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# EVOLUTION AND APPLICATION OF RAPID PROTOTYPING TECHNOLOGIES

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## ABSTRACT

*Turbulent changes from environment, caused by rapid development of computer technologies and demands of market have led to rapid development of new technologies. Time and access of forming of new product has considerably been changed in relates to conventional manufacturing. Significant accomplishments in diverse spheres of computer and manufacturing technologies, have led to to changes in process of rapid development of products. Observing evolution stages of product development we can see that the changes in product design needed long time period. Evolution in any of branches high quality more. There are several rapid prototyping techniques available on market, such as: stereo lithography – SL, laminated object manufacturing – LOM, selective laser sintering – SLS, fused deposition modeling – FDM, solid ground curing – SGC, three dimensional printing – 3DP, etc. Purpose of this paper is to represent the rapid product technologies and separately 3D printers as one of the most recent techniques of rapid prototyping. Rapid prototyping technique using 3D printers is represented by high speed, creating multi color parts, various materials, and relatively good quality of finished part. Therefore this technique is used for rapid tooling and rapid manufacturing. The meaning of rapid prototyping is related to the significant time saving at the new product development. Basic advantages of rapid prototyping are regarded to visualization and possibility of further product testing.*
*Therefore, this paper presents of technologies evolution in rapid product development and application of rapid production technologies.*
***Keywords:*** *evolution, product development, rapid tooling, reverse engineering, rapid prototyping, rapid manufacturing*

## 1. INTRODUCTION

In the modern production, productivity and quality are achieved by product developing from concept to market on fast and cheap way. Oftenly, time and costs of product projecting are bigger than producing process. Ago 15 years that comes to occurrence and application of the new philosophy of rapid product developing which is called Rapid Prototyping (RP). The RP technology implementation of physical model possess to team for product developing when a work with 3D model is finished. The faster product developing and processing secure competition at the global market. Today the modern product developing cannot think without program equipment for 3D physical model producing that really and functionally takes part in new product occurrence [1-12]. The certainly relation between RP and conventional technologies in according to producing time and costs in the function of product complexity is presented by figure 1.

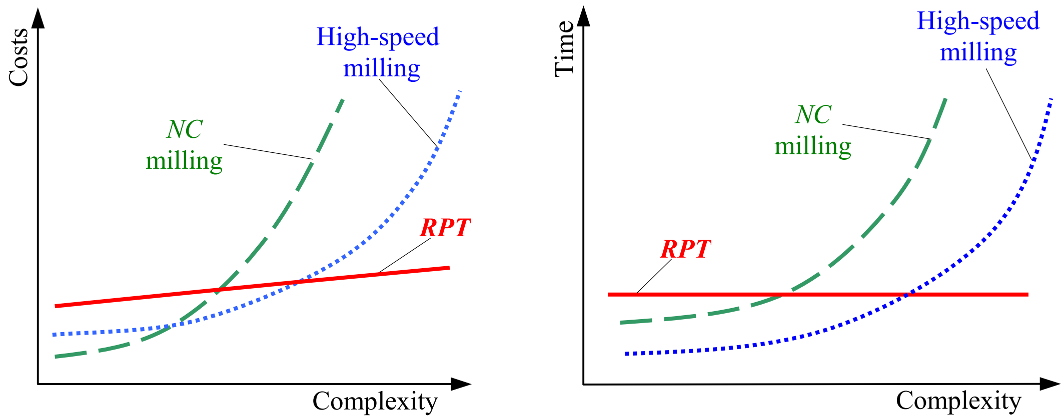



*Figure 1. Comparing of conventional and Rapid Prototyping technology*

In the run for the worlds market development of the new products is of the biggest importance. Before leading the product into the production it is necessary to justify investments. For several reasons, in this part of the production process main place is given to making the prototype or model of the new product:

- three-dimensional, physical model gives clearly picture than classical 2D drawings,
- it facilitates communication among departments and associates,
- it is possible to carry-out tests on the model in the field of design and ergonomics, and product exploitation performances as well.

