent positive cash flows (inflows – own contribution, revenues, or receipts), and downward arrows represent negative cash flows (payments or expenses). All amounts are illustrated in EUR.

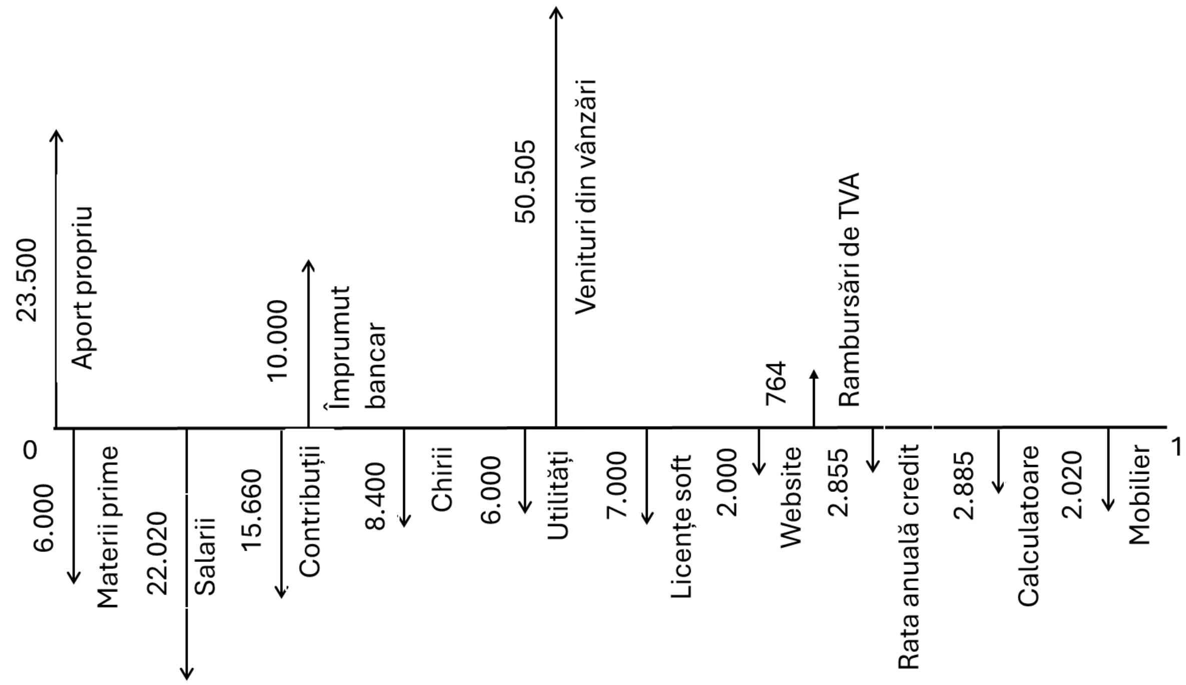



Figure 10 – Cash Flow diagram

From the BCR bank offer obtained on September 8, 2022, for a loan of 10,000 EUR, we obtained a fixed annual interest rate of 15% and a 2% administration fee. The fee is paid once, at the time of granting the loan. The monthly rate is fixed at 237.90 EUR, equivalent to 1.177,60 RON.

$$RL = \frac{\frac{15\%}{12} \cdot 10.000}{1-(1+\frac{15\%}{12})^{-60}} = 237,90\ EUR \tag{3}$$

The projected cash flow in the probable scenario is positive from the first year of the company's activity. The final available balance for the first three years is distributed as follows: in the first year 9,859 EUR, in the second year 66,366 EUR, and in the third year 169,176 EUR.

Table 8 – The substantiation decision – Favorable scenario

| An | Element | Valoare | VAN | RIR | IP |
|---|---|---|---|---|---|
| 0 | Investiția | 4.061 | | | |
| 1 | CF1 | 3.877 | 160.728,46 | 5796% | 39,58 |
| 2 | CF2 | 66.366 | | | |
| 3 | CF3 | 169.176 | | | |

The investment decision is based on the analysis of the three scenarios and the general scheme of innovative business models (Figure 6).

From all three scenarios, where the revenue projection, expense projection (including the calculation of the monthly rate for each loan obtained and the calculation of interest), cash flow, and investment project evaluation indicators (NPV, PI, IRR) were analyzed, the favorable scenario is considered as the best.

The decision to establish the SME will be based on the previously presented favorable scenario. Based on this scenario, the optimal 3D manufacturing option for parts involves recovering and reusing the powder. The recovered powder can be mixed with new powder in equal proportions and reused in a new manufacturing cycle without affecting the material's characteristics. Additionally, this hypothesis leads to a considerable reduction in hazardous waste produced during the printing process and the valorization of recovered and decontaminated powders.

# *Chapter* 8. Contributions to determining financial projections of the new business model

The total cost of the project includes the following main categories: personnel expenses, direct expenses, and indirect expenses.

Table 9 – Monthly payroll

| Nume Prenume | Funcția | Salariu Brut [EUR] | CAS 25% [EUR] | CASS 10% [EUR] | Salariul brut fără contribuții [EUR] | Impozit 10% [EUR] | Salariu Net [EUR] |
|---|---|---|---|---|---|---|---|
| Popescu Ion | Ing. Proiectant | 870 | 218 | 87 | 565 | 57 | 508 |
| Vasilache Dan | Ing. Proiectant | 870 | 218 | 87 | 565 | 57 | 508 |
| Mocanu Cristina | Administrator | 1400 | 350 | 140 | 910 | 91 | 819 |
| TOTAL | | 3140 | 786 | 314 | 2040 | 205 | 1835 |

Table 9 illustrates the gross monthly incomes of the three employees, the contributions related to the gross incomes, and the net salary. The annual personnel expenses amount to approximately 37,680 EUR, equivalent to 186,516 RON at an exchange rate of 4.95 RON. The total number of employees is 3.

**Loan Repayment Schedule**

From the BCR bank offer obtained on September 8, 2022, for a loan of 10.000 EUR, we obtained a fixed monthly interest rate of 1.25% and a 2% administration fee at the granting of the credit. The fee is paid once, at the granting of the credit. The loan repayment is made in constant monthly annuities. The monthly annuity is fixed and amounts to 1,177.60 RON. The total payable amount (loan balance) is 70,656 RON plus a 2% fee, paid at granting.

The loan repayment schedule is presented in Table 10 and contains the first three months and the last three months until the full repayment of the loan.

Table 10 – Repayment schedule

| Luna | Sold [RON] | Dobânda [RON] | Principal [RON] | Comision [RON] | Rata lunară [RON] |
|---|---|---|---|---|---|
| **Comision la acordare** | | | | 974,0 | 974,0 |
| 1 | 49 500 | 618,8 | 558,9 | 0 | 1 177,6 |
| 2 | 48 941 | 611,8 | 565,8 | 0 | 1 177,6 |
| 3 | 48 375 | 604,7 | 572,9 | 0 | 1 177,6 |
| 58 | 3 446 | 43,1 | 1 134,5 | 0 | 1 177,6 |
| 59 | 2 312 | 28,9 | 1 148,7 | 0 | 1 177,6 |
| 60 | 1 163 | 14,5 | 1 163,1 | 0 | 1 177,6 |
| **Total** | **0** | **21 156,4** | **49 500** | **990** | **70 656** |

The formula for calculating the monthly rate is as follows ( Radu Daniel, 2018):

$$RL = \frac{\frac{r}{12} \cdot C}{1 - (1 + \frac{r}{12})^{-n}} \tag{4}$$

Unde:

$RL - Monthly\ rate\ [RON]$;

$r - The\ annual\ amount\ of\ interest[\%]$;

C – *Loan* $[RON]$;

n – *Number of months*

$$RL = \frac{\frac{15\%}{12} \cdot 49500}{1 - (1 + \frac{15\%}{12})^{-60}} = 1177.60\ RON \tag{5}$$

The production cost includes CAD Modeling and data transfer (CAD Design, Positioning in the virtual tank, model sectioning, verification, and data transfer to the 3D printer) + Preparation of the 3D printer and materials for printing + actual printing (material consumption, energy consumption, post-processing part) + related consumables (isopropyl alcohol, optical wipes) + Waste management costs.

**Business operation and organization**

The raw material, Nylon 12 powder, will be purchased from EOS GmBH. Supply is done JIT (just in time). The main objectives of using this method are to eliminate stocks, reduce inventory, lower costs, and improve quality.

