1

Optimization of Additive Manufacturing Processes Focused on 3D Printing

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1. Introduction

Under the umbrella of Rapid-X (Udroiu & Ivan, 2008) there are some specific terms such as: Rapid Product Development (RPD), Rapid Technology, Rapid Nanotechnology, Rapid Prototyping (RP), Rapid Tooling (RT) and Rapid Manufacturing (RM). Additive manufacturing (AM) is an important component of the rapid product development process. Additive manufacturing technologies (AMT) represents a group of technologies used for building physical models, prototypes, tooling components and finished parts, all from three dimensional (3D) computer aided design (CAD) data or data from 3D scanning system. AMT involves automated fabrication of physically complex shapes directly from 3D CAD, using a layer-by-layer deposition principle. Based on AM principles, RP produces parts with limited functionality (prototypes and test parts), RM built end products and RT manufacture tools, jigs or moulds. Today's additive technologies offer advantages in many applications compared to classical subtractive fabrication methods like as milling, turning etc. Thus, parts can be formed with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly. Also, AMT can lower manufacturing time of new products with 8-10 times in comparison with the conventional technologies and it reduces the costs of the products.

There are a lot of additive manufacturing technologies in the world. The most popular AM technologies used worldwide are stereolithography (SL), selective laser sintering (SLS), Three dimensional printing (3DP), laminated object manufacturing (LOM), fused deposition modelling (FDM), polymer jetting (PolyJet), selective laser melting (SLM), direct metal laser sintering (DMLS), direct metal deposition (DMD), electron beam melting (EBM) and laser engineered net shaping (LENS).

This chapter is focused on 3DP technologies that represent 44.3% of all additive systems installed worldwide at the end of 2005 (Wohler, 2006). The 3DP technologies (inkjet printing) can be classifying in the following main categories (Dimitrov et al., 2004): continuous printing (fused deposition modelling), drop on drop printing (polymer jetting) and drop on powder printing (3D Printing by ZCorp).

The research was done under the umbrella of interdisciplinary platform PLADETINO (Platform for Innovative Technological Development), (Ivan, 2009). PLADETINO was aiming at create an interdisciplinary development and research centre regarding the innovation and the integration of the technologies of designing and manufacturing the products considering the new concepts (Rapid Manufacturing/ Prototyping, Reverse

Engineering, Concurrent Engineering, Virtual Engineering, Knowledge Engineering, Quality Engineering), and also the technologic management by on-line and long distance processing of data. PLADETINO is integrated in a research and multidisciplinary training unitary structure of Transilvania University of Brasov (Romania) and it is the main support of the research department D05 named Advanced Manufacturing Technologies and Systems. This research platform has developed new laboratories that allow professional education development and scientific research activities. Under the umbrella of Integrated Technologies was created a lot of laboratories, one of this being the Industrial Innovative Technologies laboratory. This platform was capable of allowing the development of new scientific research contracts with industrial companies. All of these contracts were developed within the Industrial Innovative Technologies laboratory and all of these are focused on the additive manufacturing technologies. In this chapter are presented some results obtained within the PLADETINO interdisciplinary platform.

In the field of AM optimisation there are some major research directions (Berce et al., 2000; Canellidis et al., 2006; Ancau & Caizar, 2010): slicing algorithms, process parameters, surface quality, mechanical characteristics of the RP/ RM material, modelling and simulation, part orientation, packing many parts, optimal selection of AM technology etc. Because post-processing require additional time and cost, the optimisation of AM process is an important factor.

This chapter is organised in the following main paragraphs: The software input data for 3D Printing systems, 3D printing process chain, optimization of 3D printing performance within the pre-processing stage, products built by Additive manufacturing at Transilvania University of Brasov, surface quality of additive manufacturing products and conclusions.

2. The software input data for 3D printing systems. STL file optimization

The industry standard exchange format for additive manufacturing is the STL (STereoLithography or Standard Triangulation Language) file. Basically, it is a file that replaces the original surface of solid, surface or scanned model with a mesh of triangulated surface segments. Almost all of today's CAD systems are capable of producing a STL file, as selecting File, Save As and STL.

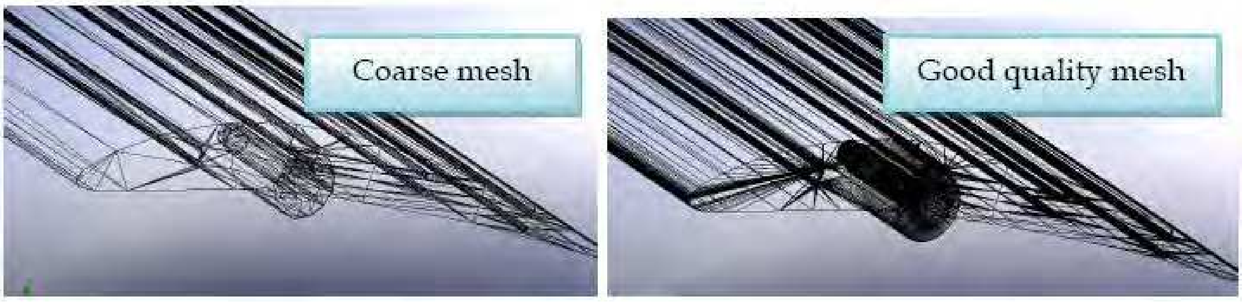
Faceting is controlled by the output settings of the CAD package being used. The most common variables that control the STL file resolution are deviation or chord height, and angle control or angle tolerance. The value of these variables can be set from most CAD packages. Two examples of various STL faceting outputs determined by varying angle, deviation and chord height are shown in the fig. 1: coarse faceting (poor) and good quality faceting (best). Depending of RP system sometimes, increasing the resolution excessively does not improve the quality of the produced part and cause delays in processing and uploading of parts because of the larger size.

To save a CAD model (part or assembly) in STL file using Solid Works, it must press the Option button from Save as dialog box and follow the steps shown in the fig.2.

Before saving a model in STL file, using CATIA V5, it is advisable to set some parameters that determine the good accuracy of the model. These parameters (fig. 3) can be found in the Options dialog box (from the Tools menu, select Options) selecting Performance tab. Under the General category (on the left), select Display and focus on the 3D Accuracy settings:

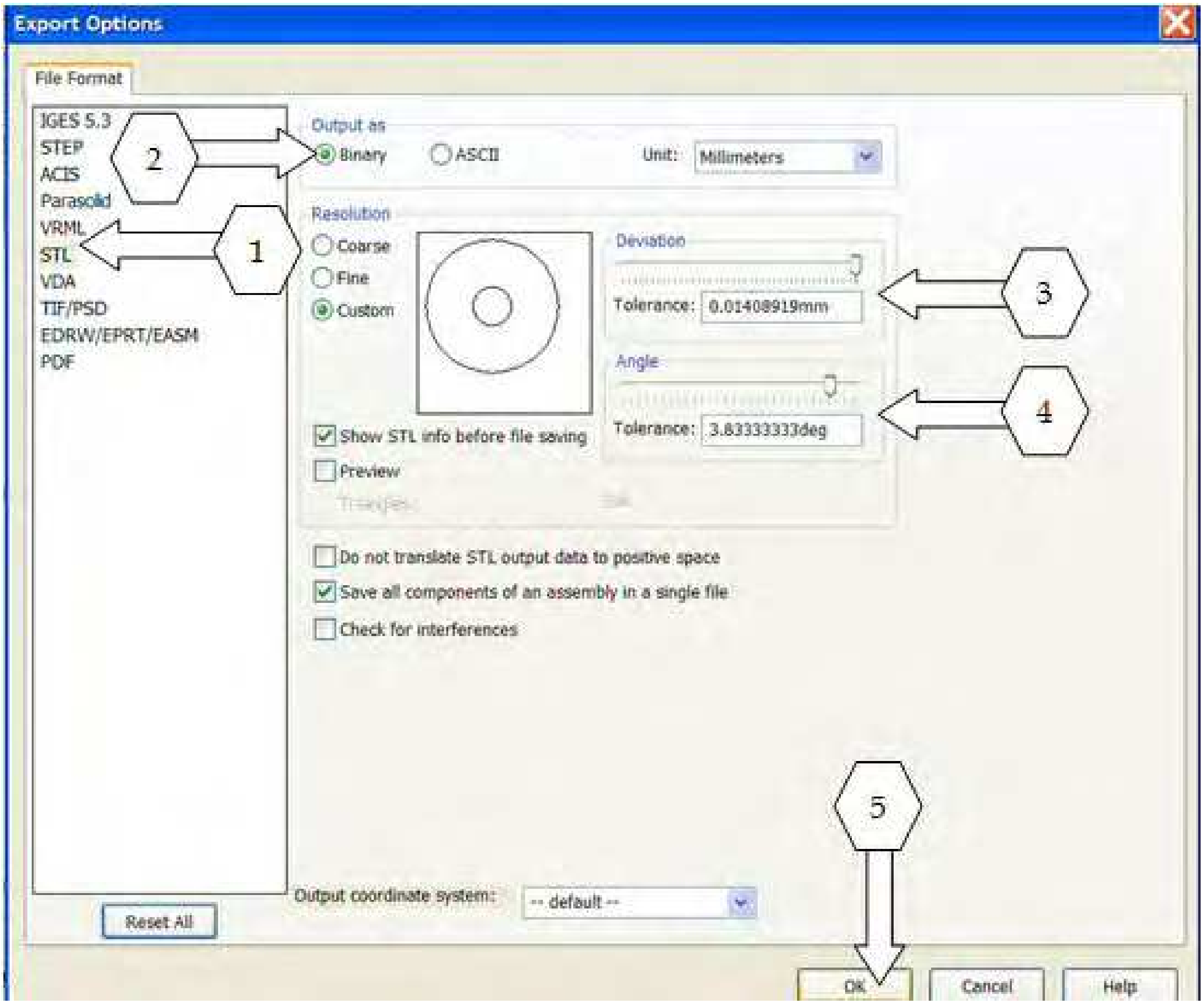
- Fixed – a lower value allow creation of the finer STL file. A very small setting results in a very large STL file.

- Curves' accuracy ratio –when dealing with complex geometries (small radii) a smaller value is advisable to set.



a) b)

Fig. 1. STL faceting outputs resolution



Output as
● Binary ○ ASCII
Unit: Millimeters

Resolution
○ Coarse
○ Fine
● Custom

Deviation
Tolerance: 0.01408919mm

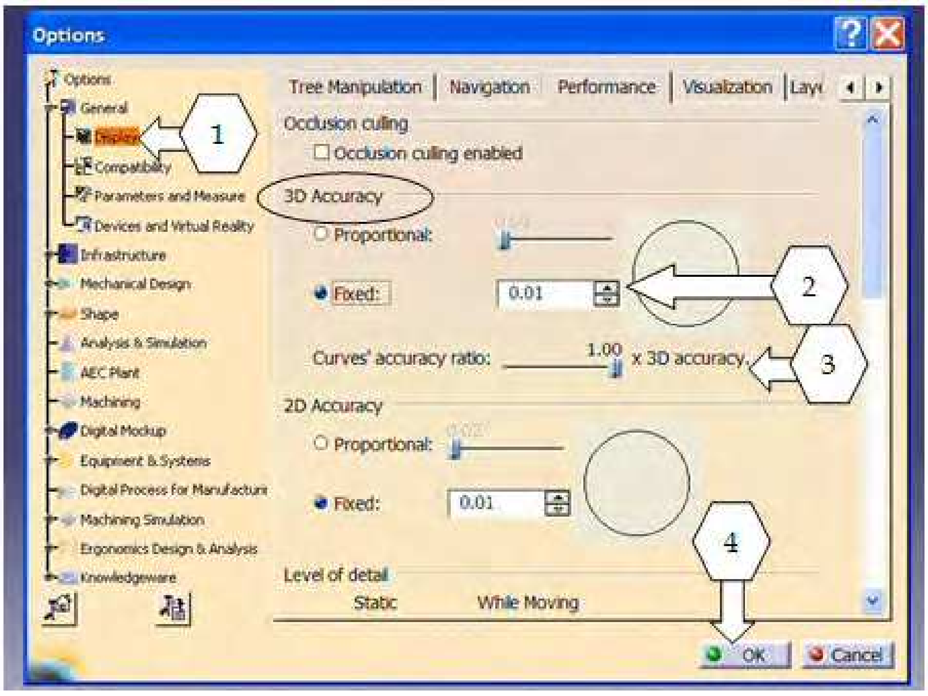
Angle
Tolerance: 3.83333333deg

☑ Show STL info before file saving
☐ Preview

☐ Do not translate STL output data to positive space
☑ Save all components of an assembly in a single file
☐ Check for interferences

Output coordinate system: -- default --

Fig. 2. Setting the STL file within Solid Works software



Occlusion culling
☐ Occlusion culling enabled

3D Accuracy
○ Proportional:
● Fixed: 0.01
Curves' accuracy ratio: 1.00 x 3D accuracy

2D Accuracy
○ Proportional:
● Fixed: 0.01

Level of detail
Static While Moving

Fig. 3. Setting the STL file within CATIA V5 software

3. 3D printing process chain

In this paragraph we present a comparative study of 3D printers, Z 310 Plus versus Objet 350.

