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AMAZE

Erasmus+ Programme Key Action 2 Cooperation Partnerships for Higher Education (KA220-HED)
Agreement number 2023-1-RO01-KA220-HED-000155412

European Network for Additive Manufacturing in Industrial Design for Ukrainian Context

E-CASE STUDY – NO.1

Virtual platform for Additive Manufacturing

Project Title	**European Network for Additive Manufacturing in Industrial Design for Ukrainian Context 2023-1-RO01-KA220-HED-000155412**
Output	**IO4 - AMAZE e-case study**
Module	**E-case study – No.1** **Realizing the VR/AR e-learning platform**
Date of Delivery	**November 2024**
	EDIBON International S.A., Spain
Version	**FINAL VARIANT, *14.11.2024**

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1 *Introduction*

In an increasingly digital world, distance learning has become a vital component of education across various fields, including additive manufacturing. This chapter focuses on an online platform designed specifically to deliver comprehensive distance education and allow for remote control of specialized equipment. This tool offers a robust learning experience by combining theoretical knowledge with hands-on practice through direct interaction with machinery, which is crucial in the field of additive manufacturing, as in Figure 1.

Fig.1. VR/AR e-learning Platform for engineers (Formación técnica)

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2 *Overview of the Platform*

The online platform is an all-encompassing solution for distance learning in additive manufacturing, seamlessly integrating both theoretical instruction and practical sessions. Through its user-friendly interface, students can access a wide range of educational resources, communicate with instructors and peers, and remotely control manufacturing equipment—all within a single portal, as in Figure 2.

2.1. Key Features of the Platform:

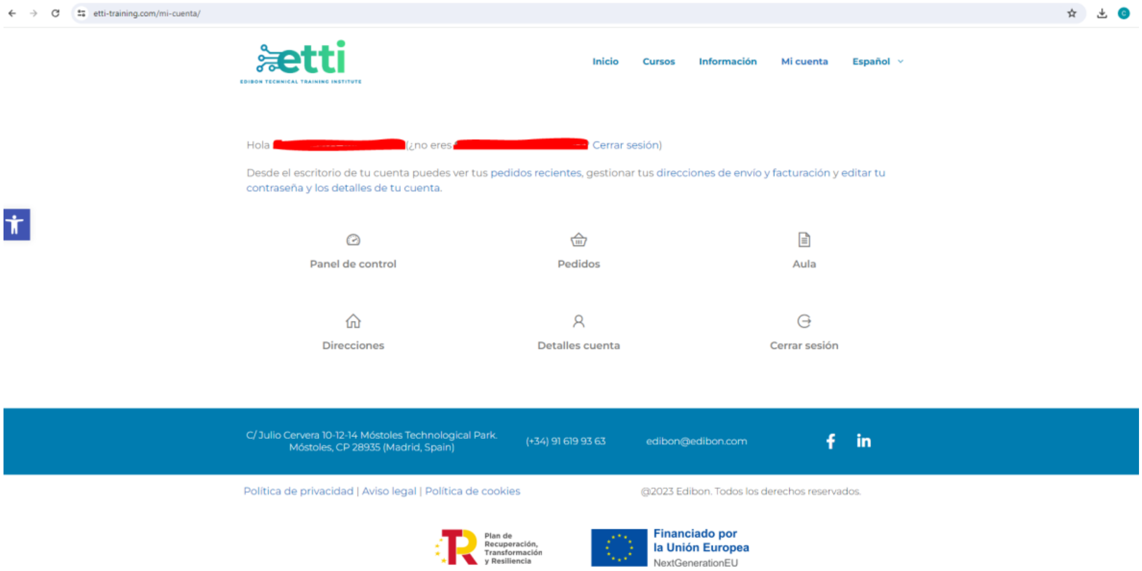

Fig.2. Key Features of the VR/AR e-learning platform

- Student Login: The platform provides secure login functionality, ensuring that only authorized users can access the course content and tools. Each student has personalized access, which protects sensitive information and allows for a customized learning experience, as in Figure 3.

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Fig.3. Edibon VR/AR e-learning platform

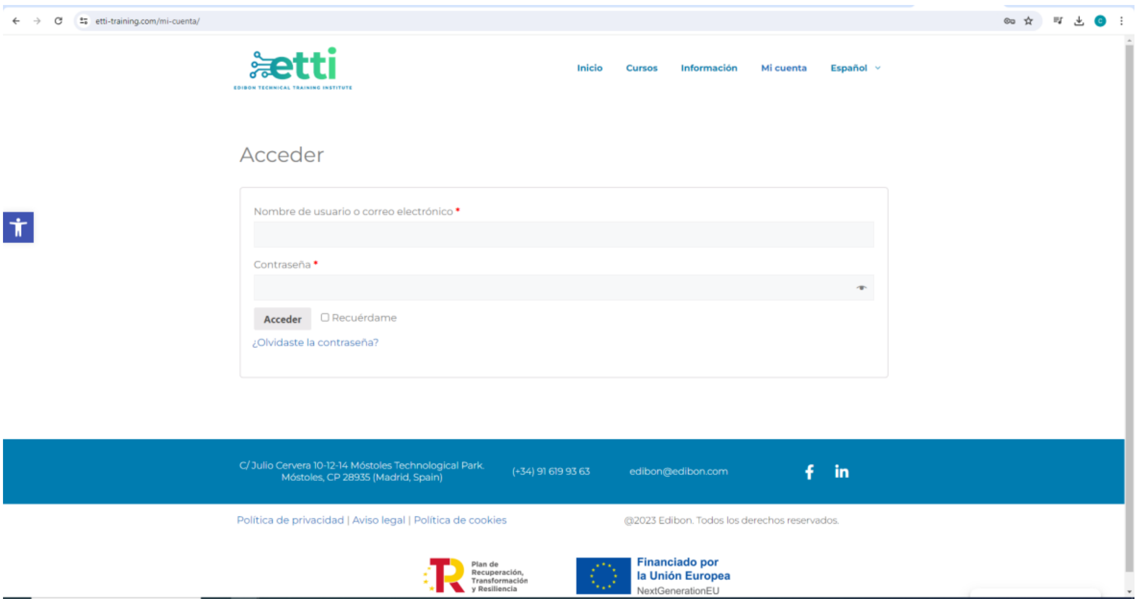

Fig.4. VR/AR e-learning platform for students

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- Calendars: Customizable calendars help students keep track of the course schedule, including important dates for exams, project submissions, and remote-control sessions. This feature helps in maintaining an organized and timely approach to learning, as in Figure 4.

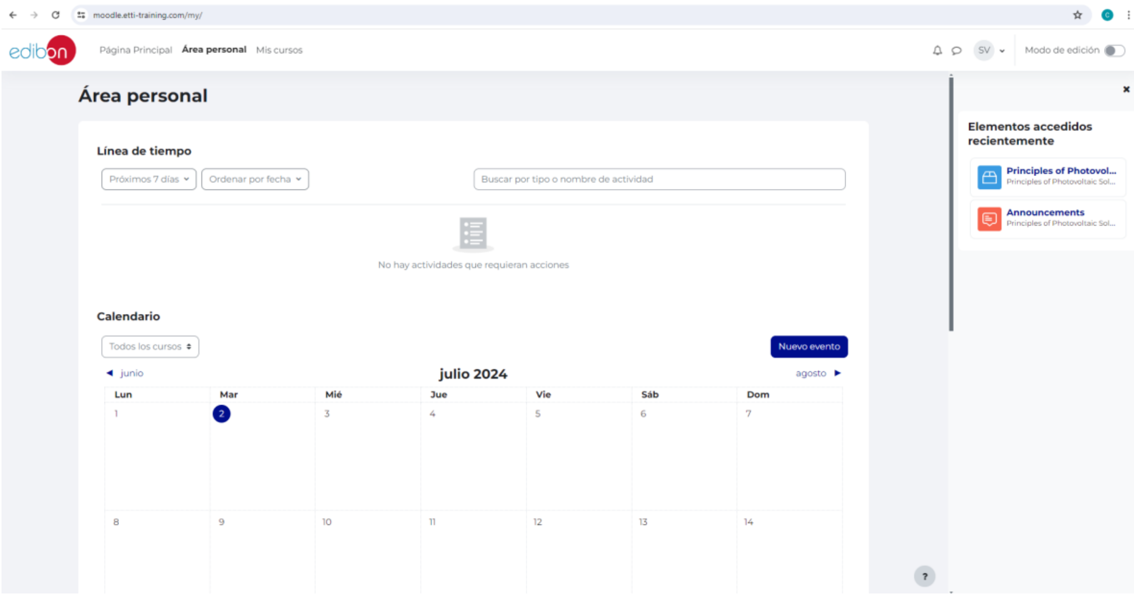

Fig.5. Personal area of the user

- Chat and Messaging: These features facilitate direct communication between students and instructors, as well as group collaboration. Real-time chat and private messaging ensure that queries and discussions are handled efficiently, enhancing the overall learning experience, as in Figure 5.

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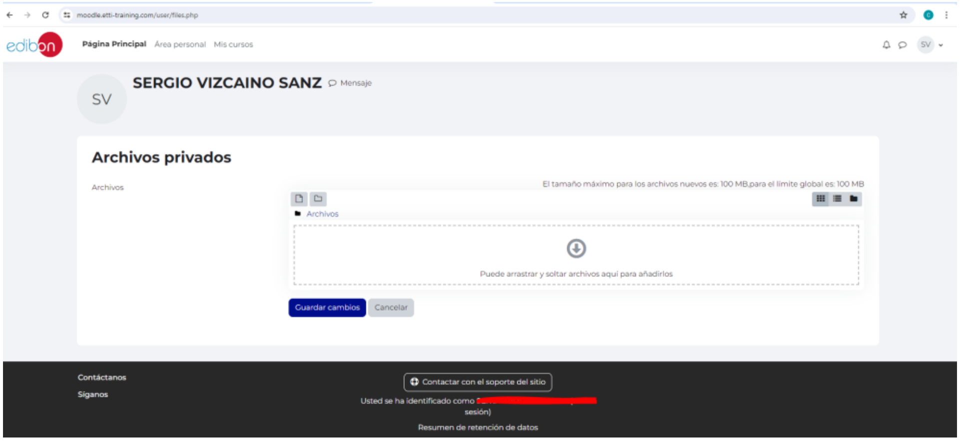

Fig.6. Private archive on the VR/AR e-learning platform

- Theory and Course Introduction: The platform provides access to theoretical content in digital format, with modules that cover everything from basic concepts to advanced topics. Each course begins with a detailed introduction that sets out the expectations and learning objectives, as in Figures 6, 7 and 8.

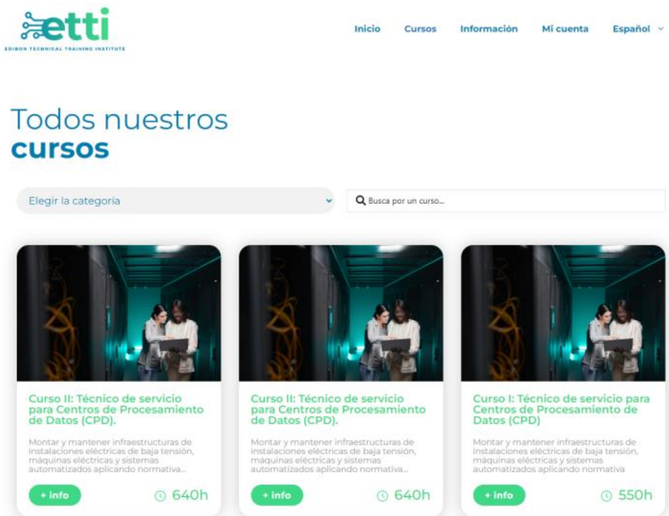

Fig.7. Cours on VR/AR e-learning platform

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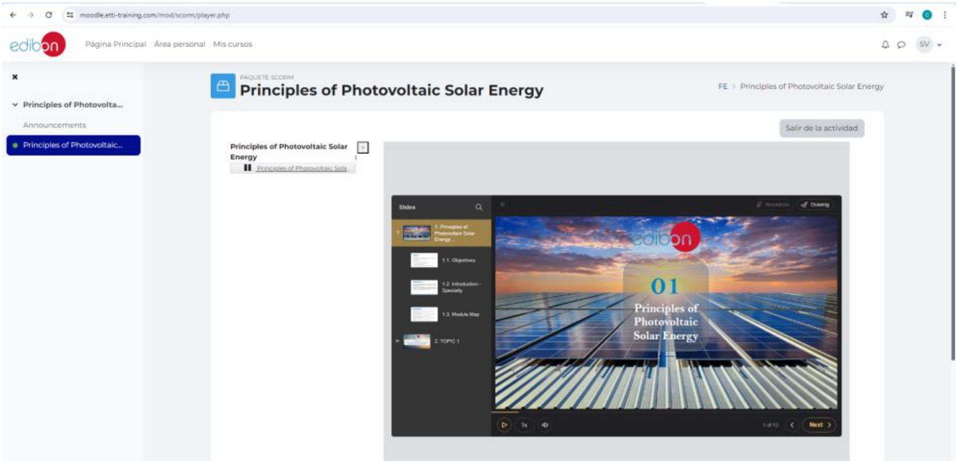

Fig.8. Topic of the course – Principles of photovoltaic solar energy

- Remote Equipment Control: One of the platform's most innovative features is the ability to control additive manufacturing equipment remotely via webcams and PLC (Programmable Logic Controller) systems. This enables students to perform practical tasks on real machines without needing to be physically present, offering an unparalleled hands-on experience, as in Figure 9.

Fig.9. Remote equipment control using VR/AR e-learning platform

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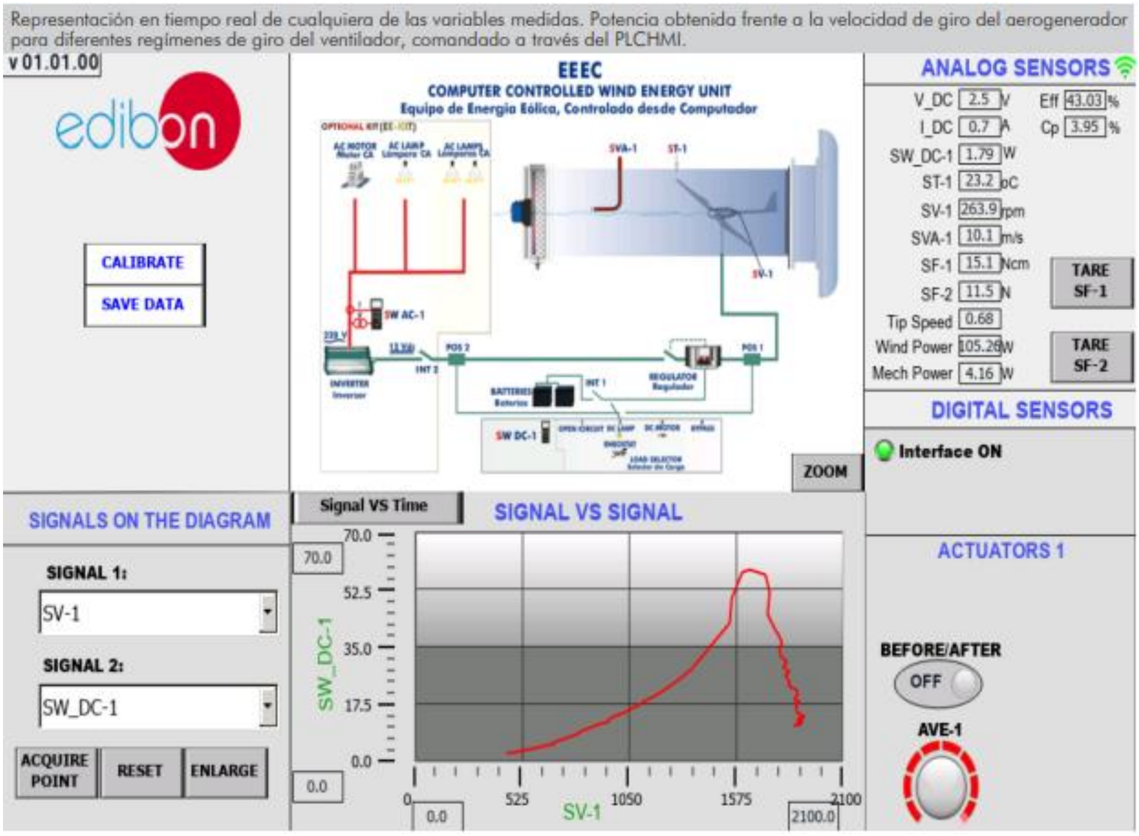

Fig.10. Results of experimental test using VR/AR e-learning platform

- Tests/Examinations and Results: Students can complete online assessments to gauge their progress, with immediate access to results and feedback. This feature supports continuous learning and improvement throughout the course, as in Figures 10 and 11.