The main stages in the production process consist of receiving manufacturing requests, correcting/designing the CAD model, and launching the final parts into production. Products are made only on request, based on a contract.

The software used by the company to design accessories and spare parts is ANSYS SpaceClaim and the software used to print the parts is Materialise Magics.

**Environmental Impact**

Plastic pollution is one of the biggest problems of the ecosystem. The company aims to collect the remaining powder from the manufacturing process and recycle it, in an effort that aligns with the concept of sustainable development promoted by the company.

# *Chapter* 9. Contributions regarding products developed based on the new business model

Chapter 9 refers to the prototyping, consulting, and design services (1, 2, and 4) within the general scheme of the innovative business model presented in Chapter 5, Figure 6.

The chapter includes the design of components for UAVs, consulting services regarding the manufacturing of parts for clients, and an additional service that the SME can offer, which consists of decontaminating Nylon 12 (PA 2200) powder that can no longer be used in a new manufacturing cycle.

In terms of consulting, an SME employee has a discussion with the client to better understand their needs and to create the desired part that meets their requirements.

**Design of protective grid, support, and landing gear**

This subchapter presents the detailed design of accessories conceived for the DJI Mavic PRO. I chose this model because it is one of the best-selling drones nationally. The main stages for manufacturing the accessories are design, creation of the drawing, verification of the CAD model, and 3D printing.

In this chapter, for the detailed design of the parts, the design rules for additive manufacturing were considered.

In the event of possible damage, the main affected elements will be the propellers. Printing the propellers is not possible through SLS manufacturing technology with Nylon 12. The properties of nylon do not allow the manufacturing of these accessories because nylon built in a very thin layer is flexible and the tolerances are very small. For these reasons, a set of protective grids for the propellers was designed. The set of protective grids was made from Nylon 12 (PA 2200). The dimensions for a single protective grid are 102.02 mm x 132.01 mm x 15.59 mm.

Figure 11 illustrates the protective grid for DJI Mavic PRO. In the design, increasing the resistance by enlarging the contact surface between the six arms and the protective frame was considered. The maximum resistance limit is given by the area of the arm that supported the stiffening. The protective grid has a thickness of 2 mm and is constructed in such a way as not to significantly weigh down the UAV. The attachment of the protective grid to the UAV arm is done with a moveable part.

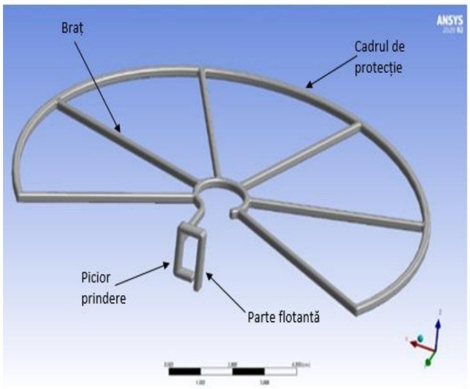


Figure 11 – Propeller protective grid

As a support element, a stand for DJI Mavic PRO was designed. The dimensions of the stand are illustrated in Figure 12.

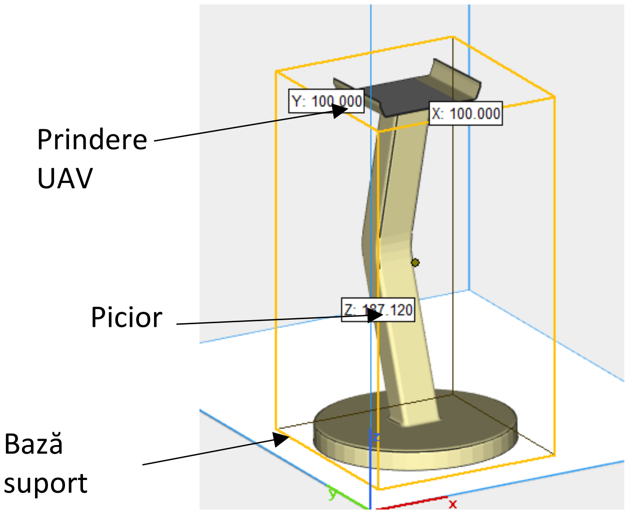


Figure 12 – Stand dimensions

The legs of the DJI Mavic PRO UAV are very thin, and for this reason, landing on surfaces with mud, snow, or sand could become difficult as it would sink. For these reasons, I chose to 3D print a landing gear for any surfaces for the UAV. The construction of the landing gear began by sectioning the UAV leg and designing the section on a new plane.

Figure 13 illustrates the construction method of the front part of the landing gear.

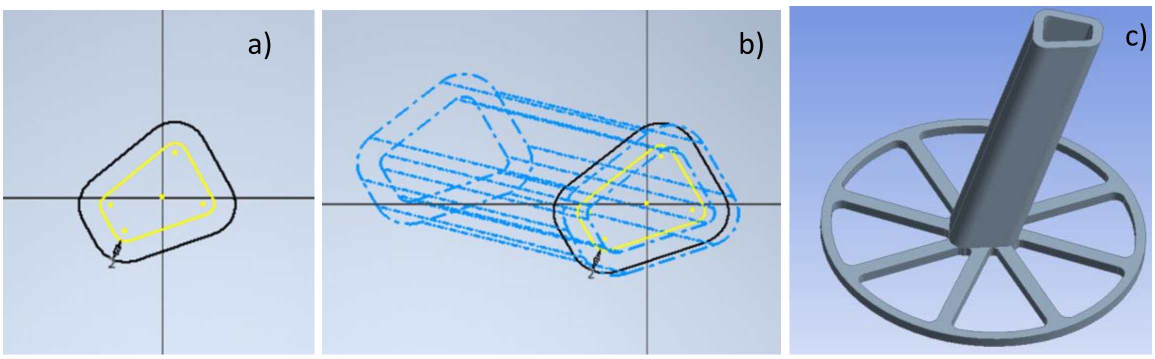


Figure 13 – The front part of the landing gear for DJI Mavic PRO

For the front landing gear, a circle with a diameter of 65 mm was created, which is connected by 8 arms. The thickness of the arms is 3 mm, and the height is 2 mm. To stiffen the landing support, the fillet function was used between the arms and frame. The dimensions of the front landing gear are 65 mm x 65 mm x 46.23 mm.

For the rear landing gear, the attachment of the landing support to the UAV leg was created. The attachment part was sectioned with a plane, and part of the material was removed to allow attachment with a moveable part. Using the extrude function, the connecting leg between the attachment and the landing frame was created. The landing frame has a thickness of 1.5 mm and a height of 2 mm. The frame is connected to the gear through eight arms, each arm having a thickness of 1.25 mm and a height of 2 mm. The outer diameter of the frame is 60 mm. The dimensions of the rear landing gear are 60 mm x 60 mm x 44.39 mm.

Figure 14 illustrates the construction method of the rear landing gear.

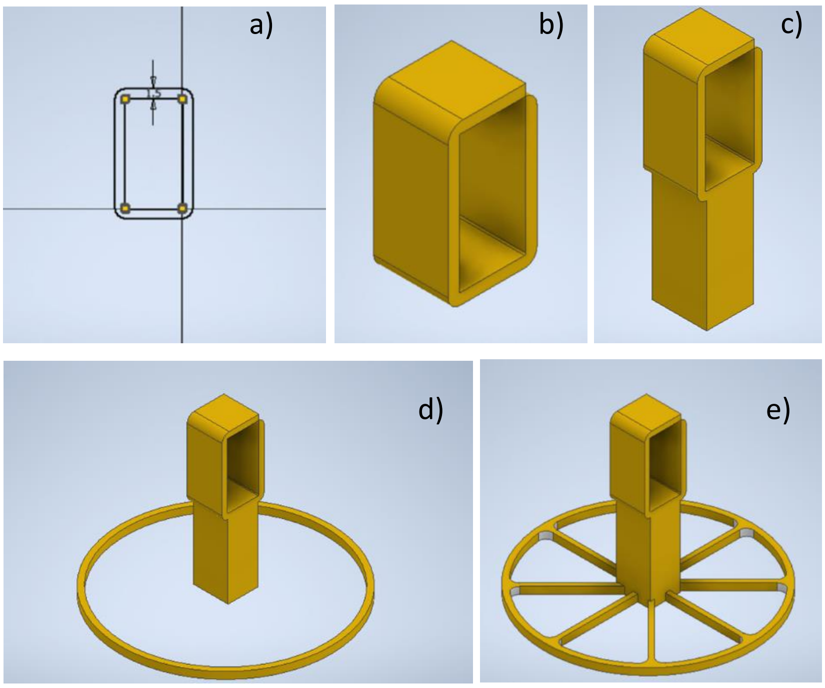



Figure 14 – The rear part of the landing gear for DJI Mavic PRO

Working method

The parts created in Ansys SpaceClaim were exported in STL format. The STL data format was subsequently imported into the Materialise Magics program. The program has a module that allows diagnosing and fixing problems. After checking and fixing any errors, the parts are launched into production. The parts, having low complexity, did not show any errors. The Materialise Magics program has a varied library of 3D printers. The Formiga P100 printer was chosen for making the parts.