3.1 3D printing techniques

The 3D printing technologies can be divided in the following: inkjet printing, fused deposition modelling, and polymer jetting (polyjet). First of all, the polyjet and inkjet technologies briefly are described.

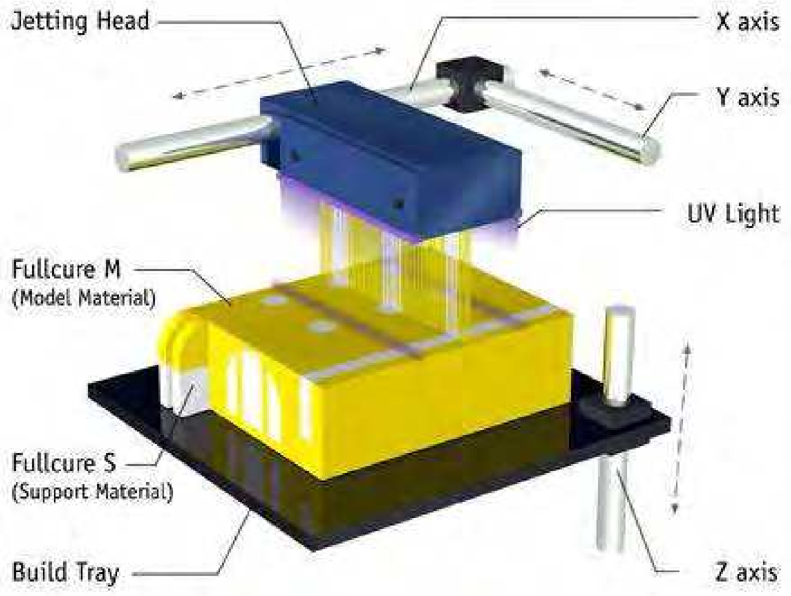


Fig. 4. "Polymer jetting" printing (photo courtesy of Objet) (Objet Geometries Ltd., 2010)

Objet Geometries machines build parts layer by layer combining inkjet technology with photo-polymerisation (UV curing) process, fig. 4. The Objet 3D printers can build 3D models from single material or many materials. Thus, the EDEN printers create 3D models using a single model material. Connex printers are able to fabricate multi-materials part by simultaneously jetting more than one model materials to create new composite materials.

ZCorp 3D Printers create 3D model, layer by layer, by spreading layers of powder and then inkjet printing a binder in each from these layers, fig. 5.

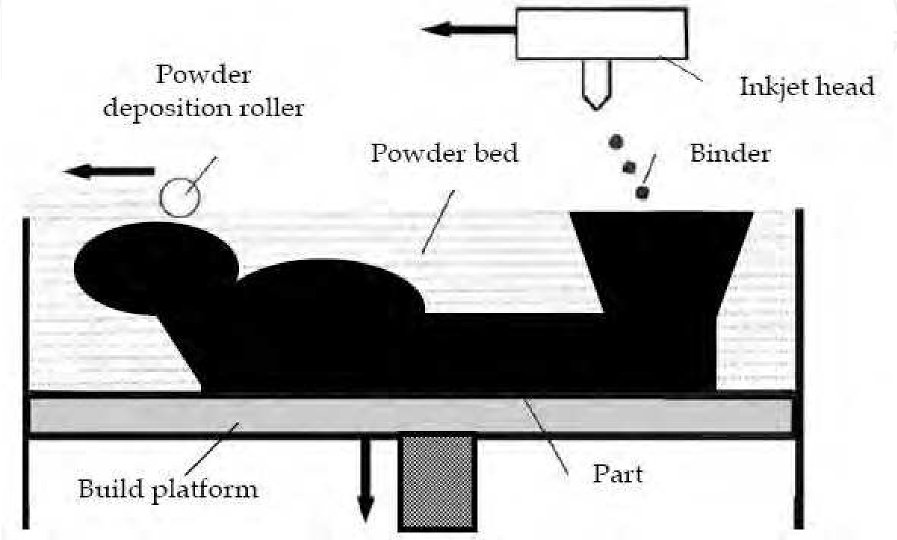


Fig. 5. “Inkjet” printing

3.2 3D printing process

ZCorp 3D printer (fig. 6) work just like a desktop inkjet printer, but instead of printing ink on paper the ZCorp printer prints water-based glue onto a layer of powder.

Fig. 6. Z 310 Plus printer and its depowdering station (compressed air system and vacuum suction system) - Transilvania University of Brasov

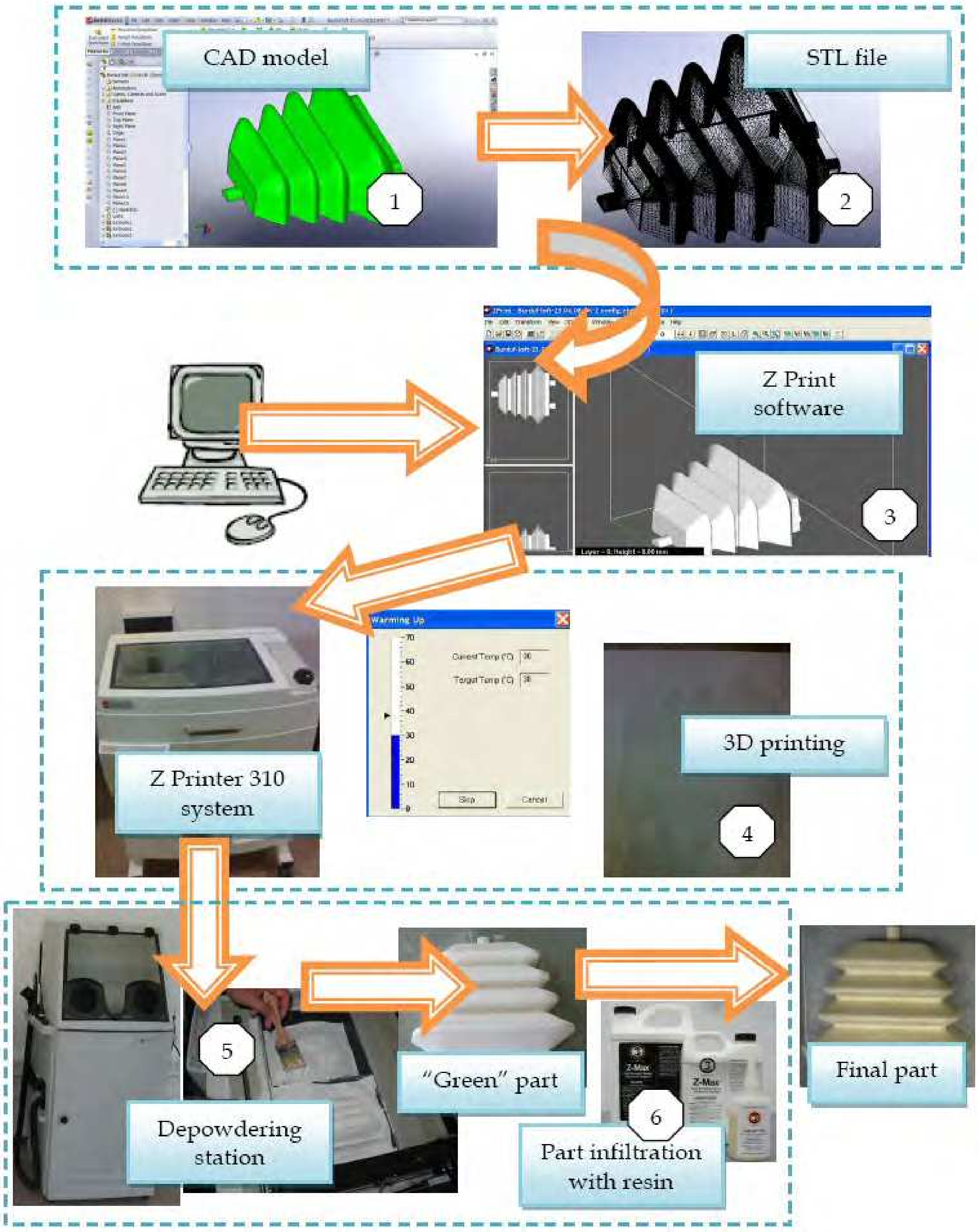


Fig. 7. ZPrint flow chart

Generally, the 3D printing process consists in the following main steps: pre-processing, processing and post-processing. The ZPrint flow chart is shown in fig. 7.

In the **pre-processing** stage a 3D file is imported into the ZPrint software (STL, PLY or VRML file), scale it (if necessary), orientate the part and simulate the manufacturing process layer by layer. Before starting the processing stage it is necessary to prepare the printer bed powder by spreading powder from the feed bed onto the build bed to create a smooth first layer.

Processing (3D printing process) stage consists in warming up to 38° of the work environment and then, prints the part, layer by layer from the bottom of the design to the top. The printer first spreads a layer of powder in the same thickness as the cross section to be printed. Then, the HP print head applies a binder solution to the powder, causing the powder particles to bind to one another and to the printed cross-section one level below. The feed piston comes up and the build piston drops one layer of the thickness. The printer then spreads a new layer of powder and repeats the process.

When the printing process is completed wait approximately one hour to consolidate the 3D model. The resulting model is porous.

Post-processing process consist in removing of the part from the powder bed, followed by part depowdering using compressed air place within a recycling station. Finally, the part is infiltrated with resin, in order to add strength, durability and to ensure vibrant colours.

3.3 PolyJet process

EDEN 350 (fig. 8) is a 3D printer that works just like a desktop inkjet printer using polymer jetting technology.

Fig. 8. EDEN 350 printer and its water jet recycle station - Transilvania University of Brasov

In the Objet **pre-processing** stage a STL file is imported into the Objet Studio software. Objet Studio software allows simulating the manufacturing process, scaling of the virtual 3D model (if it is necessary) and optimising the orientation of the 3D part onto the built tray.

A server, typically next to the 3-D printer, acts as a job manager that sends production jobs to the printer for production (fig. 9). The Job Manager software installed on the client computer displays the queue and status for jobs sent to the 3-D printer server from that computer, and allows the user to edit only these jobs.

The EDEN 350 software enables to monitor the progress of printing jobs.

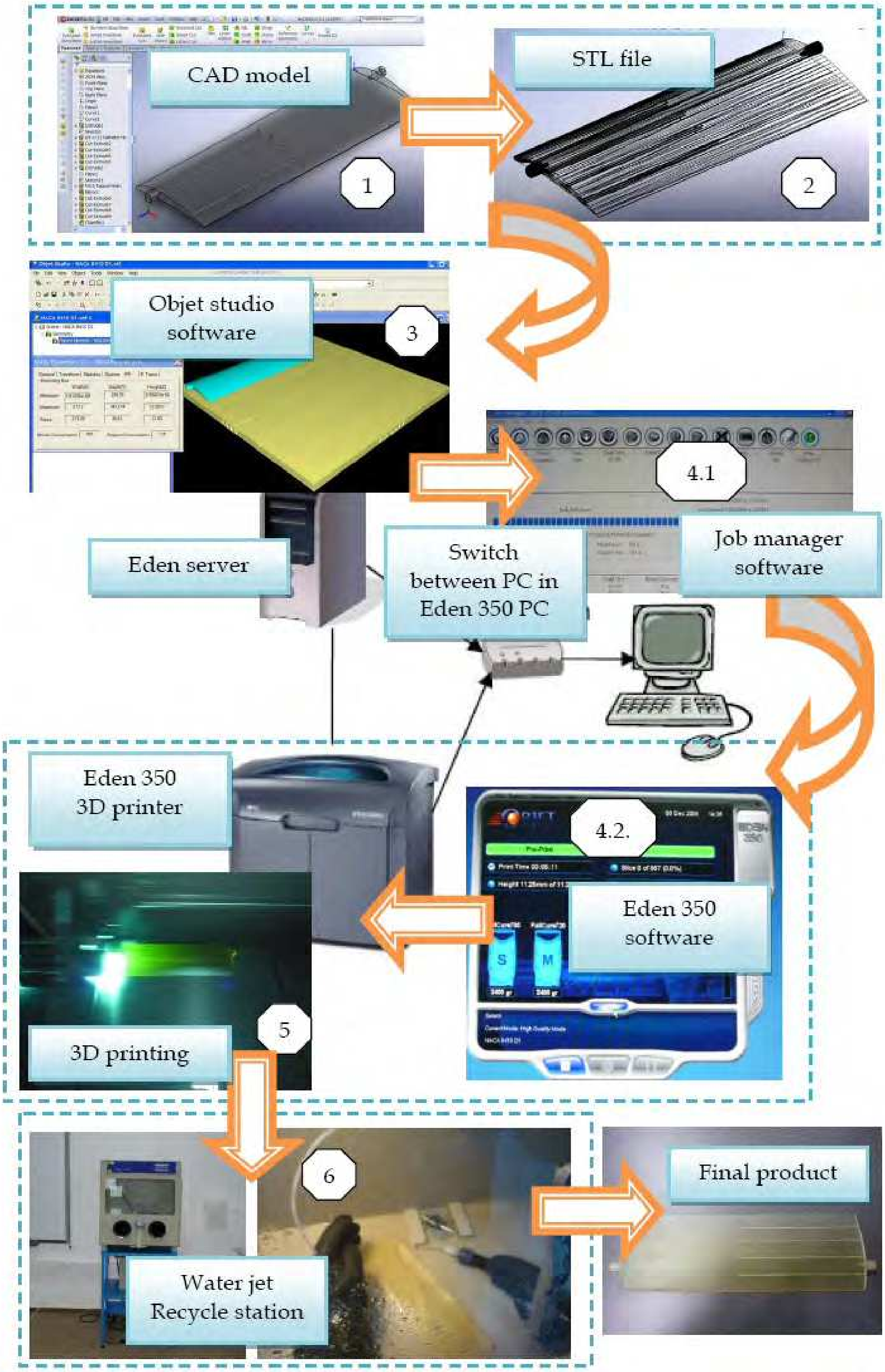


Fig. 9. EDEN 350 flow chart

In the **processing** (3D printing process) stage the head printer moves back and forth along the X-axis, depositing super-thin layers (16 micron) of photopolymer onto the build tray (fig. 4 and fig. 9). Immediately, UV bulbs alongside the jetting bridge emit UV light curing and hardening each layer. The building tray moves down and the jet heads continue building, layer by layer, until the model is complete. Two different photopolymer materials are used for building: one for the model, and another gel-like material for support. When the printing process is complete wait to consolidate of the part.

