Proceedings of the 17th International Conference on Manufacturing Systems – ICMaS
ISSN 1842-3183
University POLITEHNICA of Bucharest, Machine and Manufacturing Systems Department
Bucharest, Romania

ON THE EVOLUTION OF RAPID PROTOTYPING TECHNOLOGIES

Zoltan-Gabor BAKI-HARI, Carmen Gabriela BĂCILĂ

Abstract: *Two decades ago, once with the appearance of* ***R****apid* ***P****rototyping* ***T****echnologies (RPT), the design activity was radically changed, as well as the products developing of the products. Thus became true the great dream of the designers to see their activity materialized as soon as possible. But they went on dreaming about more rapid, precise and cheap methods. Nowadays these dreams come true, as newer and newer RP methods appear, with superior performances. This is the result of the research and development activities made in all the corners of the world. Thus different methods were combined; new materials were adapted, till the applicability of these technologies was extended almost to infinite, from the different branches of mechanical engineering to medicine.*

Key words: *rapid prototyping, rapid manufacturing, rapid tooling, product development, CAD/CAM/CAE, STL.*

1. INTRODUCTION

Lately, when human needs have also changed radically, we witness a very intensive development of science and technology. Due to this development, there appear new principles, methods, making goods technologies and new materials compatible with the new technologies.

Thus we can speak about the radical change regarding the products development, caused by the achievement of the designers' great dream to see the outcome of their activity materialized as soon as possible. This was actually the appearance of Rapid Prototyping (RP) technologies, which in time had a great development. This happened because the designers continued to dream about methods that could offer them models with very good properties.

Thus, in time, different new methods of product development appeared, satisfying more and more the requests of the market.

From the category of these methods are, for example, those based on the so called *Rapid X* procedures, such as the **R**apid **P**rototyping (RP), the **R**apid **T**ooling (RT), and the **R**apid **M**anufacturing (RM). This happens due to the fact that they provide a high CAD/CAM/CAE integration, schematically presented in Fig. 1., and by this providing an overlapping between the finishing of the product, as well as the study and making of the necessary tools, thus reducing considerably the time of manufacturing preparation, which makes possible the early appearance on the market with the new product.

This is nothing else than Concurrent Engineering [7].

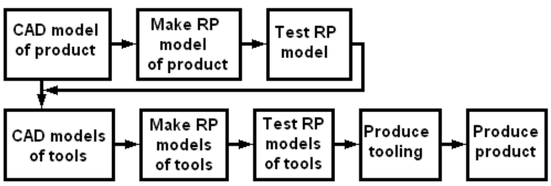


Fig. 1. The CAD/CAM/CAE integration with the Concurrent Engineering.

2. RAPID PROTOTYPING TECHNOLOGIES

2.1. Generalities

The RP technologies are a new category of technologies, with a revolutionary way of making the pieces, which in fact are the RP models, through depositing the material in the right place in the necessary quantity, without using any tool, at least in the classic

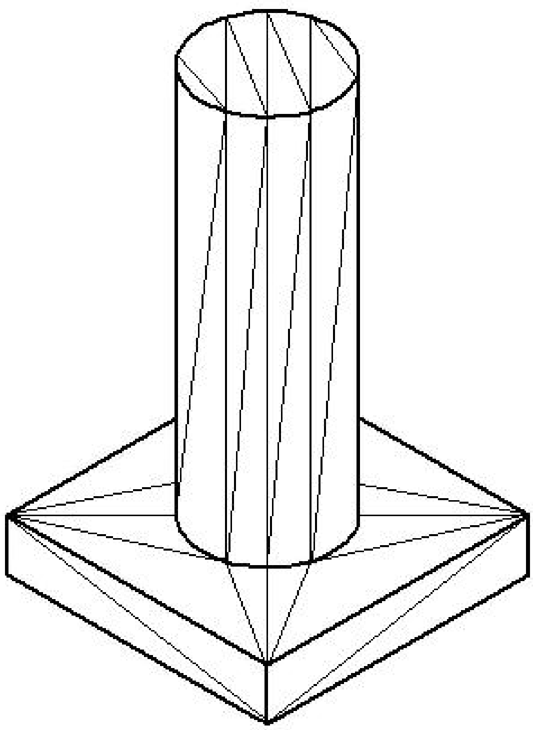


Fig. 2. The STL representation of a CAD model.

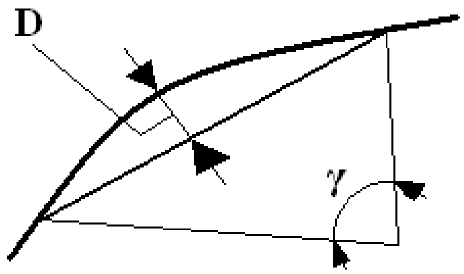


Fig. 3. The definition of **.stl* file.

meaning of the word. The making of the model is done layer by layer. Recently however a few methods have appeared that use the removal of the material, due to the appearance and development of High Speed Cutting (HSC).