Figure 15 illustrates the positioning of the parts in the virtual tank. The parts were positioned to optimize space and printing time. As can be seen in the following figure, the protective grid was placed 3 cm from the bottom of the tank, and the front landing gear can be seen between its arms.

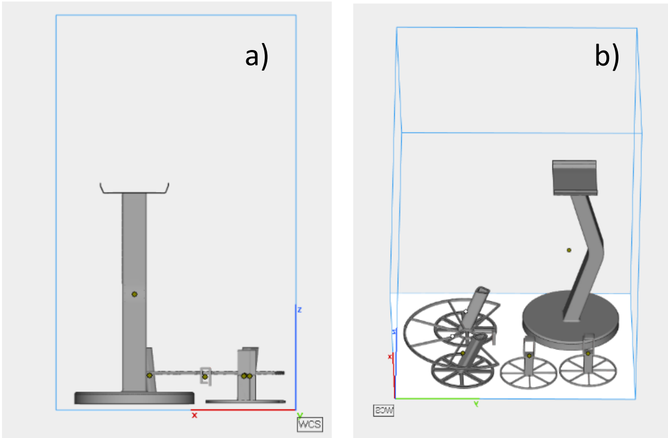



Figure 15 – Positioning of parts in the virtual tank a) XZ view b) XY view

The parts were positioned with the base down. Thus, during 3D printing, the lower part of the object (the base) is created first. The base is built first as support, and at the same time, being a larger printed surface, it maintains uniform heat across the entire surface of the object, resulting in efficient sintering of the powder, which provides rigidity to the piece.

The parts are positioned at a height of 50 mm from the bottom of the tank. This allows the successive deposition of layers of nylon powder as support for the parts to be printed. The thickness of each layer is 0.1 mm.

The laser follows an alternating longitudinal-transversal motion in the construction of the object so that the parts have the best possible mechanical resistance. The laser power is 30 W, and the scanning speed is 5 m/s.

In the Materialise Magics program, an STL file is created that includes the tank with all the parts. This new file is imported into the EOS program called PSW3.3_P100. The program has a slice view module that allows the STL file to be transformed into an SLI file. At this point, the tank along with the parts is sectioned into layers with a thickness of 0.1 mm. In Figure 16, two of the layers can be seen. The first layer a) illustrates the beginning of the printing process, and the front and rear landing gear and the UAV support can be seen. In the second illustrated layer, the protective grid can also be seen.

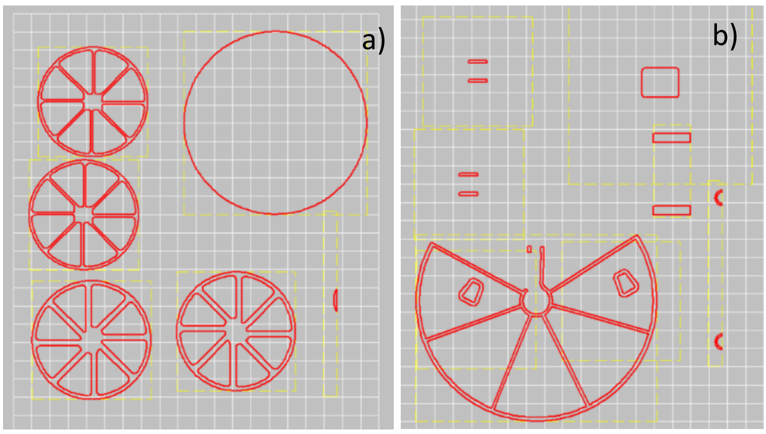



Figure 16 – Screenshots from the PSW3.3_P100 Program

Figure 17 indicates the construction process of the parts in the EOS Formiga P100 printer program. In the first figure a) layer 62 is illustrated. In this layer, the construction of the bases of the front and rear landing gear and the UAV support can be seen. b) illustrates layer 300, where the propeller protective grid can be seen.

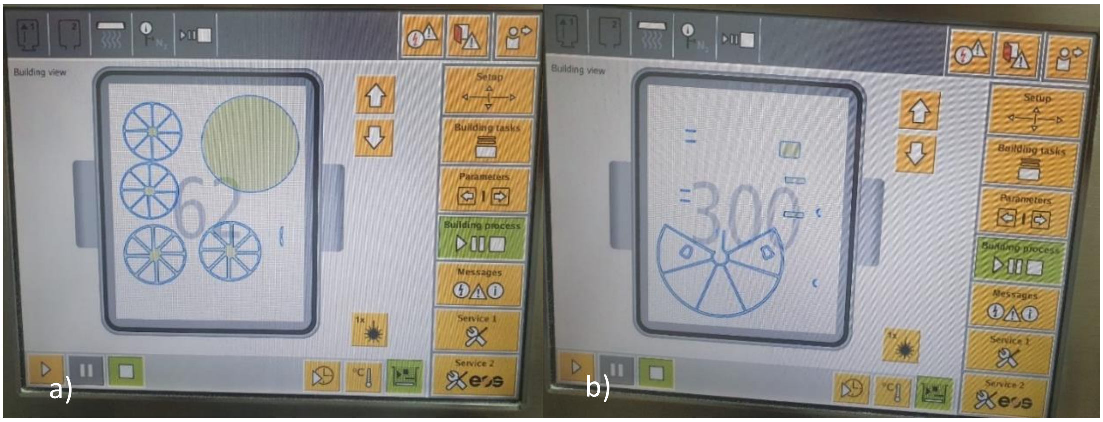



Figure 17 – Construction process a) 62mm b) 300 mm

After completing the 3D printing process, cooling the tank and powder to a temperature of 37°C, the next step is to remove the tank from the printer. The first step is to extract the parts from the tank and remove unsintered nylon from the surface of the parts. The second step is blowing the parts with compressed air in a controlled environment to remove residual powders from the 3D printing stage.

For the 3D printing of the parts, the printer's reservoirs were loaded with 7 kg of powder. New powder was used in a proportion of 50% and recovered powder in a proportion of 50%. Recovered powder means it has been through a manufacturing cycle before. Calculations and measurements were made to determine the percentage of powder that can be recovered and reused in a new manufacturing cycle and the percentage of powder that can no longer be used in 3D printing but will be recycled and used as raw material in other industries.

For printing the 18 parts, with a total mass of 315,5 grams, 5.469 grams of powder were used. From the total amount of nylon powder used, 4.832 grams can be recovered and reused in a new manufacturing cycle. In the context of the circular economy, this 3D printing process results in 321,5 grams of powder that will be decontaminated and recycled.

Considering the mass of powder that can no longer be reused, it results that after 3-4 manufacturing cycles, one kilogram of residual powder (which can be recycled) will result.

After using 16 kg of powder, 1 kg of residual powder will result, which will be decontaminated and recycled, resulting in a recycled powder ratio of 1:16.

**Design rules for AM**

3D printing using Selective Laser Sintering (SLS) technology allows for the construction of complex geometries. SLS technology is a scalable method that produces functional prototypes.

In the case of 3D printing with Nylon 12 powder, it is not necessary to build support structures.

This allows for more freedom in design and construction compared to other printing technologies.

Printing with SLS technology has an anisotropic behavior, meaning it does not have the same physical properties in all printing directions. The maximum strength of sintered parts is in the XY plane. In the creation of UAV accessories by the SME, this aspect was considered, so the parts were positioned on the XY axis, parallel to the bottom of the tank. The positioning of the parts in the printer tank is illustrated in the previous subchapter.

To obtain good mechanical properties, the recommended layer thickness is 0.1 mm, and the printing direction is horizontal, at 0° (PD = 0°).