Post-processing stage consists in the removing of the support material using water jet, within the recycling station.

In the following paragraph we present a comparative study regarding pre-processing methodology for optimizing 3D printing performance. First of all we describe a pre-processing methodology based on rules that allow finding the best manufacturing orientation of the parts on build tray. Secondly, we propose rules regarding the problem of optimal orientation and packing of many parts on the build tray.

4. Optimization of 3D printing performance within the pre-processing stage

In this paragraph, we present some comparative case studies regarding the additive manufacturing optimization focused on 3D printers like Z 310 Plus and Objet 350.

4.1 Case study 1. Additive manufacturing optimization of a model

In the first case study, a NACA airfoil was taken into consideration. The NACA airfoil was designed, by the main author, within Solid Works software. A particularity of this 3D model (fig. 10) is a series of small holes (0.8 mm) on a high deep (100 mm) useful to measure the air pressure on different locations of the wing during the wind tunnel testing.

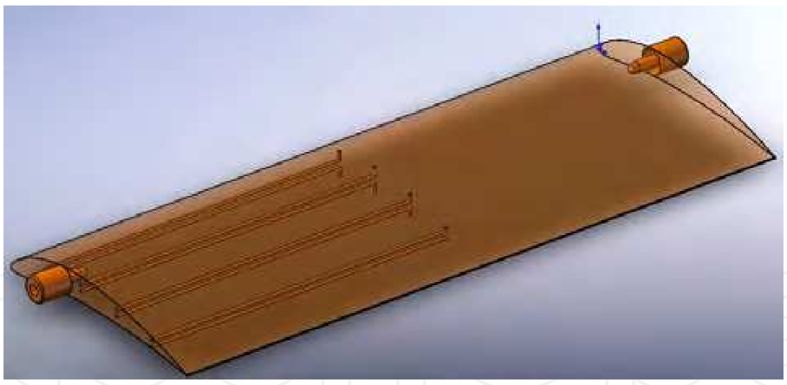
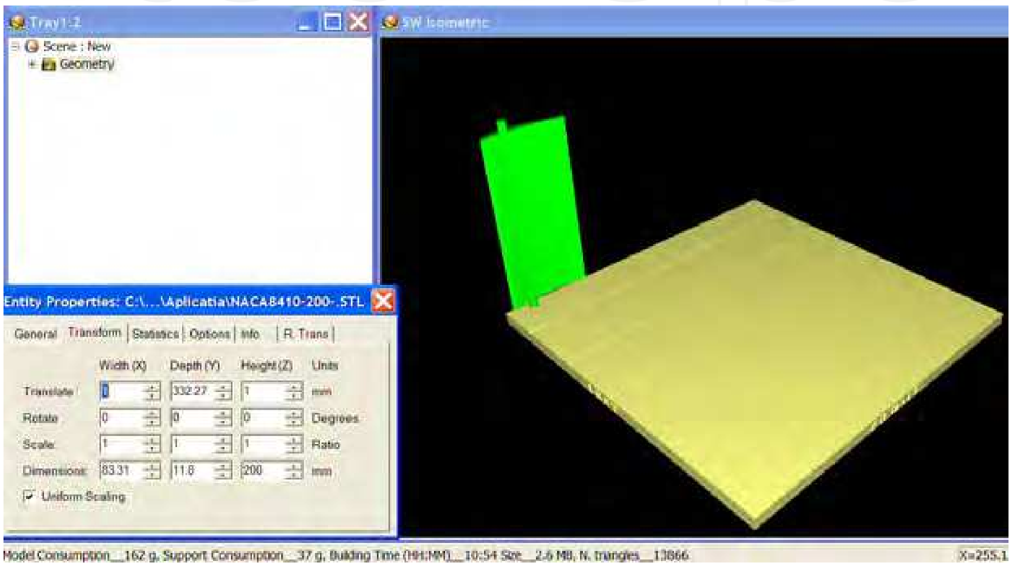


Fig. 10. NACA airfoil virtual model

Finding an optimal orientation of the airfoil on a build tray (Udroiu & Dogaru, 2009)is important for several reasons. First, properties of rapid prototypes can vary from one direction to another, like along X, Y and Z. Also, the model orientation on a build tray, determines the build time. Placing the shortest model dimension on the Z direction reduces the number of layers, thereby shortening the building time. In this case study, the optimization of the 3D model orientation on the build tray, according to the minimization of the building time and the material consumption was done.

First of all, we consider the additive manufacturing of NACA airfoil using polyjet technology. Thus, we took into consideration three different orientations of the model on the build tray (fig. 11, fig. 12 and fig. 13). Placing the biggest model dimension along the X, Y and Z axis, material consumption and build time were calculated. The minimum build time of NACA model was found in the third case (biggest model dimension orientated along X axis). The new rule regarding part orientation on the XY plane (polyjet technology) is called "XY-0^0 rule". Also, it is important to align the model to the machine's axis, especially if the model has straight line walls.

The quality of the surface can be chosen from two options: matte and glossy finish. Choosing the glossy option, the upper surface of the model is printed in glossy mode and the lower surface in mate mode. The minimum material consumption was obtained in the fourth case (fig. 14), "XY-0^0 rule in glossy mode".



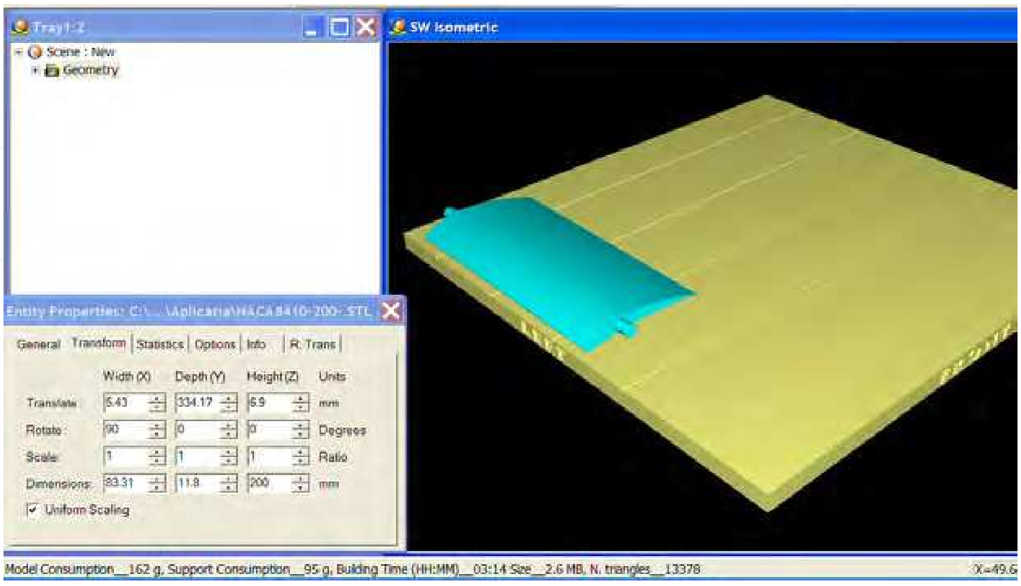
Entity Properties: C:\...\Aplicatia\NACA8410-200-.STL

	Width (X)	Depth (Y)	Height (Z)	Units
Translate	0	332.27	1	mm
Rotate	0	0	0	Degrees
Scale	1	1	1	Ratio
Dimensions	83.31	11.8	200	mm

☑ Uniform Scaling

Model Consumption__162 g, Support Consumption__37 g, Building Time (HH:MM)__10:54 Size__2.6 MB, N. triangles__13866 X=255.1

Fig. 11. The orientation of the 3D model on the EDEN350 build tray: the biggest dimension along Z



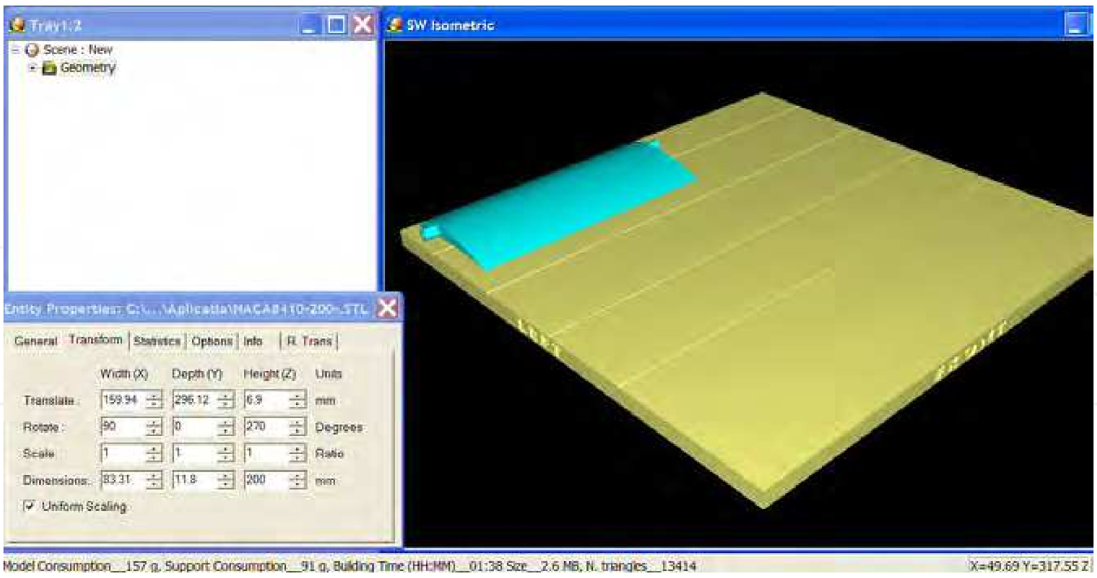
Entity Properties: C:\...\Aplicatia\NACA8410-200-.STL

	Width (X)	Depth (Y)	Height (Z)	Units
Translate	5.43	334.17	6.9	mm
Rotate	90	0	0	Degrees
Scale	1	1	1	Ratio
Dimensions	83.31	11.8	200	mm

☑ Uniform Scaling

Model Consumption__162 g, Support Consumption__95 g, Building Time (HH:MM)__03:14 Size__2.6 MB, N. triangles__13378 X=49.6

Fig. 12. The orientation of the 3D model on the EDEN350 build tray: 90° (the biggest dimension along Y)



Entity Properties: C:\...\Aplicatia\NACA8410-200-.STL

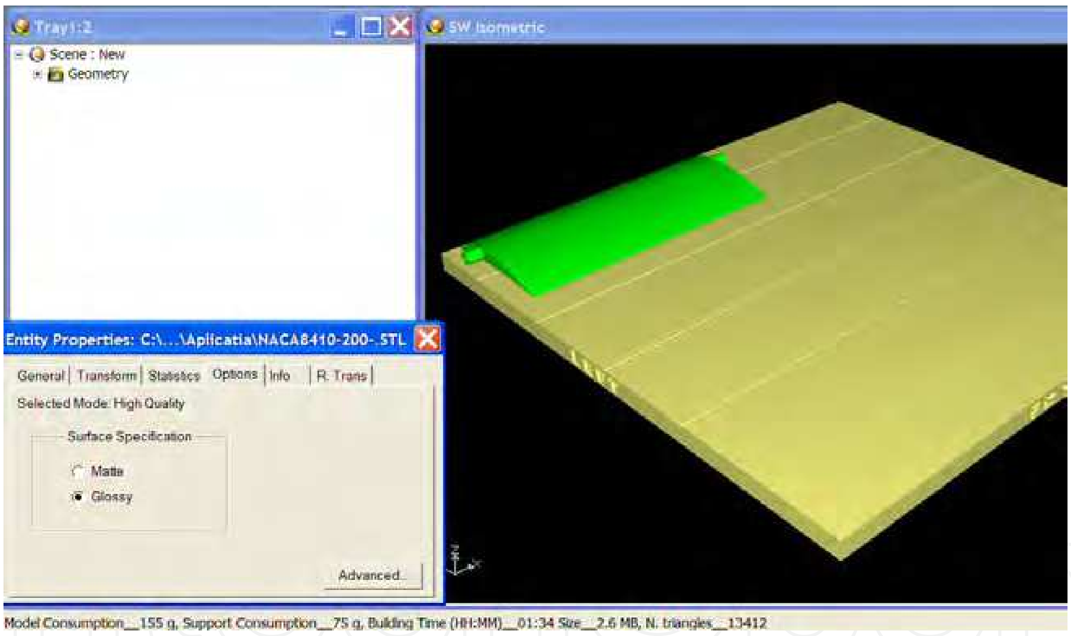
	Width (X)	Depth (Y)	Height (Z)	Units
Translate:	159.94	296.12	6.9	mm
Rotate:	90	0	270	Degrees
Scale	1	1	1	Ratio
Dimensions:	83.31	11.8	200	mm

☑ Uniform Scaling

Model Consumption__157 g, Support Consumption__91 g, Building Time (HH:MM)__01:38 Size__2.6 MB, N. triangles__13414

X=49.69 Y=317.55 Z

Fig. 13. The orientation of the 3D model on the EDEN350 build tray: 0o (the biggest dimension along X)



Entity Properties: C:\...\Aplicatia\NACA8410-200-.STL

Selected Mode: High Quality

Surface Specification

○ Matte
● Glossy

Model Consumption__155 g, Support Consumption__75 g, Building Time (HH:MM)__01:34 Size__2.6 MB, N. triangles__13412

Fig. 14. The orientation of the 3D model on the EDEN350 build tray: 0o, glossy mode

Results regarding this case study are presented in the table 1.

