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RAPID PROTOTYPING AND RAPID MANUFACTURING APPLICATIONS AT TRANSILVANIA UNIVERSITY OF BRAŞOV

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Abstract: *Under the umbrella of the generic issue of Rapid X there are some concepts such as: Rapid Prototyping (RP), Rapid Tooling (RT) and Rapid Manufacturing (RM). This paper presents industrial applications of the RP/ RM techniques, developed at the Industrial Innovative Technologies Laboratory, within the Manufacturing Engineering Department from Transilvania University of Braşov. The focus is on the determination of optimal strategies used in polyjet and" inkjet" RP technologies. The optimal strategies affects on the build time, support structure, surface quality as well as the cost of the physical prototype.*

Key words: *Rapid prototyping, polyjet, 3D printing, optimal strategies.*

1. Industrial Innovative Technological Developments within *Transilvania* University of Braşov

The Platform **PLADETINO** (Platform for Innovative Technological Development) [2] was aiming at building a centre for interdisciplinary development and research regarding the innovation and the integration of the technologies of designing and manufacturing the products considering the new concepts (CAD/CAPP/CAM/CIM, 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.

The Platform is integrated in a research and multidisciplinary training unitary structure of *Transilvania* University of Braşov and it is the main support of the **research department D05** named **Advanced Manufacturing Technologies and Systems** (decision No. 3119/9.01.2008 and order No. 3120/12.01.2008).

PLADETINO 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**.

The scientific research component is aiming at the integration of the processes related to the product life cycle being focused on innovative technologies bearer of computerized technologies. The approaches are part of the priority fields: Computerized Society Technologies, Materials and

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Innovative Products. The aim is to reduce the time of introducing high quality products on the market, having attractive prices, stimulating scientific research and supporting the professional education process.

This platform was capable of allowing the development of new scientific research contracts with industrial companies such as the following 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 and no. 1359/3.02.2010. All of these contracts are focused on **Rapid X technologies**. In this paper is presented some results obtained within these research contracts.

2. Introduction within Rapid X

Under the umbrella of Rapid X [4] 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). Such technologies are also known by the names additive fabrication, three dimensional printing, solid freeform fabrication and layered manufacturing. Unlike machining processes, which are subtractive in nature, additive systems, based on thin and horizontal cross sections taken from a 3D computer model, join together liquid, powder or sheet materials to produce plastic, ceramic, metal or composite parts.

Today’s additive technologies offer advantages in many applications compared to classical subtractive fabrication methods such as milling or turning: objects can be formed with any geometric complexity or intricacy without the need for elaborate machine setup or final assembly, 8-10 times lower time in manufacturing a new model in comparison with the conventional technologies, important savings regarding the costs of the models.

Rapid prototyping (RP) [1], [3], [4] represents a general term, which describes a variety of systems that can construct three-dimensional physical objects directly from electronic data (CAD data). The main advantage of rapid prototyping processes is that they build a prototype in one step, directly from the geometric model of the part to be manufactured. RP produces components in an additive manner by slicing the 3D-CAD model into a series of discrete layers. These layers are then reconstituted by the RP machine to produce a physical representation of the 3D-CAD model.

Rapid Tooling [1], [3], [4] is the technology that adopts RP techniques and applies them to tool and die making. RT technology is classified as a soft tooling process and a hard tooling process according to the applied material. Also RT can be divided into hard direct or indirect tooling. Tooling for short manufacturing runs is often known as soft tooling as these tools are often made from materials such as silicon rubber, epoxy resins, low-melting-point alloys, or aluminium. In direct tooling, the tool or the die is created directly by the RP process. In indirect tooling, only the master is created using the RP technology. From this master, a mould is made out a material such as silicone rubber, epoxy resin, soft metal, or ceramic.

Rapid manufacturing [1], [3], [4] is based on rapid prototyping processes and methods and consist in fast production of functional parts of small series. RM is making functional end products “directly” from CAD using additive technologies. RM has many differences over conventional manufacturing methods such as machining (milling, grinding etc.), or forming (injection moulding, casting etc.), the main distinction is the absence of special tools. In conclusion, rapid manufacturing is the direct production of finished goods using a RP machine that eliminate tooling.

Today, there are a lot of rapid prototyping technologies in the world. The most popular RP technologies [4] used worldwide are stereolithography (SL), selective laser sintering (SLS), 3D printing (3DP) and laminated object manufacturing (LOM).