Stress concentrations are another important aspect in part design. In the design, increasing strength by rounding the edges between the six arms and the protective frame (propeller protective grid) was considered. The same rules as for the protective grid were followed in the construction of the landing legs. All edges and corners were rounded using the fillet function to provide better strength to the part.

Cantilever wall, the attachment of the protective grid to the UAV arm is with a foot with a moveable part. Nylon built in a thin layer is flexible and allows the construction of the attachment in this way; This rule was also followed for attaching the rear landing gear to the UAV leg.

**Consulting services in design and manufacturing**

The consulting service plays an important role in the development of the SME. The first step before even designing and manufacturing a component is the discussion between the employee/design engineer and the client. The discussion aims to understand exactly the needs of each client and thus create a part according to the client's needs.

Any client can contact the company directly from the company's website or by phone. Along with the message on the site, the client can upload the CAD part, and a specialized person will check and correct it.

# *Chapter* 10. Informational resources

Informational resources are input data in the activities of the SME, illustrated in Chapter 5, Figure 6.

The business financing, amounting to 70.15% (116,325 RON), will be provided by the sole shareholder, who holds the position of general manager of UAV 3D Printing Lab SRL. The co-financing, amounting to 30% (49,500 RON), will be obtained through a bank loan. The amount of the bank loan is 10.000 EUR, over a period of 5 years with an interest rate of 15% per year. The revenues obtained from the sale of products will be reinvested.

The shareholder has not held the position of administrator or sole shareholder in a commercial company that has been declared insolvent or bankrupt in the last 5 years (2019, 2020, 2021, 2022, 2023).

**Position of the company's products/services on the market compared to competition**

Considering the upward trend in drone sales, as realized by Drone Industry Insights, and presented in the introduction, and in relation to the increasing demand for related accessories, the company could capture a significant market share.

The type of business is B2C. The company will deliver finished products to end customers (individuals). The enterprise opts to enter the market with a medium price. The pricing strategy aims to attract many customers and generate profit. To maintain the price at a medium level, SC UAV 3D Printing Lab will need to accumulate a minimum of 3-4 orders to optimize fixed costs, including energy consumption.

The product sales strategy is through retail. The company fulfills small orders (small and medium series products) for end users based on a contract. Products can be picked up personally from the company's headquarters or delivered to the customer's address through collaborating transport companies.

To produce UAV accessories (propeller grid, support, front landing and rear landing gear), the total cost is detailed in Table 11.

Table 11 – UAV Accessories Cost

| Produse: accesorii UAV (139 g) | Cost |
|---|---|
| Materie primă – PA2200 | 84,20 RON |
| Materiale consumabile auxiliare (alcool izopropilic, șervețele optice); /produs | 5 RON |
| Manoperă | 148,5 RON |
| Utilități/Energie electrică | 46,30 RON |
| **Cost de fabricație** | **284 RON** |
| Adaosul comercial (RON) | **62,5 RON** |
| **Adaosul comercial (%)** | **22%** |
| **Preț de vânzare** | **346,5 RON** |

The selling price for accessories weighing 139 g is 346.50 RON, with a commercial markup of 22%. Thus, to simplify calculations for production forecasting, an order for accessories weighing 100 g is considered. The selling price for accessories weighing 100 g is 250 RON, calculated as follows: 346.5/139*100.

The price for 1 kg of Nylon powder is 60 EUR, with an exchange rate of 1 EUR = 4.95 RON. This results in a price of 297 RON per kg of Nylon powder.

Production corresponds to a calendar year, 365 days. The forecast calculation was performed for the period 2024-2026. The year 2024 has 252 working days, excluding weekends and national holidays, 2025 has 248 working days, and 2026 has 249 working days.

One of the proposed objectives for the first year is to attract 1000 customers. A UAV accessory can weigh from a few grams to several tens of grams depending on the size of the drone, the size of the accessories, and the volume of the part. An average of 100 g per accessory/customer is estimated, thus the production forecast is detailed in Table 12.

Table 12 - Production forecast

| Produs | UM | AN I | AN II | AN III |
|---|---|---|---|---|
| Accesoriu UAV | 1 Buc / 100 g | 1000 | 3000 | 5000 |

Order execution will be launched for finished products of at least 100 grams. Thus, 2-3 orders will be collected to optimize the use of electrical energy and maintain prices at a medium level.

Promotion represents the main communication channel with the consumer. For UAV 3D Printing SRL, the company's promotion will be done through its own website and direct sales. Promoting the company through the web page is cost-effective and has the advantage of being continuously improved and updated. The company's website presents both the services offered to customers and the values and mission. The web address of the company is: https://uav3dprinting.wixsite.com/uav-3d-printing-lab.

In the first year of the company's operation, the customer will fill out a request form (Figure 18) in which they describe the component they need and optionally upload the CAD model if they have it. The request will be taken and analyzed by one of the design engineers. They will analyze the CAD model, make a cost calculation, and send the offer to the customer within 24 working hours. Starting from the second year, a calculation algorithm will be integrated into the platform that will automatically calculate the indicative price when the customer uploads the part.

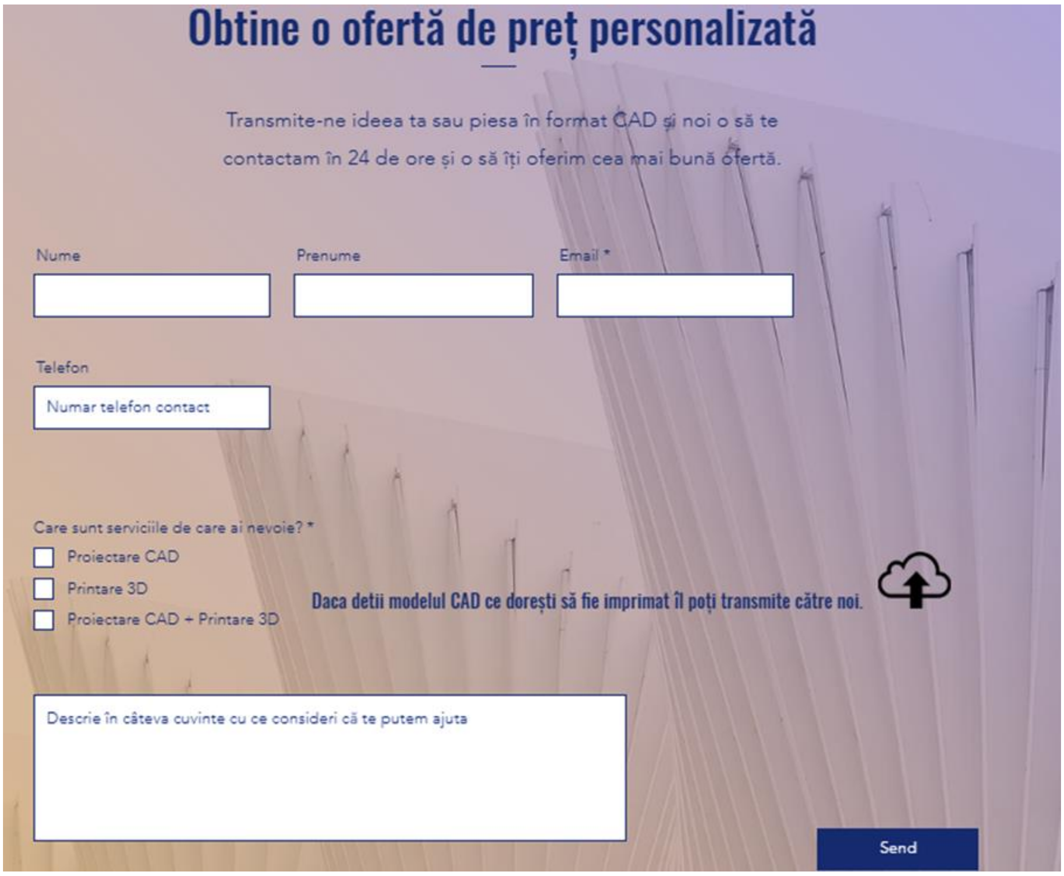



Figure 18 – Request for quotation form

The company's logo embodies a modern vision and illustrates the main field of activity, 3D manufacturing of UAV components. The logo is carefully chosen to convey the type of services offered by the company to potential customers.