Rapid prototyping concept includes group of the technologies that are able to automatically make physical model of the future product based on the CAD data. These techniques are based on the material addition, in contrast to the classical techniques that where based on the material removal. Several different techniques of the rapid prototyping are attainable on the market [13]: stereo-lithography, laminating, selective laser sintering, fused deposition modeling, solid surface vulcanization, 3D printing, who function on the same principle.
Firstly 3D model of the object that is going to be produced is made using one of the CAD software packages. During this it is better to use programs for the solid modeling (such as Pro/ENGINEER), which attain better results than "wire frame models" (such as AutoCAD). User can use existing CAD file or create new one especially for the purpose of the prototyping. In the second step software package converts CAD file into STL file format, which is being divided into number of the thin layers (~0,1mm). On the rapid prototyping machines paper, plastic or wax layers are being formed each on top of another, based on this file. Rapid prototyping, by combining these layers, makes possible to create objects with complex internal surfaces that can not be made in any other way. Except for the prototypes, techniques of the rapid prototyping can be used for the rapid tooling as well as for the rapid manufacturing. The word "rapid" in this case is relative. Depending of the technique, size and the complexity of the object, production of one

product lasts between 3 and 72 hours. Beside this, volume of specific parts is limited depending on the used machine (~*0,125m*$^3$). Generally it can be said that for the production of small production series and complicated objects rapid prototyping is better process, while for the metal parts, big production series or simple shapes conventional production techniques are more economic. No matter what eventual limitations are, techniques of the rapid prototyping represent innovation, by whose introduction greater time savings are achieved. In the finish for the producer this means faster and cheaper introduction of the new products to the market.

## 2. TECHNOLOGY EVOLUTION OF RAPID DEVELOPING AND PRODUCT PROCESSING

Along ground values that a product posses and that are functionality and quality, the market sets a requirement for time limit of product occurrence. The continuous changes in the product functionality occurred by application of the new and innovating technologies influence on product market value. The process of the new technologies of rapid developing is also occurred therefore market requirements of the new product forming that will be fill of customer wishes.

### 2.1. Process phases of product developing

The ground changes in the product design process occur in projecting, rapid processing of the parts, rapid tool processing and final product prototype processing. The evolution of product development are presented [8,9] by figure 2.

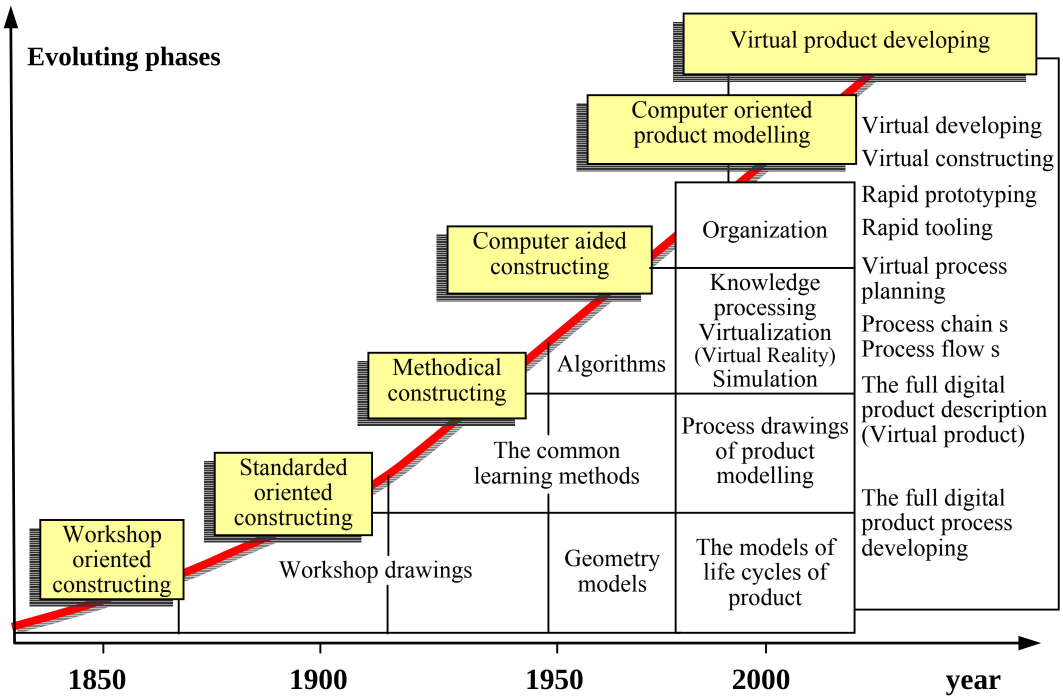



*Figure 2. Evolution phases of product process developing*

Looking at the evolution phases of product occurrence, can be taken a look into changes of product design that require a longer time period beginning from workshop constructing, standard involving and application, computer aided constructing and geometry models and after that rapid developing of computer oriented product (modelling and simulation) and virtual product developing, rapid prototype, rapid tooling, digitalizing process of product development.