	Model consumption	**Support consumption**	**Building time**
Case A1 (fig. 11)	162 grams	**37 grams**	10 h 54 min
Case B1 (fig. 12)	162 grams	95 grams	3 h 14 min
Case C1 (fig. 13)	157 grams	91 grams	1 h 38 min
Case D1 (fig. 14)	**155 grams**	75 grams	**1 h 34 min**

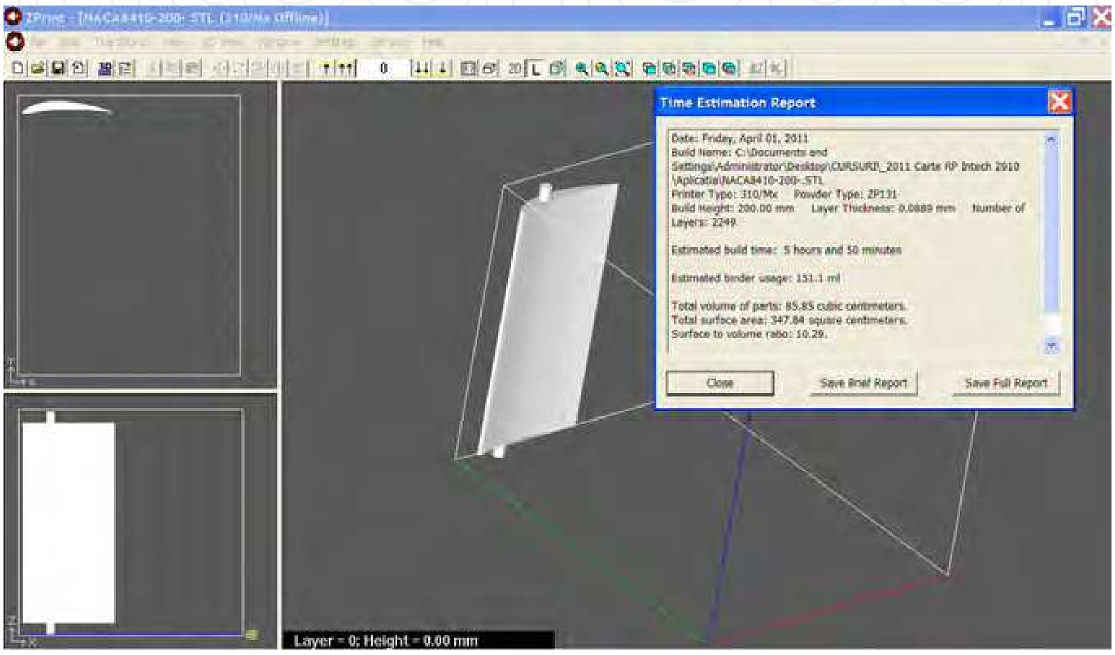
Table 1. Estimated parameters of AM by polyjet technology

In the case of manufacturing of the NACA model using inkjet technology, three positions on the build tray was chosen into consideration (fig. 15, fig. 16 and fig. 17). The layer thickness of the ZP 131 powder used is set to 0.0875 mm.

Placing of the model in the same way like in the previous case, material consumption and building time was calculated. The minimum building time of NACA model was taken in the third case (fig. 17). Also, in this case the minimum binder consumption was estimated.

The new rule regarding part orientation on the XY plane (inkjet technology) is called "XY-90^0 rule" (Udroiu & Ivan, 2010).

Some intermediate conclusions are presented in the table 2.



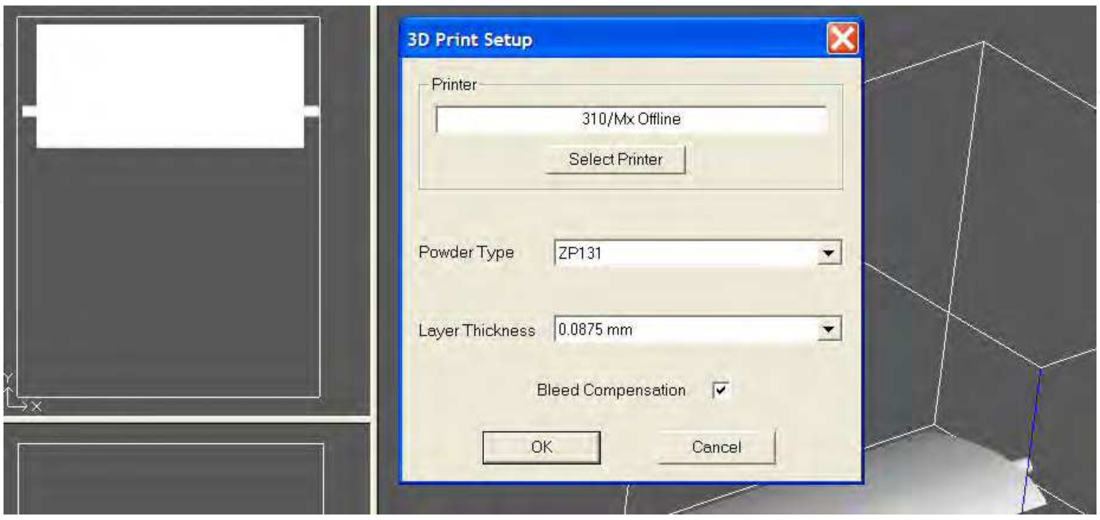
Date: Friday, April 01, 2011
Build Name: C:\Documents and Settings\Administrator\Desktop\CURSURI_2011 Carte RP Intech 2010\Aplicatia\NACA8410-200-.STL
Printer Type: 310/Mx Powder Type: ZP131
Build Height: 200.00 mm Layer Thickness: 0.0889 mm Number of Layers: 2249

Estimated build time: 5 hours and 50 minutes

Estimated binder usage: 151.1 ml

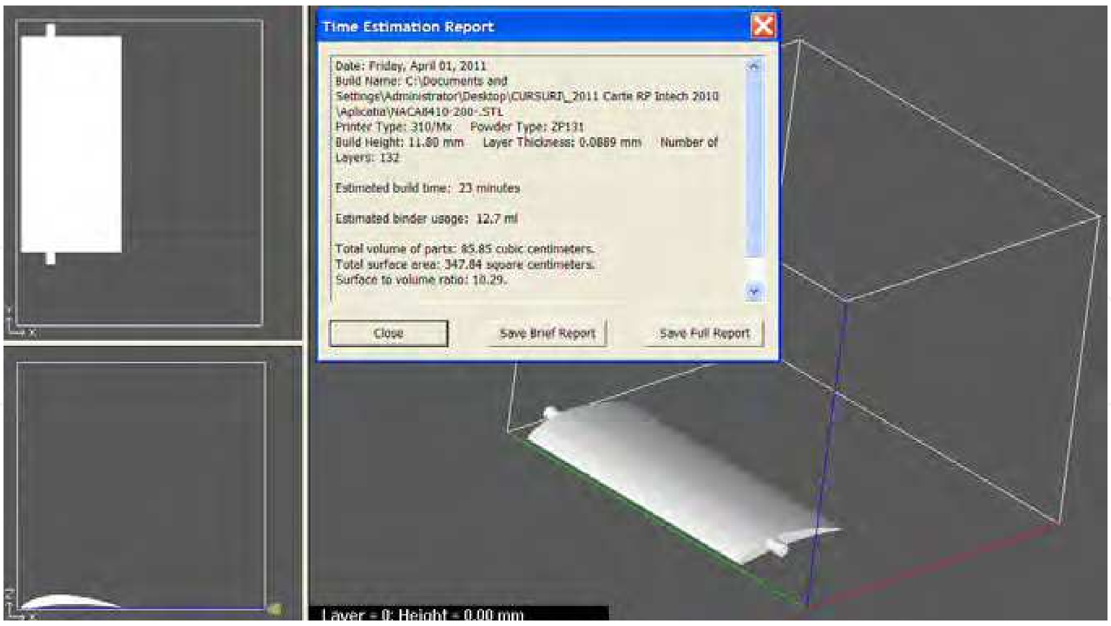
Total volume of parts: 85.85 cubic centimeters.
Total surface area: 347.84 square centimeters.
Surface to volume ratio: 10.29.

Fig. 15. The orientation of the 3D model on the Z310 Plus build tray: the biggest dimension along Z



Printer: 310/Mx Offline
Powder Type: ZP131
Layer Thickness: 0.0875 mm
Bleed Compensation ☑

Fig. 16. The orientation of the 3D model on the Z310 Plus build tray: 0^o (the biggest dimension along X); setting the powder type and the layer thickness for the Z310 Plus printer



```
Date: Friday, April 01, 2011
Build Name: C:\Documents and
Settings\Administrator\Desktop\CURSURI_2011 Carte RP Intech 2010
\Aplicatia\NACA8410-200-.STL
Printer Type: 310/Mx    Powder Type: ZP131
Build Height: 11.80 mm    Layer Thickness: 0.0889 mm    Number of
Layers: 132

Estimated build time:  23 minutes

Estimated binder usage:  12.7 ml

Total volume of parts: 85.85 cubic centimeters.
Total surface area: 347.84 square centimeters.
Surface to volume ratio: 10.29.
```

Fig. 17. The orientation of the 3D model on the Z310 Plus build tray: 90° (the biggest dimension along Y)

	Powder consumption	Binder consumption	Building time
Case A2 (fig. 15)	85,85 cm^3	151,1 ml	5 h 50 min
Case B2 (fig. 16)	85,85 cm^3	13,1 ml	34 min
Case C2 (fig. 17)	85,85 cm^3	**12,7 ml**	**23 min**

Table 2. Estimated parameters of AM by inkjet technology

4.2 Case study 2. Additive manufacturing by 3D printing for fit testing

In this case study, we consider an assembly composed from two parts (lower part and upper part) that must be fitted together. The assembly (fig. 18) was designed in Solid Works software.