Figure 19 – Logo UAV 3D Printing Lab

Other promotion methods include participating in additive manufacturing exhibitions, entering into agreements with companies to display advertisements for the company on their websites, and establishing collaboration relationships with the National University of Science and Technology POLITEHNICA BUCHAREST (conducting internships).

One of the important elements of the marketing mix is identifying the target market segment. The target market is represented by individual consumers.

Direct sales are characterized by face-to-face communication, which leads to maintaining future relationships so that they return. Attracting customers is done by promoting quality products offered at competitive prices. On the company's website, there is a section where customers can leave feedback. Customers will receive a response whether the feedback is positive or negative.

# *Chapter* 11. Contributions to the design of powder decontamination services within business models

The decontamination services offered by the SME are illustrated in Service 5 of the general scheme of innovative business models (Figure 6).

**Purification and treatment method**

A method was designed for the purification and treatment of powder, aiming to eliminate impurities from the heterogeneous mixture.

The main stages in the purification process are:

1. Cleaning the powder;
2. Thermal treatment of the powder;
3. Washing and filtering;
4. Drying.

**Powder cleaning method**

From the perspective of efficiency and costs, it was concluded that washing the powder with a solution of water and potassium hydroxide, as described below, will be used. To verify the effectiveness of contaminant removal, seven samples were analyzed. The conditions for the seven samples are presented in Table 13.

Table 13 - Test conditions and sets for decontamination of nylon powder

| Condiții<br>Set de teste | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Set 1 | $C_{KOH}$= 40% | T=80$^{O}$C | T=2h | 3h; T=60$^{O}$C |
| Set 2 | $C_{KOH}$= 40% | T=60$^{O}$C | T=2h | |
| Set 3 | $C_{KOH}$= 40% | T=90$^{O}$C | T=1h | |
| Set 4 | $C_{KOH}$= 20% | T=80$^{O}$C | T=2h | |
| Set 5 | $C_{KOH}$= 20% | T=60$^{O}$C | T=2h | |
| Set 6 | $C_{KOH}$= 60% | T=80$^{O}$C | T=1h | |
| Set 7 | $C_{KOH}$= 60% | T=60$^{O}$C | T=1h | |

For better efficiency, thermal treatment of the powder was also considered.

**Thermal treatment in aqueous KOH solution**

In a Berzelius beaker, the polymer powder was dispersed in a potassium hydroxide solution (KOH 99.8% purity) with varying concentrations in the range of 20-60% (Condition C1). The solution was heated on a hot plate under magnetic stirring at temperatures between 60-90°C (Condition C2) and maintained for 1-2 hours (Condition C3). After the procedure, it was left to decant for 24 hours, then the powder was placed in a vacuum oven at a temperature of 60°C for 3 hours (Condition C4).

**Washing and filtering**

In this stage, a filtering funnel (borosilicate glass 3.3) and a vacuum pump were used. This helps accelerate the process of separating the powder from the suspension. To remove traces of KOH, the aqueous polymer dispersion was washed with deionized water and filtered 6 times. The suspension remains in the filtering funnel, while KOH along with impurities are collected in the beaker.

In the sixth washing stage, the filtered bed of wet polymer was redispersed in one liter of deionized water where 50 ml of isopropyl alcohol (VLSI grade, BASF) and 25 ml of freshly prepared 1% hydrochloric acid aqueous solution (Sigma Aldrich, 37%) were added. For more effective removal of potassium ions, the diluted hydrochloric acid solution was used to neutralize the polymer dispersion. The pH of the aqueous dispersion was 5.5-6, close to the pH of deionized water, indicating proper neutralization of the dispersion.

Isopropyl alcohol was used for better wetting of the polymer particles in water and to improve the removal of potassium ions from the surface of the polymer particles. Traces of isopropanol also help in the removal of water during the drying stage.

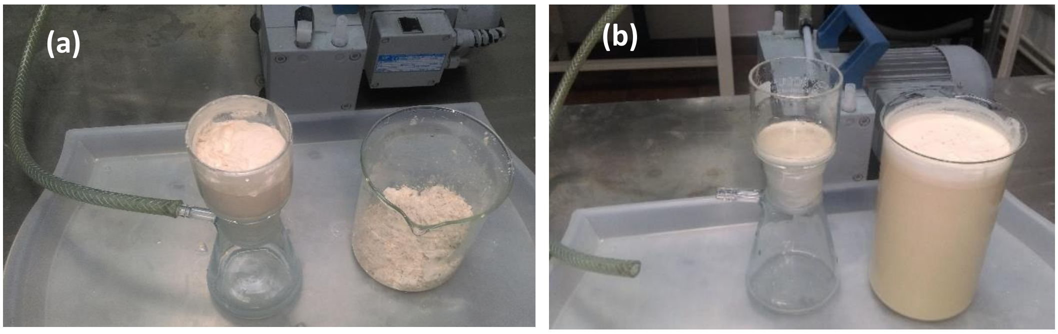



Figure 20 - (a) the aqueous polymer powder after a deionized water washing stage;(b) Powder washing stage with hydrochloric acid and isopropyl alcohol mixed with deionized water.

**Drying**

The wet polymer powder was collected in a cylindrical vessel, which was then placed in a vacuum oven (Memmert VO400, Germany) at a temperature of 60°C for 3 hours, at a vacuum of 30 mbar. The vacuum was released with nitrogen, and the powder was allowed to cool to room temperature.

**Microbial contamination control**

This method was used to determine the extent to which biological decontamination of Nylon 12 powder was achieved. The first set of tests consisted of microbiological control of the seven samples resulting from the use of different decontamination conditions. Additionally, a sample of new powder, as commercially available, was tested as a reference, along with a sample of contaminated powder.

To determine the microbial contamination of nylon (PA12) powder, qualitative, quantitative, and microorganism identification tests were used.

The qualitative test was performed by the direct inoculation method in the medium. This method involves transferring a predetermined amount of sample directly into the culture medium and incubating it at temperatures between 30-37°C for bacteria and 20-25°C for fungi (Council of Europe, 2004).

The quantitative test was used to determine the total number of aerobic microorganisms (aerobic bacteria, yeasts, and filamentous fungi).

The microorganism identification test was conducted to detect the following species: Enterobacteriaceae, Escherichia (E.) coli, Salmonella sp., Pseudomonas (P.) aeruginosa, and Staphylococcus aureus (S.).

The first stage involves **weighing the samples**, specifically 10 g from each sample.

The second stage involves **making decimal dilutions** using the same type of diluent. The diluent used is buffered peptone water (a weak broth with pH 7). The dilutions made are 1/10; 1/100; 1/1000.

The third stage involves **inoculating Petri dishes**. To control potential contamination, work was done in a sterile environment, at a flame. Thus, each instrument was sterilized before and after use.

Using an electronic pipette, Petri dishes were inoculated, dropwise, with 1 ml from the 3 dilutions obtained in the previous step. Three plates were used for each sample.

**The total number of aerobic bacteria** was determined by dropping 1 ml from the 3 dilutions of each sample into Petri dishes to which 15-20 ml of liquefied and cooled Trypticase Soy Agar (TSA) at 45°C was added. Each dilution was worked in triplicate (three samples from each). The samples were homogeneously incorporated into the culture medium by gently rotating each plate. After solidification, the plates were incubated at 37°C for 24-48 hours. Only plates with a maximum of 300 colonies were considered for calculation.

**The total number of yeasts and filamentous fungi** was determined by dropping 1 ml from the 3 dilutions of each sample into Petri dishes to which 15-20 ml of melted and cooled Sabouraud Dextrose Agar (SAB) at 45°C was added. Each dilution was worked in triplicate. The samples were homogeneously incorporated into the culture medium by gently rotating each plate. After solidification, the samples were kept at room temperature (20-25°C) for up to 5 days. Only plates with a maximum of 100 colonies were considered for calculation. Colonies on each plate were counted.

TSA and SAB are solid media, but they were liquefied and kept in a water bath at temperatures of 45-50°C to be poured onto the plates inoculated with the dilutions from the second stage and to allow homogenization. Each plate was labeled with the sample number, dilution, and date.

**Identification of microorganisms contaminated with potential pathogens**

The samples were tested for the detection of specific microorganisms considered bacteriological indicators of contamination using selective media and biochemical tests for confirmation.

Before starting the identification of bacteria, the workbench was prepared, and the plates with culture media (Cetrimide, XLD, McConkey, VRDB) were placed in the hood for drying and then prepared for inoculation.