One purpose of this paper is to present some RP/RM industrial applications witch was developed within the Industrial Innovative Technologies Laboratory, Manufacturing Engineering Department from *Transilvania* University of Braşov.

3. 3D Printing Technologies

The 3D printing technologies can be divided in the following: inkjet printing, fused deposition modelling, and polymer jeting (polyjet) or multi-jet. First of all, it will describe briefly the most used 3D printing technologies.

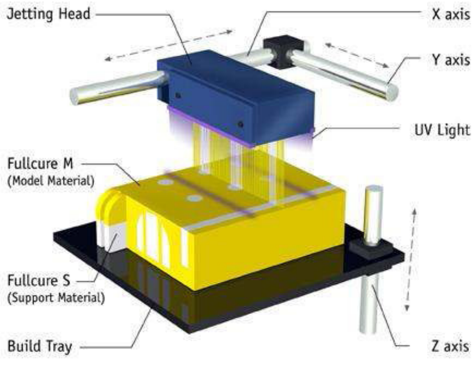


Fig. 1. *"Polymer jetting" printing*

Objet Geometries [5] launched its first RP system based on 3D polyjet printing technology in 2000 - the Quadra, and since then has been a competitive player within the RP market with the Eden range of machines (Eden 250, 260, 350, 500), Connex 500) and Alaris printer. The Connex 500 printer is able to fabricate multi-materials part by simultaneously jetting more than one model materials to create new composite materials. All Objet machines create parts layer by layer combining inkjet technology with photo-polymerisation (UV curing) process, Figure 1.

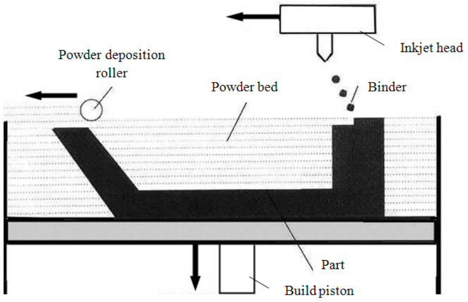


Fig. 2. *"Inkjet" printing*

Z Corporation [6] 3D Printer processes are based on the Massachusetts Institute of Technology's patented 3DP technology. All ZCorp 3D Printers create the model one layer at a time by spreading a layer of powder and inkjet printing a binder in the cross-section of the part. The process, Figure 2 is repeated until every layer is printed and the part is complete and ready to be removed.

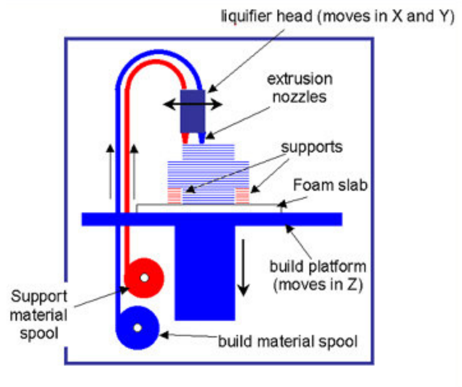


Fig. 3. *Fused deposition printing*

Stratasys patented the rapid prototyping process known as fused deposition modelling (FDM) [3], [4]. The process, Figure 3 creates parts layer by layer by extruding thermoplastic material (ABS plastic, polycarbonate, PPSF) in a liquid state. This process is relatively simple but its use is limited to thermoplastic materials.

InVision [4] rapid prototyping system from 3D Systems combines 3D Systems' patented multi-jet modelling (MJM) printing technology with thermal material application and UV-curing of an acrylic photopolymer.

MCor Technologies was developed a 3D printer that combines an eco-friendly water-based adhesive with standard A4/letter paper to create wood-like three-dimensional models.

ProMetal [4] printers selectively dispense micro-droplets of specially-engineered binder into micron-thin layers of powder metal. In fact this manufacturing process is a combination of depositing binder onto metal powder followed by sintering and infiltration.

4. Z310 versus Objet 350

In this chapter it is presented a comparative study of 3D printers, Z 310 Plus versus Objet 350.

4.1. 3D Printing Using Z 310 Plus

ZCorp 3D printer (Figure 4) 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. The printing process consists in the following main steps:

- **Pre-processing**

- import the 3D file into the ZPrint software (STL, PLY or VRML data);
- scale and orientate the part;
- simulate the manufacturing process layer by layer;
- prepare the printer by spreading powder from the feed bed onto the build bed to create a smooth first layer.