The RP technologies make the pieces directly, on special machines from their 3D virtual models made with a 3D projecting program, such as AutoCAD, Inventor, CATIA, SolidWorks, SolidEdge, UG-NX, Pro/Engineer, RHINO, I-DEAS, etc. The connection between the computer and the RP machine is the **.stl* file, which is a presentation of the body through triangular facets. This thing leads to an error regarding the presentation of the body. This can be controlled with two parameters, which are actually also used in generating the triangular facets by the CAD programs, meaning the maximum distance *D* (see Fig. 3.) between the cord, materialized by the facet and the real surface and the other one is the center angle *γ* (see Fig. 3.) corresponding to the cord.

These errors decrease once with the increase of the facets number, but there is an economical limit regarding this number, given by the resources of the informatics system that is used, respectively the processing period. To exemplify this, in Table 1 is given data of the errors variations according to the number of the facets for the cylinder, and in Table 2 for the sphere. The grey fields represent an optimum.

Table 1

Designing data referring to the cylinder [13]

The number of triangular facets	The cord error	The surface error	The volume error
10	19.10%	6.45%	24.32%
20	4.89%	1.64%	6.45%
30	2.19%	0.73%	2.90%
40	1.23%	0.41%	1.64%
100	0.20%	0.07%	0.26%

Table 2

Designing data referring to the sphere [13]

The number of triangular facets	The cord error	The surface error	The volume error
20	83.49%	29.80%	88.41%
30	58.89%	20.53%	67.33%
40	45.42%	15.66%	53.97%
100	19.10%	6.45%	24.32%
500	3.92%	1.31%	5.18%
1000	1.97%	0.66%	2.61%
5000	0.39	0.13%	0.53%

2.2. The classification of Rapid Prototyping technologies

The RP technologies can be classified according to two criteria. The first is the state of the used material, meaning liquid or solid. The latter can be divided into materials such as particles, films, and respectively massive blocks – for HSC. The second one is the way of making, in 2D or directly in 3D. The 2D method can be through dots – discrete or continuous, respectively through layers and the 3D method through dots – discrete or continuous, respectively through surfaces.

2.3. The appearance of Rapid Prototyping technologies

The RP technologies appeared as a necessity at the end of the 80's in the twentieth century. Once with their appearance, the possibility of the early and extremely tangible visualization was created. But at that time these technologies made models that were exclusively for visualization, because the quality of the models obtained at that time was low, regarding the dimensional precision, respectively the roughness, as well as the used materials, such as their properties and the stability in time.

But at that moment, when the CAD programs were less developed, a tangible model that could be examined even in its own work environment was extremely important from the point of view of the different verifications (for example an ordinary handle or a remote control).

2.4. The evolution and the development of the Rapid Prototyping technologies

Due to the human characteristic of improving, the RP technologies had a spectacular evolution in time. Newer and newer methods with superior achievements were developed. This was achieved by adopting new materials and methods, respectively their combination. Thus the main material started to be put at once, from the same working head with the supports material that is water soluble, in order to ease the removal of the supports, respectively the maintaining of the model quality.

In the case of *Objet PolyJet* method, developed by the high-tech company Objet Geometries Ltd. from Israel, there can be used more types of material for the making of the model, which can be also combined in the printing head, thus being made a blade of "digital" material. This is a revolutionary aspect of the method, which facilitates

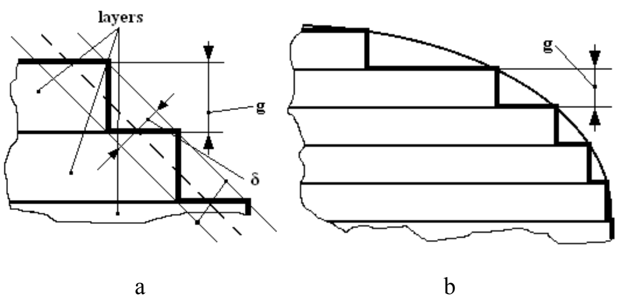


Fig. 4. The ladder effect in RP models a) with inclined surfaces; b) with curved surfaces.

Table 3

Comparison between the precision of the Rapid Prototyping technologies and other classical technologies [1, 2, 3, 13]

Technology		IT classes										
		6	7	8	9	10	11	12	13	14	15	16
Sand casting												
Die casting												
Forging												
Cutting												
RP	At the beginning											
	Today											

the making of multi-material models. This way we remove the necessity for the parts which must be made from different materials to be made separately, perhaps through different methods, and finally be assembled. Besides the productivity, this method also provides a higher precision.

