THE PROBLEM OF CORRECT TECHNOLOGY SELECTION IN RAPID PROTOTYPING

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Abstract: *Rapid Prototyping (RP) Technology gives a possibility fast projection of data saved in files by CAD programs on real object. Rapid Prototyping Technology gives a possibility fast projection of data saved in files by CAD programs on real object. RP allows on "3D printing" for objects even with complicated structure. This is not a machining. Prototypes are built layer by layer. Producing is faster than in machining. Numbers of available technologies RP and used materials is large. Technologies have own preferred materials. The materials have different physical and chemical properties. Choosing of right technology for particular object is not easy. We should take into consideration many features, which affect on produced object. In process of choosing we can use collected properties from catalogues related to the algorithm in software of decision support. This article presents a few RP technologies and materials. Contains characterization of known decision support systems in RP processes. The main topic is a new concept of base system for RP. The first part is system based on catalogue data for machines and materials. It provides first selection in decision making process. Next step will be using empirical data. There is a purpose to use a neural network structures to determine right technology.*

Keywords*: Decision supporting, Rapid prototyping.*

ACM Classification Keywords*: A.0 General Literature - Conference proceedings, I. Computing Methodologies, I.2.1 Applications and Expert Systems, J. Computer Applications.*

Introduction

Computer-aided machine design (CAD) is the basic stage in the modern digital design of machines. It is applicable in industrial sectors, but not only. This technology, due to its possibilities can successfully be used also for modelling other structures apart from machine parts, e.g., in medicine for the reconstruction of the skeletal system. It involves the mapping of the physical geometrical three-dimensional model into the digital model. Such action can be used in order to write down the structure of detail, which can be the part of the object or the whole object. This way there is created the digital prototype of the designed object.

Thanks to Rapid Prototyping (RP) technology, there is a possibility of the quick transition of the digital CAD model to the physical object. In contrast to the machining, RP is the incremental technology. Thus, creating the physical model from digital STL data after the design CAD stage does not take place through removing the material like in the machining, but by adding material or by the phase change from the liquid into solid state. The object is built in layers. This allows to make objects with very complex structure, both internal and external.

In a typical process of the computer design support there can be specified several characteristic steps:

1. Establishment of the concept of the built object or its parts.
2. Implementation of the model of the main element in the digital form.
3. Implementation of the digital mock of the object with the determination of the technical and technological specification for the object.
4. Performing durability calculations of the elements of the object, checking the correctness of operation (analysis of collision), selection of material for the object.
5. Making the prototype (among others Rapid Prototyping Technology)
6. Implementation of the necessary documentation.

Rapid Prototyping technology combines the digital stage, conceptual with the Real physical model of the constructed object. It allows the quick mapping of the design as the prototype, which in case of some RP methods may have physical-chemical parameters close or even identical to the design. Currently, the spectrum of available RP methods is quite large, and therefore, there appears the need of decision, which of the methods is the right one in case of the particular design. The topic of decision support in the selection of the optimal RP technology for prototypes is not new. Many academic centres dealt with this topic. So far the complex system has not been developed, which would support this type of actions. Decisions about the selection of technology apart from support using computer programs are still performed based on experience of designers specialising in the RP technology.

The accurate selection of the RP technology is important because it favours the growth of the product quality [Sobolak Budzik 2008]. Already at an early stage of designing we can eliminate all errors accompanying the construction or modify the object before it goes to the mass production. In some cases there can be made the missing element of the object, which cannot be repeated. The example is the area of medicine, where the modelled part of bones, e.g., skull can be made in the RP technology in almost 100% compliance with the need without performing the finishing. The prototypes made by Rapid Prototyping technology are used in many cases. The objects or parts are used in many measurements in researches. There are a researches of cooperation between parts of machine [Sobolak Budzik 2008, Budzik at al. 2013] especially in machine gear boxes, accuracy of geometry a machine parts [Grzelka at al. 2012], visualizations of mechanism and the others.

Rapid Prototyping Technology

The range of creating real models as prototypes of machine parts in RP technology is very rich. We can distinguish the classical division of technologies taking into account both the material, of which the prototype is made, and the way of its use.

