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# USING FUNCTIONAL REQUIREMENTS TO DETERMINE OPTIMAL ADDITIVE MANUFACTURING TECHNOLOGY

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**Abstract:** *In the past few years the amount of machines that utilise additive manufacturing technology has risen remarkably. More companies are providing the service of additive manufacturing (or 3D printing in commons terms) and it has become more accessible to non-professionals and novice engineers. But the selection of those technologies is still complicated. The reason behind this is that the selector has to be knowledgeable about the different materials, machines and technologies. To make a reasonably informed decision a lot of research has to be done.*

*In order to make the decision making process easier, this paper proposes a new approach to technology selection in the field of additive manufacturing. This is done by answering a questionnaire that defines the product's functional requirements. The composition and some of the programming has been described in this paper. Also a case study has been presented*

*Key words: additive manufacturing, functional requirements, technology selection, 3D printing*

## 1. INTRODUCTION

It has been 29 years since the first additive manufacturing (AM) technology became commercially available [1] but because the patents expired only recently the amount of additive manufacturing machines, companies that produce them or offer a service in this field has risen remarkably [1]. This means that additive manufacturing technologies have become more widely usable by the general public. This in turn means that the focus in this field of manufacturing is even more turned to individual products, small patch manufacturing and mass customization. It should be emphasised that the individual orders of products has increased significantly and companies providing additive manufacturing services have tried to include non-engineers to try to create something themselves.

This increase has also been supported by the rapid development of IT technologies such as Internet of Things, cloud-based-manufacturing, 3D scanners, development and increased accessibility of computer aided design (CAD) software over the years.

Because the whole manufacturing process in AM is highly computerized and no technical drawings on paper are any more actually needed the CAD model can be transferred from computer straight to the machine. This allows monitoring the whole process with much more ease compared to more traditional fields of manufacturing. This means that AM would be suitable for using real time monitoring of the shop floor [2].

The scientific strides in material sciences which has increased the attainable accuracy in geometrical measurements and improved the mechanical properties of the products manufactured thus increasing their functionality and where these products can be used.

One of the problems in the field of AM is the technology, material and machine selection. The existing solutions for selection require the potential customer to have extensive and up-to-date knowledge about the whole field. This is especially evident when we look at the online price quoting, ordering and also special software for additive manufacturing machines selection.

## 2. ADDITIVE MANUFACTURING TECHNOLOGY SELECTION

The two biggest manufacturers and developers of additive manufacturing machines and technologies are 3D Systems and Stratasys. Both of these companies have an online environment, where one can order parts by choosing technology, machine and the material. 3D Systems has the QuickParts ™ environment [3] and Stratasys Rapid Quotes [4]. Both of these environments let you upload your CAD file with the correct extension and get a price estimate. There are also smaller service providers of AM but the selection process remains the same [5].