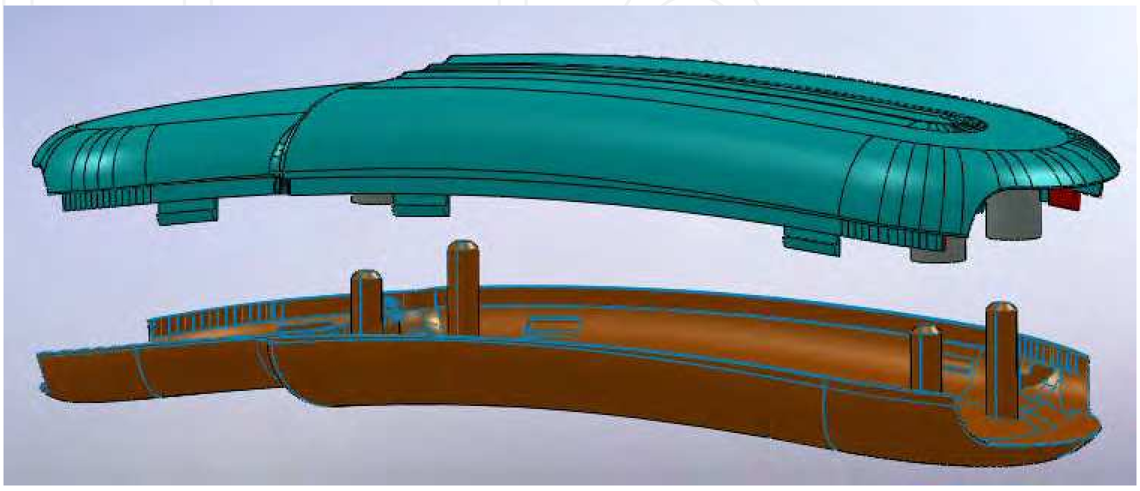
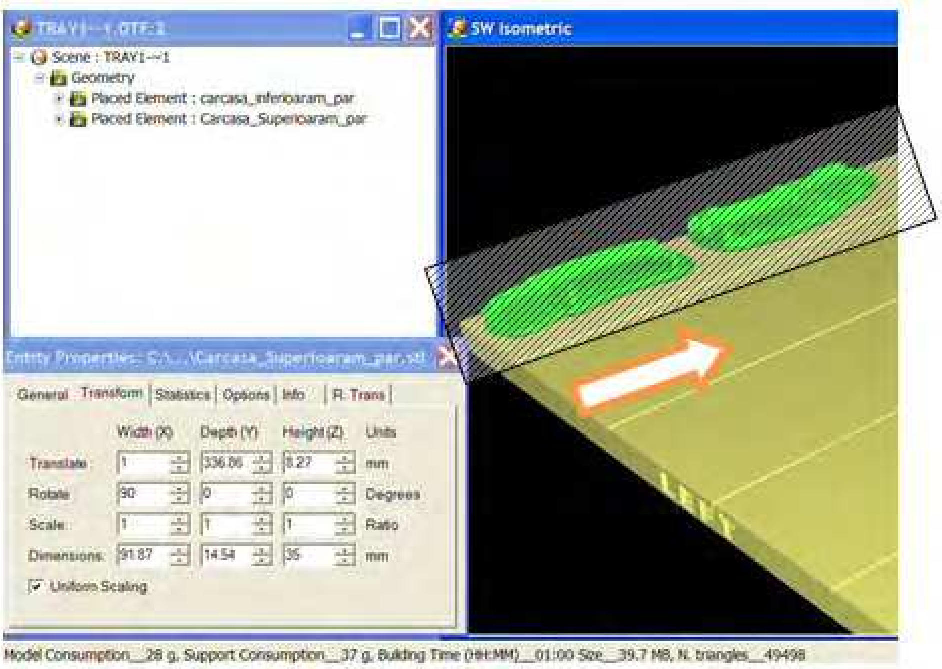


Fig. 18. CAD models of fitted parts

The conclusions for preview paragraph were taken into consideration. We consider that the best way positioning of the parts, within polyjet technology, is with their fitted surfaces facing upwards (Fig. 19). The parts were oriented to satisfy minimum support structure, minimum building time and good quality surface for the fitted test. Using glossy printing mode, the external surfaces are normally smooth and post-processing is easy to perform.



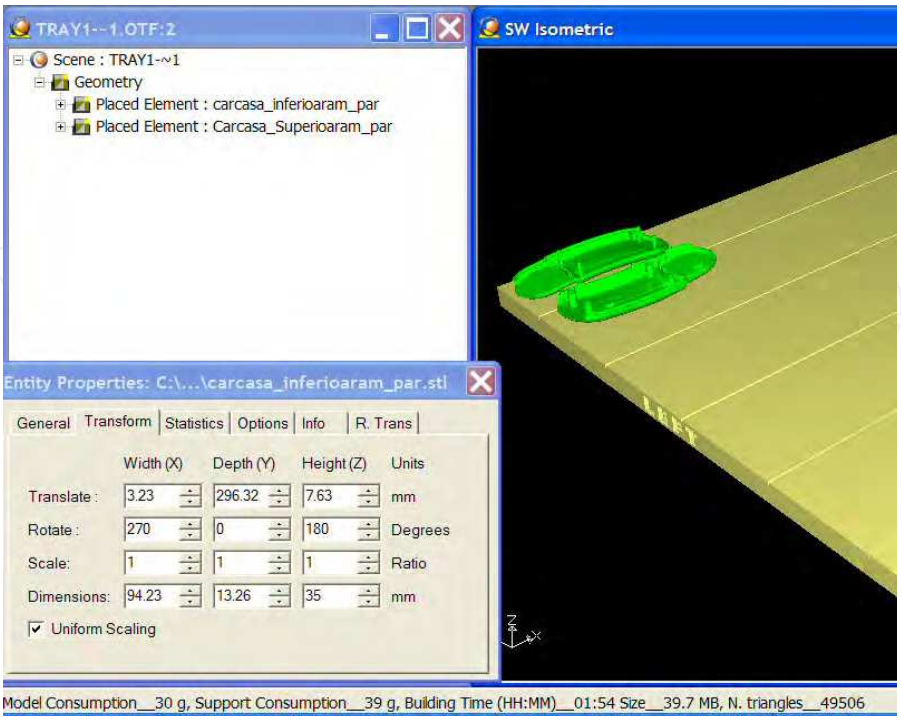
Scene : TRAY1~1
Geometry
Placed Element : carcasa_inferioaram_par
Placed Element : Carcasa_Superioaram_par

	Width (X)	Depth (Y)	Height (Z)	Units
Translate	1	336.86	8.27	mm
Rotate	90	0	0	Degrees
Scale	1	1	1	Ratio
Dimensions	91.87	14.54	35	mm

☑ Uniform Scaling

Model Consumption__28 g, Support Consumption__37 g, Building Time (HH:MM)__01:00 Size__39.7 MB, N. triangles__49498

Fig. 19. Positioning of the parts along X axis, “XY-0⁰” rule satisfied (polyjet technology)



Scene : TRAY1~1
Geometry
Placed Element : carcasa_inferioaram_par
Placed Element : Carcasa_Superioaram_par

	Width (X)	Depth (Y)	Height (Z)	Units
Translate :	3.23	296.32	7.63	mm
Rotate :	270	0	180	Degrees
Scale:	1	1	1	Ratio
Dimensions:	94.23	13.26	35	mm

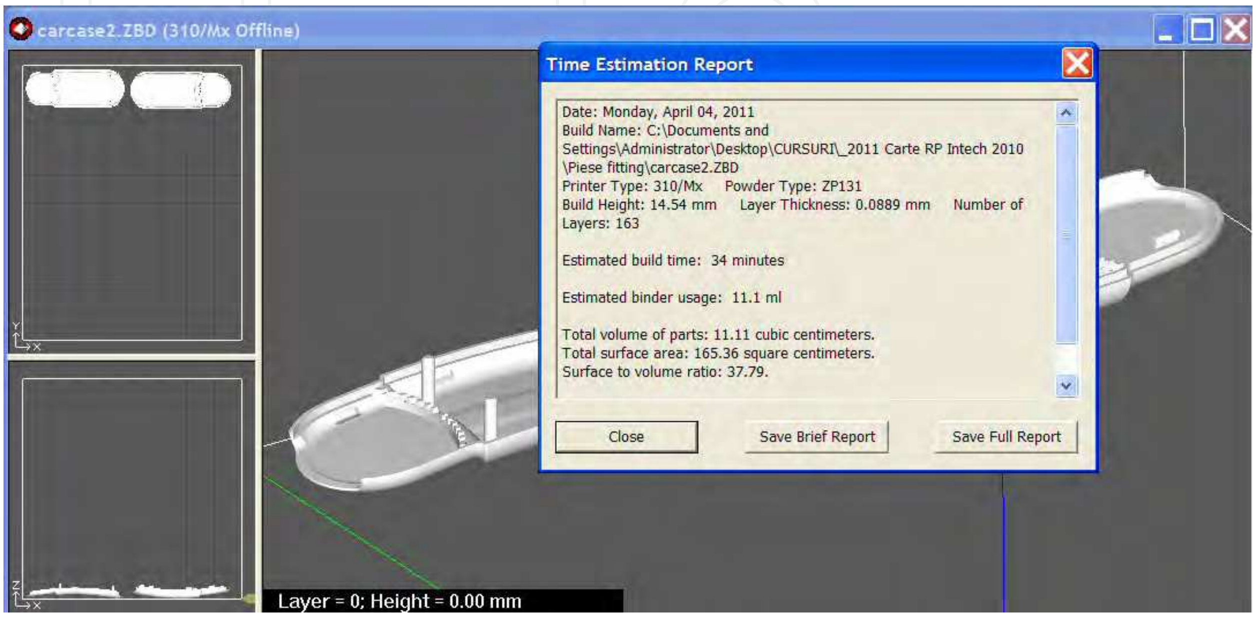
☑ Uniform Scaling

Model Consumption__30 g, Support Consumption__39 g, Building Time (HH:MM)__01:54 Size__39.7 MB, N. triangles__49506

Fig. 20. Positioning of parts along Y axis, “XY-0⁰” rule satisfied (polyjet technology)

In the case of manufacturing on Z 310 printer, polyjet rules can't be applied because the part is supported by powder. The best way to position the parts is with their fitted surfaces facing downwards. This assures an easy powder removal.

The conclusions regarding this case study (fig. 19, fig. 20, fig. 21, fig. 22 and fig.23) are shown in the table 3.



Date: Monday, April 04, 2011
Build Name: C:\Documents and Settings\Administrator\Desktop\CURSURI_2011 Carte RP Intech 2010 \Piese fitting\carcase2.ZBD
Printer Type: 310/Mx Powder Type: ZP131
Build Height: 14.54 mm Layer Thickness: 0.0889 mm Number of Layers: 163

Estimated build time: 34 minutes

Estimated binder usage: 11.1 ml

Total volume of parts: 11.11 cubic centimeters.
Total surface area: 165.36 square centimeters.
Surface to volume ratio: 37.79.

Fig. 21. Positioning of parts along X axis combining with the biggest dimensions along X (inkjet technology)

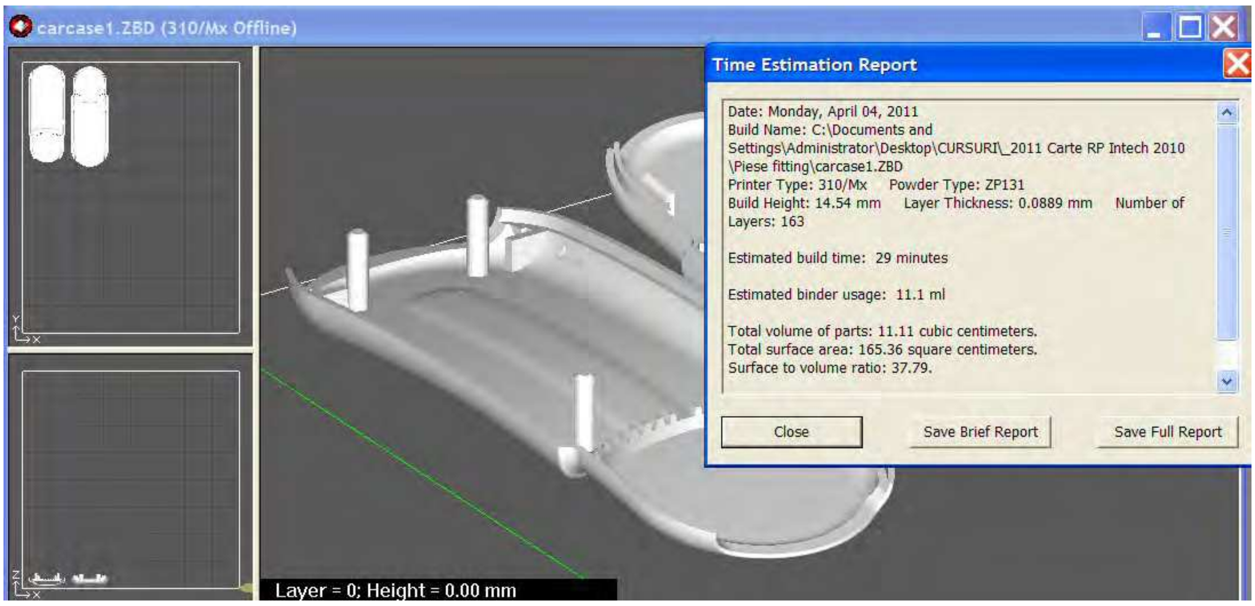
Date: Monday, April 04, 2011
Build Name: C:\Documents and Settings\Administrator\Desktop\CURSURI_2011 Carte RP Intech 2010 \Piese fitting\carcasa_inferioaram_par.stl
Printer Type: 310/Mx Powder Type: ZP131
Build Height: 14.54 mm Layer Thickness: 0.0889 mm Number of Layers: 163

Estimated build time: 26 minutes

Estimated binder usage: 11.1 ml

Total volume of parts: 11.11 cubic centimeters.
Total surface area: 165.36 square centimeters.
Surface to volume ratio: 37.79.