In Fig.1. we can see the diagram describing the current methods of rapid prototyping with regard to materials for the produced details.

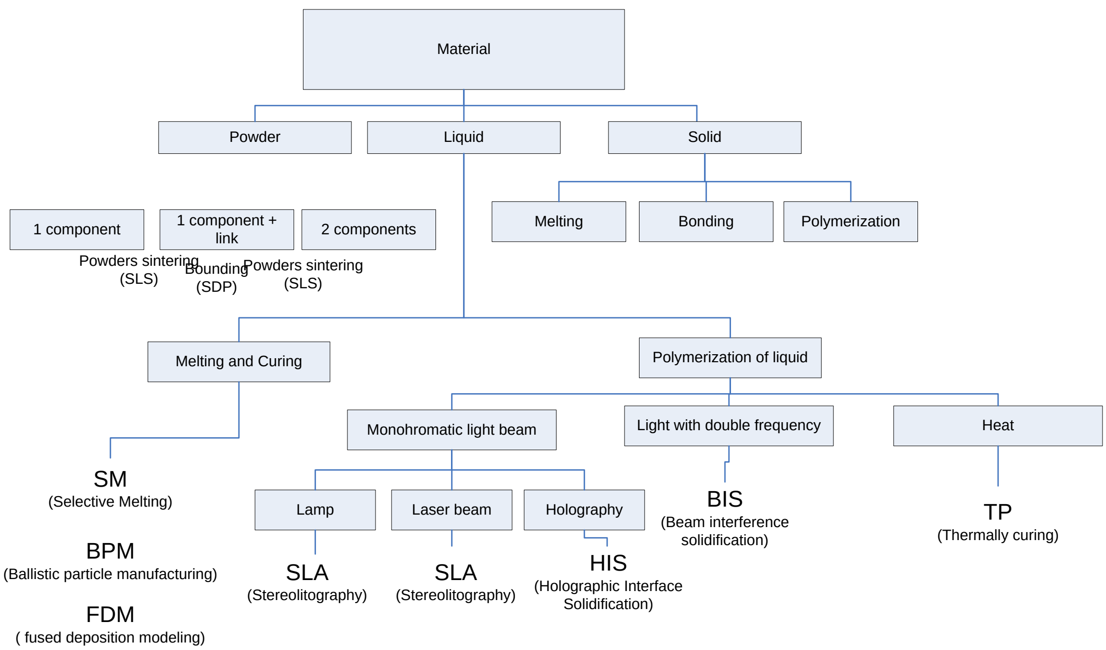

Figure 1. Diagram of methods in Rapid Prototyping technology

[Budzik 2011] characterises precisely the particular methods, of which the basic group considered in the content is:

- **Stereolithography (SLA) -** That is hardening next layers of resin by the laser in the liquid form according to the prototype model. Hardening takes place only in the particular place, hence the high accuracy of this method .A example of SLA object is set on fig.2.

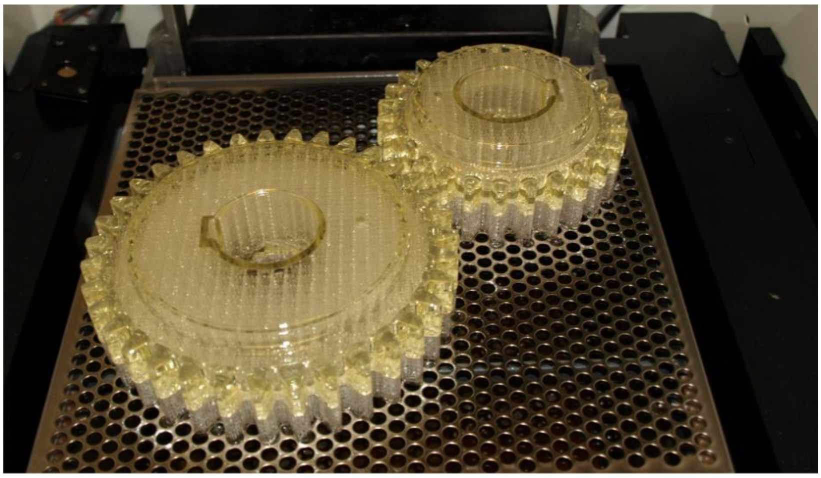

Figure 2. Gear wheels made by SLA method

Selective Laser Sintering (SLS) - In this technique next layers of material are placed by the machine, and then the laser hardens the selected points. Unhardened powder is then removed and we obtain the finished item. The process must take place in the vacuum. Example on fig.3.