2.5. Used materials

In comparison with the beginning time, when only a few materials were available, nowadays we have a very large blade of materials which is used in the RP technologies. These materials can be metallic or non-metallic. The metallic ones can be ferrous or non-ferrous alloys. The blade of non-metallic materials is very large, starting with the paper up to the plastics (different resins, polymers, etc.) through ceramic materials. Their combined use is very largely spread lately, meaning the powder metallic and ceramic materials, which form the base matrix, the binder being a polymeric material.

In RP technologies usually two types of materials are used, a main one for the making of the model itself and another one for making the supports, necessary for pieces with undercuts. The generating of the supports is done automatically by the ordering soft of the RP machine.

This manner of building on supports is the great disadvantage of these technologies, because their removal is very hard, endangering the quality of the model and increasing the making time. Nowadays there are methods that don't need supports, and others that make water soluble supports, a fact that eliminates the necessity of mechanical removal.

2.6. Performances

The performances of the RP technologies became better and better in time. Nowadays these technologies can have applications in different fields, applications that can seem strange in certain moments.

We have to mention that the used materials have improved very much, till functional models could be made. But for this was necessary the improvement of the precision offered by the RP machines.

In these conditions, the medium precision of the RP models is around ±0.075 mm. Once with the diminishing of the thickness g of the layers (see Fig. 4.), the ladder effect (which appear at inclined and curved surfaces and it is variable) was reduced. Thus the quality of the surface improved considerably.

In order to exemplify these achievements, the IT precision is presented in Table 3, and the general roughness obtained through RP technologies in comparison with other classical technologies is presented in Table 4.

2.7. Applications

If at the beginning the only main application of the RP models was the materialization for tangible visualization, nowadays the applications area has extended enormously. Thus we meet applications in the mechanic engineering, medicine etc. [4, 5, 6, 8, 9].

All these applications are actually part of the *Rapid **X*** concept. Thus, beside the classical RP we also meet **R**apid **T**ooling (RT) and **R**apid **M**anufacturing (RM). So we can state that the RP, through its different developments got to mean new technologies.

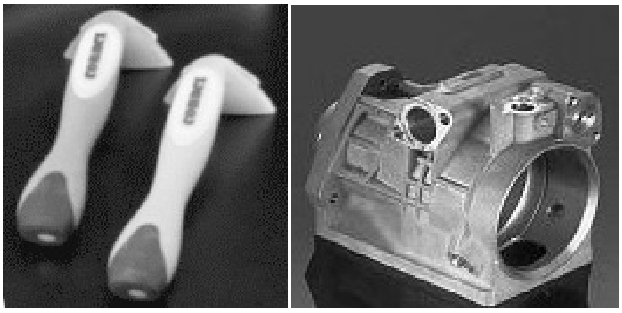
But the most important applications are those from the field of mechanic engineering, as the most developments took place in this category, such as RT and RM. Thus we can meet among these applications the making of models for visualization and the performing of different tests, respectively as functional pieces. It is made in a various series and different pieces, especially for the making of pieces from plastics. These moulds can be either made of metallic materials – hard or light alloys – or ceramic, but also from different resins.

The medical applications are also spectacular, regarding both the making of medical implants from biocompatible materials or of the models of the affected areas destined for their study and/or the making of the necessary implants.

Table 4

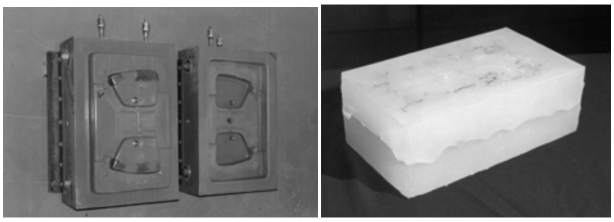
Comparison between the general roughness obtained in the case of Rapid Prototyping technologies and other classical technologies [1, 2, 3, 13]

Technology		Roughness Ra (μm)										
		0.2	0.4	0.8	1.6	3.2	6.3	12.5	25	50	100	200
Sand casting												
Die casting												
Forging												
Cutting												
RP	At the beginning											
	Today											



a b

Fig. 5. RP models a) for visualization; b) as functional pieces [10, 11].



a b

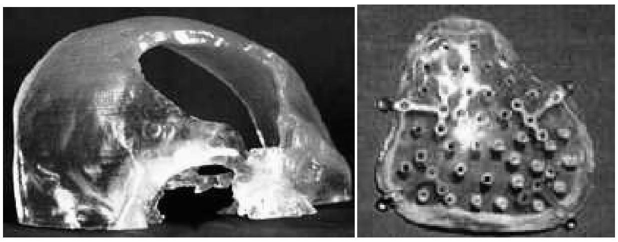
Fig. 6. Moulds made through RP a) from metallic material; b) from silicone rubber [11].

3. CONCLUSIONS

As results from this paperwork, in approximately two decades of existence, the RP technologies had an impressive development, getting to revolutionize the making methods, as well as the methods of products development.