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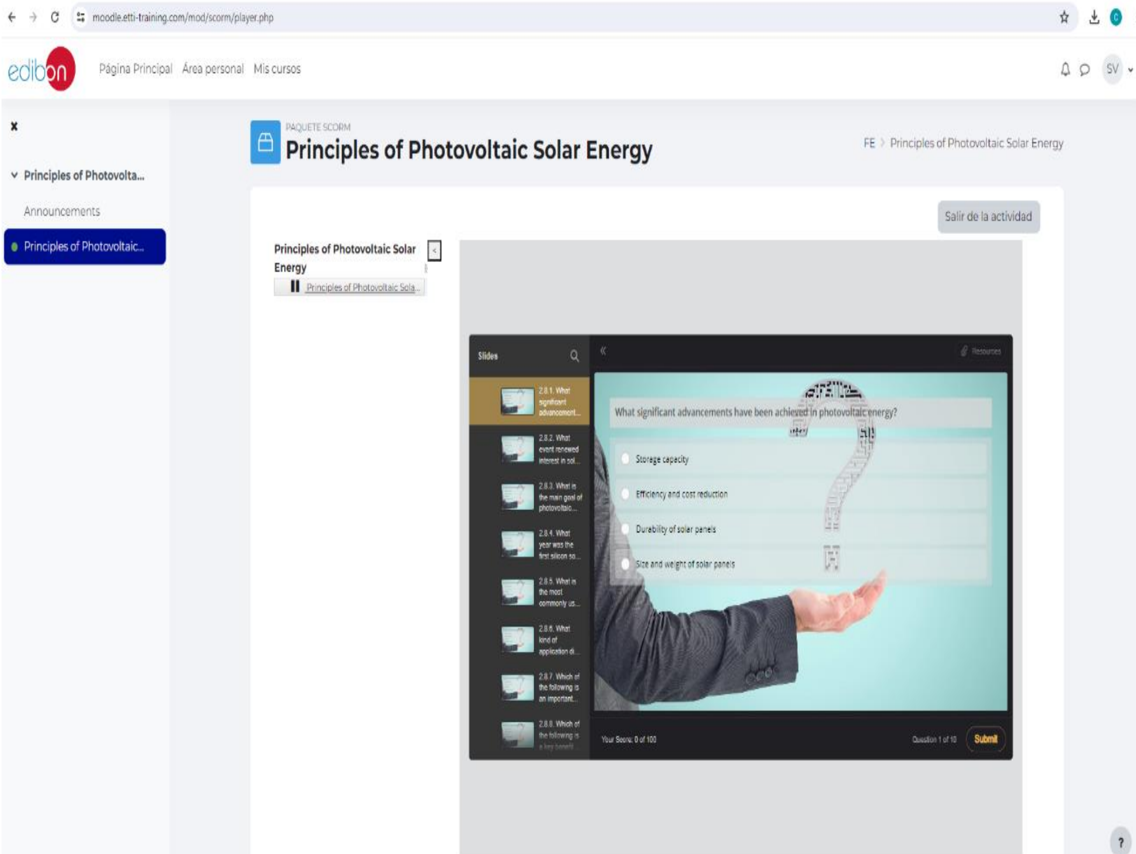

Fig.11. Tests/Examinations using VR/AR e-learning platform

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3 *Additive Manufacturing Course: Theory and Practice*

The additive manufacturing course available on the platform is meticulously designed to provide an in-depth understanding of 3D design and 3D printing, seamlessly integrating comprehensive theoretical knowledge with practical remote sessions.

3.1. Theory on 3D Design and Design Code

This module covers the fundamental principles of design in additive manufacturing, which include:

- Introduction to 3D Design: Students are introduced to the basics of 3D modeling, including creating and manipulating shapes, as well as using specialized software. This foundational knowledge is crucial for understanding the subsequent steps in the manufacturing process.

- Design for Additive Manufacturing: Here, specific considerations for designing objects intended for additive manufacturing are explored. This includes optimizing geometries, selecting appropriate materials, and understanding the limitations and advantages of various additive manufacturing techniques.

- G-Code Generation: Students learn how to convert their 3D designs into G-code, the programming language that 3D printers use to execute print commands. This section covers the most common commands and how to configure print parameters to achieve the desired output.

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3.2. Practical Component: Remote Equipment Control

The platform's practical component allows students to transition from theory to hands-on practice without leaving their learning environment:

- 3D Printing Simulation: Before accessing the actual equipment, students can use simulators to practice setting up and executing print jobs. This reduces the learning curve and minimizes the risk of costly errors when working with real machines, as in Figure 12.

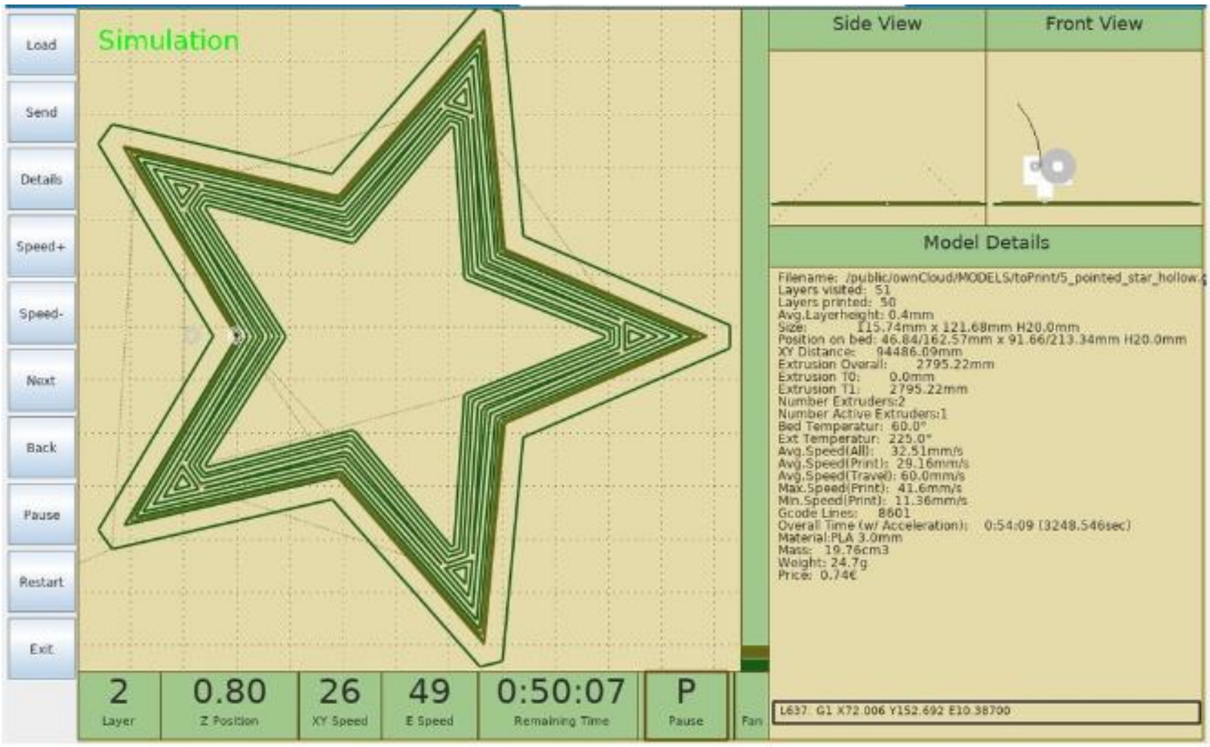

Fig.12. 3D Printing Simulation

- Remote Control via PLC: Through remote control of 3D printers located in our company's laboratory, students can upload their G-code and monitor the printing process in real-time via

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webcams. This practical experience is essential for understanding the complexities of additive manufacturing processes, using a 3D printer, as in Figure 13.

Fig.13. 3D Printer

- Real-Time Monitoring and Adjustments: During the practical sessions, students have the ability to adjust printing parameters in real-time, allowing them to respond to issues such as layer adhesion or surface quality. This feature ensures a deeper understanding of how to troubleshoot and optimize the printing process, as in Figure 14.

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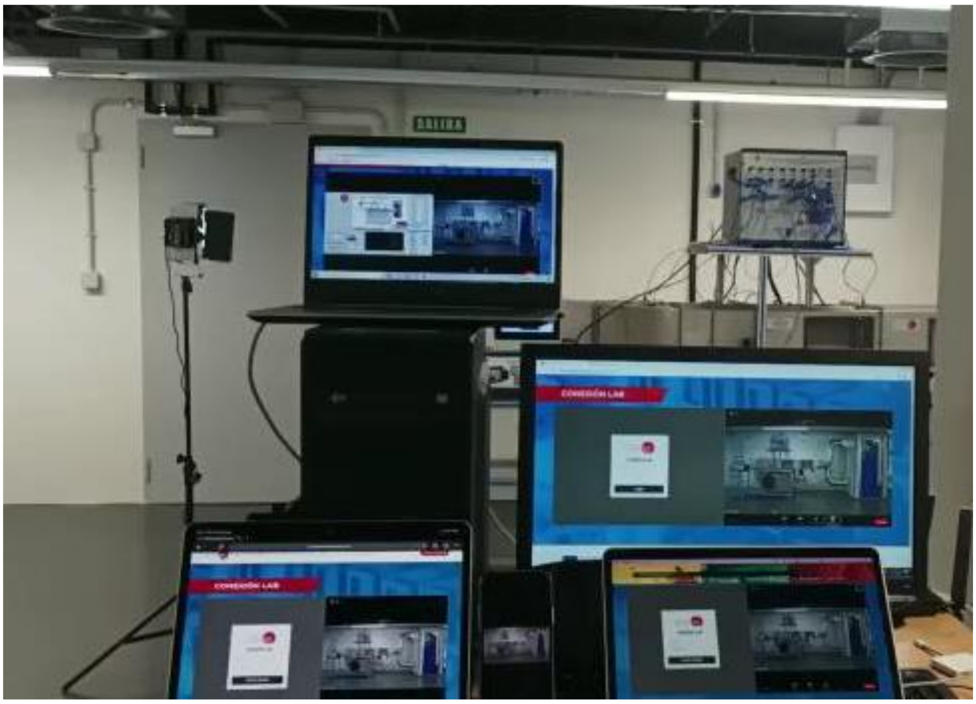

Fig.14. Real-Time Monitoring and Adjustments during the practical sessions using VR/AR e-learning platform

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4 Benefits and Applications of the Platform

4.1. Flexibility in Learning

The platform offers students the flexibility to learn at their own pace, accessing materials and tools whenever and wherever it suits them. This flexibility is especially valuable for professionals looking to expand their knowledge without compromising their work responsibilities, as in Figure 15.

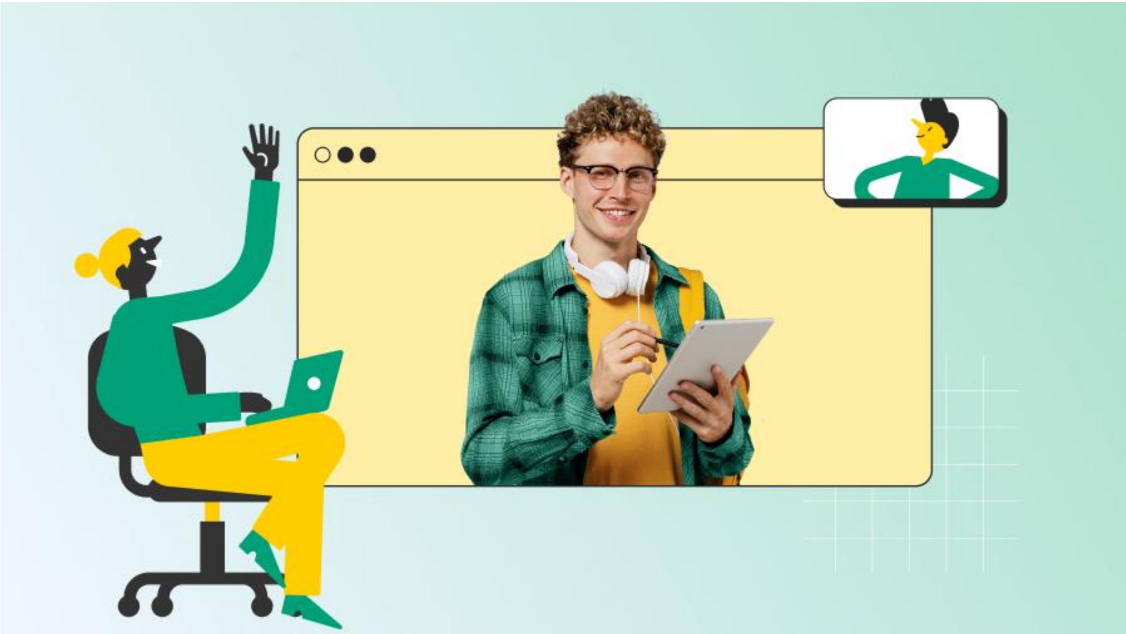

Fig.15. Flexibility on VR/AR e-learning platform to learn at their own pace, accessing materials and tools

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4.2. Hands-On Experience Without Geographical Limitations

The remote control of equipment removes geographical barriers, allowing students from around the world to access advanced additive manufacturing technologies. This capability is unique and positions the platform at the forefront of technical education, as in Figure 16.

Fig.16. Hands-On Experience Without Geographical Limitations

4.3. Continuous Integration of New Technologies

The e-learning VR/AR platform is designed to be adaptable, allowing the integration of new tools and technologies as they emerge in the field of additive manufacturing. This ensures that students always have access to the latest innovations and best practices, as in Figure 17.

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Fig.17. Adaptability of VR/AR e-learning platform, allowing the integration of new tools and technologies

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5 Conclusions

This platform represents a significant advancement in the field of distance learning, specifically designed for additive manufacturing. This innovative approach seamlessly combines theoretical content with remote practice, offering students a comprehensive and deeply enriching educational experience, as in Fig.18.

Fig.18. VR/AR e-learning platform used for Additive Manufacturing

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In a world where technology evolves at a rapid pace, the ability to adapt to new tools and methodologies is essential. This platform not only provides fundamental theoretical knowledge but also allows students to apply these concepts in a practical environment, even when they are miles away from traditional equipment and laboratories. This unique combination ensures that students not only understand the theoretical principles of additive manufacturing but also develop the practical skills necessary to face the real challenges they will encounter in the industry, especially in Industry 5.0, as in Figure 19.