**Results and discussions on microbial contamination control**

To determine the total number of aerobic bacteria and the total number of fungi, the results are expressed as CFU/ml (g) - the number of colony-forming units per ml or g of product. The equation is as follows:

$$\frac{a+b+c}{3} \text{ x } 10^{-d} = \text{UFC/ml} \quad (6)$$

Where:

$\frac{a+b+c}{3}$ - arithmetic mean of counted colonies

$10^{-d}$ – dilution factor (ex: $10^{-1}$ dilution 1/10)

The results detected on the samples are presented in Table 14 and Table 15. In the case of the total number of aerobic bacteria and fungi, the colonies developed on the plate were calculated for each dilution in triplicate.

Table 14 – Determination of total number of aerobic bacteria on TSA culture medium

| Proba | Diluția | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1/10 | | | 1/100 | | | 1/1000 | | |
| S1 | - | - | - | 23 | 16 | 26 | - | - | - |
| S2 | 1 | 1 | 7 | 2 | - | - | 10 | 2 | 1 |
| S3 | 1 | 1 | 3 | - | - | - | 1 | - | - |
| S4 | 20 | 2 | - | 1 | 1 | 1 | 1 | 1 | 6 |
| S5 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | - |
| S6 | 1 | 2 | - | 4 | 2 | - | 1 | - | - |
| S7 | - | - | - | - | - | - | - | - | - |
| Pulberea netratată/contaminată | Contaminare masivă cu fungi | | | | | | | | |

Exemple: For 1/100 dilution for S1 sample, UFC is:

$$UFC = \frac{23+16+26}{3} \text{ x } 10^{-2} = 25.33\text{x}10^{-2} \text{ UFC/ml} \quad (7)$$

A small number of bacteria developed on the TSA medium can be observed. The untreated sample was heavily contaminated with fungi, which prevented the reading of bacterial growth. The best result was obtained for the S7 test set. In this test set, no bacterial growth was recorded in any of the dilutions.

For the determination of the number of yeasts and filamentous fungi, Sabouraud Dextrose Agar (SAB) medium was used. This medium is used in research to favor the growth of fungi and other types of molds. Additionally, the agar in the composition has an acidic pH that inhibits bacterial growth. The plates were incubated at room temperature, approximately 20-25°C.

For calculation, only plates containing a maximum of 100 colonies were considered. Each Petri dish was divided into 4 quadrants, and the colonies were counted. The results obtained are presented in Table 16.

Table 15 - Determination of total number of fungi in the SAB culture medium

| Proba | Diluția | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1/10 | | | 1/100 | | | 1/1000 | | |
| S1 | 1 | - | - | 2 | 1 | 11 | 1 | 3 | - |
| S2 | 1 | - | - | - | - | - | - | - | - |
| S3 | - | - | - | - | - | - | - | - | - |
| S4 | - | - | - | - | - | - | 1 | - | - |
| S5 | - | - | - | - | - | - | - | - | - |
| S6 | 1 | - | - | 1 | - | - | - | - | - |
| S7 | - | - | - | - | - | - | - | - | - |
| Pulberea netratată | Contaminare masivă cu fungi | | | | | | | | |

The untreated sample was massively contaminated with fungi, which prevented the reading of bacterial growth.

The chemical treatment of nylon powders proved to be effective, with a reduced number of fungi observed in the following powder sets: S1, S2, S4, and S6, and even a total 100% reduction of fungal contamination for samples S3, S5, and S7.

To determine the number of Gram-positive and Gram-negative microorganisms, the following culture media were used: VRBD, MacConkey, XLD, Cetrimide, and Baird Parker.

In the contaminated sample, the following microorganisms were identified: strains of Staphylococcus aureus, Pseudomonas aeruginosa, and E. coli.

No microorganism used as a bacteriological indicator (E. coli, Salmonella sp., P. aeruginosa, or S. aureus) developed on specific media in the treated samples.

**Decontamination of 1 kg of nylon powder** involves the following costs: waste management costs; raw materials; electricity; related consumables, and human resources.

In this first stage, 3 kg of KOH pellets and 5 liters of deionized water were used for 1 kg of nylon powder to prepare a 60% KOH solution. The solution was equally divided into two Berzelius beakers and heated on a hot plate under magnetic stirring at 80°C for 2 hours each. From this initial solution, lower concentration solutions were prepared.

The polymer dispersion was washed with 5 liters of deionized water and filtered five times to remove traces of the KOH solution. The vacuum pump was used for 10 minutes. In the final washing stage, two liters of deionized water were used to which 100 ml of isopropyl alcohol (VLSI grade, BASF) and 50 ml of 1% hydrochloric acid were added. For drying, the powder was placed in the vacuum oven for 3 hours.

Although decontamination has proven effective in removing dirt and contaminants, it also has a cost. Considering all these elements and the duration of each stage during decontamination, the resulting cost of the recovered powder amounts to 30.16 Euros per kg, equivalent to 149.31 RON. The total amount of powder used in this manufacturing cycle is 5469 g, and the amount of powder to be recycled is 321.5 g.

# *Chapter* 12. Contributions of the morphological and spectral characterization of Nylon 12 (PA 2200) powder

The microbiological and spectral characterization services offered by the SME are illustrated in Service 5 of the general scheme of innovative business models (Figure 6).

The second set of tests consisted of characterizing the decontaminated powder in comparison with new, unused powder and contaminated powder. The reason for this second set of tests is to determine whether the decontamination process affects the structure and composition of the powder. For this purpose, several techniques were used, such as scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), infrared spectroscopy (FTIR), and RAMAN spectroscopy.

**Scanning Electron Microscopy (SEM)**

For performing scanning electron microscopy, the FEI Nova Nano SEM 630 equipment was used. Scanning electron microscopy produces images of a sample by scanning the surface with a focused beam of electrons and provides information about the surface topography and composition of the sample.

In Figure 21, the SEM surface morphologies of the reference, contaminated, and decontaminated powders are represented.

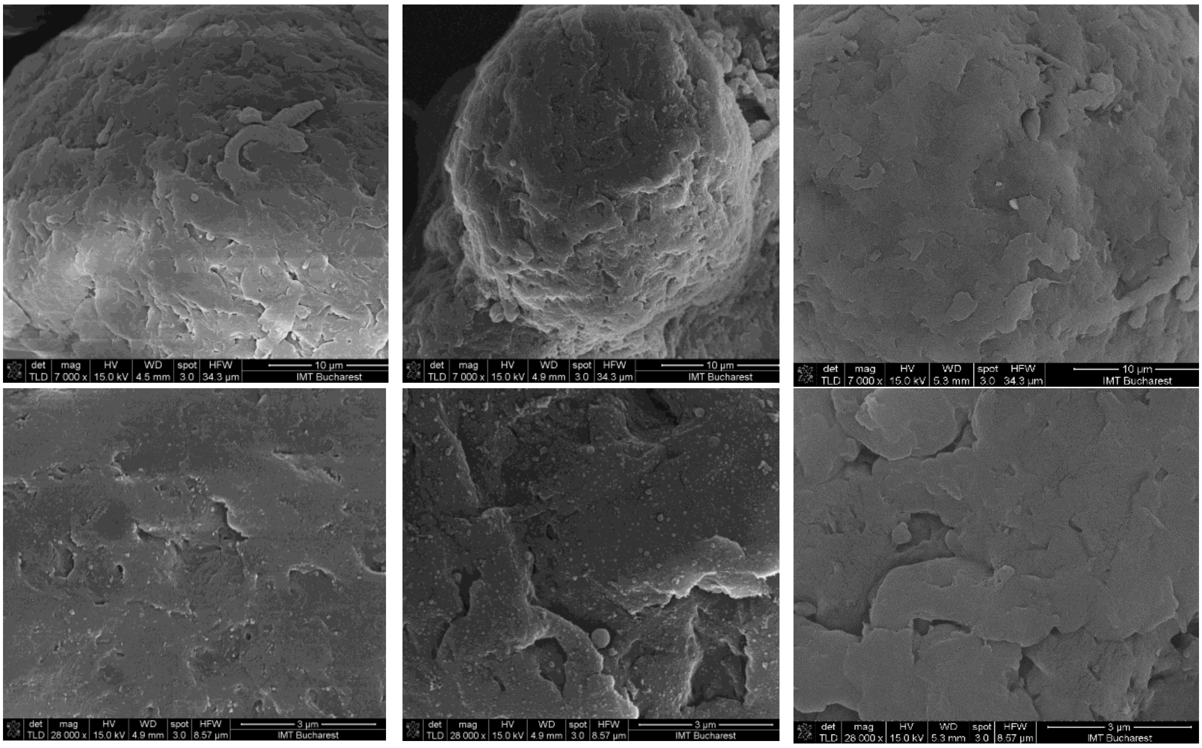


Figure 21 - Micrograph of the: a) reference; b) contaminated; c) decontaminated powder sample having different magnification (7kx top images, 28kx lower images)