Figure. 3. Rotor made by SLS method

Electron Beam Melting (EBM) - Method of making the model using the electron beam melting metal powders. Each layer of the model is made by melting the next section of the model according to data from the control file.

Laminated Object Manufacturing LOM - Is the creation of the model of thin layers of paper, most often adhesive, creating layers of another section consisting the given prototype. Such made parts are easily workable and may serve as the design verification – they have no limitation in terms of complexity of detail. They may serve as models for making forms.

Fused Deposition Modelling FDM - Fused deposition modelling. It involves placing the model material by the head (e.g. ABS) according to another levels of sections based on the 3D model. The ready project is practically ready for use after its creation (fig. 4).

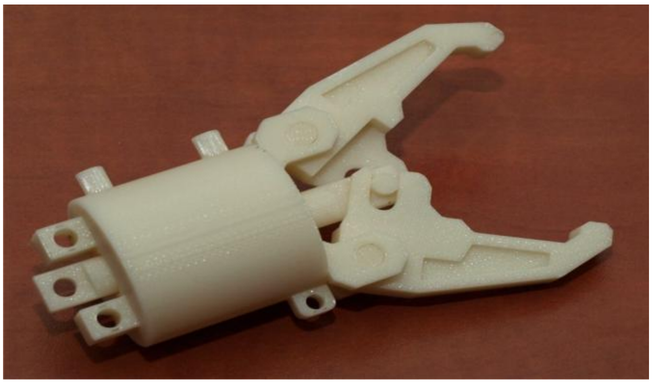

Figure 4. Gripper made by FDM methods

Digital Light Processing 3D printing (DLP) - The liquid polymer is hardened with the laser beam.

Three Dimensional Printing (3DP) - This method uses powders: ceramic, polymer or metal. Powders are connected with an adhesive, which links them together layer by layer of the model. After creation the model is heated and next layers are connected together linking, and as a result the adhesive disappears (fig. 5).

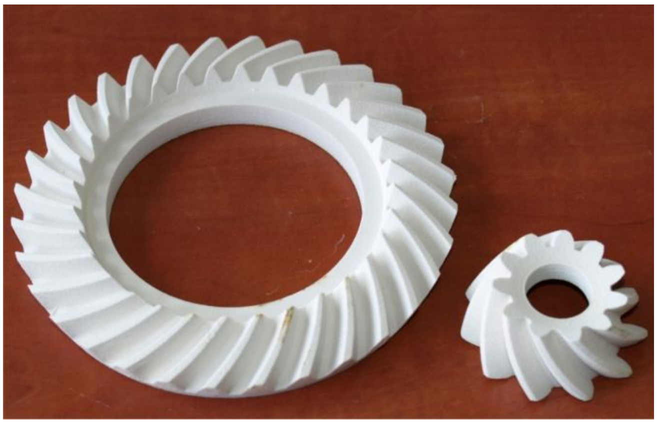

Figure 5. Models produced by 3DP method - gear wheels

Digital Light Processing 3D printing (DLP) - The liquid polymer is hardened with the laser beam.

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Figure 6. Element produced by PolyJet method

The above classification is the presentation only of the selected methods and examples of the created prototypes. It does not include all ways of prototyping. As it can be easily observed, already in case of this group the decision about the selection of the particular method may constitute a problem, especially in case of people not being experts in the RP technology.

Decision in the Method Selection

Decisions about the selection of the appropriate technology in creation of a prototype in the context of a number of presented methods are a difficult stage. It requires insight into the general range of technologies from the designer. This is not always possible, even due to the number of their number and diversity of materials used for the selection of prototypes. Each material has different physical-chemical properties, which determine the performance of the designed part in some group, e.g., endurance. Selection criteria of the optimal material, and at the same time technology, can be based on determinants of the material properties, machines as well as tests conducted on the created details. The scope and accuracy of the selection and of the undertaken decision concerning technology will depend on the area of knowledge that will be built for the algorithm supporting the choice.