### 2.2. Rapid prototyping technologies

The importance achievements in the different areas of information and producing technologies come to changes in the process of rapid product developing:
- Computer Integrated Manufacturing (CIM),
- Hardware interface between man and computer,
- Different software packages,
- Scanning technology (laser scanning),
- Computer tomography (CT),
- Magnet resonance (MR),
- Virtual reality technique,
- Layered technology for tools and product production.

These changes come to development of the new technologies of product shaping methods as:
- Stereolithography Apparatus – SLA,
- Selective Laser Sintering – SLS,
- Laminated Object Manufacturing – LOM,
- Fused Deposition Modeling – FDM,
- Solid Ground Curing – SGC,
- Shape Deposition Manufacturing – SDM,
- Three – Dimensional Printing – 3DP,
- Rapid Freeze Prototyping – RFP,
- Direct Photo Shaping – DPS,
- Direct Metal Laser Sintering – DMLS.

### 2.3. The rapid product developing and reverse engineering process

Competition along the product value and reliability in most of size depends on capability of changing of the new tools and technique for rapid product development. Under rapid product developing is understand four ground requirement synchronization: product price, developing speed, product performances and costs of developing program.

In the process of rapid product developing, the principles of reverse engineering scopes the important method and technique groups. The reverse engineering presents a process that scopes all engineering activities from physical model scanning of product, making of new internal computing model to projecting of technology processing. The reverse engineering is grounded on process that enables converting of real model into digital form to aim further using. The reverse engineering presents a reversible approach to product producing that requires the good knowing of technological producing.

The requirements for rapid product developing come to developing of the reverse engineering that has three ground phases: scanning technology, reconstruction and layered producing technology.

The internal presentation of geometries of workpiece has the main role in the reverse engineering and layered producing technology. The concept of computer model processing of product on the ground of voxels has key solution for problem orders that stay in the system of rapid product developing [2,3,4,5]. At the figure 3 is presented a realization of the reverse engineering.

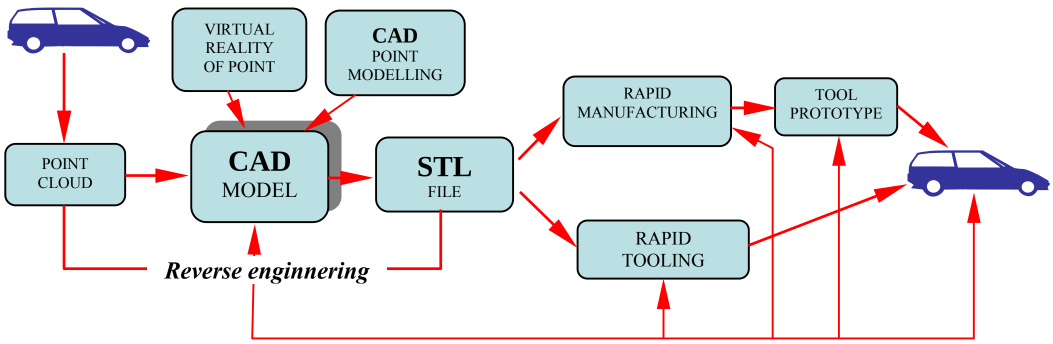



*Figure 3. Example of product developing process and reverse engineering*

## 3. THE RAPID PRODUCTION TECHNOLOGIES

The technologies for rapid processing supporting of the new products are grounded on the knowledge base of today's theoretical and experimental researches at the area of technological processes [1,2,4].

### 3.1. Stereolitography Apparatus-SLA

Stereolitography is producing grounded on photo polymerization where a product is occurred layer by layer. Acting of lighting on the upper surface of fluid is made a layer hardening, moving down the platform, hardening of the new part.

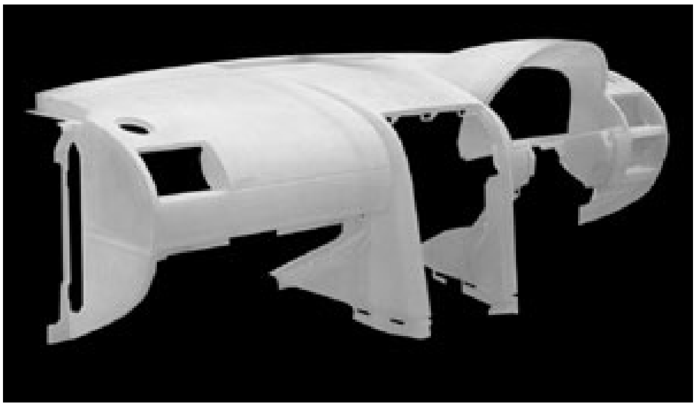


*Figure 4. Cockpit, Ford Mondeo [11]*

### 3.2. Selective Laser Sintering-SLS

The selective laser sintering is made by laser ray that acts on material particules by thermal energy and hardens product layer.