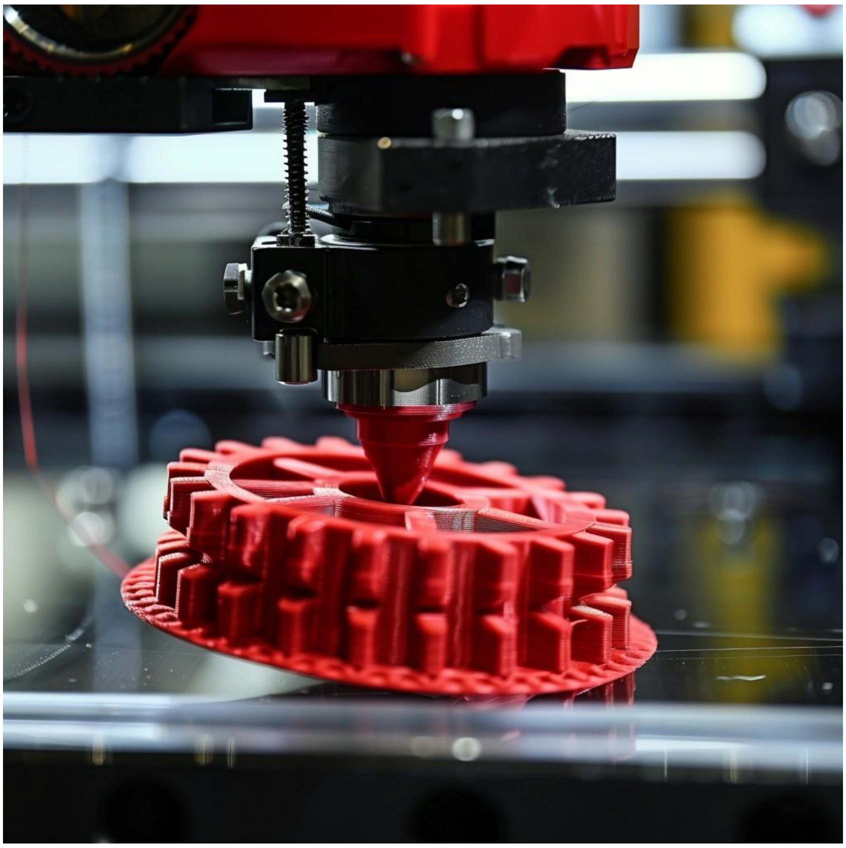

Fig.19. VR/AR e-learning platform combines theoretical principles of additive manufacturing and practical skills for Industry 5.0.

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Moreover, the system has been designed to be highly interactive and adaptable to the individual needs of each student. It utilizes advanced simulations and real-time collaboration tools that allow students to experiment and solve problems in a controlled yet dynamic environment. This approach not only enhances knowledge retention but also fosters creativity and critical thinking, qualities that are indispensable in the field of additive manufacturing.

Another key aspect of this platform is accessibility. It is understood that access to specialized equipment can be limited, especially for those living in remote areas or lacking the resources to attend in-person courses. Therefore, an infrastructure has been developed that allows students to interact with state-of-the-art machinery and software from the comfort of their homes. This flexibility not only democratizes access to quality education but also prepares a new generation of professionals capable of leading the future of digital manufacturing, as in Figure 20.

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Fig.20. Accessibility of VR/AR e-learning platform as an educational resource

In summary, this platform is more than just an educational resource; it is a transformative tool that empowers students to face real-world challenges in additive manufacturing. By integrating theoretical knowledge with remote practice, it creates a learning environment that is both accessible and highly effective, preparing students to excel in an ever-evolving industry.

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6 References

Books and Publications:

- "The SAGE Handbook of E-learning Research" by Richard Andrews and Caroline Haythornthwaite: a comprehensive resource on e-learning research.

- "Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing" by Ian Gibson, David W. Rosen, and Brent Stucker: a key book on additive manufacturing technologies.

- "Teaching in a Digital Age: Guidelines for Designing Teaching and Learning" by A.W. (Tony) Bates: a resource for designing and implementing online courses.

Academic Articles:

- A systematic review on the role of e-learning and virtual laboratories in engineering education. (Educational Research Review)
- "Remote Control of Additive Manufacturing Machines: Enhancing Learning Through Practical Engagement at a Distance" (Journal of Manufacturing Processes).

Articles and Technical Reports:

- "Advances in Remote Monitoring and Control Systems for Manufacturing" (Journal of Manufacturing Systems)
- "The Impact of Distance Learning Technologies on Technical Education in the Manufacturing Industry" (Industry Report, 2023).

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Project No: 2023-1-RO01-KA220-HED-000155412
Project title: European Network for Additive Manufacturing in Industrial Design for Ukrainian Context – Acronym: AMAZE

E-case study – No.2

Additive Manufacturing of industrial parts

Project Title	**European Network for Additive Manufacturing in Industrial Design for Ukrainian Context 2023-1-RO01-KA220-HED-000155412**
Output	**IO4 - AMAZE e-case study**
Module	**E-case study – No.2** **Additive Manufacturing of industrial parts**
Date of Delivery	**November 2024**
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Version	**FINAL VARIANT, *14.11.2024**

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E-case study – No.1 - cable fixing clamp

1. *Introduction*

Thermoplastic extrusion/melt deposition modeling is the most widely used additive manufacturing technology due to its simplicity and affordability. It is used in modeling, prototyping but also in production applications.

FDM printing technology consists of passing a plastic filament through an extruder that heats it up to melting point, then applying it uniformly (by extruding) layer upon layer with high accuracy to physically print the 3D model according to the CAD file .

The thermoplastic material is heated until it reaches a semi-liquid state, then it is extruded through a small diameter nozzle and is deposited in layers with a thickness of several tenths of a millimeter.

The deposition is carried out with the help of a modeling head equipped with one or two extrusion nozzles.

The raw material used from a physical point of view is in the form of a filament with a diameter of approximately 1.75; 2.85 or 3 mm.

The essential element of the FDM process is maintaining, inside the heating-extrusion head, a temperature corresponding to the pasty state of the material.

The advantages of FDM technology are very user-friendly, silent and safe office technology.

Usable objects and parts can be produced, the palette of materials being quite wide. The price of 3D printers (kits and assembled models) as well as consumables (rolls with plastic filaments) is extremely affordable. FDM manufacturing technology features ease of use. The disadvantages of this process are the slow construction speed in the case of complex geometries, the possibility of non-uniformly printed areas (non-glued layers), low impermeability, poor resolution and accuracy for small parts and fine details (microns).

Applications of the FDM process consist of making durable parts and subassemblies for functional testing, conceptual design, presentation and marketing models, detail parts for

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food or medical applications, plastic subassemblies for high temperature applications, very small series productions.

Stereolithography (SLA or SL) is an additive manufacturing technology, known as a manufacturing process by solidifying the raw material in a liquid state due to photopolymerization. Stereolithography was the first process that allowed the generation of a physical model, using model data, directly from the computer. The parts are solidified in the presence of the laser, at low laser powers (5-10 W).

This technology allows the creation and manufacture of models, prototypes and parts layer by layer, using for solidification, the process of selective photopolymerization, a process that is activated by a light beam and forms bonds between unsaturated molecules forming polymer chains.

The desired 3D model is initially sliced into cross sections. For each layer, the laser beam traces a cross-section of the partial pattern on the surface of the liquid resin. Exposure to ultraviolet laser light solidifies the model drawn on liquid resin resulting in a solid built (3D printed) layer that is added to the previous built layer.

After the pattern has been drawn, the platform descends a distance equal to the thickness of a single layer, typically between 0.05 mm and 0.15 mm.

The accuracy of the printed parts is very good, the finish of the printed surfaces is very good, the printing speed is good to very good.

Materials used are photo-sensitive liquid resins, ceramic materials (newly developed).

SLA technological advantages are the prototyping of parts with complex and highly detailed geometries, very fine and precise printed surfaces, large part construction sizes, the printed parts can be used as a master mold for the industries of injection molding (injection molding), thermoforming, casting metals and parts resistant to high temperatures.

SLA technological disadvantages consist of average resistance to mechanical processing, unsustainability over time, long exposure to the sun damages parts that become brittle and

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brittle, requires troublesome post-processing operations (with potentially dangerous chemicals).

DLP (digital light exposure) printing technology is an additive manufacturing process based on the use of UV light to solidify liquid photopolymer resins. The DLP process is a form of stereolithography that is used in rapid prototyping services.

The main difference between DLP and SLA is the use of a light projector that solidifies the resin of a photosensitive polymer, versus a laser as used in the stereolithography process.

A DLP printer projects the 3D cross-sectional image of the object onto the surface of the resin.

The resin exposed to the light source hardens as the car's build platform lowers, allowing a new layer of fresh resin to be deposited to be solidified by the light.

Once the part is fully fabricated, additional post-processing such as backing material removal, chemical bath and UV drying can be performed.

Since the entire cross-section is designed in a single exposure, the construction speed of a layer (section) is constant regardless of the complexity of the geometry.

Regardless of whether a simple part is printed or 10 complex parts simultaneously, the printing speed remains constant. DLP technology costs are superior to FDM.

In the case of DLP technology, the accuracy of the printed parts is very good.

The finish of the printed surfaces is very good. Print speed is good (for multiple objects and complex geometries).

The materials used by DLP technology are different types of resins, photopolymers, transparent resins, wax-based polymers.

The advantages of DLP technology are fine and precise printed surfaces (use in the jewelry industry, dental technology, electronics), fairly resistant prototypes for processing, diverse range of resins including biomedical materials (certified for use in the medical field) and transparent resins (prototypes in the industry packaging), stable printers with few moving parts.

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2. Experimental research

As part of the experimental research, different functional prototypes of some 3D parts were made. The 3D printers used in the research were: Formlab (SLA technology), Photocentric Crystal (DLP technology) and Zortrax (FDM technology).

The Formlab Form2 3D printer (fig. 1) is a modern, state-of-the-art printer that produces parts with an accuracy of 25-300 microns. It is equipped with a low-power laser (P=250 mW and λ=405 nm). The software used is Preform. The file types used are STL, OBJ or FORM.

Fig.1. 3D printer - Form 2 [5]

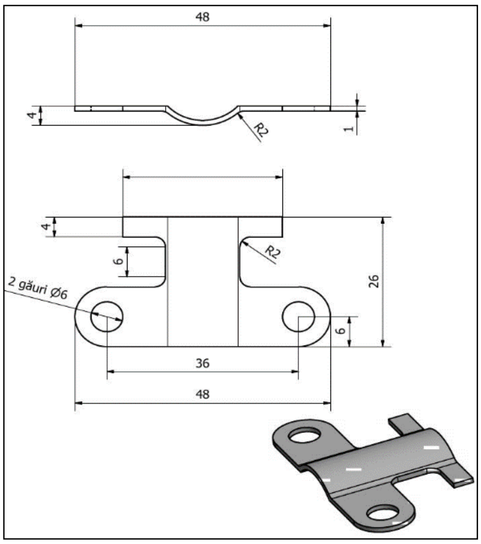

Fig.2. Reper- cable fixing clamp

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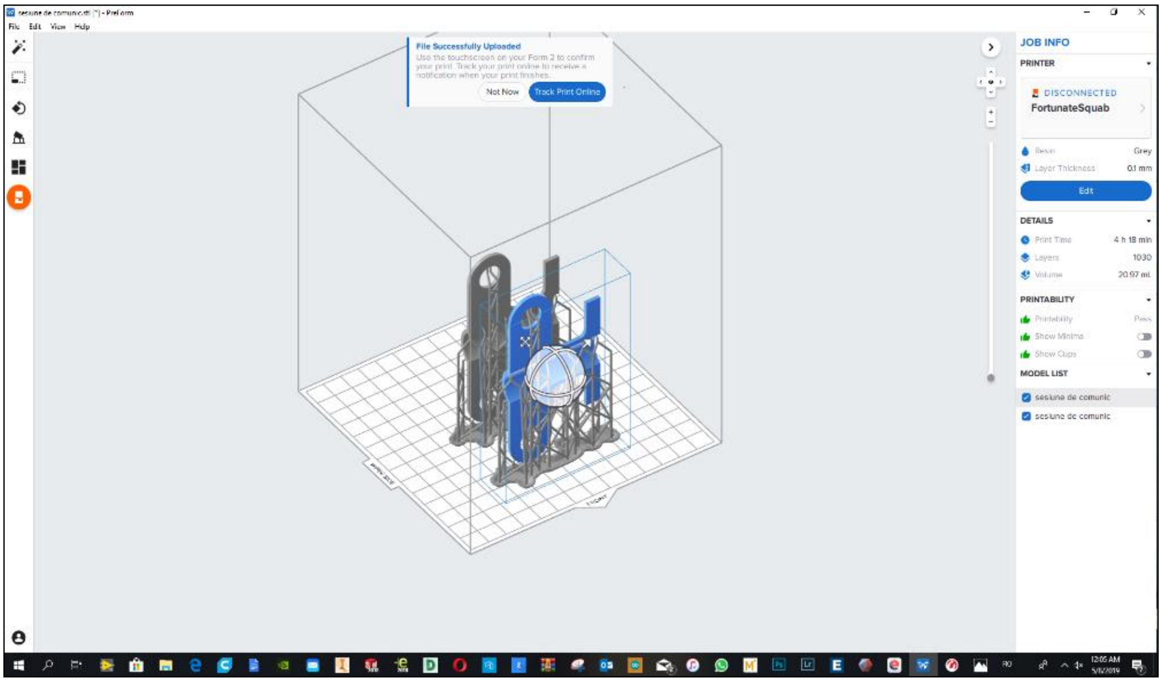

Fig.3. The STL file of the Cable fixing clamp, using the PreForm software

It made the 3D design, using the SolidWorks software, and it made the cable fixing clip, within the TDPR project. The Preform software was used to prepare the 3D printing of the landmark, as in figure 3. The landmark will have 1030 layers, the printing duration will be 4 h and 18 min and around 20.97 ml of photopolymerizable resin will be consumed.

The material used was a gray photopolymerizable resin, with special mechanical resistance, used for the manufacture of prototypes and models in the field of mechanical engineering that require high rigidity. The mechanical properties of this material are given in table 1, and the chemical properties are presented in table 2. The cost of this resin is 149 $.

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Fig.4. The PreForm software and the manufacturing parameters

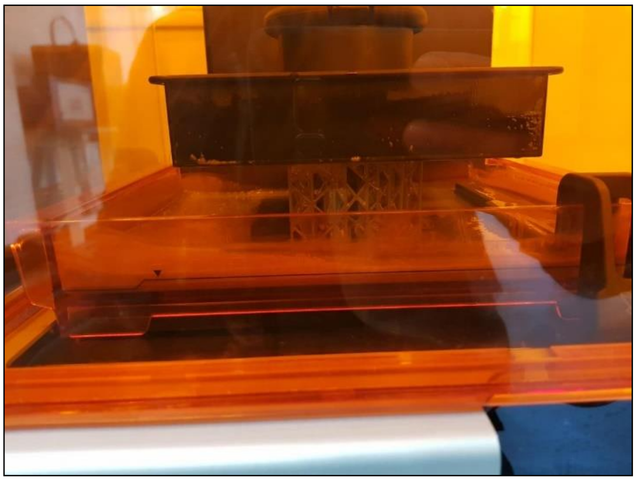

Fig.5. The SLA processing for the Cable Fixing Clamp

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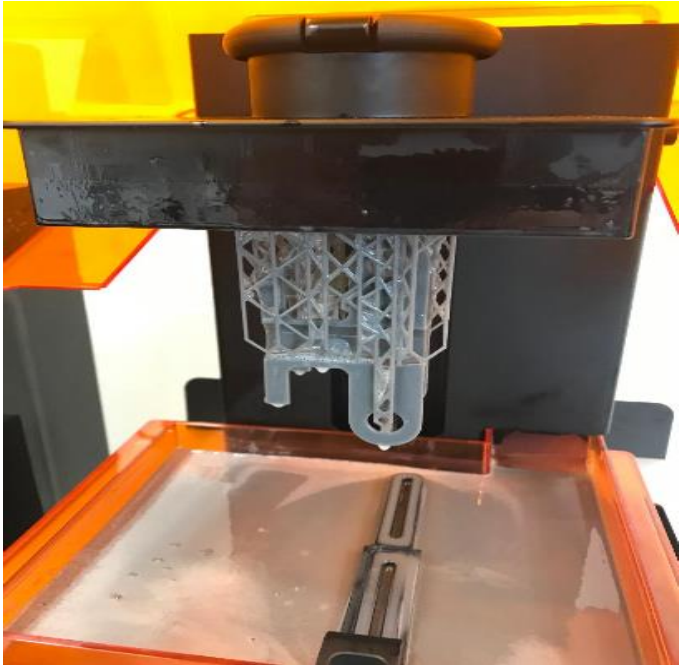

Fig.6. The cable fixing clamp with supports, printed on FormLab 3D printer

Table 1. The mechanical properties of the gray photopolymerizable resin used in SLA technology