In the reference sample we can observe a few nanoparticles of about 50 nm. Furthermore, in the contaminated samples we can notice a multitude of nanoparticles in the range of 70-430 nm. In the decontaminated sample the nanoparticles are not present due to KOH solutions. The poorly fixed nanoparticles that were at the surface of the sample were removed during the decontamination treatment and passed through the filters used in the experiment. Moreover, a slight etching of the polymer might have happened, as results from the comparison between figures 22a and 22c, respectively. The surface of the decontaminated sample is a little bit smoother than the surface of the reference powder, suggesting a slight etching at the powder grain surface. Another important observation is that the contaminated powder has a rougher surface than the fresh one, aspect that is specific to polymer SLS. This rougher surface offers a better fixing of any microbiological contaminants, especially if we take into consideration also the polar groups of PA2200 molecules that can offer 'anchors' for these contaminants.

**X-ray Spectroscopy (EDX)**

EDX is an analytical technique for determining the elemental composition or characteristic structure of a sample. EDX analysis is performed on a desktop SEM with an EDS Element system.

The chemical constituents of interest within the PA2200 sample were revealed by the EDX spectra at 4kx magnification. From the EDX spectra we noticed different concentrations of Carbon, Nitrogen and Oxygen. We can notice a difference between the concentration of Nitrogen and Oxygen from the reference to the contaminated sample (Table 17). These differences are most probably due to the contaminants existing on the surface of the respective sample. Also, it can be observed that the reference sample is not significantly different from the decontaminated sample.

Table 16 - Elemental composition of the polymer powder sets as resulted from EDX analysis

| | ***Reference*** | | ***Contaminated*** | | ***Decontaminated*** | |
|---|---|---|---|---|---|---|
| Element | Masa % | Atomic % | Masa % | Atomic % | Masa % | Atomic % |
| C | 66.8 | 71.4 | 68.9 | 74.1 | 63.4 | 68.4 |
| N | 17.8 | 16.3 | 6.2 | 5.8 | 16.9 | 15.6 |
| O | 15.4 | 12.3 | 24.9 | 20.1 | 19.7 | 16.0 |

Regarding the composition of carbon (C), nitrogen (N), and oxygen (O) in the EDX spectra, a small variation can be observed between the concentration of carbon and oxygen for the reference powder and the decontaminated powder (Table 16).

From the EDX spectra, it is observed that the contaminated powder also contains Si, P, and S. While silicon can be attributed to the mineral component of the dust ($SiO_2$), phosphorus can be attributed to both the organic contaminant and a phosphate-based component in the mineral fraction. The sulfur component can also be considered. What is important to see from the EDX analysis is that the decontaminated powder does not have contaminants, at least within the detection limit of the EDX system (0.5% at a resolution of 129.2 eV).

Regarding N, there is a significant decrease in it for the contaminated powder compared to the fresh one and a return of the nitrogen concentration for the decontaminated powder. This variation is also found in the case of oxygen.

**Infrared spectroscopy (FTIR)**

FTIR spectroscopy was performed to determine the effect of decontamination on the polymer composition. The equipment used is an FTIR spectrometer – Tensor 27/Bruker Optics/2006. The FTIR spectra of the reference, contaminated and decontaminated powders are presented in Figure 22.

In the reference sample, the peaks at 3358 and 1581 $cm^{-1}$ are attributed to the stretching and bending vibrations of the NH mode. The peaks at 2945 and 2860 $cm^{-1}$ correspond to the stretching vibrations of the $CH_2$ mode. The peak at 1666 $cm^{-1}$ is attributed to the C=O vibrational mode.

In the FTIR spectra of the contaminated sample, some small changes in the peak positions of the C=O and -CH vibrational modes can be observed. The presence of contaminants on the surface may be responsible for this shift in peaks.

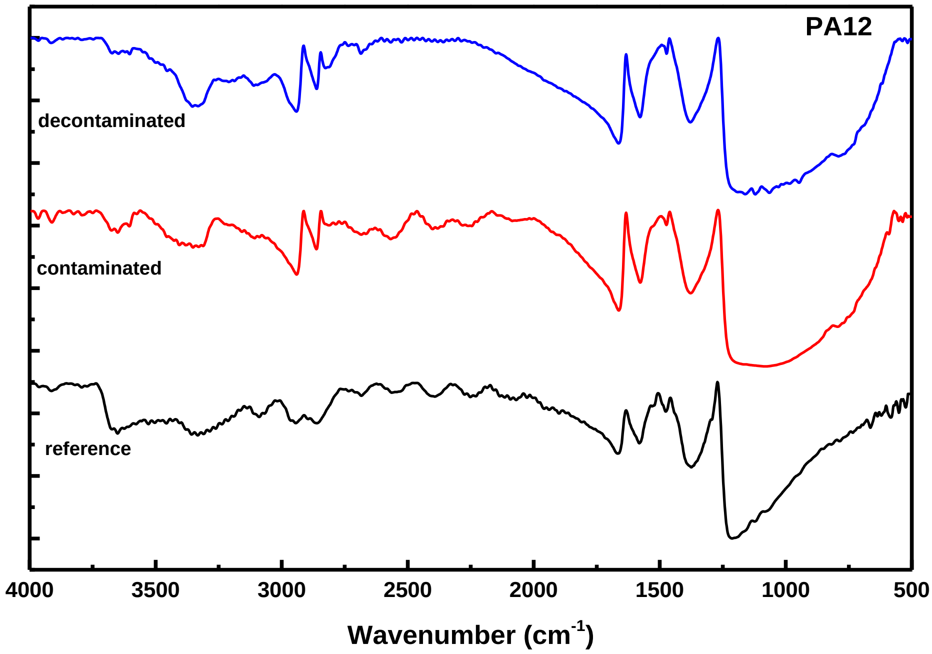



Figure 22 - FTIR spectra of reference, contaminated and decontaminated PA2200 powders

Another reason for the change in peak position is that the contaminated powder underwent a thermal heating process during SLS. Traces of solvents contained in the powder granules were removed by evaporation. This could explain why the contaminated and decontaminated samples have quite similar spectra at low wavenumber values and around the 2750 – 3000 $cm^{-1}$ range.

**Raman Spectroscopy**

Raman spectroscopy is a technique used to observe vibrational, rotational, and other low-frequency modes in a system. The equipment used is a WITec RAMAN spectrometer alpha 300S/2008. Raman spectroscopy shows the chemical compounds in which the elements are found.

In the RAMAN spectra, for the contaminated sample, peaks can be observed at positions 449.6 and 610.96. We can conclude that the peak at 610.96 $cm^{-1}$ is due to the presence of SiO2, most likely from dust particles. The presence of silicon is also supported by the EDX spectra, while the Raman data show the compound in which Si is found.

The most part of the identified groups are ascribable to polyamide. This means that, within the detection limit of the system, the chemical composition of the material was not altered by the decontamination process. Some slight differences (as regards position of lines) appear between reference and contaminated, respectively decontaminated, ones. This shift may be because of heat during the SLS process through which the contaminated sample has passed. Also, the presence of additional lines in the contaminated sample is an indicator for the presence of SiO2, most probably from dust particles. The presence of Si is supported also by the EDX spectra, while the Raman data show the compound in which Si is found.