*Figure 5. The tool gotten by SLS process [18]*

### 3.3. Laminated Object Manufacturing-LOM

LOM process uses $CO_2$ laser for making of cross sectional areas from paper layers, sheet of metal lines and so on.

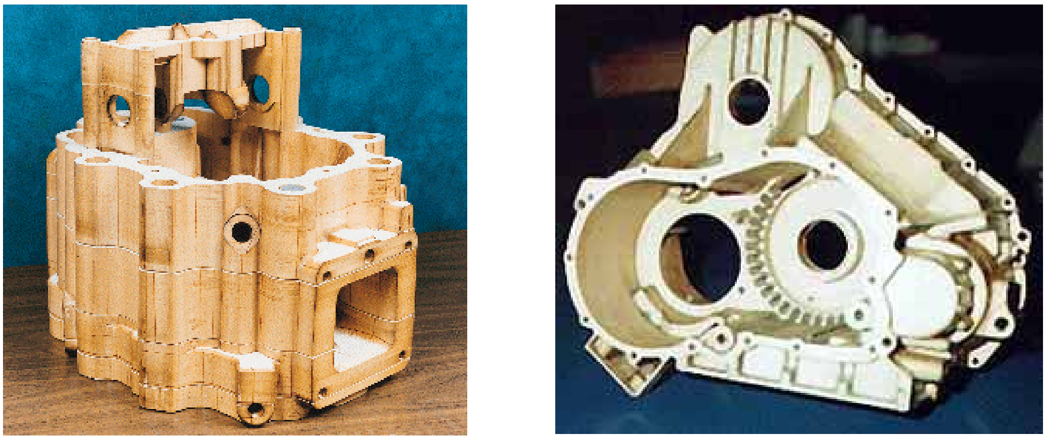


*Figure 6. Workpieces gotten by LOM processing [10]*

By this process can be gotten products of very complex geometry forms of different dimensions.

### 3.4. Fused Deposition Modelling-FDM

FDM is the second in order presented in use of RP technologies after SLA. The plastic material is rolled out with coils and supplies syringe with material.

The syringe becomes warm, melt the plastic and it has mechanism that enables that the jet for plastic melting can be on and off. The syringe is mounted on mechanical mount that can be moved into vertical and horizontal direction. As the syringe moves over the table according to defined geometry it take of a thin covering of plastic that forms each layer. The plastic hardens just after pushing out fro syringe and coming in on the previously layer. The whole system is equipped with chamber that is at the temperature a little over plastic melting point. The used materials are ABS and wax for casting. The carrying structure is made for hanging geometry and it is taken off through breaking of object rest. This method requires small working room and doesn't make a noise. The workpieces gotten by this method has weaker surface quality than SLA.

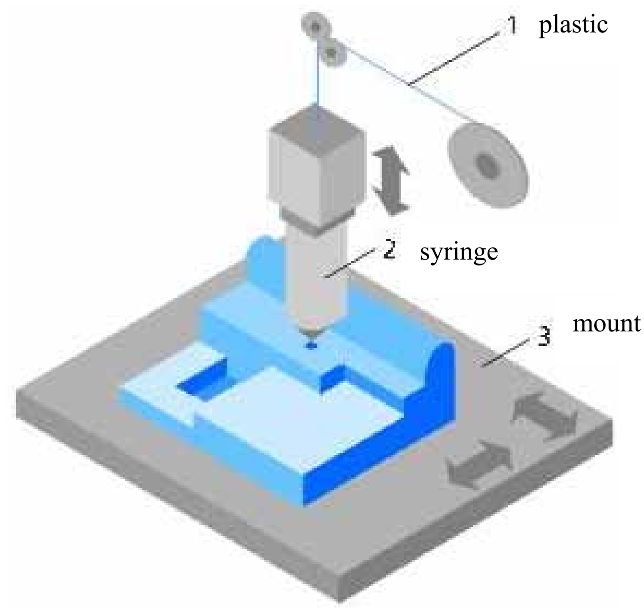



*Figure 7. The ground parts and work principle of machine for Fused Deposition Modeling FDM [10]*

**3.5 Three-dimensional printers- 3DP**

One of the most modern techniques of the rapid prototyping is 3D printing, which has number of advantages over other techniques: huge production speed, good software support, possibility for multi-color work, usage of the variety of materials, simple handling and accessible price.