	METRIC[1]		IMPERIAL[1]		METHOD
	Green[2]	Post-Cured[3]	Green[2]	Post-Cured[3]	
Tensile Properties					
Ultimate Tensile Strength	35 MPa	61 MPa	5076 psi	8876 psi	ASTM D 638-14
Tensile Modulus	1.4 GPa	2.6 GPa	203 ksi	377 ksi	ASTM D 638-14
Elongation	32.5 %	13 %	32.5 %	13 %	ASTM D 638-14
Flexural Properties					
Flexural Stress at 5% Strain	39 MPa	86 MPa	5598 psi	12400 psi	ASTM D 790-15
Flexural Modulus	0.94 GPa	2.2 GPa	136 ksi	319 ksi	ASTM D 790-15
Impact Properties					
Notched IZOD	not tested	18.7 J/m	not tested	0.351 ft-lbf/in	ASTM D256-10
Temperature Properties					
Head Deflection Temp. @ 1.8 MPa	not tested	62.4 C	not tested	144.3 °F	ASTM D 648-16
Heat Deflection Temp. @ 0.45 MPa	not tested	77.5 C	not tested	171.5 °F	ASTM D 648-16
Thermal Expansion (-30 to 30° C)	not tested	78.5 um/m/C	not tested	43.4 µin/in/°F	ASTM E 831-13

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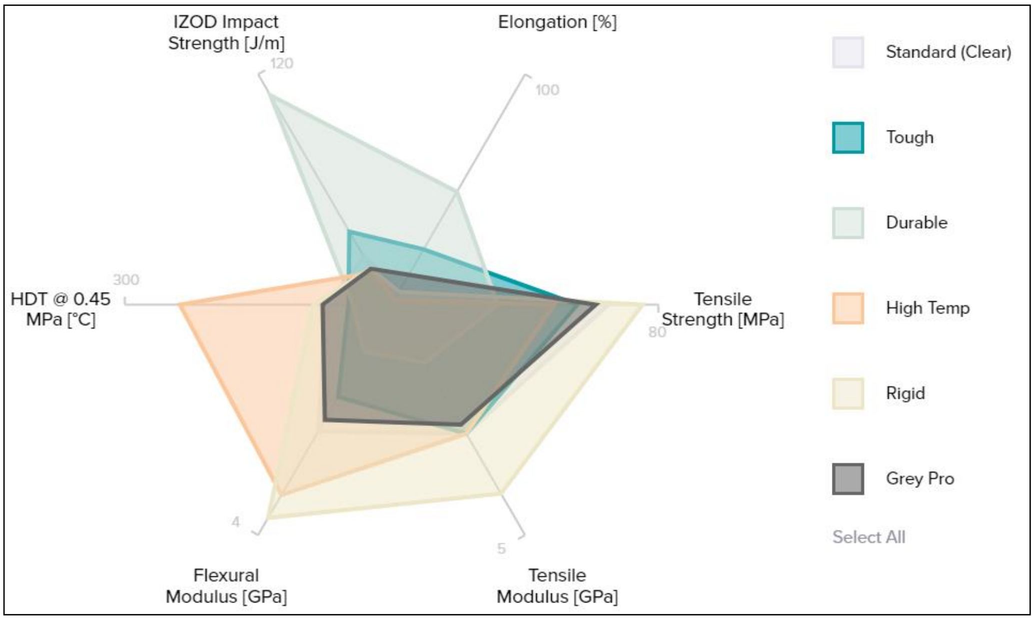
Table 2. The chemical properties of the light-curing resin used in SLA technology

Mechanical Properties	24 hr weight gain (%)	Mechanical Properties	24 hr weight gain (%)
Acetic Acid, 5 %	0.75	Hydrogen Peroxide (3 %)	0.75
Acetone	10.77	Isooctane	0.02
Isopropyl Alcohol	1.56	Mineral Oil, light	0.35
Bleach, ˜5 % NaOCl	0.65	Mineral Oil, heavy	0.27
Butyl Acetate	0.84	Salt Water (3.5 % NaCl)	0.64
Diesel	0.08	Sodium hydroxide (0.025 %, pH = 10)	0.72
Diethyl glycol monomethyl ether	2.38	Water	0.83
Hydrolic Oil	0.16	Xylene	0.42
Skydrol 5	0.54	Strong Acid (HCl Conc)	8.21

Table 3. The mechanical properties of the different types of resins used by the Formlab Form2 3D printer



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The mechanical properties of the different types of resins used by the Formlab Form2 3D printer are presented in table 3. The resins used by SLA technology are used in the aeronautical industry, the automobile industry, medicine (dentistry, orthodontics), in the jewelry industry, architecture, etc. .

It was tried to manufacture the same part on a 3D printer, Zortrax from fig.7, using FDM technology, the software used being the ZSuite software from fig.8. The thickness of the deposited layer is 0.09 mm, the material used is ABS, and the filament melting temperature in the extruder is between 200-220^{o}C. The table is heated up to 20oC during manufacturing. For efficient cooling of the deposited layer, 1 cooler is used. The generation of g-code is carried out for 3D printing. In this case, the piece will have 980 layers, the layer thickness is 0.09 mm, 7.34 m of ABS filament will be used and the 3D printing time will be approximately 5 hours and 22 minutes. The 3D printed part by FDM technology is shown in fig.9. The cost of a roll of ABS filament is 20 $.

Fig.7. 3D printer - Zortrax M200 [6]

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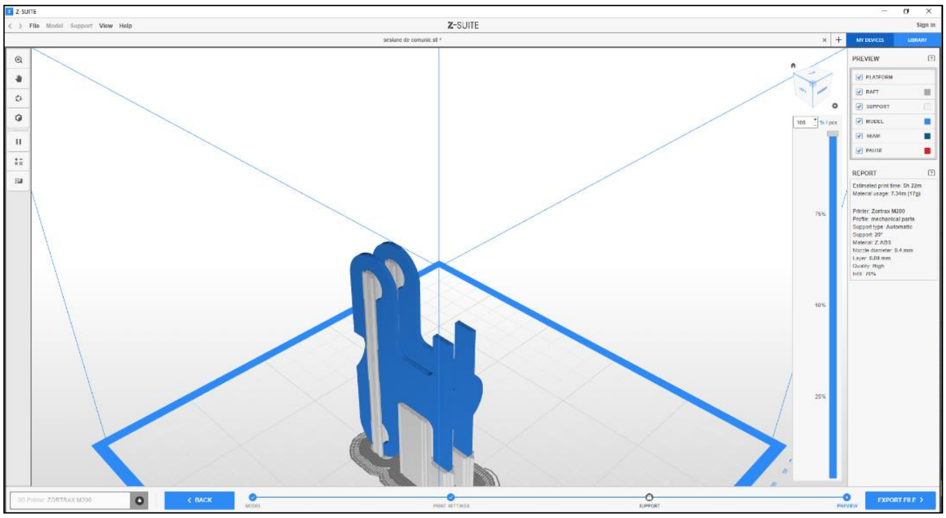

Fig.8. The ZSuite software used for preparing 3D printing through FDM technology

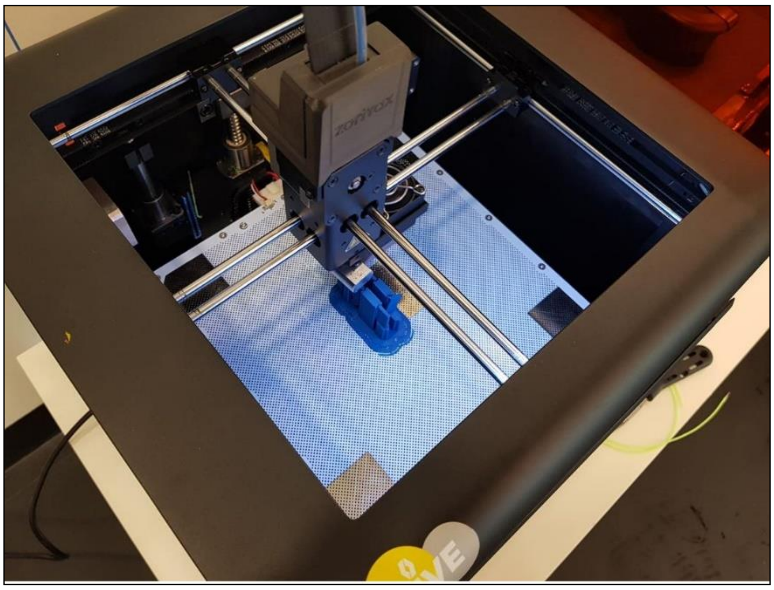

Fig.9. The manufacturing process using FDM technology for the Cable Fixing Clamp

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Fig.10. The cable fixing clamp printed using FDM technology, with supports

For the DLP (Digital Light Processing) technology, a 3D printer, Photocentric Crystal from fig.12, was used, and the material used is bisphenol A ethoxylate diacrylate (Ebecryl 150), and the mechanical and chemical properties are presented in table 4. The software used by this the printer is Photocentric Studio. The piece was sectioned into approximately 24 layers, as in fig.13. The duration of 3D printing will be 20 minutes, and 0.20 ml of photopolymerizable resin. In figure 14, the DLP printed part is presented, through DLP technology.

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Fig.11. The cable fixing clamp printed using FDM technology, after cleaning the supports

Fig.12. 3D printer - Photocentric Crystal [7]

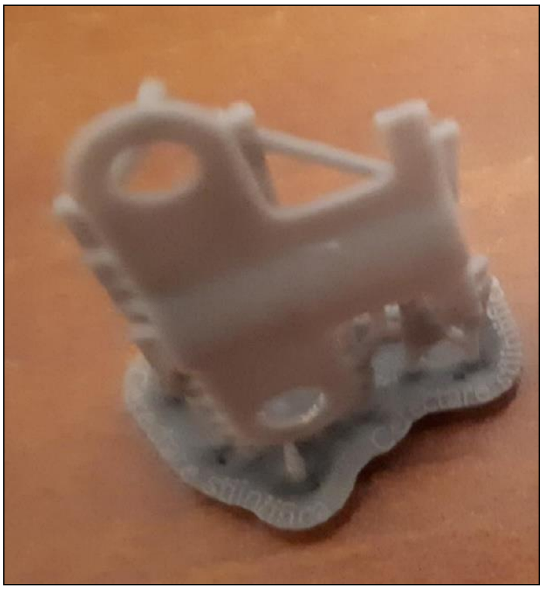

Fig.13. The parts printed using DLP technology

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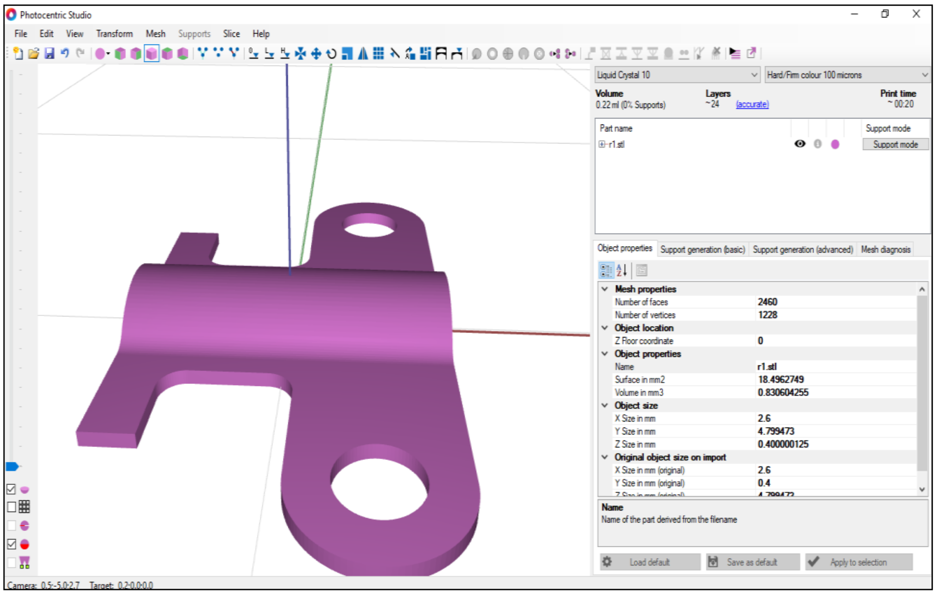

Fig.14 The Photocentric Studio software used to prepare 3D printing through DLP technology

Table 4. The mechanical and chemical properties of the resin photopolymerizable Ebecryl 150

SPECIFICATIONS[1]	VALUE
Acid value, mg KOH/g, max.	5
Appearance	Clear liquid
Color, Gardner scale, max.	2
Viscosity, 25°C, cP/mPa·s	1150-1650
TYPICAL PHYSICAL PROPERTIES	
Density, g/ml at 25°C	1.14
Flash point, Setaflash, °C	>100
Functionality, theoretical	2
Refractive index (n_D at 20°C)	1.5294
Vapor pressure, mm Hg at 20°C	<0.01
TYPICAL CURED PROPERTIES[2]	
Tensile strength, psi (MPa)	6300 (43)
Elongation at break, %	9
Young's modulus, psi (MPa)	180000 (1241)
Glass transition temperature, °C[3]	41

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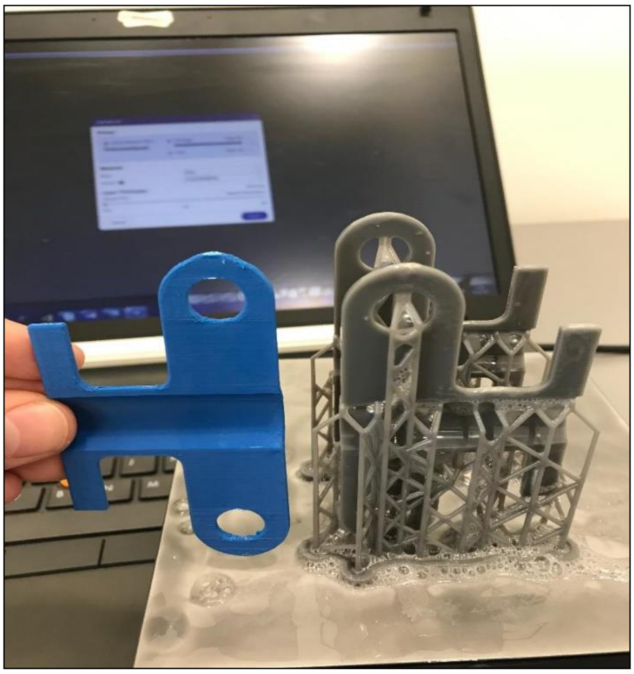

Fig.15. The cable fixing clamp printed using FDM technology and by DLP technology

3. Conclusions

After the comparison made between the 3 variants of 3D technologies that can be used for the manufacture of the Cable Fixing Clip, it was noted that the optimal variant is the SLA technology, because even if it is a more expensive variant, it ensures the necessary precision in the manufacture of the part. Looking at the duration of time, it is noted that all 3 technologies ensure approximately equal durations of time, but the prices differ, FDM technology clearly ensuring the lowest manufacturing price. The Photocentric Studio software is quite complex. The parts manufactured by SLA and DLP technologies require a post-

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processing treatment in a UV oven, at a temperature of 200oC, for half an hour to improve the mechanical properties.

It is recommended that FDM technology be used for the creation of more robust functional prototypes that do not require very high precision and do not present fine details, such as those in TFP projects, and SLA, respectively DLP technology is recommended for the manufacture of landmarks from TDPR, where the part sizes are smaller.

All 3 technologies generally use traditional plastic materials or reinforced with different metal, wood or glass particles and are used to manufacture functional prototypes with complex surfaces, depending on the desired mechanical properties.

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AMAZE

Erasmus+ Programme Key Action 2 Cooperation Partnerships for Higher Education (KA220-HED)
Project No: 2023-1-RO01-KA220-HED-000155412
Project title: European Network for Additive Manufacturing in Industrial Design for Ukrainian Context – Acronym: AMAZE

E-case study – No.3

CAD/CAM /CAE software

Project Title	**European Network for Additive Manufacturing in Industrial Design for Ukrainian Context 2023-1-RO01-KA220-HED-000155412**
Output	**IO4 - AMAZE e-case study**
Module	**E-case study – No.3 – CAD/CAM/CAE software**
Date of Delivery	**November 2024**
	Poznań University of Technology, Poland
Version	**FINAL VARIANT, *14.11.2024**

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1.Theoretical Introduction to Designing a Phone Case in Autodesk Inventor

Designing a phone case using Autodesk Inventor is based on fundamental principles of CAD (Computer-Aided Design), enabling the creation of precise, three-dimensional models of objects. A phone case serves as an example of a product that requires a combination of aesthetics, ergonomics, and functionality. The design process in Inventor involves several stages, from analyzing user requirements, creating solid geometry, to optimizing the final project.