Fig. 22. Positioning of parts along Y axis, “XY-90^0” rule satisfied (inkjet technology)



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Date: Monday, April 04, 2011
Build Name: C:\Documents and
Settings\Administrator\Desktop\CURSURI\_2011 Carte RP Intech 2010
\Piese fitting\carcase1.ZBD
Printer Type: 310/Mx    Powder Type: ZP131
Build Height: 14.54 mm    Layer Thickness: 0.0889 mm    Number of
Layers: 163

Estimated build time:  29 minutes

Estimated binder usage:  11.1 ml

Total volume of parts: 11.11 cubic centimeters.
Total surface area: 165.36 square centimeters.
Surface to volume ratio: 37.79.
```

Fig. 23. Positioning of parts along X axis, “XY-90^0” rule satisfied (inkjet technology)

	ZPrint software (inkjet technology)		
	Powder consumption	Binder consumption	Building time
Case A4 (along X) - fig. 21	11,11 cm^3	11.2 ml	34 min
Case B4 (along Y) - fig. 22	**11,11 cm^3**	**11.2 ml**	**26 min**
Case C4 - fig. 23	11,11 cm^3	11.2 ml	29 min
	Objet studio software (polyjet technology)		
	Model consumption	Support consumption	Building time
Case A3 – fig. 19	**28 grams**	**37 grams**	**1 h**
Case B3 –fig. 20	30 grams	39 grams	1 h 54 min

Table 3. Estimated parameters of 3D printing for fit testing

4.3 Case study 3. Optimization of simultaneous additive manufacturing by 3D printing of many parts

In this case study, problem of simultaneous manufacturing of many parts on the build tray was taken into consideration.

In the case of 3D printing of complex products, big assemblies or many parts is necessary to minimize the manufacturing process cost. Taking this into account, some printing parameters must be optimised, such as 3D printing time, post-processing time and material consumption. A main step is to separate the CAD model into optimal parts or subassemblies and then finding the best manufacturing orientation of the components.

The proposed method is a two step procedure. First, we orient all the parts according to the “XY-method” based on the following criterions: minimum build time, minimum support structure and the best surface quality. Having oriented the parts, the next step will be different for inkjet and polyjet technology.

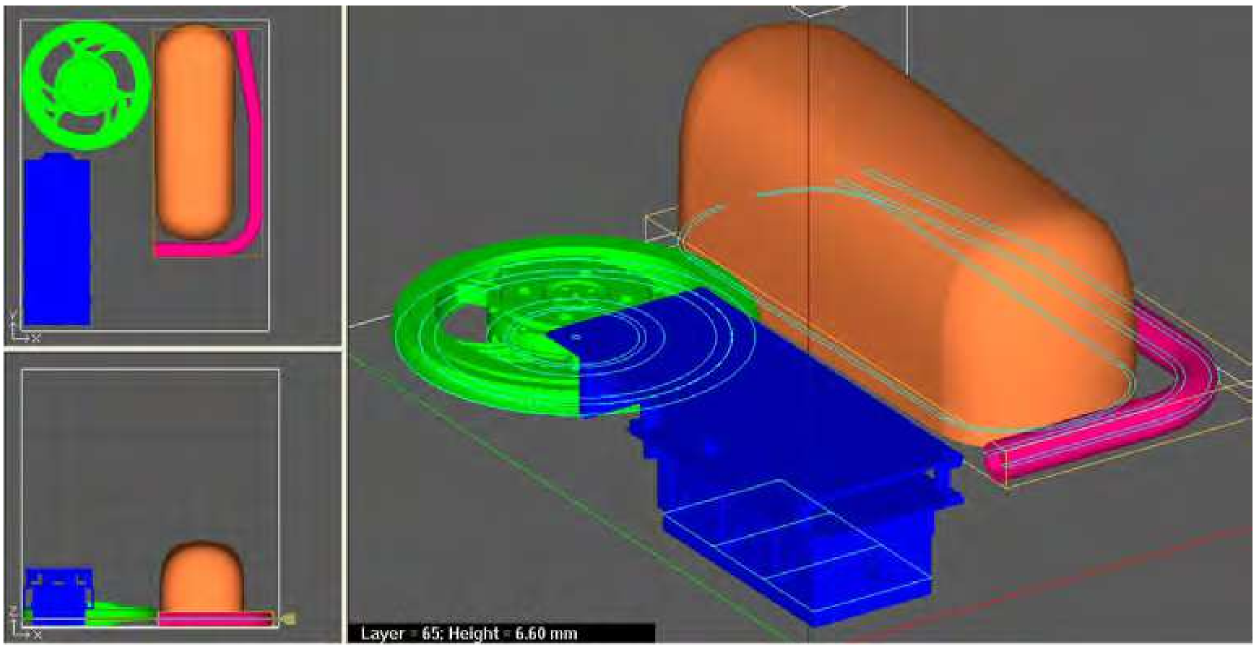


Fig. 24. Case A5. Orientation of many parts on the build tray (inkjet technology)

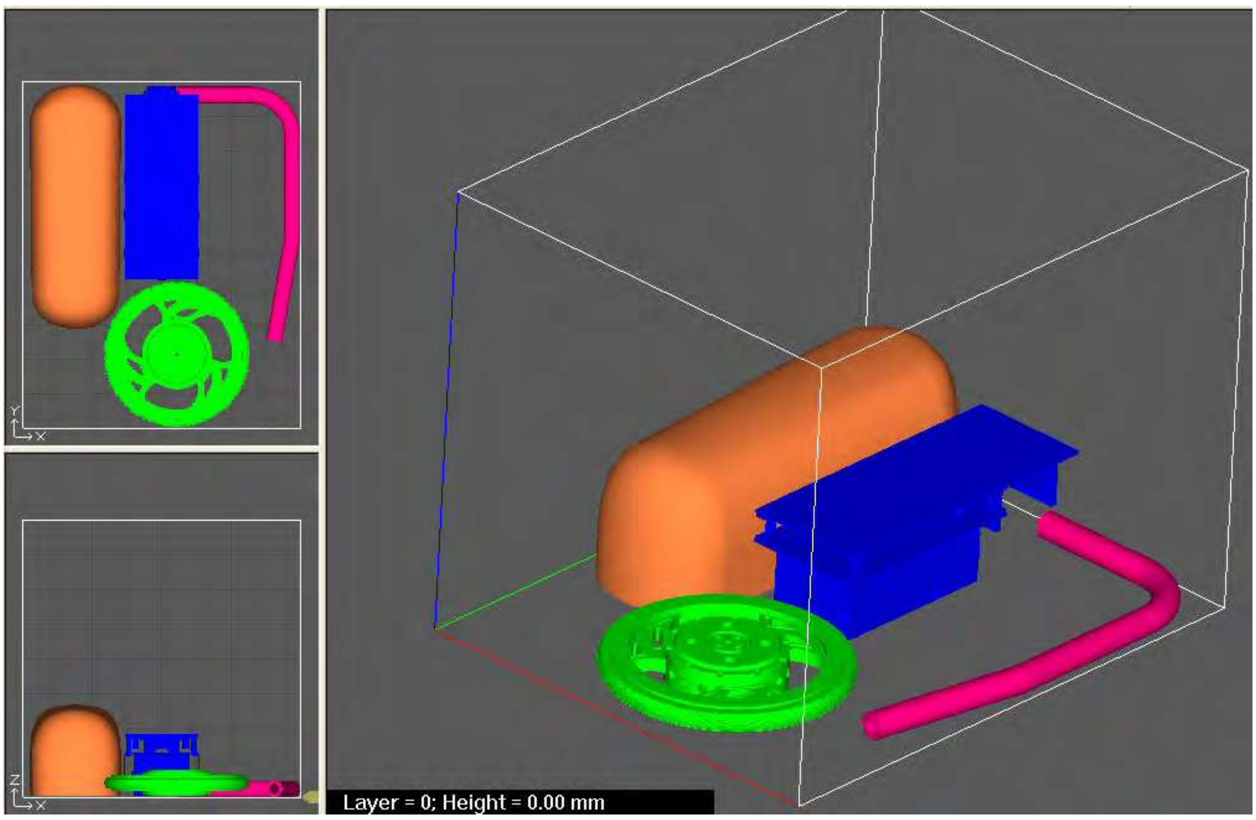


Fig. 25. Case B5. Best orientation of many parts on the build tray (inkjet technology)

Having all the 3D models oriented according to “XY-method”, their optimal packing on the ZPrint tray, can be found by placing from left to the right of 3D models having the Z dimension decrease. The resulting rule is “Highest part left” with “the biggest dimension along Y axis”.

The optimal packing on the Eden 350 tray is placing the tallest part to the left. The resulting rule is "Highest part left" with "the biggest dimension along X axis".

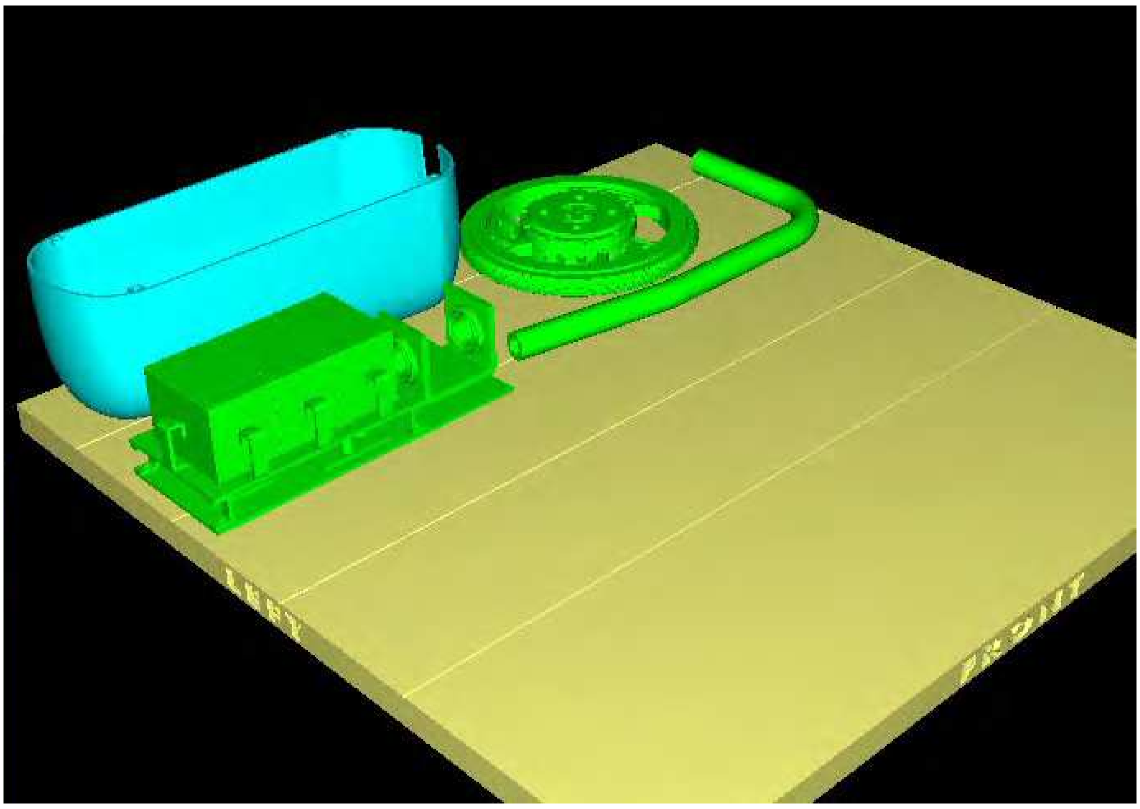


Fig. 26. Case A6. Orientation of many parts on the build tray (polyjet technology)

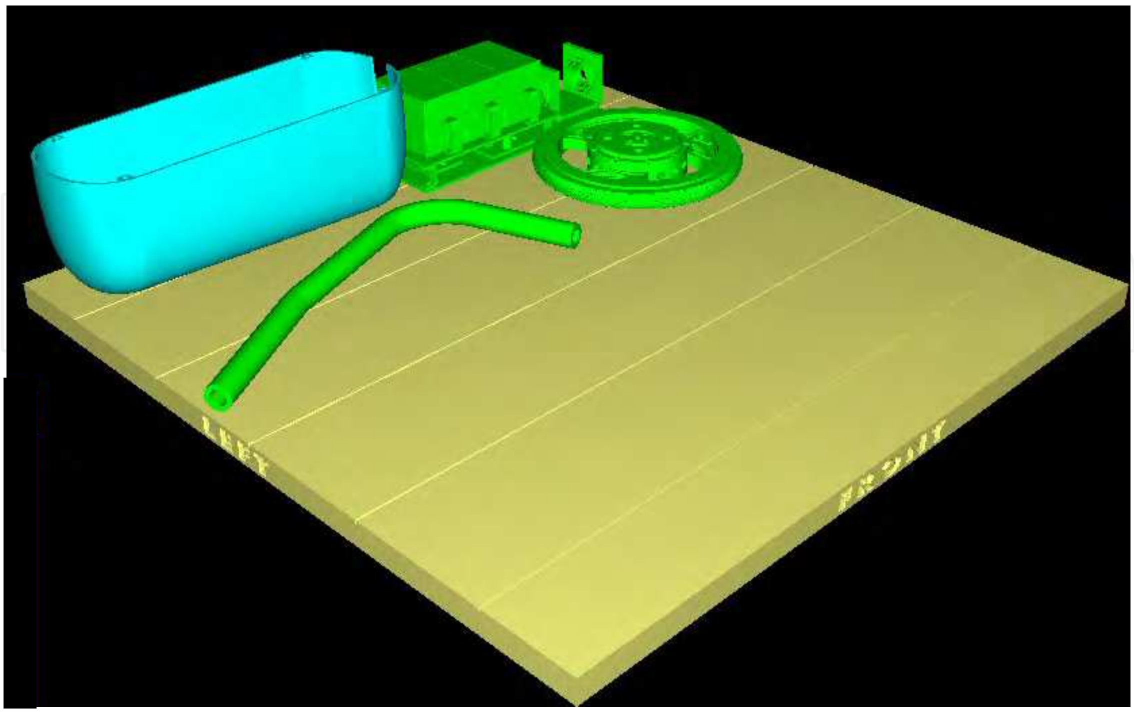


Fig. 27. Case B6. Best orientation of many parts on the build tray (polyjet technology)

The results are presented in the table 4.

	ZPrint software (inkjet technology)		
	Powder consumption	Binder consumption	Building time
Case A5 - fig. 24	269,11 cm^3	112,2 ml	3 h 4 min
Case B5 - fig. 25	**269,11 cm^3**	**112,2 ml**	**2h 45 min**
	Objet studio software (polyjet technology)		
	Model consumption	Support consumption	Building time
Case A6 - fig. 26	530 grams	353 grams	12 h 56 min
Case B6 - fig. 27	**527 grams**	**350 grams**	**12 h 11 min**

Table 4. Estimated parameters of 3D printing for many parts manufacturing

4.4 Products built by additive manufacturing at Transilvania university of Brasov, Romania

Some products additive manufactured at the Industrial Innovative Technologies laboratory within Transilvania University of Brasov (Udroiu & Ivan, 2010), are illustrated in fig. 28 and fig. 29. Thus are presented complex parts, parts with small details, tools and assemblies obtained from different materials.

Fig. 28. Products obtained by "inkjet" printing (Z310 Plus), Transilvania University of Brasov

Products obtained by polyjet technology (fig. 29), are made from photopolymers like FullCure 720, VeroWhite, VeroBlue, VeroBlack and Durus materials (Park, 2008).
The parts built by ZPrint technology (fig. 28), are made of ZP 131 powder, gluing by ZP 60 binder.

Fig. 29. Products obtained by "polyjet" printing (EDEN 350), Transilvania University of Brasov

5. Surface quality of additive manufacturing products

5.1 Introduction

The surface roughness of products obtained by additive manufacturing is an important parameter that can reduce post-processing time and cost.
Regarding quality of the surface in RP/RM we can mention that the roughness influences the quality of final product. As example, the surface roughness is very important for aerodynamic models tested in the wind tunnel (Adelnia et al., 2006).
A study regarding the surface roughness of the vertical wall for different rapid prototyping processes was done in (Pal & Ravi, 2007) (fig. 30). The surface roughness was measured using a Mahr Perthometer surface roughness tester.