**3.5.1. Construction and work principle of the 3D printers**

In the production of these machines multi jet systems for binder distribution are mainly used, by which solidification of the powder material is being done. Solidification can be done in the room temperature or under the influence of the UV rays. On the Figure 8. [12,14,15] mechanism for the deposition of powder and binding fluid in 3D printers is shown.
Construction is based on two pistons:

1. feed piston, which in every other step is being moved up,
2. build piston, which is being moved incrementally down.

Roller is equally spreading polymer powder and levels the work surface, while by special system binder is brought from the reservoir to the print head. Computer guided print head spreads binder on designated parts of the surface, according to the appropriate layer given in the *.stl* file.

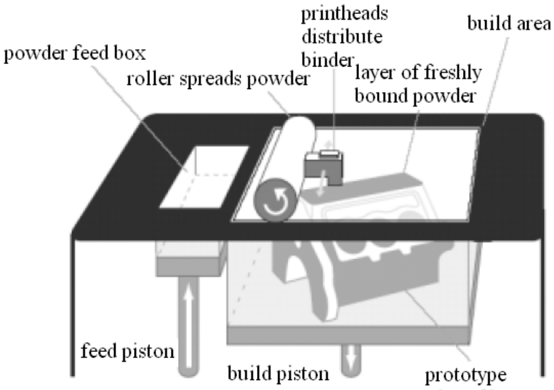



*Figure 8. Construction of the 3D printers*

This way solidification of the surface in the dedicated areas is carried out, and this procedure is repeated until prototype is finished. Eventual cavities inside the prototype remains filled with the powder that is later being removed by vacuuming and is carried back to the reservoir for reuse. Final product is removed from the printer together with the support palette and if needed is carried to the additional treatment includes cleaning, repairing, waxing etc.

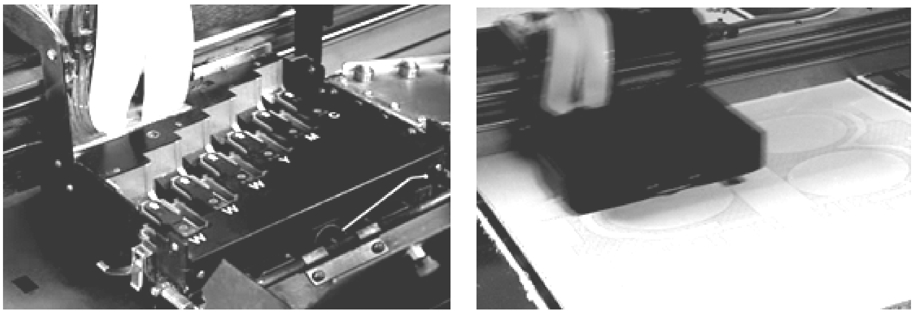


*Figure 9. Housing with 6 print heads, open on the left, in the printing process on the right [14]*

Modern 3D printers use several heads for binder distribution, which are placed in the same housing, each consisting of few hundreds jets. Liquids of various color and/or composition are brought through these jets, whose mixing results in appropriate binder. Head is moving in the direction of the *x* and *y* axis, where control signals are received from the computer, similar to the 2D printers. Figure 10. shows system composed of six print heads each consisting of 300 jets, that are part of the Z Corp *Z810* 3D printer. Production speed and the production quality are directly connected to the layer thickness. User can, according to its priorities, determine layer thickness in range of *0,076 -0,254* mm [14]. Working area size, in regard to the maximal product size varies at different producers, as follows[14,16]:

- for printer *Z406*, of *Z Corp corporation* : *203 x 254 x 203 mm*,
- for printer *Z810*, of *Z Corp corporation*: *600 x 500 x 400 mm*,
- for *MJM* printer type *In Vision*, of *3DSystem corporation* : *298 x 185 x 203 mm*,

- for *MJM* printer type *Thermo Jet*, of *3DSystems corporation*: *250 x 190 x 200 mm*.

### 3.5.2. 3D printer software support

Each 3D printer producer supplies together with the machine appropriate software, that accepts solid models in one of the CAD formats such as *.dwg*, *.prt*, *.step*, *.iges*, *.ipt* and converts them to format suitable for machine control. Here we usually talk about already mentioned *.stl* format that is recognized by the majority rapid prototyping machines, although some 3D printers use other file formats such as *.vrml*, *.ply*, *.sfx*, *.zcp* formats, that support wider color spectra.