1.1 Basics of CAD Design in Autodesk Inventor

Autodesk Inventor is an advanced parametric modeling tool that allows precise creation of 3D models. With parametric technology, it is easy to make changes to geometry and adjust the design to meet specific needs. Features like 2D sketching, solid and surface modeling, and analytical modules make the software suitable for designing both simple and complex components.

1.2 Analysis of Design Requirements

The design of a phone case requires an analysis of several key aspects:

- Phone dimensions : Accurate dimensions, such as length, width, thickness, and the location of buttons and ports, are critical for creating a functional case.
- Device protection : The case should provide adequate protection against mechanical damage, such as drops, scratches, or shocks.
- Ergonomics and aesthetics : The design must ensure user comfort and an appealing appearance, increasing the product's usability and value.

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1.3 Design Process in Autodesk Inventor

The process of designing a phone case in Inventor consists of the following stages:

- Creating a 2D Sketch : Using the phone's dimensions, a base sketch is created to define the case's shape. This involves sketching tools like lines, arcs, splines, and dimensioning tools.
- Solid Modeling : The 2D sketch is transformed into a 3D model using tools such as extrusion, revolution, and Boolean operations, creating the case's basic structure.
- Adding Details : Specific cutouts for buttons, ports, and the camera are added using tools like cut, fillet, or chamfer.
- Optimizing the Design : Once the basic model is complete, it can be optimized, for example, by conducting strength analysis (FEA) or enhancing its ergonomic features.

1.4 Advantages of Using Inventor

Autodesk Inventor offers a variety of tools that support the design process, such as:

- Simulation modules to test the model's durability.
- A parametric design approach, allowing easy modifications.
- An intuitive interface for fast and precise project creation.

1.5 Application of 3D Printing Technology

The finished phone case model can be exported as an STL file, which can then be used for 3D printing. This ensures the design in Autodesk Inventor can be easily transformed into a physical product.

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2. *E-case study*

This case study has been prepared for implementation by students during the summer school as part of the Amaze program. It provides a practical example of using Autodesk Inventor to solve real-world design problems and familiarize students with modern design and manufacturing technologies.

Step 1

Measure the overall dimensions of the cover using calipers.

Figure 1 Example of measurement implementation and guidelines

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Modelling instruction

Create a model of a rectangular prism based on the sketch of a rectangle with the recorded dimensions:

Length = 162 mm

Width = 79 mm

Height = 10 mm

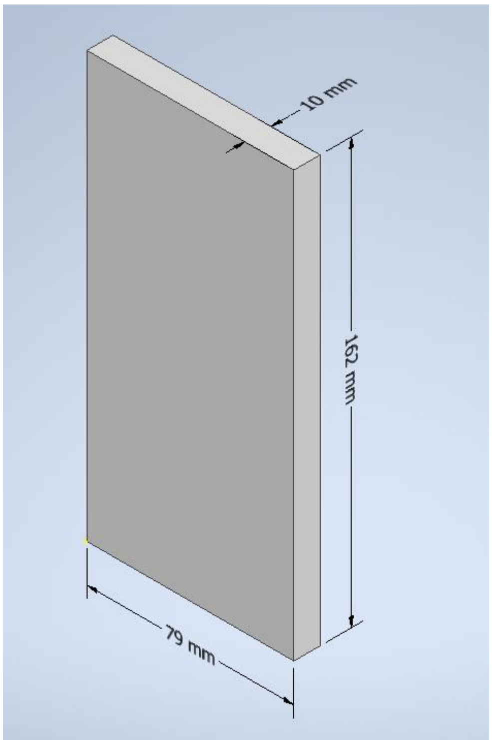

Figure 2 Model view

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Step 2

Measure the rounding of the corner marked in the photograph

Figure 3 Example of measurement implementation and guidelines

Modelling instruction

Add fillets to the corners with a radius value of:

R = 8 mm

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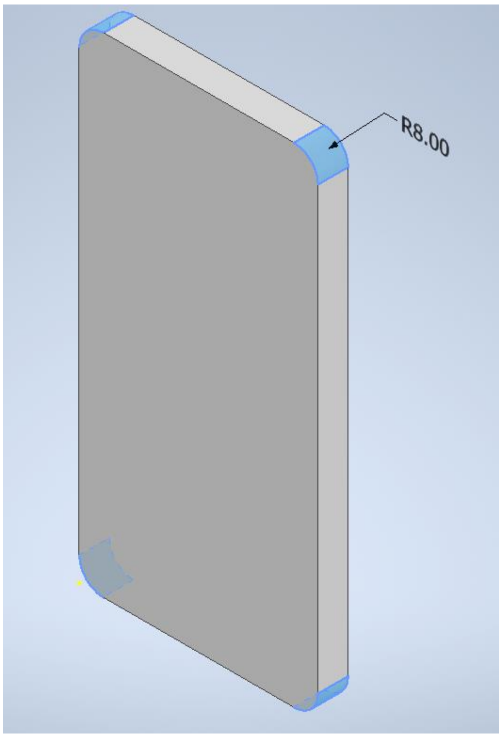

Figure 4 Model view

Step 3

Estimate the type and quantity of roundings along the side edges of the housing

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Figure 5 Example of measurement implementation and guidelines

Modelling instruction

Add fillets along the top and bottom edges of the planar face of the cuboid.

R = 1.5 mm

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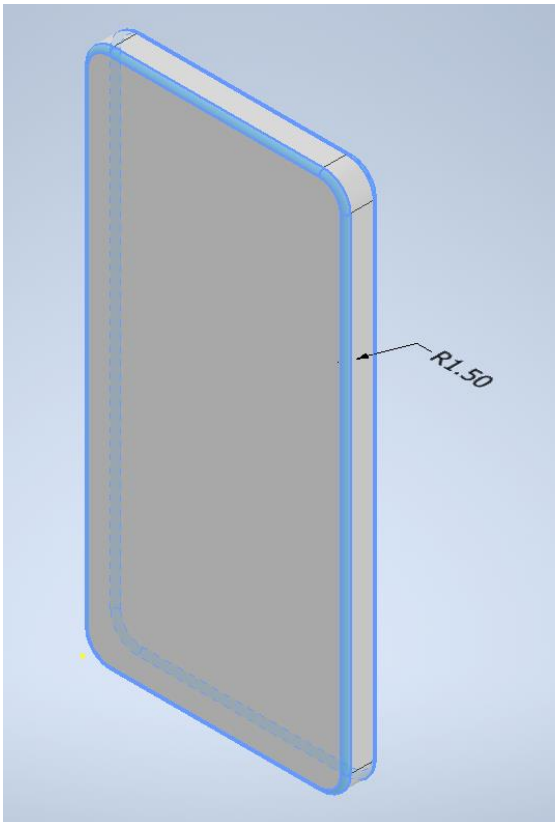

Figure 6 Model view

Step 4.1

Measure the internal dimensions of the cover

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Figure 7 Example of measurement implementation and guidelines

Figure 8 Example of measurement implementation and guidelines

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Modelling instruction

Width: 71 mm
Length: 154 mm

The noted dimensions are 8 mm smaller than the overall dimensions.

Insert a sketch on the front face of the model, considering a 4 mm inset.

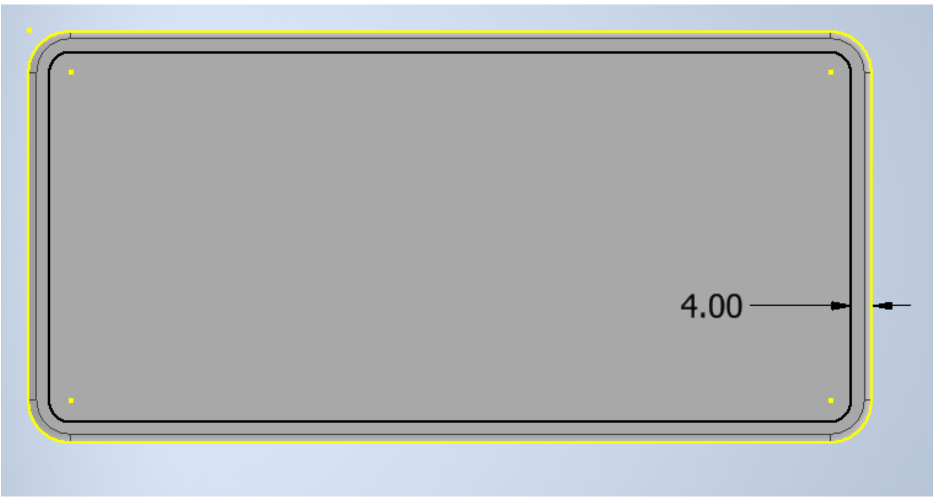

Figure 9 Model view

Step 4.2

Using the created sketch, you need to split the front face.

Project the sketch onto the front face using the "split" function.

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Figure 10 Model view

Step 4.3

In the next step, apply the "Shell" operation with the following parameters:

Thickness = 1.5 mm

Wall to remove = the surface defined in the previous step.

Figure 11 Model view

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Step 5

Measure the dimensions and position of the hole for the camera lens

Figure 12 Example of measurement implementation and guidelines

Modelling instruction

Cut out with dimensions:

Width = 15 mm

Length = 37 mm

Distance from the outer edge = 25 mm

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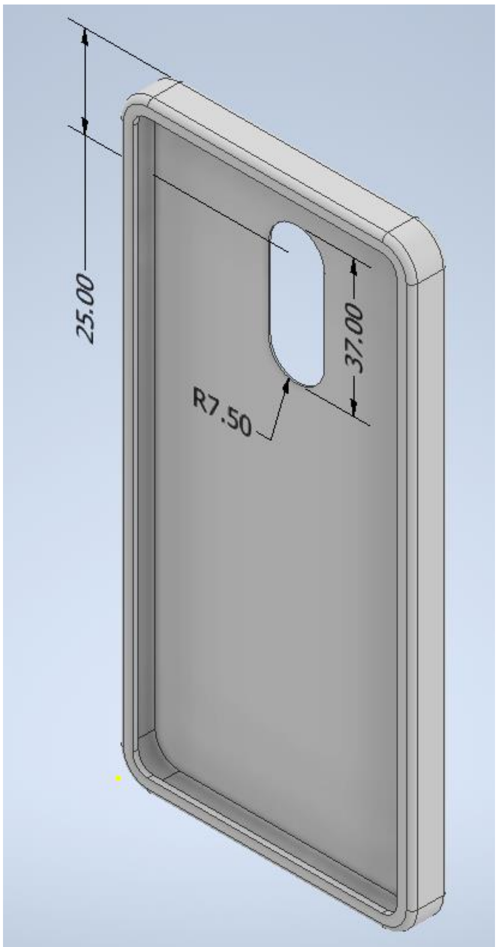

Figure 13 Model view

Step 6

Estimate the extent of chamfering.

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Figure 14 Example of measurement implementation and guidelines

Modelling instruction

Perform edge chamfering for the outer edge of the hole.

Dimension: 1 mm

Angle: 60°

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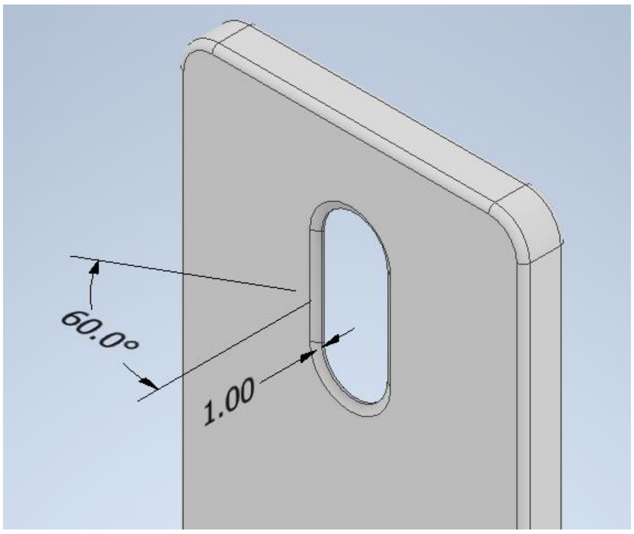

Figure 15 Model view

Step 7

Measure the holes in the bottom part of the cover. Assume that the centre of the larger hole is located on the central axis of the entire cover.

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Figure 16 Example of measurement implementation and guidelines

Modelling instruction

Create an array of cuts based on the given parameters.

Central hole:

Width: 14 mm

Height: 6 mm

Side holes:

Width: 14 mm

Height: 3 mm

Distance between holes: 6.5 mm

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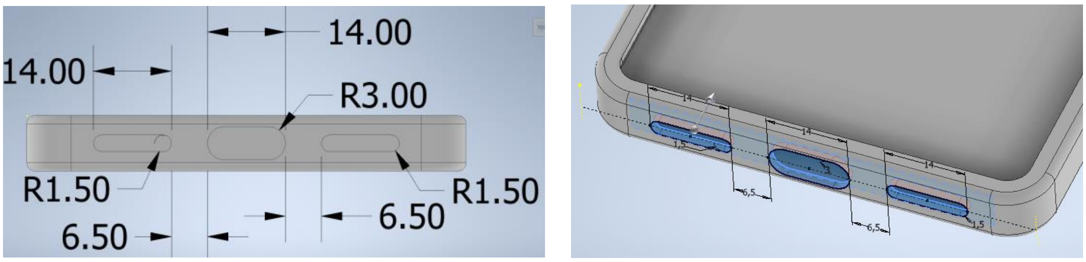

Figure 17 Model view

Step 8

Measure the holes in the top part of the cover.

Figure 18 Example of measurement implementation and guidelines

Modelling instruction

Create three holes with the following dimensions:

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Longitudinal hole:

Width: 11 mm

Height: 6 mm

Distance from the edge of the chamfer: 8 mm

Smaller circular hole:

Diameter: 2 dmm

Distance from the center of the longitudinal hole: 8 mm

Larger circular hole:

Diameter: 3 mm

Distance from the edge of the chamfer: 6 mm

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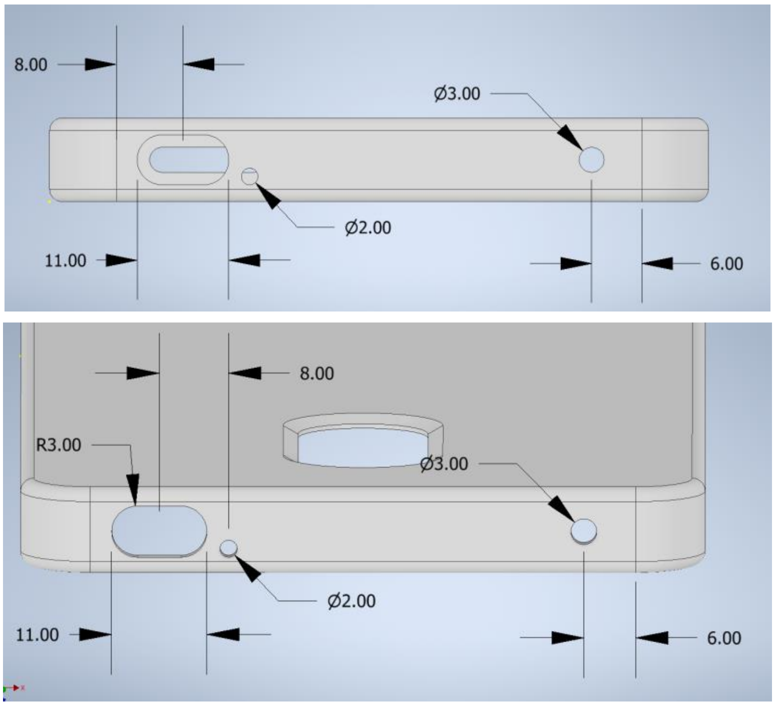

Figure 19 Model view

Step 9

Assign material: Rubber

Additionally, measure the mass of the element:

23.33 g

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Figure 20 Model view

Step 9

Conducting a strength analysis

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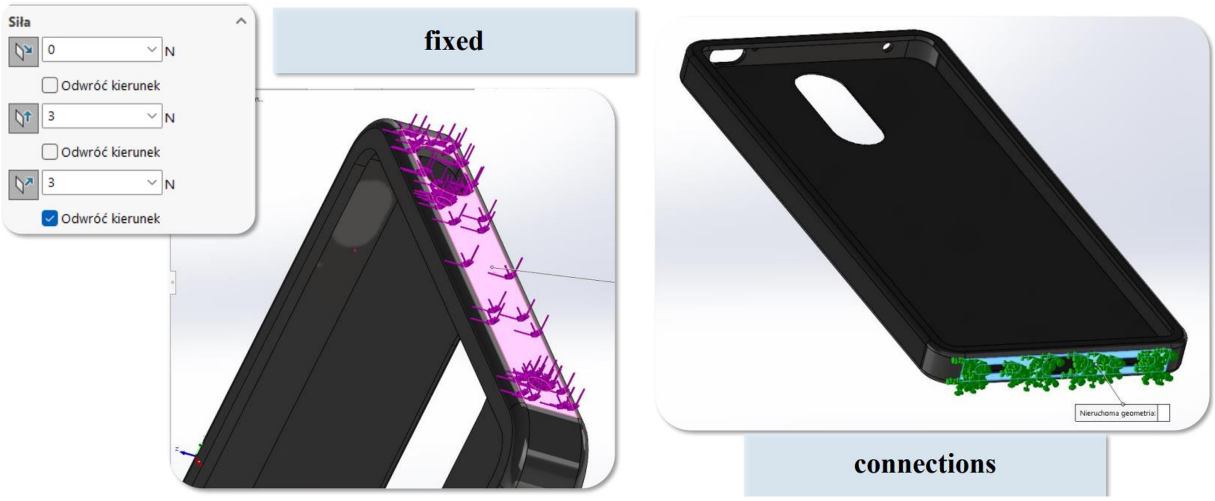

Figure 21 Applying loads for strength analysis

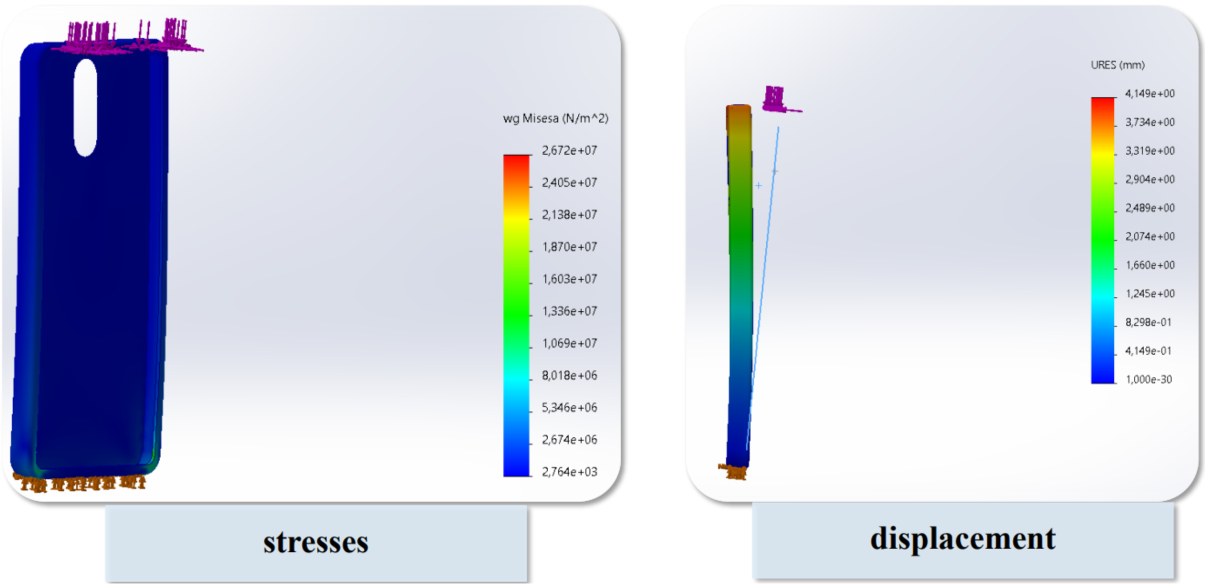

Figure 22 Results of strength analysis

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3. *Summary*

The process of designing a phone case in Autodesk Inventor demonstrates the use of advanced CAD technologies for creating functional and aesthetic products. With its parametric approach, advanced modeling features, and simulation capabilities, Inventor enables precise translation of design ideas into a final product, offering students a hands-on experience with innovative engineering tools.

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AMAZE

Erasmus+ Programme Key Action 2 Cooperation Partnerships for Higher Education (KA220-HED)
Project No: 2023-1-RO01-KA220-HED-000155412
Project title: European Network for Additive Manufacturing in Industrial Design for Ukrainian Context – Acronym: AMAZE

E-case study – No.4

Design of complex industrial assembly using SolidWorks

Project Title	**European Network for Additive Manufacturing in Industrial Design for Ukrainian Context 2023-1-RO01-KA220-HED-000155412**
Output	**IO4 - AMAZE e-case study**
Module	**E-case study – No.4 Design of complex industrial assembly using SolidWorks**
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	National University of Science and Technology Politehnica Bucharest, Romania
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E-case study – No.4 - DEVELOPMENT OF A LOZENGE MANUFACTURING EQUIPMENT

1.Introduction

The purpose of this research is the 3D design (in SolidWorks), the 3D simulation of the assembly for the manufacturing equipment for lozenge powders and experimental, practical realization of him, and pills fabrication using powders with different granulations and from different materials (ceramics, composites, metal, plastic). This equipment can be used in various fields of industries such as: rapid prototyping, electronics, pharmaceutical, chemistry and in food field. The press PAI 6TF will be used in the experimental research that can press of 6 tons force. As part of the research, pills were obtained from pharmaceutical and food powders, using different compaction pressures. Also, a vibration process can be used to level the powder. This research opens new research directions and can be continued by determining the microhardness of the obtained tablets, respectively the realization of experimental research in the presence of the magnetic field of different types of pills.

The paper presents the 3D design and practical realization of lozenge manufacturing equipment for pharmaceutical and food powders of different granulations. The 3D simulation was also carried out operation of the lozenge manufacturing equipment. It was also tried to realize experimentally some pills from food and pharmaceutical powders.

2. Experimental research

Powder lozenge machines were made and used, especially in the field of chemistry and in the pharmaceutical field. Depending on the punch and the active plate, pellets of different geometric shapes and sizes can be obtained. The most used geometric shapes are circular, rectangular or annular, as in figure 1. [1]

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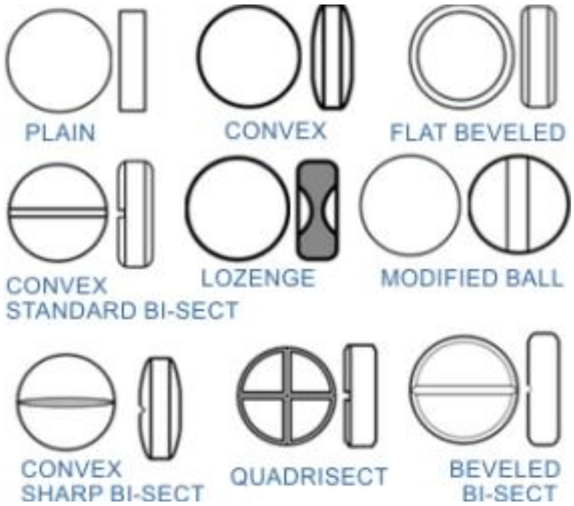

Fig. 1. Geometric shapes of pills [1]

The lozenge manufacturing equipment assembly is realized from stainless steel. The machine features a protective transparent plexiglass camera with sliding windows. The machine features an adjustable compression speed. [1]

Moisture influences the compaction and pressing of the powder, that's why the machine is equipped with a protective plexiglass camera. The pills are obtained by hydraulic and rotary pressing.

3.Design of lozenge *manufacturing equipment*

The powder lozenge manufacturing equipment was designed in 2D using the software SolidWorks, as in figure 2. [8]

The components of the lozenge manufacturing equipment are:

1-plate upper;

2-base plate;

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3-2 guide columns;

4-2 guide bushings;

5- transducer;

6-body transducer;

7-pin;

8-nut;

9-active plate;

10-port-punch plate;

11-extractor;

12- 4 screws (M8x25);

13-2 screws (M8x30);

14 – 2 washers.

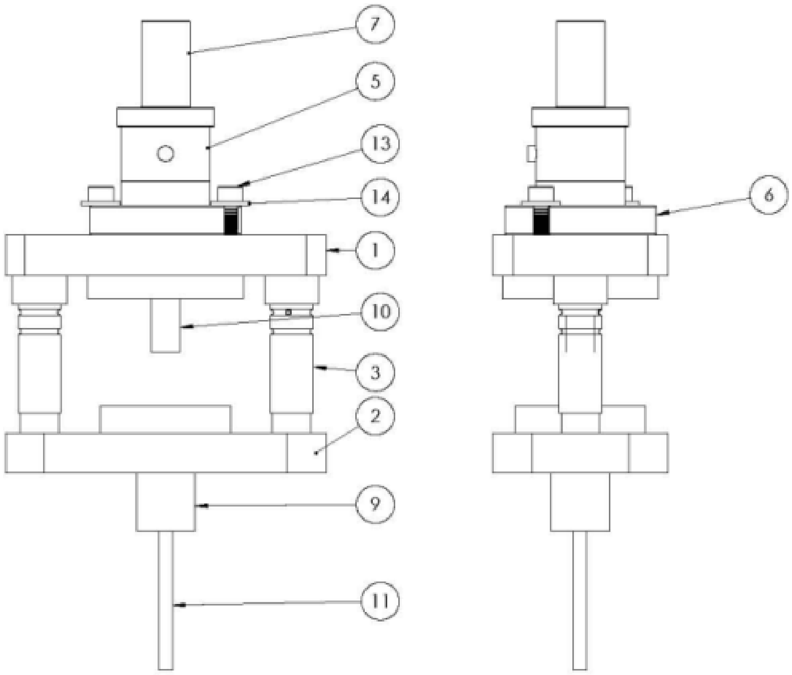

Fig. 2. Design of lozenge manufacturing equipment

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Figure 3 shows the 3D model of the lozenge manufacturing equipment with all assembled components. [8]

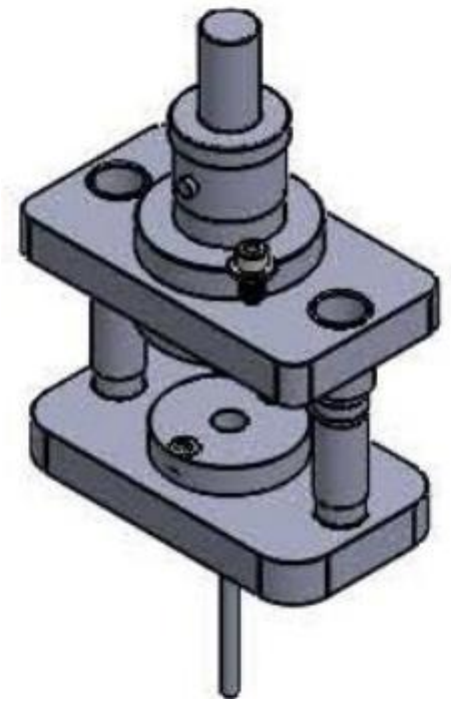

Fig. 3. The manufacturing equipment for lozenge powders

The lozenge manufacturing equipment was made by adjusting a two-column bending die, which has been fitted with the active plate and punch plate suitable for pelletizing powders. The manufactured pills will have a circular shape with a diameter of 15 mm and a height of 10 mm.

The experimental research contribution consisted of the design of the active plate (fig. 4) and the punch plate (fig. 5), as well as in the assembly of lozenge manufacturing equipment. The material used for the construction of the equipment was nitride alloy steel.

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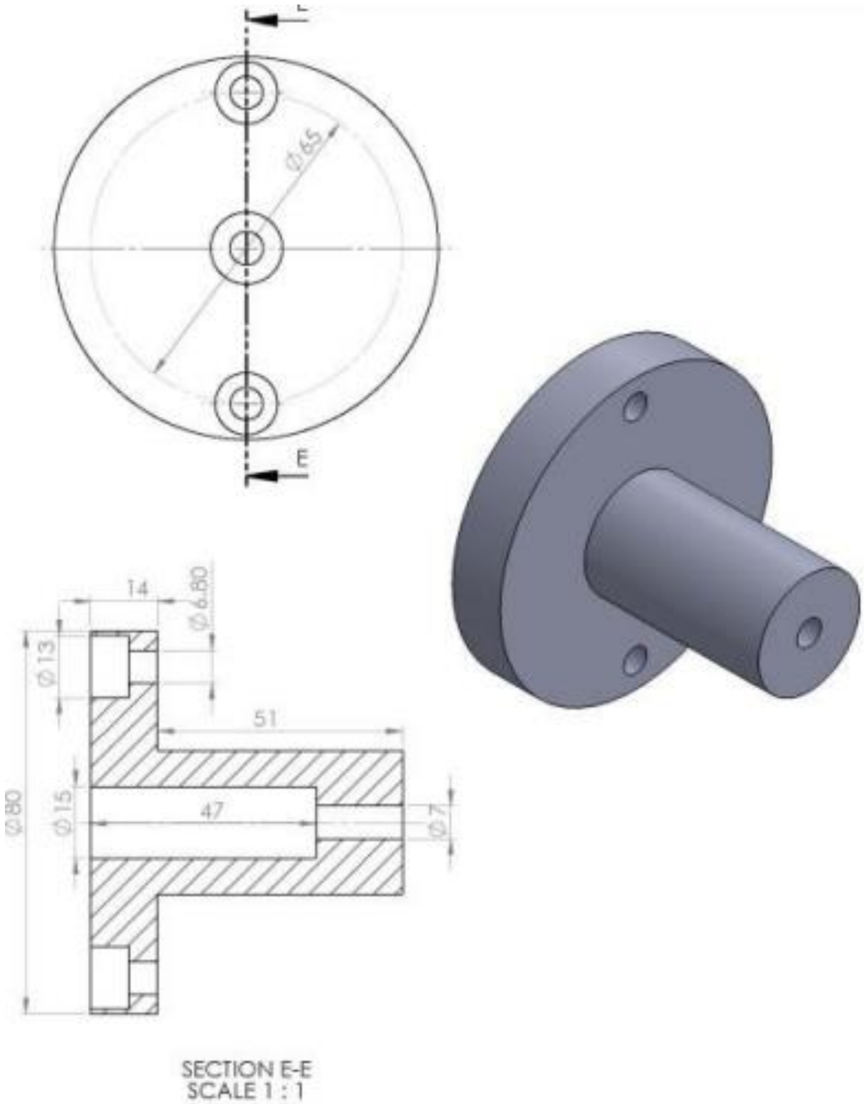

Fig.4. Active platen

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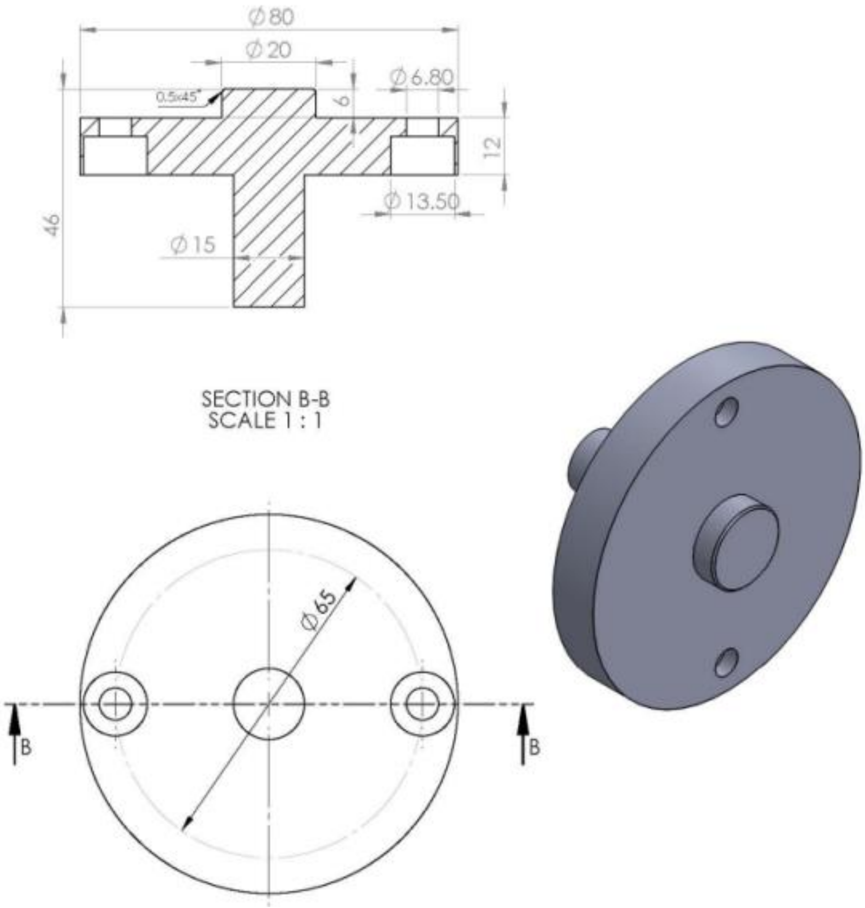

Fig.5. Punch port plate

The components have been assembled and we have obtained the manufacturing equipment for lozenge powders. To carry out the experimental research, a press of 6 tons of force was used, with hydraulic drive.