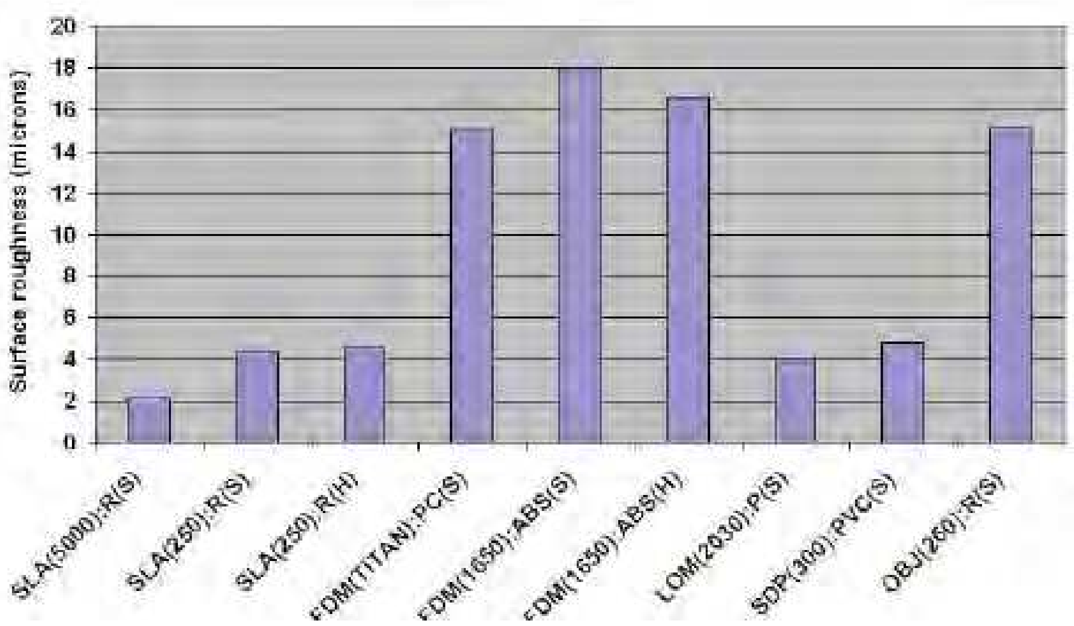
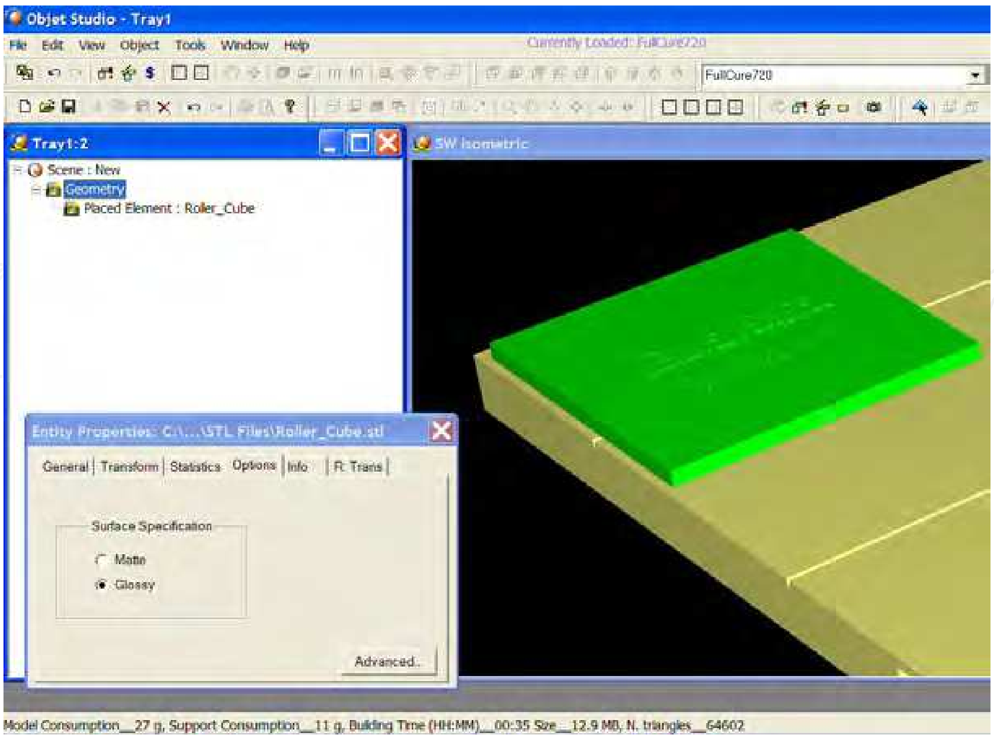


Fig. 30. Comparison of surface roughness on vertical wall (Pal & Ravi, 2007)

In this paragraph, an experimental investigation on surface roughness of rapid prototyping products produced by polyjet technology, was done.

Using Solid Works software, a part for experimental investigation was designed. The digital model of the part is then converted to STL format file and imported within Objet studio software in order to be sending it to RP machine. Using Objet studio software (fig. 31) we defined the building parameters in order to minimize the building time and the material consumption.



Surface Specification

○ Matte

● Glossy

Model Consumption__27 g, Support Consumption__11 g, Building Time (HH:MM)__00:35 Size__12.9 MB, N. triangles__64602

Fig. 31. Orientation of the test part within Objet studio software

As we mention in the last paragraph, surface specification of parts obtained by polyjet technology can be setting to: matte and glossy. The upper surface of test part is printed in glossy mode and the lower surface in matte mode.
The materials used are Fullcure 720 resin for the model and Fullcure 705 for the support.

5.2 Experimental determination of surface roughness of parts obtained by PolyJet technology

"Surtronic 25" surface roughness tester (Taylor Hobson), as per DIN EN ISO 4288/ASME B461 and manufacturer's recommendations, was used to measure the surface roughness.

a) b)

Fig. 32. The parameters calculated by "Surtronic 25"

The "Surtronic 25" can be used either freestanding (on horizontal, vertical or even inverted surfaces) or bench mounted with fixturing for batch measurement and laboratory applications. This instrument calculates up to 10 parameters (fig. 32b) according to the measurement application (Udroiu & Mihail, 2009):

- amplitude parameters (measures the vertical characteristics of the surface deviations): Ra (Arithmetic Mean Deviation), Rsk (Skewness), Rz (Average peak to valley height), Rt (Total height of profile), Rp (Max profile peak height), Rz1max (Max peak to valley height);
- spacing parameters (measures the horizontal characteristics of the surface deviations): RPc (Peak count), RSm (Mean width of profile elements);
- hybrid parameters (combinations of spacing and amplitude parameters): Rmr (Material Ratio), Rda - R Delta a (Arithmetic Mean Slope).

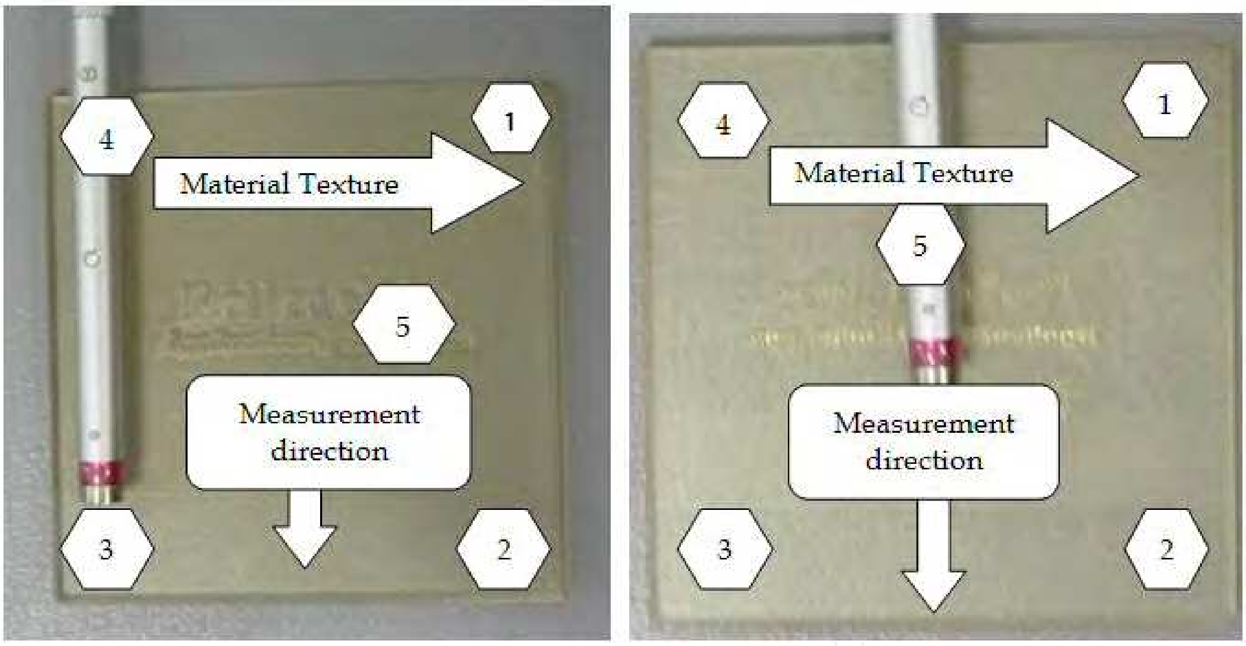
The experimental instrumentation connected to the laptop is shown in the fig. 32a.
The first step is the calibration of the "Surtronic 25" roughness checker.
The "Surtronic 25" stylus can traverse up to 25mm (or as little as 0.25mm) depending on the component. The Gauss filtered measurements were done for an evaluation length of 4 mm with a cut off value of 0.8 mm.
To determine the surface roughness of the test part we proposed two sketches where the locations of measurement areas on the surface part, was indicated. The measurement

strategy is resume in two sketch presented in fig. 33a and fig. 33b, first for glossy surface (upper surface of the test part) and the second used for the matte surface (lower surface of the test part).

Five measurements were taken on each surface and the average values of Ra and Rz on horizontal surfaces (matte and glossy) were recorded (fig. 34 and fig. 35). Four of these measurements (1, 2, 3 and 4) were taken in transversal direction of the material texture and the last (5) in material texture direction.

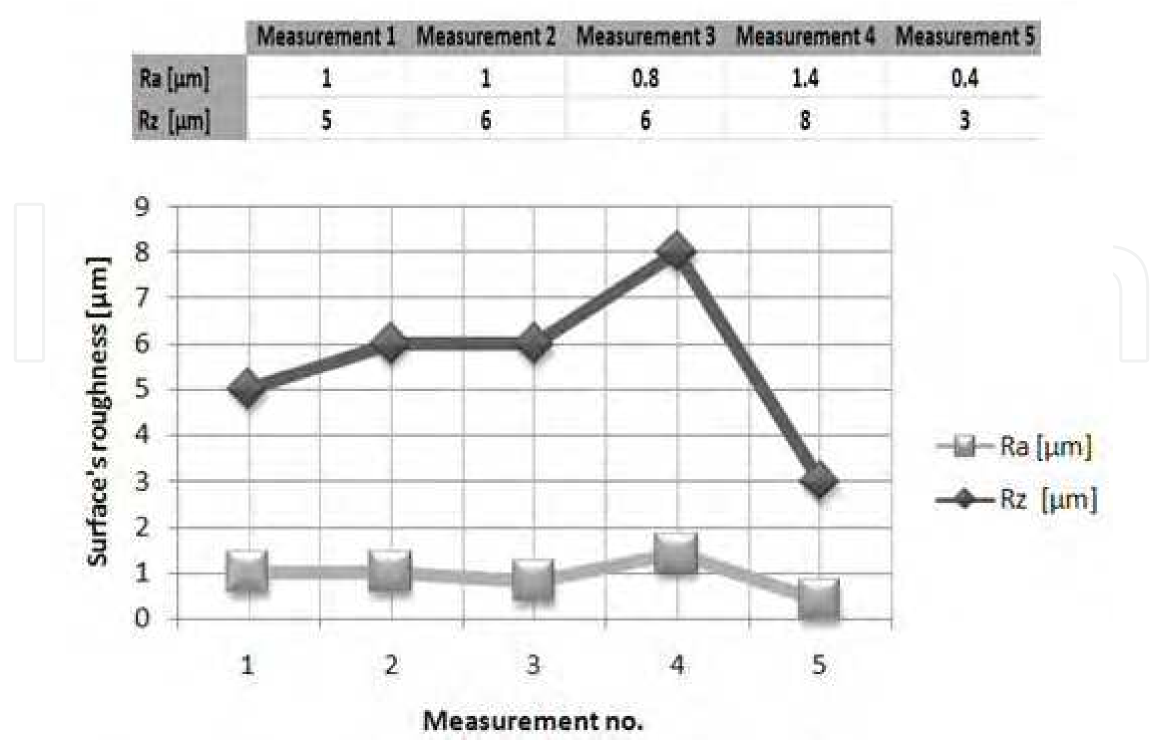
The surfaces roughness of parts fabricated by polyjet technology, was calculated like an average value of all measurements. Thus, for the mate surface results the following value: Ra_m=1.04 microns and Rz_m=5.6 microns. The glossy surface roughness are Ra_m=0.84 microns and Rz_m=3.8 microns.

Finally, using an ETALON TCM 50 measuring microscope (30x magnification) the surface texture was analyzed. The internal structure of the part surface obtained by polyjet technology is shown in the fig. 36.



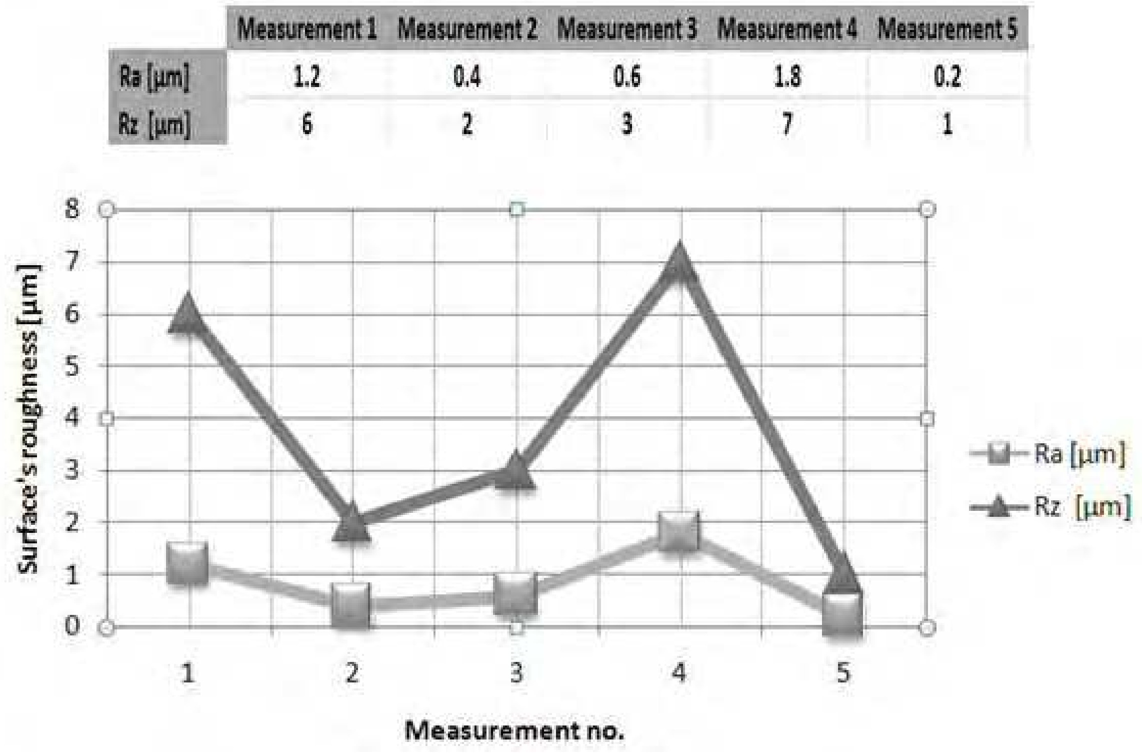
a) b)

Fig. 33. The measurement strategy of the surface roughness using the Surtronic 25 instrument



	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Measurement 5
Ra [µm]	1	1	0.8	1.4	0.4
Rz [µm]	5	6	6	8	3

Fig. 34. The surface roughness values measurement on the matte surface



	Measurement 1	Measurement 2	Measurement 3	Measurement 4	Measurement 5
Ra [µm]	1.2	0.4	0.6	1.8	0.2
Rz [µm]	6	2	3	7	1

Fig. 35. The surface roughness values measurement on the glossy surface

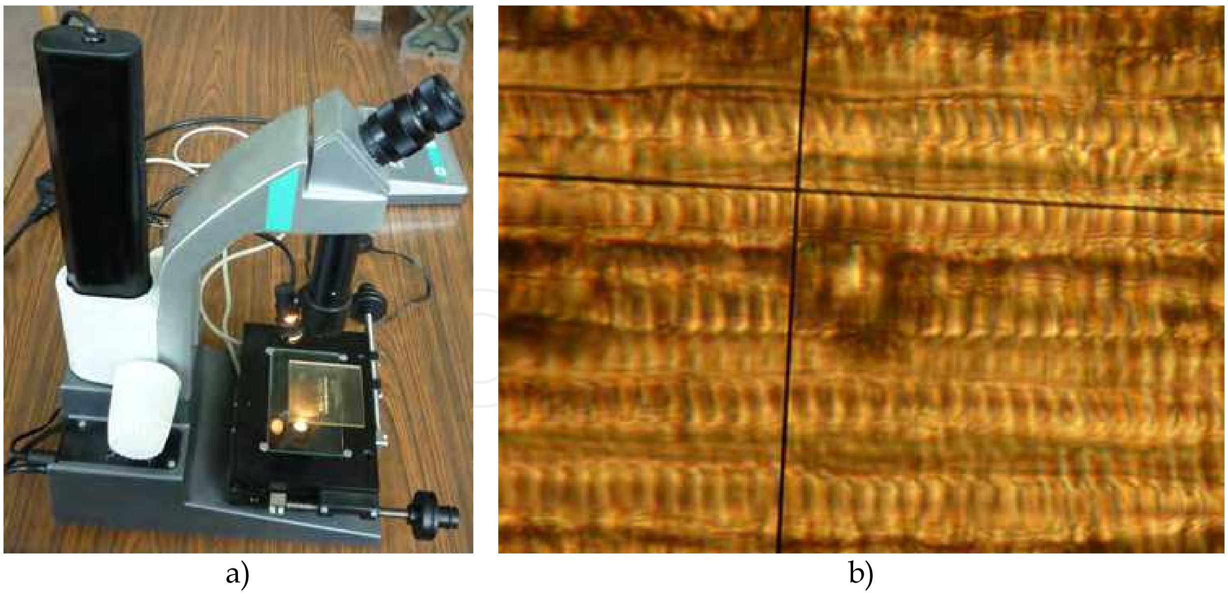

a) b)

Fig. 36. ETALON TCM 50 measuring microscope and the texture of the polyjet RP surface

6. Conclusions

In this chapter, some methods of optimisation of additive manufacturing process and experimental surface roughness investigation are presented. The main author has chosen two different 3D printing technologies, inkjet printing and polymer jetting. First technology use a powder that is gluing by a binder and the second technology combine polymer inkjet with photo-polymerisation process.