- **Processing (3D printing process)**

- wait to warm at 38° the work environment;
- print the part, layer by layer from the bottom of the design to the top; the printer first spreads a layer of zp series powder in the same thickness as the cross section to be printed. The HP print head then 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 complete wait to consolidate of the part 1 hour. The models are porous at this stage.

- **Post-processing**

- remove the part from the powder bed;
- place the part in recycling station to remove any excess powder using compressed air;
- infiltrate the part to add strength, durability and to ensure vibrant colours.

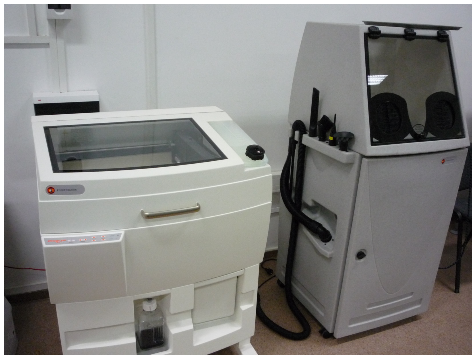


Fig. 4. *Z 310 Plus printer and its compressed air recycle station - Transilvania University of Braşov*

4.2. 3D Printing Using EDEN 350

EDEN 350 (Figure 5) is a 3D printer that works just like a desktop inkjet printer using polymer jetting technology.

Fig. 5. *EDEN 350 printer and its water jet recycle station - Transilvania University of Braşov*

The printing process consists in the following steps:

- **Pre-processing**
  - import the 3D file into the Objet Studio software (*.STL and *.SLC);
  - scale and orientate the part;
  - simulate the manufacturing process layer by layer.
- **Processing (3D printing process)**
  - the head printer moves back and forth along the X-axis, depositing super-thin layers of photopolymer onto the build tray. Immediately after building each layer, 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**
  - remove the part from the machine table;
  - place the part in recycling station to remove the support material using water jet.

5. Simulation and Optimisation of RP Process

Each RP/RM techniques need a software package to allow the linkage between computer and RP machine. Generally the RP software allows choosing of materials, offer tools for model orientation, tools for estimate the consumption material an building time and so on.

One of the most important factors that affect the cost, building time and quality of the part is building orientation. For prototypes with complex geometry finding the best orientation can be a complicated task. Hence, it will be highly important for the designer to know and analyse all these aspects.

General rules regarding optimising the building orientation of the part:

- positions the parts with the smallest dimension in the *z* (vertical) axis, called “minZ rule”;
- place the part in the left bottom position, called “LB rule”.

Is necessary for each RP techniques to investigate and find new rules. Starting with the same CAD part it will be investigated two RP techniques, inkjet (ZCorp) and polyjet (Objet). We intend to get the optimal part orientation on the RP platform when the criterion of minimum building time is met.

5.1. Case Study Using Z310 3D Printer

In this case study it was used Z310 Plus printer and the specific software ZPrint. ZPrint software is a powerful tool for preparing CAD files for optimal printing. In the Figure 6 it is presented the Z Print flowchart.

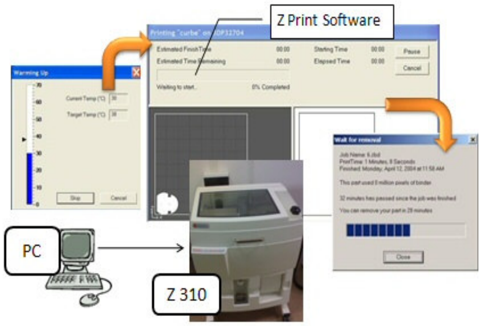


Fig. 6. *ZPrint flow chart*

The CAD model (Figure 7) that will be used in this case study was modelled in Solid Works software and save than as STL file.

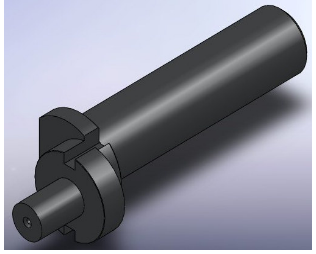
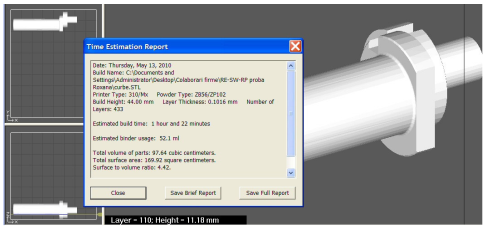