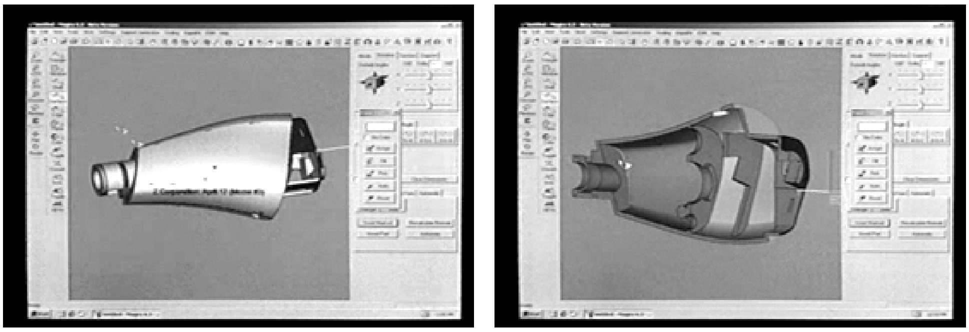


*Figure 10. Three-dimensional view, rotation and cross-section operation in the 3D printer's software[14]*

These program packages can work in the *Windows* surrounding, in other words are supported by the following systems: *Microsoft Windows NT*, *Windows 2000 Professional* and/or *Windows XP Professional* what enables data exchange over the internet and intranet [14,16]. Due to the interactive interface use of the software is very simple and easy to learn. This software has possibility of zooming and spinning of the solid model, its proportional scaling, make of the specific cross-sections, and entering the text into a model. Coping makes possible production of the several models at once, depending on the available work area.
Beside production of the *.stl* or some other appropriate file format, software plays monitoring role too in other words it monitors system condition. Sensor system sends data on the position of the print head, powder and liquid binder quantity, where in case of disturbance control software automatically stops printing. Software remembers last condition and is able to continue printing process without difficulties after disturbances that caused system to stop are removed.

### 3.5.3. Characteristics of the objects made by 3D printing

When making objects on 3D printers it is possible to, depending on the machine, get different products by shape and size, as well as by color and mechanical characteristics. Simple monochromatic printers do not have possibility to regulate color, but they produce products models in one of the basic colors – white or grey. Sophisticated printers can achieve palette of five different colors by mixing different liquids (black, white, grey, blue, red) or full spectra, depending on the software and machine complexity.
Talking about shape complexity there is almost no shape that can not be made on 3D printers. Limiting factor can be size of the work area and software support, but comparing to other methods of the rapid prototyping possibility of 3D printers application is very wide. Therefore they are justified in the production industry and in other areas such as medicine and architecture.

Mechanical characteristics may also vary by use of the different materials for the prototype production. It is to be expected that with application of this technique we get elements of sudden hardness and stiffness, but it is also possible to achieve their elasticity, what is shown on Fig, 11.

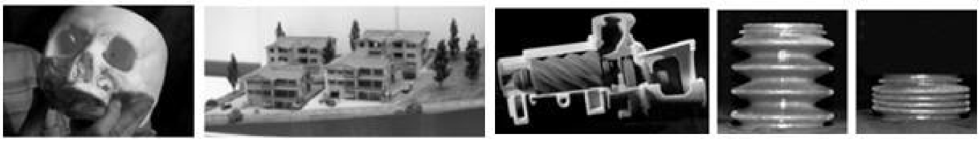


*Figure 11. Prototypes made by 3D printing [14]*

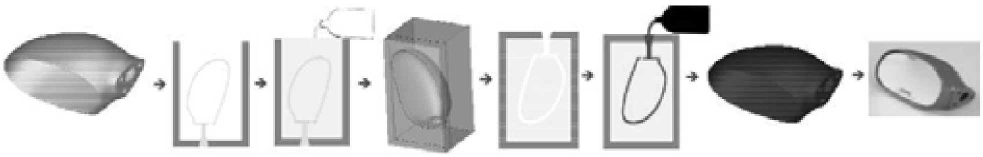
### 3.5.4. Application of 3D printers for production of casting moulds

There are two ways of application of prototypes made on 3D printers for production of casting moulds:

1. use of prototypes for production of silicone moulds for polyurethane pouring and
2. direct use of the prototypes as moulds for metal casting.