The researches have started and have developed by the main author, within Industrial Innovative Technologies laboratory from Advanced Manufacturing Technologies and Systems department, Transilvania University of Braşov, Romania.

The proposed optimisation approach is focused on three additive manufacturing applications. First, the orientation of one part on a build tray taking into accord minimum build time criterion, minimum support structure and best quality surface.

Second application is focused on fitted testing of parts obtained by 3D printing. Taking into accord the rules for the first two applications, it was proposed rules for packing many parts on the build tray.

In the last part of this chapter an experimental investigation on surface roughness of rapid prototyping products produced by polyjet technology, were done. The experimental investigations was done using “Surtronic 25” roughness checker from Taylor Hobson. It is important to mention that in the polyjet process we can choose between two parameters that affect the surface quality: mate or glossy. The average value for the mate surface are Ra_m=1.04 microns, Rz_m=5.6 microns and for the glossy surface are Ra_m=0.84 microns, Rz_m=3.8 microns. The surface texture was analyzed using an ETALON TCM 50 measuring microscope.

The quality of part surface obtained by polyjet technology is very good and is not necessary a post processing of the RP part. The part produced on the ZPrinter seems to have the lowest precision and it is the most fragile (needs post-processing), but it was produced much faster and cheaper.

The final conclusions, regarding Z310 versus EDEN350 studies are shown in the table 5.
The future work will be focused on implemented the new rules into an innovative software.

RP machine type	**Z 310**		**EDEN 350**	
Materials	composite materials (powder and binder)		photopolymers	
Layer thickness [mm]	0.0875		0.016	
3D printing optimisation of an individual part				
	Pos 0^o	**Pos 90^0**	**Pos 0^o**	Pos 90^0
Best position of the part on the build platform (minimum building time and cost) – "XY rule"		x	x	
	"the smallest dimension along Z axis"		"the smallest dimension along Z axis"	
	"XY -90^O rule" or "the biggest dimension along Y axis"		"XY -0^O rule" or "the biggest dimension along X axis"	
	"Align the model with machines axis"		"Align the model with machines axis"	
3D printing optimisation of fitted part				
	"Concave surface downwards"		"Glossy fitted surface upwards"	
Optimization of simultaneous additive manufacturing of many parts				
	"Highest part left" with "the biggest dimension along Y axis"		"Highest part left" with "the biggest dimension along X axis"	
Conclusions				
Input files	STL, PLY, VRML, 3DS		STL, SLC	
Printing speed	faster		good	
Surface finish and accuracy	lower / 0.5 mm		best / 0.1mm	
Need to build support structure?	No (only for delicate and big parts)		Yes	
Need post-processing	Yes (infiltration with resins and sand blasting)		No (only removing of the support by water jet)	

Table 6. Conclusions of Z310 versus EDEN350 study

7. Acknowledgment

Based on PLADETINO platform the main research author has developed new research contracts, like director, with industrial companies. In this chapter results regarding optimization of additive manufacturing, from contracts: no. 18543/ 05.12.2008, no. 5516/ 23.04.2008, no. 6427/ 19.05.2009, no. 6428/ 19.05.2009, no.1967/ 18.02.2009, no. 5442/

27.04.2010, no. 1359/ 3.02.2010, no. 9290/ 14.07.2010 and no. 9997/ 23.07.2010, was presented. The authors express their gratitude to all partners for the fruitful collaboration.

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Modern engineering often deals with customized design that requires easy, low-cost and rapid fabrication. Rapid prototyping (RP) is a popular technology that enables quick and easy fabrication of customized forms/objects directly from computer aided design (CAD) model. The needs for quick product development, decreased time to market, and highly customized and low quantity parts are driving the demand for RP technology. Today, RP technology also known as solid freeform fabrication (SFF) or desktop manufacturing (DM) or layer manufacturing (LM) is regarded as an efficient tool to bring the product concept into the product realization rapidly. Though all the RP technologies are additive they are still different from each other in the way of building layers and/or nature of building materials. This book delivers up-to-date information about RP technology focusing on the overview of the principles, functional requirements, design constraints etc. of specific technology.

Razvan Udroiu and Anisor Nedelcu (2011). Optimization of Additive Manufacturing Processes Focused on 3D Printing, Rapid Prototyping Technology - Principles and Functional Requirements, Dr. M. Hoque (Ed.), ISBN: 978-953-307-970-7, InTech, Available from: http://www.intechopen.com/books/rapid-prototyping-technology-principles-and-functional-requirements/optimization-of-additive-manufacturing-processes-focused-on-3d-printing

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