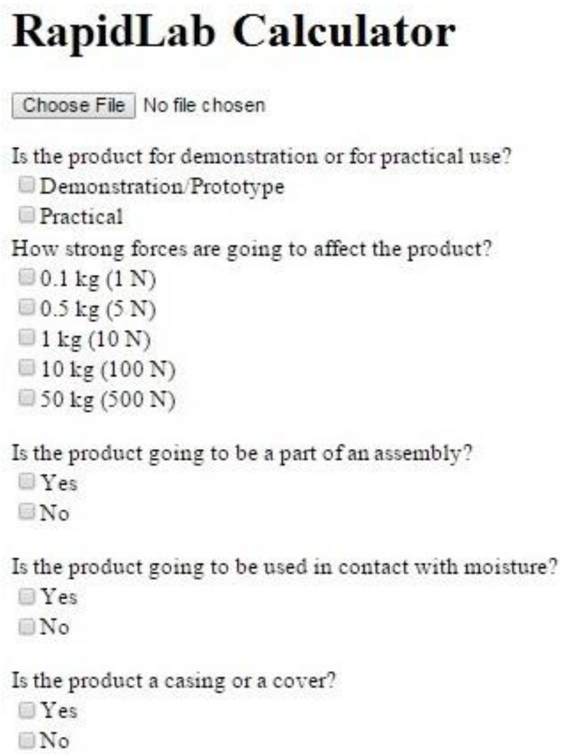
The difficult part of ordering products is that the customer has to define what AM technology to use, after that to select the suitable machine, then define the material used and finally define the after treatment method and it's extent. The selection from all the available options means that the customer must do a lot of research on all of this information. For example selecting between these machines - SDSL, PolyJet, FDM XD7 or DMLS SD40 is impossible without doing some research. After the machine selection the customer has to select material from ABS M30-White, ASA White, PC White or ABSi Translucent Natural which also requires some knowledge about the materials. Few categories have a short description accompanying them, but usually not enough to make an informed decision. One of the objectives of using this kind of service is to reach out to the non-engineering community and let them create their own products with ease. But going through the laborious selection process is counterproductive to that objective. One of the selections options in these environments is "Technician's choice" which means that a qualified worker has to look at the individual product and decide the correct technology, machine and material. In addition the customer can specify any special needs that are expected from the product which also adds to the technician's workload. In the next section of the paper a new approach has been described using functional requirements to determine the optimal AM technology without extensive knowledge of the field and reduce the workload and time spent when selecting the suitable machine both for the customer and technician.

## 3. USING FUNCTIONAL REQUIREMENTS TO DETERMINE OPTIMAL ADDITIVE MANUFACTURING TECHNOLOGY

Functional requirements (FR) define what a product must accomplish or what is its' purpose without limiting how the functionality must be achieved.

FRs are usually used when defining the goals of a software program [6] because very often it doesn't matter which kind of programming language to use. Some of languages are more suitable for certain functionality but it's often more important which kind of language the programmers are fluent in. FR have also been used in mechanical engineering to acquire information about functional design [7].

AM technologies and machines are capable of producing any geometrical shape and this is why the functionality of the product becomes even more important - you can physically manufacture the product with any AM machine, but only a few of them can provide the functionality needed for the product. An example of this would be side-release buckles that has to be elastically flexible. So not only do we need to know which machine is capable of creating this product geometrically but also provide the needed functionality.


RapidLab Calculator

Choose File No file chosen

Is the product for demonstration or for practical use?
Demonstration/Prototype
Practical
How strong forces are going to affect the product?
0.1 kg (1 N)
0.5 kg (5 N)
1 kg (10 N)
10 kg (100 N)
50 kg (500 N)

Is the product going to be a part of an assembly?
Yes
No

Is the product going to be used in contact with moisture?
Yes
No

Is the product a casing or a cover?
Yes
No

Fig. 1. Example of the questionnaire to determine functional requirements

To help to define the FR for the product a questionnaire has been compiled, shown in Fig 1. It consists of 17 questions and the questions have been presented in two formats - “yes/no” and “selection from a list”. Example of this is shown in Fig 2. This kind of presentation of questions is necessary because free form answers would need analysis by the technician and it would defeat the purpose of the questionnaire because the technician could as easily just look at the CAD model. Although determining FR from a text file could be something to look into in the future as research has been done in this field [8].

Any number of AM machines can be compared in the questionnaire provided that the company has them. The machines are compared with each other so the answers to all the questions are relative to each other and are not connected to absolute values. In Fig. 3. it is shown how “selection from a list” question type is processed. Three machines are compared with each other in this paper: Printer1 – Formiga 100, Printer 2 – ZPrinter 310 and Printer3 – 3D Touch. These machines are selected because they all use different technologies and are all available for testing in Tallinn University of Technology (TUT).

The example is about the necessity of installing or using the product in order to define the requirements for wear and abrasive qualities. Certain materials are very sensitive about this functionality (especially plaster based materials). Question processing for “yes/no” type is done in similar fashion, but the list is only two entries long.