This development is very well represented by the equipment sales. For example is presented in Fig. 8. the diagram of RP equipment sales for the XXth century.

But this tendency continued and even became stronger in the new millennium. And having in view the daily realities and necessities, we can state that this tendency will also last in the future.



a b

F d

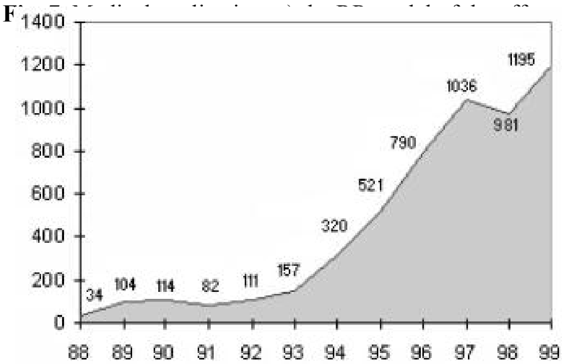


Fig. 8. RP equipment sales per years for the XXth century [13].

REFERENCES

[1] Bâlc, N. (2001). *Tehnologii neconvenţionale* (Non conventional technologies), Edit. Dacia, ISBN 973-35-1130-7, Cluj-Napoca.

[2] Berce, P., et al. (2000). *Fabricarea rapidă a prototipurilor* (Rapid Prototyping), Editura Tehnică, ISBN 973-31-1503-7, Bucureşti.

[3] Tănăsescu, F. T., et al. (1990). *Agenda Tehnică* (Technical Agenda), Edit. Tehnică, ISBN 973-31-0107-9, Bucureşti.

[4] Baki-Hari, Z. G. (2001). *The Vacuum Casting - An Interesting and Spectacular Application of Using the RP Models*, Annals of MTeM for 2001 & Proceedings of the 5th MTeM Symposium: "Modern Machines and Technologies", pp. 19 – 22, ISBN 973-85354-1-7, Technical University of Cluj-Napoca, Cluj-Napoca, Romania, October 2001.

[5] Baki-Hari, Z. G. (2002). *Flexibilis szerszámok gyártása metalizálással* (The production of flexible tools with metal coating), Műszaki Tudományos Füzetek, Fiatal Műszakiak Tudományos Ülésszaka VII., Kolozsvár, Cluj-Napoca, March 2002, pp. 41 – 46, ISBN 973-8231-16-7.

[6] Baki-Hari, Z. G. (2003). *Hybrid Patterns - Application of Rapid Prototyping Models*, Annals of MTeM for 2003 & Proceedings of the 6th Modern Technologies in Manufacturing, pp. 15 – 18, Technical University of Cluj-Napoca, Cluj-Napoca, Romania, October 2003.

[7] Băcilă, C. G., Baki-Hari, Z. G. (2003). *Concurrent Engineering - A New Product Development Strategy*, Proceedings of The 3rd International Conference on the Management of Technological Changes, pp. 347 – 352, ISBN 960-8475-03-1, Technical University of Crete, Chania, Greece, August 2003, Vol. 1, , Venus Publishing House, Chania.

[8] Băcilă, C. G., Baki-Hari, Z. G. (2004). *Mold Tooling via Rapid Tooling*, Proceedings of the International Conference on Manufacturing Systems ICMaS 2004, pp. 493 – 496, ISBN 973-27-1102-7, University Politehnica of Bucharest, Machines and Production Systems Department, Bucharest, Romania, October 2004, Edit. Academiei Române, Bucharest.

[9] Baki-Hari, Z. G. (2005). *Mold Tooling via Rapid Prototyping*, Annals of the Oradea University, Fasciycle of Management and Technological Engineering, CD-ROM Edition, Volum IV (XIV), 2005, Procedings of „IMT Oradea - 2005" Annual Session of Scientific Papers with International ParticipationN, May, 2005, Oradea, Felix Spa, Editura Universităţii din Oradea, ISSN 1583-0691.

[10] ***. `http://www.2objet.com/` *Accessed*: 2008-02-11.

[11] ***. `http://www.dmeeu.com/` *Accessed*: 2008-05-02.

[12] ***. `http://www.mcp-group.com/` *Accessed*: 2008-05-02.

[13] *** `http://www.pt.bme.hu/` *Accessed*: 2008-02-10.

[14] *** `http://www.prototype.hu/` *Accessed*: 2008-02-11.

Authors:

Eng, Zoltan-Gabor BAKI-HARI, Transylvanian Museum Society, Cluj-Napoca,
E-mail: `bakihari@yahoo.com`
Eng, Carmen Gabriela BĂCILĂ, Assist. Prof. PhD student, Technical University of Cluj-Napoca, Management and Systems Engineering Department,
E-mail: `gabriela_bacila@yahoo.com`