#### 3.5.4.1. Production of silicone moulds

Production process of silicone moulds for polyurethane pouring is shown on Fig. 12. Part obtained from 3D printer is placed in appropriate box which is than filled with the silicone. Silicone hardening is done relatively fast on the room temperature, 2 – 48 hours depending on the silicone type [17]. After silicone hardens box is removed, mould is cut into two parts and printed part is removed. When parting the mould it is necessary to choose appropriate parting line to achieve better mould fill. Parting needs to be carried out carefully to avoid eventual marking of the parting line on the cast.



a) b) c) d) e) f) g) h)

*Figure 12. Silicone mould production process[5]: a)printed model, b) placing model into box, c) filling with silicone, d)mould parting and model removing, e) assembling mould parts, f) polyurethane pouring, g) cast, h) final product*

Mould combining is done using adhesive or elastic tape or by simple clamping devices. Here it is necessary to take care that connection is firm enough so that leaking doesn't occur, but not too firm to avoid mould deformations. Using 3D printers for production of the basic pattern mould making time is greatly reduced in contrast to other existing methods. Mould produced in this way can be used several times for pouring thermoplastic materials like polyurethanes, various colors.

#### 3.5.4.2. Production of metal casting moulds

No matter to other advantages of printed models in the production, it is often necessary to produce metal prototypes. To produce this prototype by casting takes lot of time for making sand moulds and cores. This especially applies to the casts and moulds with the complex shape that is sometimes impossible to make of sand.

Big advantage of using 3D printers can be shown here as well, where they are being used for production of one-time moulds, that by its rigidity and high temperature resistance are good strike back at sand moulds, and at the same time they offer better preciseness. Beside this, significant time savings in mould making are achieved and costs are reduced. Moulds and cores are produced directly on the 3D printer using special ceramic powder that can stand temperatures up to 1200°C [15]. Casting is carried out through the following phases:

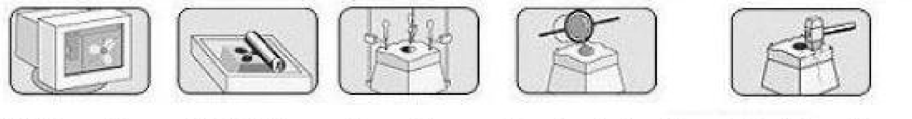



*Figure 13. Process of metal casting in the printed mould. [15]*

## 4. THE GROUND FACTORS FOR RP-TECHNOLOGY CHOICE

The ground failure is the in processes aren't used the correct engineering materials so that the produced parts haven't the same functionalities as the parts made by conventional technology application. The ground factors of RP technology choice are: dimension correctness, mechanical properties, surface quality and price.

*Table 1. Choice Rapid Prototyping technologies*

| **Process** | ***SLA*** | ***SLS*** | ***LOM*** | ***FDM*** | ***3D Printing*** |
|---|---|---|---|---|---|
| **Model** | *SLA-250* | *Sinterstation 2000* | *LOM 1015* | *FDM 1650* | *Model Maker MM – II* |
| **Producer** | *3D Systems Inc* | *DTM Corp.* | *Helisys* | *Stratasys* | *Solidscape Inc.* |
| **Maximum part size (cm)** | 25×25×25 | 30×38 (d×h) | 38×25×36 | 25×25×25 | 30×15×23 |
| **Layer thicknes (mm)** | 0,15 | 0,0762 - 0,508 | 0,05 - 0,38 | 0,05 - 0,762 | 0,013 - 0,076 |
| **Accuarcy (mm)** | 0,20 | 0,1 - 0,5 | 0,254 | 0,127 | 0,025 |
| **Processing speed** | 30 in/sec scan 0,75 - 4 $in^3$/h | 0,75 $in^3$/h | 15 in/s scan | | |
| **Material** | Photo-sensitive epoxy resin | Nylons, powdered steel, sand, polycarbonate | Adhesive coated paper, nylon | ABS, casting wax, elastomers, medical ABS | Termoplastic, polyester |
| **Machine price** | ~100.000$ | ~300.000$ | ~120.000$ | ~100.000$ | ~65.000$ |
| **Necessary postprocessing** | Remove supports, cure in UV oven | Sanding, polishing | Pick out excess material, seal & finish | Break off suports | Remove wax |

| Machine size (m) | 1,64×1,24×0,69 | 1,93×3,03×1,52 | 1,27×1,22×0,99 | 1,07×0,66×0,9 | 0,689×0,38×0,69 |
|---|---|---|---|---|---|
| **Advantages** | Large products, accuarcy, ... | Accuracy, great choice of materials, ... | Large products, appropriateness for large foundry models, cost of material | Office use, price of material, ... | Non-toxic material, fast removing support, good quality surface, ... |
| **Disadvantages** | Beginning expensive and maintance costs, expensive great part processing, refusing fluids | Expensive process, bad surface quality, small size and part weight | Relative bad surface, lost of fine details, | Unability of fine details, problem is in thin and thick walls | It can be processed only small parts, limited material choice |