Fig. 7. *3D CAD model*

The STL file was imported in ZPrint software. In order to find a new rule regarding building orientation in XY plane it was chosen two cases 0° (Figure 8) and 90° (Figure 9) orientation of the part. In each case it was estimate the building time.



```
Time Estimation Report
Date: Thursday, May 13, 2010
Build Name: C:\Documents and
Settings\Administrator\Desktop\Colaborari firme\RE-SW-RP proba
Roxana\curbe.STL
Printer Type: 310/Mx     Powder Type: ZB56/ZP102
Build Height: 44.00 mm     Layer Thickness: 0.1016 mm     Number of
Layers: 433

Estimated build time:  1 hour and 22 minutes

Estimated binder usage:  52.1 ml

Total volume of parts: 97.64 cubic centimeters.
Total surface area: 169.92 square centimeters.
Surface to volume ratio: 4.42.
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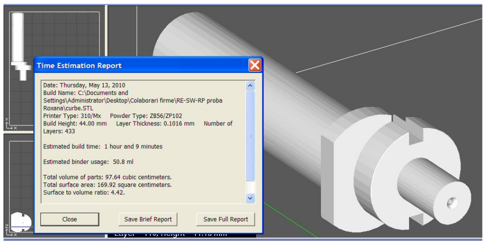
Fig. 8. *Position of the part on the ZPrint building platform: 0^o*



```
Time Estimation Report
Date: Thursday, May 13, 2010
Build Name: C:\Documents and
Settings\Administrator\Desktop\Colaborari firme\RE-SW-RP proba
Roxana\curbe.STL
Printer Type: 310/Mx     Powder Type: ZB56/ZP102
Build Height: 44.00 mm     Layer Thickness: 0.1016 mm     Number of
Layers: 433

Estimated build time:  1 hour and 9 minutes

Estimated binder usage:  50.8 ml

Total volume of parts: 97.64 cubic centimeters.
Total surface area: 169.92 square centimeters.
Surface to volume ratio: 4.42.
```

Fig. 9. *Position of the part on the ZPrint building platform: 90^o*

The minimum building time was resulting in the case of part orientation at 90°. The new rule regarding part orientation on the XY is called "XY-90° rule".

5.2. Case Study Using EDEN 350

Eden 350 3D printing system uses Objet Studio software to simulate manufacturing process. A server ("host"), typically next to the 3D printer, acts as a job manager that sends production jobs to the printer for production (Figure 10).

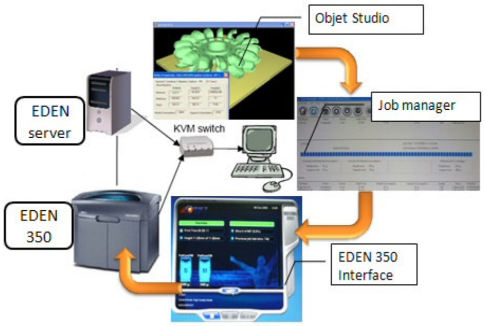
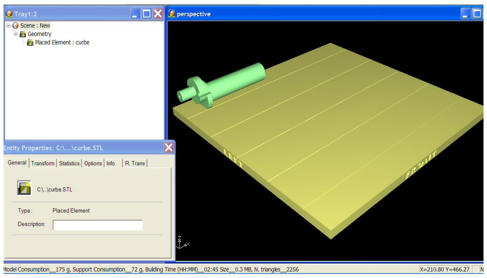


Fig. 10. *EDEN 350 flow chart*

Objet Studio software package allow preparing source files for production in Eden 3D printers. Objet Studio offers a wide variety of file preparation options, but always consists of the following basic procedure:

- inserting one or more objects on the build tray;
- positioning the object(s) on the tray;
- configuring object and tray parameters;
- saving the tray configuration and sending the tasks to the Eden 3D printer for production.

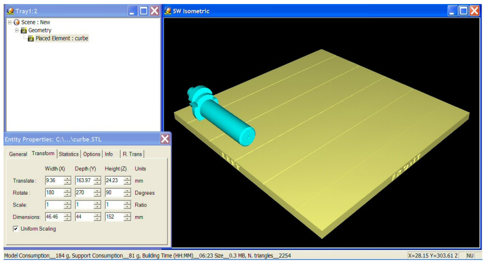


Type: Placed Element

Description:

```
Model Consumption__175 g, Support Consumption__72 g, Building Time (HH:MM)__02:45 Size__0.3 MB, N. triangles__2256     X=210.80 Y=466.27
```

Fig. 11. *Position of the part on the EDEN350 building platform: 0^o*



	Width (X)	Depth (Y)	Height (Z)	Units
Translate :	9.36	163.97	24.23	mm
Rotate :	180	270	90	Degrees
Scale:	1	1	1	Ratio
Dimensions:	46.46	44	152	mm

☑ Uniform Scaling

Model Consumption__184 g, Support Consumption__81 g, Building Time (HH:MM)__06:23 Size__0.3 MB, N. triangles__2254 X=28.15 Y=303.61 Z NU

Fig. 12. *Position of the part on the EDEN350 building platform: 90°*

The Job Manager installed on client computers displays the queue and status for jobs sent to the 3D printer server from that computer, and allows the user to edit only these jobs. The EDEN 350 interface enable to monitor the progress of printing jobs.

In this case study it was used the same 3D CAD part as in ZPrint case study and the same part orientations 0° (Figure 11) and 90° (Figure 12).

The minimum building time was resulting in the case of part orientation at 0°. The new rule regarding part orientation on the XY is called "XY-0° rule".

5.3. Results and Discussions

The results of the comparative study between Z310 and EDEN 350 additive manufacturing systems are presented in the Table 1.

Both of the RP systems analysed in this paper are 3D printers, but use different manufacturing process and different materials.

First of all it was made a comparative study regarding manufacturing process Z310 Plus and EDEN 350.

Regarding the optimisation of RP process based on the criterion of minimum building time, the focus was on to find optimal part orientation on the RP platform. Thus, there are general rules for all RP systems such as "minZ rule" and "Left-Bottom rule".

In order to find a new rule regarding building orientation in XY plane it was chosen two cases 0° and 90° orientation of the part. It was find different rules for different RP techniques: "XY-90° rule" for Z310 Plus and "XY-0° rule" for EDEN 350.

Z310 versus EDEN350 Table 1

RP machine type	**Z 310**		**EDEN 350**	
Materials	composite materials		photopolymers	
3D printing optimisation	Pos 0°	**Pos 90°**	**Pos 0°**	Pos 90°
Estimated build time [HH:MM]	1:22	**1:9**	**2:45**	6:23
Layer thickness [mm]	0.1016	**0.1016**	**0.016**	0.016
Best position of the part on the build platform (minimum building time and cost) - "XY rule"		**x**	**x**	
Conclusions				
Input files	STL, PLY, VRML, 3DS		STL, SLC	
Printing speed	faster		good	
Surface finish and accuracy	good / 0.2 mm		best / 0.1mm	
Need to build support structure?	No (only for delicate and big parts)		Yes	
Need post-processing	Yes (infiltration with resins)		No (only removing of the support)	

Some products produced at the Industrial Innovative Technologies laboratory within *Transilvania* University of Braşov, by RP/ RM technologies are illustrated in Figures 13 and 14.

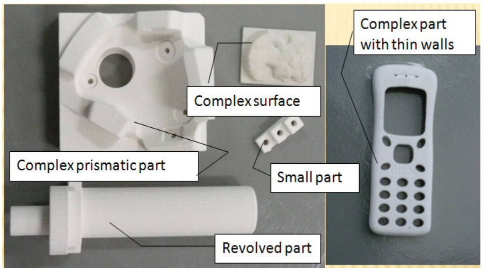


Fig. 13. *Products obtained by "Inkjet" printing* (*Z310 Plus*), *Transilvania University of Braşov*

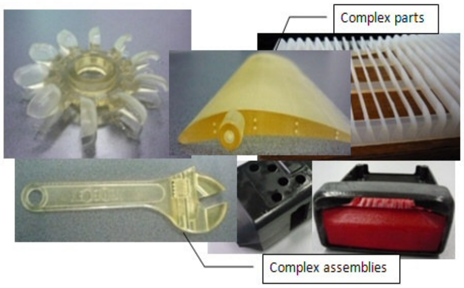


Fig. 14. *Products obtained by "polyjet" printing* (*EDEN 350*), *Transilvania University of Braşov*

6. Conclusions

PLADETINO platform was capable of allowing the development of new scientific research contracts with industrial companies. This paper presents industrial applications of the RP/RM techniques, developed at the Industrial Innovative Technologies Laboratory, *Transilvania* University of Braşov.

On the other hand it was presented a comparative study between two different RP technologies with the focus on the determination of optimal RP strategies. These affect the build time, surface quality and the cost of the physical prototype.

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