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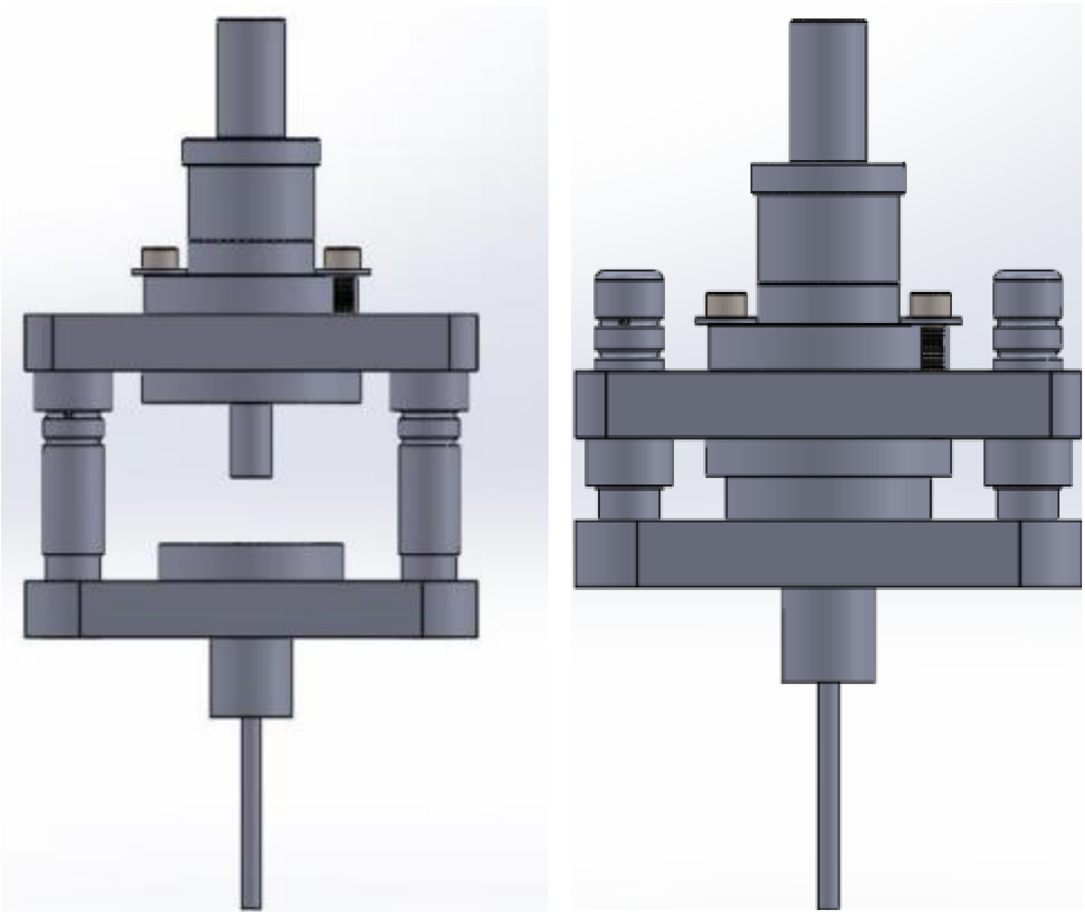
4. Simulation of 3D lozenge manufacturing equipment operation

In order to explicitly present the operating principle of the manufacturing equipment carried out a 3D simulation of its operation, as in figure 6 (a- the open position of the die and b- the closed position is shown). [8]



a) b)

Fig. 6. Operating principle: a) Open position and b) Closed position

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5.Experimental lozenge manufacturing equipment

The experimental pill made by pressing, using the lozenge manufacturing equipment, is shown in Figure 7, having a diameter of 15 mm and a height of 10 mm.

The tablets obtained presented a degree of compaction of 0.64, the appearance of some cracks is noticeable, in the material due to shocks occurring when removing the pill, also the length of the pill influences the appearance of cracks.

Due to the very fine granulation of the powder, it is necessary to use vibrations for placing the powder in the cavity. Lubrication must also be applied in the case of the extractor because there is a risk of seizure. [5,6, 8]

Fig.7. Pills obtained by pressing

In Figure 8 is presented the experimental lozenge manufacturing equipment.

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Fig. 8. The experimental lozenge manufacturing equipment

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In Figure 9 is shown the auxiliary equipment necessary to determine the force and displacement during pressing.

Fig.9. Auxiliary equipment necessary to determine the force and displacement during pressing

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To calculate the pressing force, it is necessary to use an oscilloscope and a transducer. They will perform several determinations of the degree of compaction depending on the force and they will perform specific curves.

The compaction of the pill powder will also be determined and will realize the Excel graphic for detergent, smecta and inulin, as in Figures 10-12.

It was concluded that the bore in which the pill is made must be rectified very finely and chromated or ionic nitrated or treated in a salt bath.

The steel used for the active plate and for the punch plate is C120.

The press PAI6 was used for the experimental research of the pills manufacturing and was used 6 tons force for pressing, and the experiment was carried out manual.

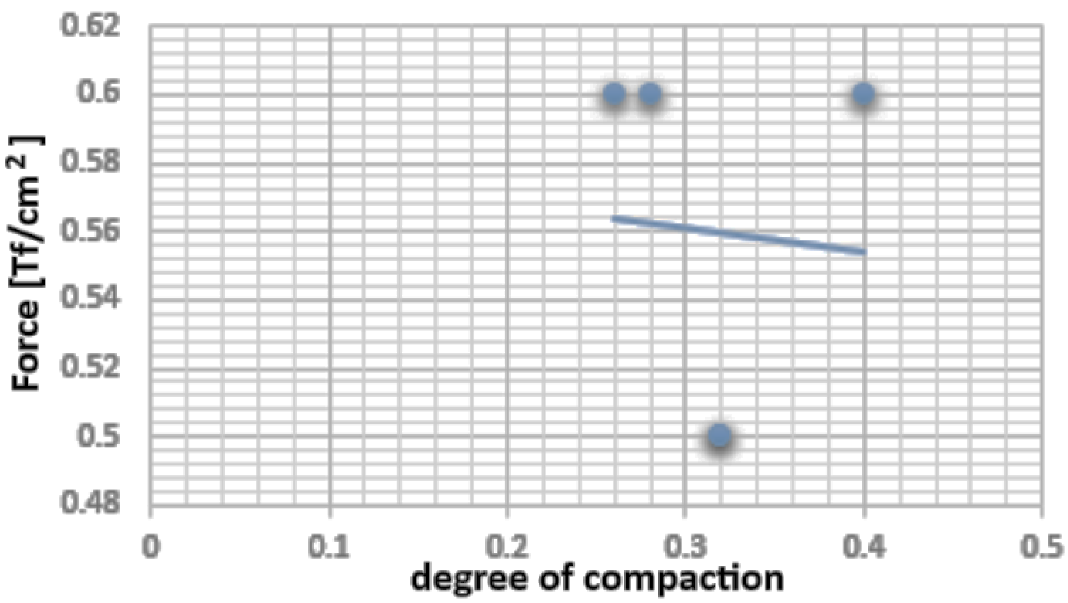

Fig.10. Pills realized from detergent powder

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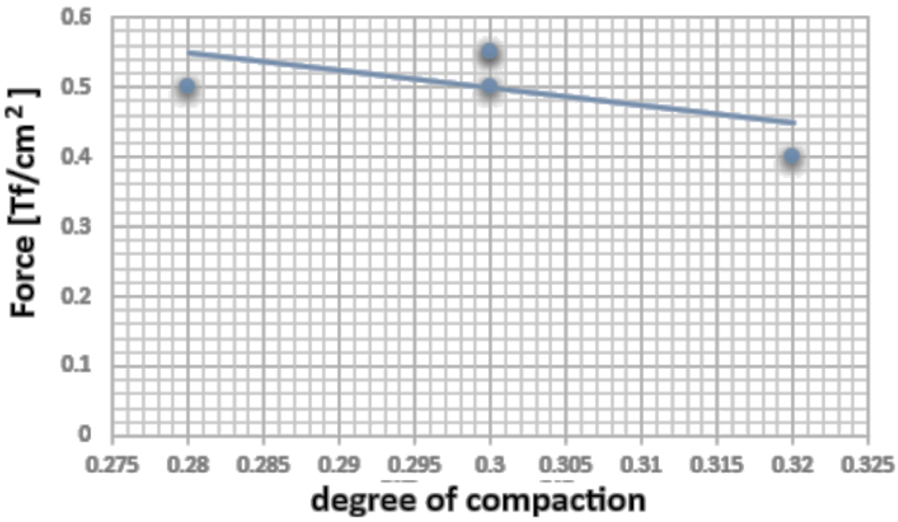

Fig.11. Pills realized from smecta powder

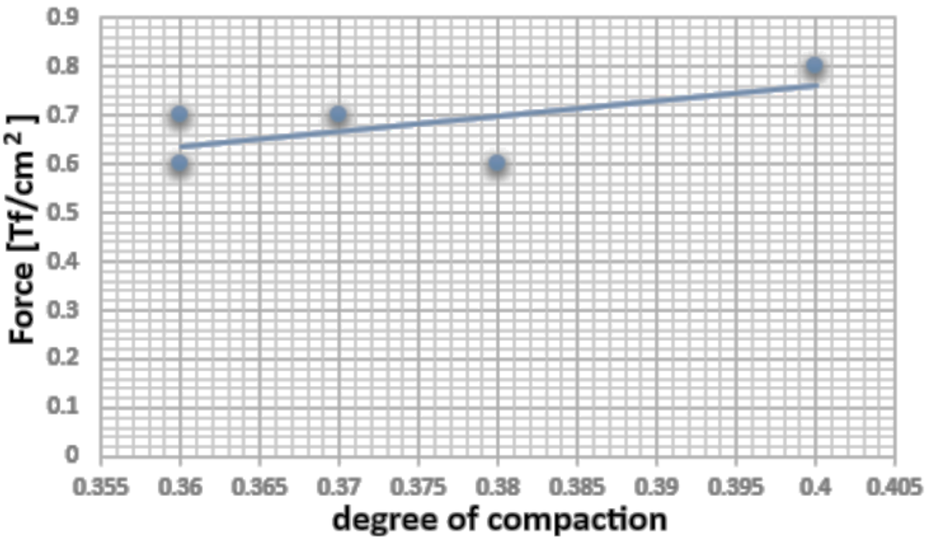

Fig.12. Pills realized from inulin powder

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6. Conclusions

Research contributions to the realization of this lozenge manufacturing equipment consisted in the design of the active plate and punch holder plate using SolidWorks software. It was realized assembling the components of lozenge manufacturing equipment.

A few powder pills (from detergent, inulin, smecta) have also been made and were characterized by their degree of compaction.

In the future, it will try to create curves regarding the influence of the pressure on the degree of compaction of the powders, respectively improving the degree of compaction and pressure force of the powder using a vibration device.

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Project No: 2023-1-RO01-KA220-HED-000155412
Project title: European Network for Additive Manufacturing in Industrial Design for Ukrainian Context – Acronym: AMAZE

E-case study – No.5

3D Design with Autodesk REvit in architecture

Project Title	**European Network for Additive Manufacturing in Industrial Design for Ukrainian Context 2023-1-RO01-KA220-HED-000155412**
Output	**IO4 - AMAZE e-case study**
Module	**E-case study – No.5 – 3D Design using Autodesk REvit software in architecture**
Date of Delivery	**November 2024**
	Yuriy Fedkovych Chernivtsi National University, Ukraine
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1 Introduction

Guidelines cover the creating process of a 3D model of a reconstructed brewery building in the Chernivtsi city, developed in the Autodesk Revit software, for printing on an ***Ultimaker* 2+** 3D printer with a scale of 1:500.

1.1 Project Tasks

Creating process of a 3D model using ***Revit Autodesk*** software [1] allows students and specialists in the architectural field to acquire the skills of:

- accurate transfer of architectural objects into a digital format;
- adaptation of the model to a specific scale;
- preparation of the 3D model for printing, including the selection of optimal settings and the solution of possible problems arising during scaling.

These guidelines also cover the important features of preparing a file for printing, such as cleaning the model of excess details, correcting mesh errors, and selecting corresponding print settings. The printed model becomes not only a demonstration object, but also a practical tool that emphasizes the value and importance of preserving historical monuments using the digital technologies.

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1.2 Equipment and Software

To perform this work, you need::

- A computer with ***Autodesk Revit*** software installed for creating and editing a 3D model.
- Software for working with STL files, such as ***Meshmixer*** for checking and cleaning the model.
- A slicing (pre-press) program, such as ***Cura*** or ***PrusaSlicer***, which allows you to adjust print settings and parameters.
- Ultimaker 2+ 3D printer that supports STL format and printing materials that provide sufficient strength and accuracy.

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2.Step-by-Step Course of Work

2.1.Stage 1. Export model from Revit

Opening the project in Revit. All the necessary elements and structures must be completely finished and located in the right places. Review the placement of windows, doors, walls, and other details so that there are no extra or unnecessary elements on the model. This will help to avoid errors during printing (Fig. 1).

Fig. 1. Checking the model

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Preparing the model for export in 3D format. It is advisable to use special views or sections (for example, the first floor only or the exterior of the building only) to reduce the file size of the model to be printed. Some elements of the interior or engineering networks are not necessary for 3D printing, so they can be hidden or turned off. This will significantly reduce the number of polygons in the model and make it easier to processing.

Export model to STL format. Revit does not support direct export to STL format, so you need to use third-party plugins. Install the ***Revit to STL*** plugin via the ***Autodesk App Store*** [2].

After installing the plugin:

- Go to the *Add-Ins* tab.
- Select *Export to STL*. In the export settings, choose a scale of 1:500 (this will reduce the size of the model while maintaining the necessary proportions).
- Select units of measurement. Millimetres are usually used for 3D printing, but it is important to maintain the proportionality specified in the scale.
- Save the file in STL format in a convenient location on your computer. •

2.2.Stage 2. Creating STL File for Printing

Checking and cleaning the model in Meshmixer or another program for working with STL files

- Load the STL file into ***Meshmixer***. This software allows you to clean and prepare files before printing.

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- Check the model for areas with poor or featureless quality:
  1. ***Holes in the grid***. If open surfaces or cavities are found in the model, they should be filled. In ***Meshmixer***, this should be done through the ***Inspector*** tool.
  2. ***Double surfaces and extra polygons*** that can reduce print quality. Delete unnecessary polygons.
  3. If the model consists of several separate parts, they should be connected to each other into a single object via the ***Make Solid*** option so that the printer recognizes it as one solid object.