At the tool producing is important correctness and preciseness also at the industrial design the quality of made surfaces. At the productions at the layers come to leveled effect. The influence of this effect can be decreased by choice of defined direction of model hardening but this increases time and costs. Usually there are applied some processes of compensated processing as polishing. It has today technologies at which the layer thickness is so small because this effect is full neglected.
At the Daimler-Benz is made so that correctness is 100 microns in the x and y direction and 250 microns in the z direction. Its aim is correctness of 70 microns in all three directions (that is made in the USA). Generally, stereolitography enables making of more correct parts.

## 5. CONCLUSIONS

The new technologies are grounded on market requirements where it has continuous neediness for product changing and also tools. Their implementation is condionited by rapid information technology development that results time shortening in the product producing.
The technology of rapid part producing and tools are of great importance in the development of industrial producing and it presents an area of permanent innovating and examine and therefore in this paper are given views to actions and methods.
Rapid prototyping procedures are very much involved in the designing process, new product development process and product testing. Which method will be chosen will depend on shape, product kind and available finances. Beside described advantages several shortages of rapid prototyping process are: huge investment expenses, still long production process and limited work area size. According to this, future development of these systems should go in the following directions:

1. Using faster computers, improved control systems and various materials production speed will be greatly increased. This will increase productivity, so production in these machines will become more economic,
2. Introducing other materials, and especially metals, prototype role in mechanical features testing will be increased,

3. Development of new technologies and improvement of the existing ones will lead to the enlargement of the work area according to the market requests.

In this paper 3D printers are introduced as one of the modern methods for rapid prototyping. Advantages of this technique toward others are represented by: production speed, wide production palette, wide application possibilities, and relatively easy handling.

Particular advantage of these machines is possibility to work under WINDOWS interface what enables data exchange over the internet and intranet. This again enables engagement of the designers that are not necessary located at the production place, in other words it simplifies communication among different interest sides. Every improvement related to the new technologies at the end leads to the incensement of the preciseness and generally product quality.

Therefore, incensement of new technologies participation in rapid tooling and rapid production is expected. Anyway it is necessary to emphasize that these methods will never fully replace classical methods, such as cutting production. However, progress of the computer technique, numerical control and dynamics of these machines will induce development of the traditional methods too.

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# EVOLUCIJA I PRIMJENA TEHNOLOGIJA BRZE IZRADE PROIZVODA

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## REZIME

*Turbulentne promjene iz okruženja, uzrokovane brzim razvojem informatičkih tehnologija i zahtjeva tržišta dovele su do brzog razvoja novih tehnologija. Vrijeme i pristup oblikovanju novog proizvoda uveliko se promijenilo u odnosu na dosadašnju klasičnu proizvodnju. Značajna dostignuća u različitim područjima informacionih i proizvodnih tehnologija dovela su do promjena u procesu brzog razvoja proizvoda. Promatrajući evolucijske faze nastanka proizvoda može se uočiti da su promjene u oblikovanju proizvoda zahtijevale duži vremenski period. Evolucija u bilo kome od područja značajnih za razvoj proizvoda doprinosi da sistem postaje efikasniji i kvalitetniji. Na tržištu je dostupno više tehnika brze izrade prototipa kao što su: stereolitografija, laminiranje, selektivno lasersko sinterovanje, FDM ekstrudiranje, vulkanizacija površina solida, 3D printanje itd.*

*Cilj ovog rada je da predstavi tehnologije brze izrade proizvoda i posebno 3D printere, kao jednu od najmodernijih tehnika brze izrade prototipa. Tehnika izrade prototipa pomoću 3D printera se odlikuje velikom brzinom, mogućnosti rada u više boja, s različitim materijalima, te relativno dobrim kvalitetom gotovog objekta. Zbog toga se ova tehnika koristi i za brzu izradu alata, te brzu proizvodnju. Pojam brze izrade prototipa povezan je s značajnom uštedom u vremenu pri razvoju novih proizvoda. Osnovne prednosti brze izrade prototipa su u pogledu vizualizacije i mogućnosti ispitivanja budućeg proizvoda.*

*Zbog toga, rad prikazuje evoluciju tehnologija za brzi razvoj proizvoda i primjenu tehnologija brze izrade proizvoda.*

***Ključne riječi:*** *evolucija, razvoj proizvoda, brza izrada alata, povratno inženjerstvo, brza izrada prototipa, brza proizvodnja*