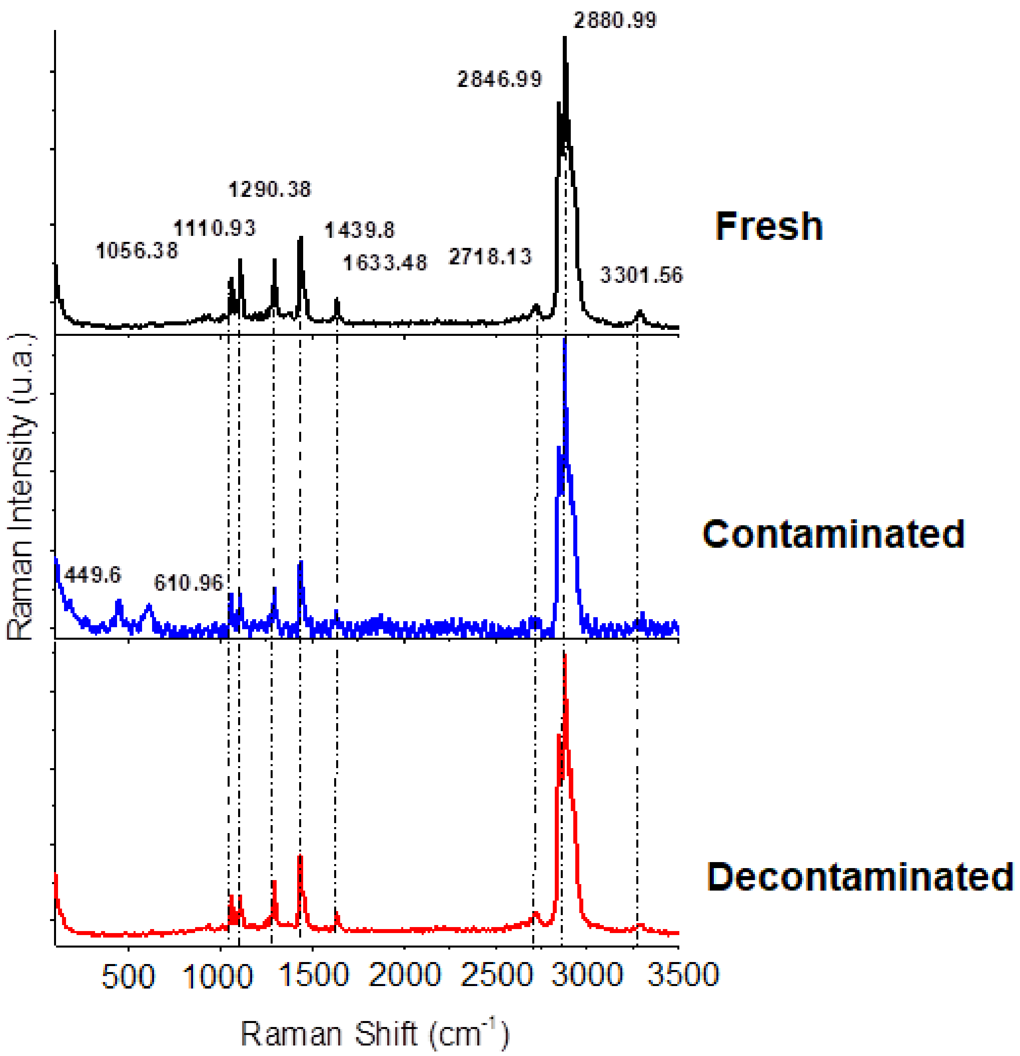



Figure 23 - Raman spectra of reference, contaminated and decontaminated PA2200 powders

Based on the FTIR and Raman data, we can affirm that the decontamination process did not change the chemical composition of the nylon powder.

# *Chapter* 13. Final conclusions, personal contributions and future research directions

**Final Conclusions**

Following the analysis of the current state presented in the first part of the thesis and the research conducted in the second part, the following final conclusions were highlighted:

The use of additive manufacturing technology through selective laser sintering (SLS) is suitable for creating UAV accessories.

A suitable material for manufacturing parts is Nylon 12 (PA2200).

A global study of companies was conducted, revealing their business models. The analyzed business models include B2B (selling 3D printers and CAD design or printing preparation software to other companies), B2C (selling 3D printers to end-users, individuals), and platform-based (offering a wide range of production services).

A national study of additive manufacturing companies showed that most companies in this field use FDM technology, utilizing materials like PLA and ABS. None of the analyzed companies in Romania adopt a circular economy.

An optimal business model for establishing a company in the field of SLS additive technologies was determnined using the AHP method.

The optimal model for establishing an SME in additive manufacturing involves creating a functional prototype with zero-series production (up to 50 pieces). The SME focuses on manufacturing parts according to customer needs, on demand. The business aims to be a spin-off, based on detailed design, with a focus on powder recycling, including microbial contamination characterization and morphological and spectral characterization.

The optimal development scenario involves establishing a spin-off business derived from INCD for Microtechnology, with 70% self-financing and 30% bank loan. The company will be established on January 4, 2024, with production starting on March 25, 2024.

The company designed accessories, created CAD models, execution drawings, 3D printing verifications, and cost calculations.

The SME aims to recycle powder, aligning with sustainable development. Tests for powder purification and microbial contaminant identification were conducted.

Morphological and spectral characterization of cleaned powder compared to reference, unused, and contaminated powder showed that the decontamination process does not affect the powder's structure and composition.

**Personal Contributions**

In this doctoral thesis titled the following personal contributions are noted:

An analysis of global additive manufacturing companies was conducted, serving as a starting point for establishing a business in this field. The business models, manufacturing technologies, printer types, and materials used by the analyzed companies were highlighted.

An analysis of Romanian companies based on CAEN codes, focusing on 3D printing, was conducted.

A statistical classification of Romanian companies based on geographical positioning, turnover, financial results (profit/loss), number of employees, technologies and materials used, and establishment date was highlighted.

Financial data of Romanian companies for 2020-2022 were analyzed, showing that five out of six analyzed companies doubled or even tripled their turnover in 2022 compared to 2020.

An original structure for generating innovative business models specific to SMEs in the SLS additive technologies field was created, resulting in 640 theoretically possible business models.

Eight business models were highlighted within the general scheme by combining the most important activities from the five services of the SME (Prototyping, Production on-demand, Consultancy, Design on-demand, and Powder Recycling).

The AHP multicriteria analysis was used, recognized as one of the most efficient multicriteria analysis methods, applied in two stages: determining the weight of criteria and establishing the optimal business variant for SMEs in additive manufacturing.

Three scenarios (favorable, probable and unfavorable) were analyzed for establishing an SME in additive manufacturing to determine and size the investment project and the investment realization schedule.

The optimal model for establishing an SME involves creating a functional prototype with detailed design and zero-series on-demand production. The newly established SME will be a Spin-Off, adopting a circular economy by collecting residual powders, decontaminating, and recycling them for reuse as raw material in other industries like the textile fiber industry.

CAD designs for a propeller protection grid, a set of landing gear, and support for DJ Mavic PRO were created. The first version of the protection grid was designed with a solid frame, reduced contact surface, and a clip fastening system. The improved second version features a reduced mass due to a hollow frame construction, increased contact surface between the frame and arms through curved joints, and an optimized fastening system with a floating part. The rear landing legs fastening system also uses a floating part. All accessories were verified, corrected, positioned in the virtual printer tank for optimization, and printed.

A significant chapter of the thesis focuses on recovering nylon powder that can no longer be reused in additive manufacturing and recycling it. Qualitative and quantitative tests were conducted to ensure 100% decontamination.

Several methods for purifying recovered nylon powder were analyzed, and washing the powder with a water and potassium hydroxide solution was chosen for its efficiency and cost-effectiveness.

The optimal method for eliminating contaminants was identified from seven analyzed samples varying in temperature, concentration, and time.

Tests for morphological and spectral characterization of reference powder (as sold), contaminated (recovered), and recycled powder were conducted. The results showed that the decontamination process did not affect the powder's structure or composition.

Costs for decontaminating one kilogram of Nylon 12 powder were calculated.

**Future Research Directions**

Pollution with plastic has become one of the most important problems of today’s ecosystems. One of its components, the so-called microplastics, presents the greatest risk, being practically in every corner of the Earth planet. The company's secondary objective focuses on environmental factors such as waste, soil, and water pollution with microplastics.

In this context, a future research direction involves analyzing the effect of powder on plants if it reaches the soil.

The influence on plant growth will be analyzed for a set of samples. One set will be the reference (plain seeds + soil + water), while other sets will be treated/watered with different concentrations of homogeneous water and powder mixtures. The roots and stems will be analyzed under a microscope to determine the long-term effects of soil pollution with microplastics.

Another research direction involves the development of new sustainable materials used in the additive manufacturing process. Additionally, these materials have to be easier to recycle and have a reduced environmental impact. Another aspect could be the use of biodegradable materials in the additive manufacturing process.

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