Scaling the model to a scale of 1:500

- In ***Meshmixer*** or another software package, check the scale of the model. If you set the scale in ***Revit***, it's worth double-checking that the model matches the selected parameters.
- Adjust the zoom/scale manually if necessary. For example, ***Meshmixe***r has a ***Transform*** tool that allows you to resize the model to exact proportions

Optimizing the model for printing

- For very small model scales, like 1:500, it is worth simplifying small elements that do not play a significant role. Such details may not be reproduced on the printer, but will create an excess load

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- Depending on the design of the building, it may be necessary to add supports for protruding or inclined elements. This will reduce the risk of the sagging some parts of the model during 3D printing. ***Meshmixer*** has a tool for automatically adding supports, but sometimes it is better to add them manually taking into account the features of the model (Fig. 2).

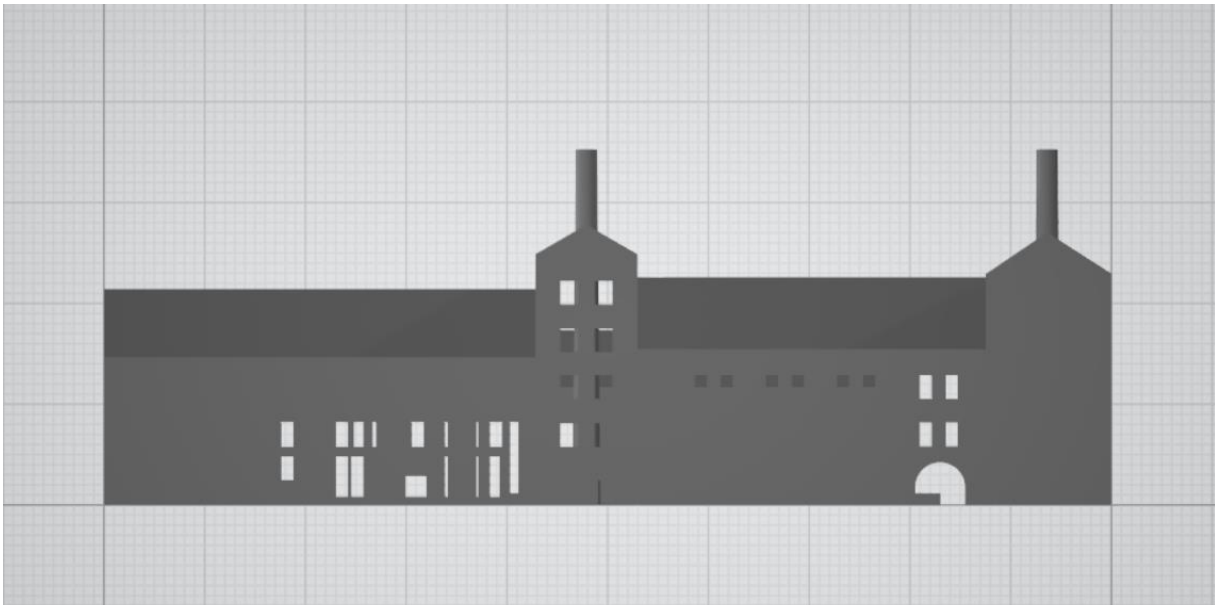

Fig. 2. Model in STL format

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2.3. Stage 3. Preparation for 3D Printing in Cura, PrusaSlicer, etc.

Importing the file into 3D printing software

- Open ***Cura***, ***PrusaSlicer***, or another platform compatible with your 3D printer. Download the STL file. You will see the model on the printer workspace..

Adjusting the settings for 3D printing

Choose the print quality. For example:

- ***Layer thickness***: For 1:500 scale models it is recommended to set a smaller layer thickness (0.1-0.2 mm) for better detailing.
- ***Infill***: traditionally, low infill (20–30%) is assumed for building models, because exterior is more important than internal strength.
- Choose the type of filament. PLA is suitable for the most architectural models, because it easily prints and has good properties.

Adjusting the model on the printing platform

- Choose the orientation of the model on the printing platform. To achieve better stability and adhesion, the model is often placed with the flat surface down. This will reduce the risk of deformation during printing.
- Make sure that the model fits in the printing area of the printer. Some programs have possibilities to automatically scale the model to fit on the platform, but for your work the scale should be fixed.

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Preview and generation of G-code

- In ***Cura*** or another slicer, you should preview the generated print layers to see how individual model elements will look on each layer. Pay attention to intricate details or protruding elements and make sure that supports are added (if they are necessary).
- After the final checking, save the G-code file on an SD card or flash card or other memory medium for transfer this file to the 3D printer (Fig. 3).

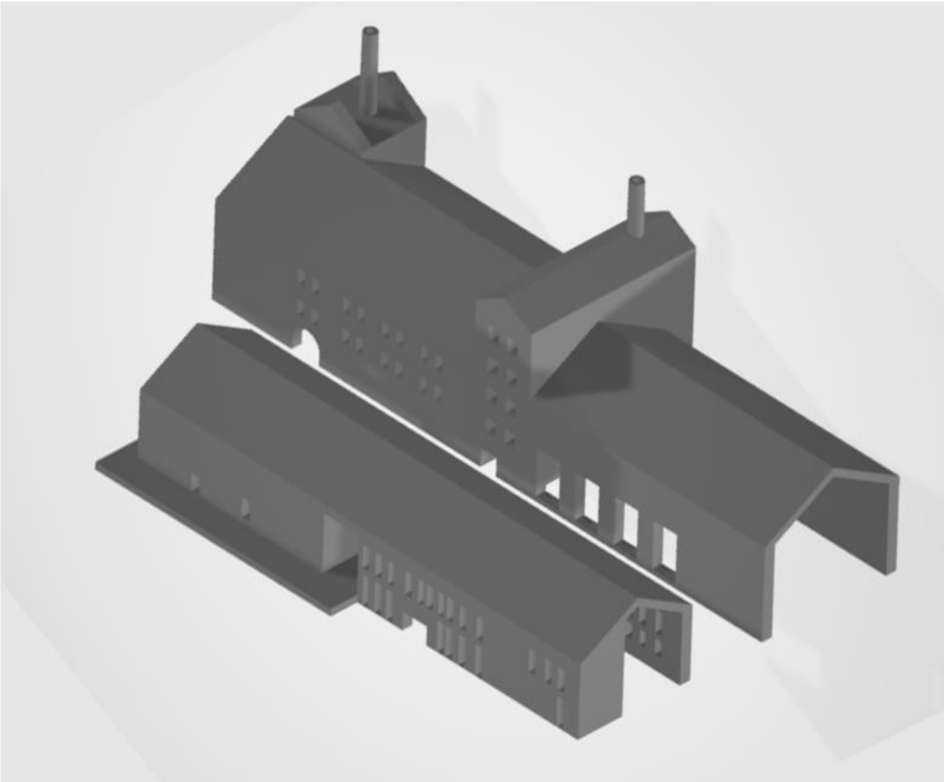

Fig. 3. Preview of the 3D model

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2.4. Stage 4. Printing Model on 3D Printer

Preparation of the 3D printer

- Clean the printer platform from dust and previous filament residues.
- Make sure the thread is set correctly and matches to the settings that you chose in the slicer.

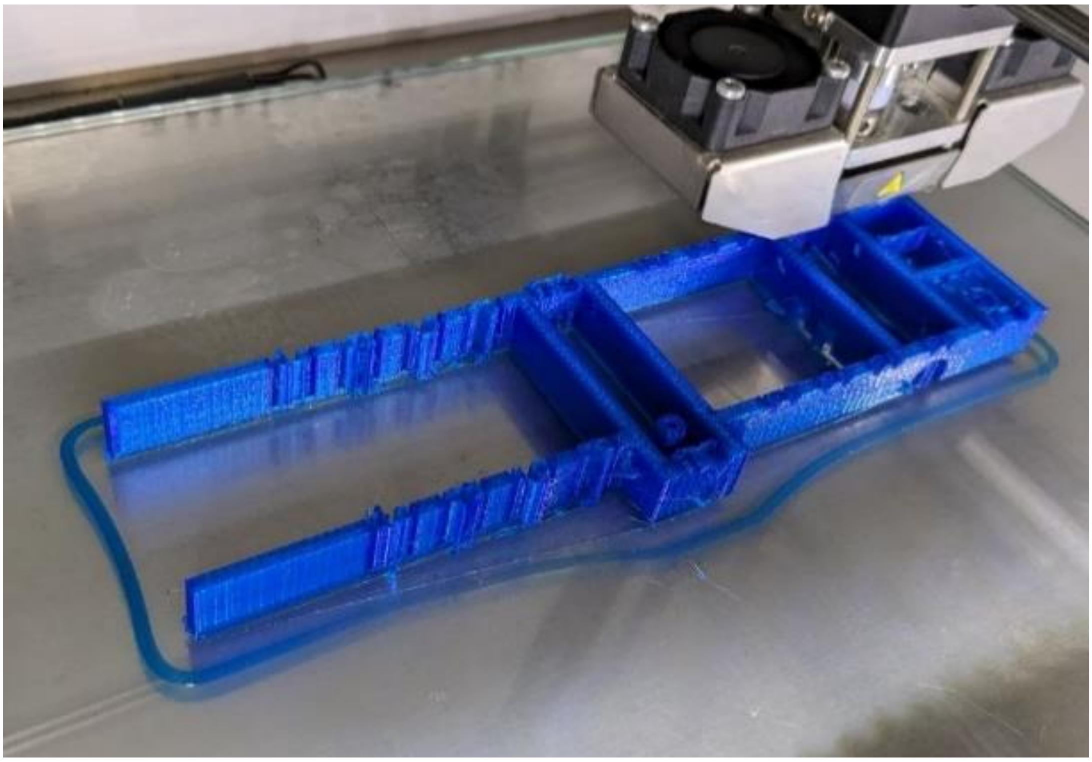

Fig. 4. The printing process of a 3D model

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Start printing

- Insert the SD card into the printer or connect the printer to the computer. Download the G-code file.
- Start printing and be sure to control the printing process, especially the first few layers. Correct adhesion of the model to the platform is very important, because if the initial layers detach, it can spoil the model (Fig. 4).

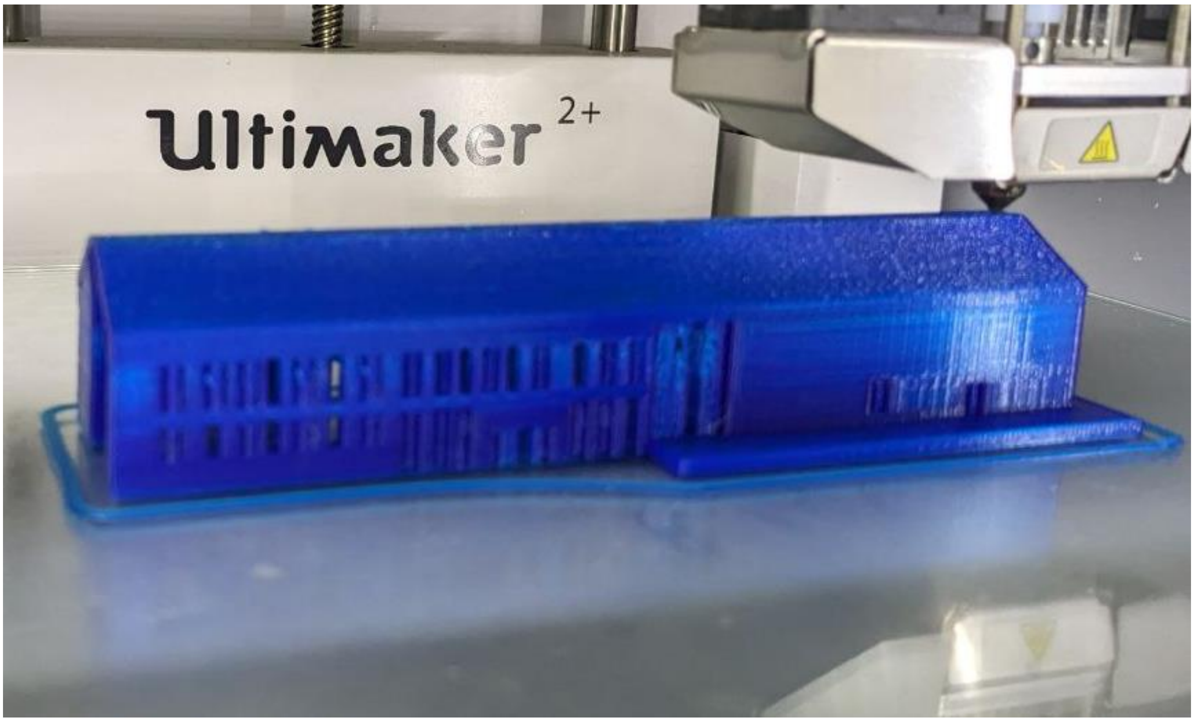

Fig. 5. Completion of printing the 3D model

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Completing printing

- After printing is finished, give the model time to cool down to reduce the risk of model deformation and to ensure easy detachment it from the platform.
- Carefully remove the model from the platform using a special tool (for example, a putty knife). If necessary, remove the supports and smooth the model edges for a clean result (Fig. 5).

2.5. Stage 5. Analysis of Results

Assessment of model quality

- Compare the sizes of the printed model with the initial sizes in Revit and the given scale of 1:500 (Fig. 6).
- Make sure that all important details are preserved and the structure of model looks correct.

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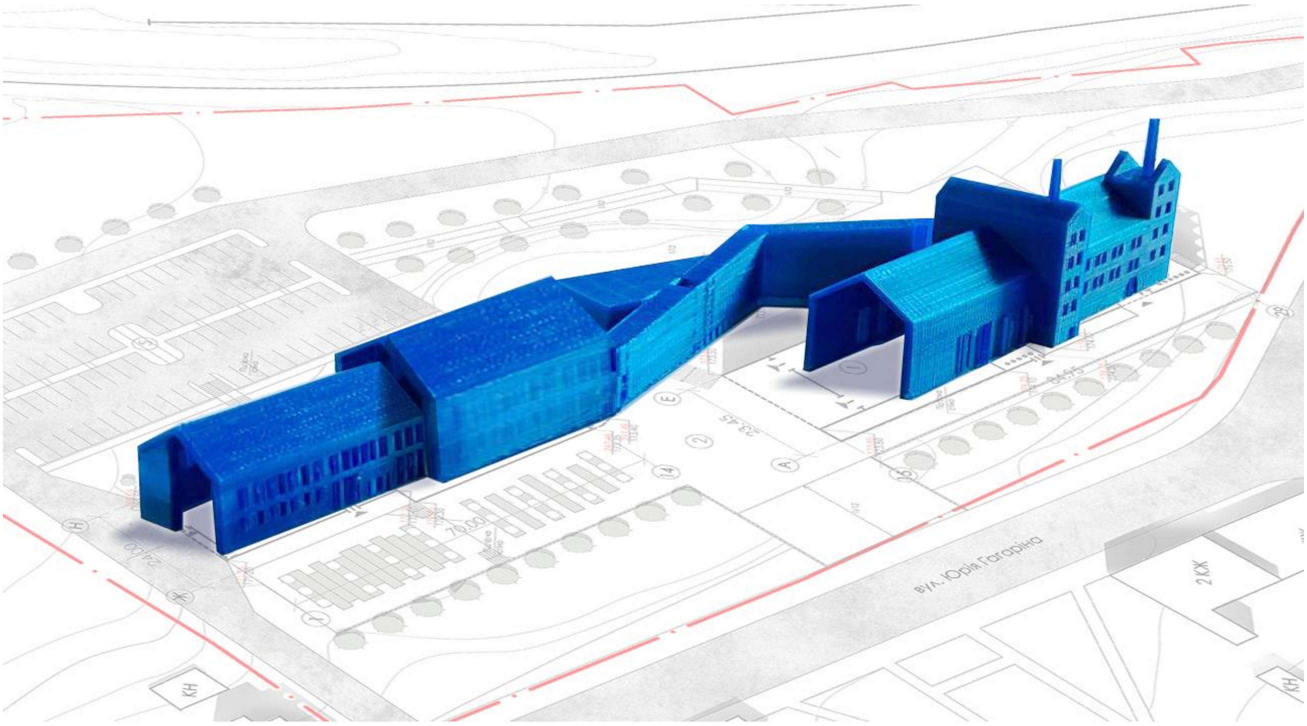

Fig. 6. The completed 3D model, which placed on the general plan. The scale is 1:500

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