The task of the decision support system would be gathering the expert knowledge for the further use on the path of the optimal RP technology for the constructed detail. Knowledge gathered by the support system would have to be so extensive so that it could in a simple way answer the simple, in terms of language, and at the same time extremely difficult, in technical terms, question: which method is suitable in our case?

Multi-criteria query for the system in assumption should be based on the basic “catalogue” data of both the machine and material, as well as some component, which is obtained on the path of studies or observations, and constitutes the expert element. To include it is the system database there should be prepared the appropriate structure of databases and find the right algorithm for inference. The algorithm based on the components determined by the designer (properties required for the detail) would indicate then the range of the most appropriate solutions in the given case.

Over the last decade many people were involved in the RP decision support using various techniques. Many of them were the composition of attempts to use IT and mathematical solutions for the most precise determination of criteria of the RP method among the selected parameters. So far, there has only been observed that the problem of decisions in this regard is so complex and complicated that it cannot be solved in a simple way, which would give 100% certainty of the right choice of technology. Among the solutions there can be noticed the simple implementation of databases and the use of more sublime methods, like the fuzzy logic. Supporting decisions in the Rapid Prototyping technology has so far been implemented several times. There have been developed a few systems supporting the selection of the right printing method. A few of the implemented solutions were described below [Byu Lee 2005].

Phillipson developed the RP Advisor. The program, which task was the selection among six available RP technologies of the right one based on time parameters of the performance of detail, cost of making and accuracy. The system worked in the MS Access database and used theories of multi-criteria optimisation, however it did not take into account other criteria, like material properties.

Bibb has developed another system. Its task was the decision support, consulting for small businesses, which wanted to use the RP technology in developing their products. In this system there were used two rules: decision-making and calculation. Decision-making rules were used for the selection of the right method based on data about quality of performance included in the STL file describing the object.

In the Institute of Industrial Technology and Applied Work Science (BIBA) there has been developed a method supporting RP decisions based on the selection of technologies from the relational database. MS Access was used for the construction of the mechanism. The system supported the decision on the basis of selection of fundamental values in catalogues and limitations of the list of the right ones for the design assumptions of machines and materials. The tool contained the combination of machines and materials and required the clarification of needs.

In the Industrial Research Institute Swinburn (IRIS) Masoon and Soo created the expert system for the selection of RP methods. The goal of the tool was the aid of the not yet implemented users, in the adjustment of the right RP methods for the performed designs and purchase of the right machine. The program included many available technologies. Compared to the previously described system it had the possibility to determine criteria regarding the price of machines, accuracy of the performance of the details, quality of the output surfaces, implementation time of the prototype, type of material and printing speed. The program allowed the user to select one out of four options: a rapid selection of parameters, careful selection of parameters, RP technology and machine type to determine the satisfactory 3D printing technique. The system was not designed to select the best technology for printing the proper part, and it was more directed towards the selection of the appropriate one for the selected parameters by the user to purchase the optimal machine.

The system described by H.S. Byun and K.H. Lee. It is the solutions of RP decision support with the multi-criteria approach. The TOPSIS algorithm is used here (Technique for Order of Preference by Similarity to Ideal Solution). TOPSIS is based on the concept of alternative, which should have the shortest geometrical distance from the perfect solution and the longest geometrical distance from the negative solution. In this case the perfect solution is the creation of the model with the assumed properties.

Table 1. Summary of RP support systems. Based on [Byu Lee 2005]

Name	Criteria for data selection	Used Method
RP Advisor (RPA)	Cost, Time, Quality	Multi-criteria optimization (MS Access)
Rapid Prototyping System Selector (RPSS)	Accuracy, Wall thickness, Material properties	Rule based (MS Access)
Muller system	Material Properties	Benefit value analysis
Intelligent RP System Selector (IRIS)	Price of the RP system Accuracy,	Rule based, Surface finish, type of material, Range of layer thickness, Building envelope, Building Speed
Multiple-attribute decision making (MADM)	Dimensional accuracy, Surface roughness, Part cost, Build time, Material properties	Fuzzy multiple-attribute TOPSIS Method

As it can be seen in table 1., there are many methods supporting RP decisions. In a more or less accurate way they present the range of available technologies limiting it to several (or one of) techniques, which meet the design requirements.