The first choice in the list is “Upto10” which means using/installing the product up to 10 times and according to that the three machines in this example are given points. Because up to 10 is a very low number for installing or using the product then only machine No. 2 (Printer2) receives any points because the machine uses material that is easily abraded (it’s plaster based). For the other machines from the standpoint of abrasion using/installing the product only 10 times is clearly a waste because the materials are capable of so

```
<p>
    <asp:label runat="server">How often is the product going to be used/installed?</asp:label>

    <asp:CheckBoxList id="UsedInstalledFrequency" runat="server">
            <asp:ListItem Text="1" Value="1" onclick = "MutExChkList(this);"/>
            <asp:ListItem Text="Up to 10" Value="UpTo10" onclick = "MutExChkList(this);"/>
            <asp:ListItem Text="Up to 100" Value="UpTo100" onclick = "MutExChkList(this);"/>
            <asp:ListItem Text="Up to 1000" Value="UpTo1000" onclick = "MutExChkList(this);"/>
            <asp:ListItem Text="1000+" Value="1000AndMore" onclick = "MutExChkList(this);"/>
    </asp:CheckBoxList>
</p>
```

Fig. 2. Example of how the question “How often is the product going to be used/installed?” is presented in the questionnaire software

much more and this is the reason why other machines didn't receive any points. For the same reason the second choice - "UpTo100" would give the least amount of points to machine No. 2 compared to the other machines.

The points are given in the scale of 10, where 1 is the least suitable for a function and 10 is the most suitable machine for this function.

All the scores for each answer are determined by an expert and adding new machines to the comparison needs an expert's evaluation on that machines functional capabilities compared to the already existing machines in the software.

When all the questions have been answered and CAD file successfully uploaded then all the scores for each machine are added. The result is then multiplied by the priorities coefficient which are defined by the customer. The customer has to select between three priorities which are contradictory - cost, quality and time. These coefficients are very often the most important factor for the customers when choosing the AM machine/technology. The coefficients are evaluated on the scale from 1 to 5 where 5 is the most important priority. The result of the multiplication of each machine score and priorities coefficient are then compared with each

```
private PrinterSuggestionResult processAnswers()
{
    PrinterSuggestionResult result = new PrinterSuggestionResult();
    switch (UsedInstalledFrequency.SelectedItem.Value)
    {
        case "UpTo10":
            result.addPrinter2Score(1);
            break;
        case "UpTo100":
            result.addPrinter1Score(9);
            result.addPrinter2Score(6);
            result.addPrinter3Score(8);
            break;
        case "UpTo1000":
            result.addPrinter1Score(9);
            result.addPrinter2Score(3);
            result.addPrinter3Score(8);
            break;
        case "1000AndMore":
            result.addPrinter1Score(9);
            result.addPrinter2Score(2);
            result.addPrinter3Score(6);
            break;
    }
    return result;
}
```

Fig. 3. Example of how the question "How often is the product going to be used/installed?" is processed

After the questionnaire has been filled the customer also needs to upload the CAD file of the product. At the moment the STL, STEP and STEP-NC are usable formats and for all of them the software has a module for calculating the volume of each file. In Fig. 1. the button for uploading of the file is shown.

other and results are presented as shown in Fig. 4. The machine with the highest score is the recommended AM machine. But the results also show alternative solution - what would the cost be if the customer would use another machine. This allows the customer to rethink their priorities and

also to change some of the answers in the questionnaire.
As mentioned the selection of the machines is a multi-criteria optimisation problem. The proposed solution in this paper is for showing the concept but it can be improved using methodology described for selection and manufacturing of composite parts [9].
Also the results show why some of the machines are excluded from the most suitable solution. As shown in the example in Fig. 4. two machines have been excluded because the product has to have flexible parts and is subjected to strong forces. Because the two AM machines are incapable of producing this kind of functionality, they are not the optimal solution even though these machines would produce the product with lower cost.

important functions were brought out. In addition the estimated cost of the product was noted. This was useful to see if the price estimation from the software were correct.
The functions compared in the questionnaire cover the following areas: is the nature of the product a prototype/show piece or practical use, what kind of temperatures the product will be subjected to, is there moisture in the environment, what kind of wear will the product be subjected to, what will the products cross-section look like, is the product going to be a cover or a gear (very often ordered products) and is the product going to be hand-held. All together there are 17 different questions defining the products FR.