In the further part of the paper there is proposed the look at the topic of RP support from a slightly different perspective. The common fragment in relation to the mentioned techniques is the gathering of the appropriate knowledge used for the new concept. This will be the “catalogue” knowledge, widely available, recognised in the framework of database created for the needs of the idea. The system proposed as the concept is to be enriched with a research component, which will extend the bases of the system’s knowledge with the empirical element. Catalogue and experience data will allow the comprehensive recognition of the problem of the selection of the appropriate RP technique in the context of the requirements for the designed part.

RP Decision System in the Scope of Catalogue Data

For the purposes of works at the construction of the RP support system using Artificial Intelligence techniques, there was developed the base system containing catalogue data, which describe the fundamental available RP technologies. The system uses the cooperation with database with the mechanism of queries using the conditional statements “if … else”. It can compile a list of available RP machines basing on the selection criteria determined by the operator. The construction contains machine parameters made available by manufacturers, like e.g., machine dimensions, of workplaces. For expanding the criterion there was also determined not only the mere material for the constructed detail, but also its physical and chemical properties. Because of that, the system while determining the border values like, e.g., impact strength, elongation hardness selects the machines also in terms of requirements concerning the mere designed part. As an additional option there was also used the classification category of parts, which determines the usefulness of the printed details in the specified class of solutions, e.g.: presentation, work demonstration, machine part, etc.

This system is the foundation for the further research part, which task is to add the empirical value. This will supplement the system with compete information about the usefulness of the technique for the creation of the part of a characteristic construction, structure and mechanical properties. Due to the adopted concept of using the technique of neural networks, there is required the gathering of a large amount of data for teaching neuron structures as well as the verification of the correctness of operation (inference).

Neural Networks in the Application of RP Support

The nature of neural networks as the part of the main algorithm of the RP support system may turn out to be the best solution. However, for their use to bring good results, it is necessary to have the sufficiently large set of data for teaching the modelled constructions as well as to verify the adopted settings. It is also important to determine the structure of the set of input data despite that the constructed neuron structure is assumed with the universality feature in the context of RP methods. As the elements and details created in RP are characterised by the high complexity, describing the common features will be a challenge. Therefore, it is planned to perform, at first, of the less complex details, designed so that there are used the single, characteristic for solids and spatial structures, features. This concerns such details, like: holes, passages between planes (rounded, sharp), detail edges, fragments with small spatial sections, etc. Each of these technological detail is described with other parameters. Incorporating them into a single shared data vector is accepted for the network is already difficult at this stage. In case of the constructed system, however, this is necessary.

Planning the structure of the input vector will be realized as the direct stage with the performance of the dimensions of accuracy for the making of the selected technological details printed with the RP method. Measurement will concern details of the same block, made in different technologies and materials appropriate for the technology.

In order to determined the usefulness of neural networks for the support of the optimal selection of the RP method for the selected design, it is necessary to check several neuron structures. It is planned to initially subject, among others: multi-layer percepton, Kohonen networks, RBF networks to tests.

Conclusion

The presented concept of the decision support system concerning the Rapid Prototyping technology in the final form assumes the two-stage approach to the decision-making. The first stage is the initial selection of technologies based on catalogue data, which determine basic parameters, both of:

- the machine (e.g. dimensions of the workplace),
- category of using the detail (e.g. presentation of the mechanism, working part),
- material features (physical-chemical properties connected with the material selected for the technology) and,
- relative accuracy, which is imposed by the mechanism of the detail implementation.

For some details, this stage of support can be sufficient to assess and select the right RP technology. In more precise cases, details characterised by greater requirements, the decision-making process will require the use of a further stage, that is the algorithm included in the neuron structure built for the needs of the system. Neuron network taught the correct selection based on the selected parameters by the RP operator will select the optimal solution for the technologically advanced detail. The effect of the system's operation will be the specific response to the initially posed question: "Which method is appropriate in this case?"

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