Fig. 4. Example on how the results of the RapidLab Calculator presents the results

The proposed solution for using FR to determine optimal AM technology uses C# programming language and Internet Information Services (IIS), an extensible web server created by Microsoft. This means the AM selection process is done through an Internet browser, no download necessary.
The questionnaire described in previous sections is based on the products ordered from TUT over the past few years. A random selection was chosen and their FR were defined. These functions were categorised and analysed and the most

A case study has been conducted to verify this software program. After the questionnaire was completed the products chosen for creating the questionnaire were run through the program. The results were with about 85 % accuracy (for both the selected machine and estimated price) because very often the customer had decided on what kind of machine to use before the product was manufactured and no alternatives were considered. In addition the questionnaire is still not final and needs additional testing and development.

## 4. CONCLUSIONS AND FURTHER RESEARCH

A new approach has been presented in this paper for the technology selection in the field of AM based on functional requirements. Based on the case study we can say that using functional requirements can be used to determine AM technology and - machine and is a viable solution. Furthermore the proposed solution reduces the amount of time and knowhow required by the customer to select the optimal AM machine. The software can also be used by technicians working with AM machines to reduce their workload. The “Yes/no” and “Selection from a list” question types are an easy and suitable way of determining FR of a product and to evaluate which machine is the most suitable to manufacture it.

In addition to the case study a closed beta-testing is planned. The companies that have ordered parts from TUT would be the suitable testers. After that the questionnaire can be adjusted, the values for each of the machines re-evaluated and tested again. In parallel with that the purpose and meaning of each question needs to be analysed to see if there are important functions missing from the questionnaire or there are overlaps in the questions and adding functionalities that have become available with new materials and machines. Additional machines can also be added to the software and the next one would be the metal powder bed fusion machine Realizer SLM50 recently purchased by TUT but a small database for products manufactured with it would be required first.

At the moment the STEP, STEP-NC and STL formats can be used. The plan is to add volume calculation modules for the more popular CAD software file types but the first thing planned is to add STL binary format (at the moment the ASCII is only usable).

Further plans are to expand this approach to other, more traditional fields of manufacturing.

## 5. REFERENCES


1. Wohlers report 2014 (2014). [WWW] http://wohlersassociates.com/history2014.pdf (02.03.2016)

2. Snatkin, A., Eiskop, T., Karjust, K., Majak, J. (2015) Production monitoring system development and modification. Proceedings of the Estonian Academy of Sciences, 64 (4S), 567–580.

3. Quickparts - 3D Systems price estimator for rapid prototyping (2016). [WWW] http://www.quickparts.com/home.aspx (29.01.2015).

4. RedEyeOnDemand - Stratasys price estimator for rapid prototyping (2015). [WWW] http://www.redeyeondemand.com/3d-printing-quote/ (15.01.2015).

5. Oomipood price estimator for rapid prototyping (2015). [WWW] http://www.oomipood.ee/page/3d (13.01.2015).

6. Roya, U., Pramanika, N., Sudarsanb, R., Sriramb, R.D., Lyonsb, K.W. (2001) Function-to-form mapping: model, representation and applications in design synthesis. Computer-Aided Design, 33 (10), 699 – 719.

7. Zhang, W.Y., Tor, S. B., Britton, G.A. (2002). A two-level modeling approach to acquire functional design knowledge in mechanical engineering system. International Journal of Advanced Manufacturing Technology, 19, 454 - 460.

8. Sagar, V.B. R. V., Abirami, S. (2014). Conceptual modeling of natural language functional requirements. Journal of Systems and Software, 88, 25 – 41.

9. Pohlak, M., Majak, J., Karjust, K., Küttner, R. (2010). Multi-criteria optimization of large composite parts. Composite Structures, 92 (9). 2146–2152.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