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Evaluation of shape complexity based on STL data

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Analysis and modelling

ABSTRACT

Purpose: Purpose of this paper is to present a part complexity, based on basic information of the STL data.
Design/methodology/approach: This paper presents a few methods of evaluating the complexity of the shape, based on the parts STL data. Methods vary from very simple based on the number of triangles in STL file and the parts volume, to the more complex mathematical determination based on the relations of the basic STL data.
Findings: We discovered that evaluation of shape complexity based only on basic data of STL data gives us some basic view on part complexity.
Research limitations/implications: For parts with large block volume/part volume ratio and thinner parts with free form surfaces only the first method is suitable and gives suitable results.
Practical implications: The complexity of the shape of a part is an important factor for all manufacturing procedures. When using conventional machining, the parts complexity presents a key factor in determining the optimal way of manufacturing. Also, when using rapid tooling (for example silicon rubber moulding) the complexity of the part determines the parting plane layout and eventual tool construction (inserts, cores, etc.). Even when using certain rapid prototyping procedures, the support material consumption depends highly on the complexity of the part and together with the problem of optimal orientation and position of the part, significantly influences the manufacturing costs. At the end of the article a few test method are presented that try to determine the complexity regarding to the procedure by which the part will be manufactured.
Originality/value: Choosing maximum efficient manufacturing processes on base of part complexity is a new perspective in manufacturing, which, properly evolved and complied can cause revolution in manufacturing optimization, especially in hybrid manufacturing processes.
Keywords: Engineering design; Shape complexity; STL file; STL file parameters

1. Introduction

Nowadays it is often said, that by using the rapid prototyping procedures, »we get the complexity for free«. This statement emphasizes, that the complexity of a parts shape does not represent a mayor issue, when manufactured by rapid prototyping. So, what is the purpose of evaluating the shape complexity? Unlike with rapid prototyping, when using conventional machining, the parts complexity presents a key factor in determining the optimal way of manufacturing [1, 2]. Also, when using rapid tooling (for example silicon rubber moulding) the complexity of the part determines the parting plane layout and eventual tool construction (inserts, cores, etc.) [3, 4]. Even when using certain rapid prototyping procedures, the support material consumption depends highly on the complexity of the part and together with the problem of optimal orientation and position of the part, significantly influences the manufacturing costs.

Evaluation of the shape complexity can be made in several ways [5, 6]. Usually, evaluation based on previous experiences regarding a certain manufacturing procedure is made.

But such an estimate is very subjective and largely depends on the person that made it. This paper presents few possibilities of objectively evaluating shape complexity based on STL CAD file format data. The methods presented are simple mathematical equations based on fundamental information that can be acquired from STL data.

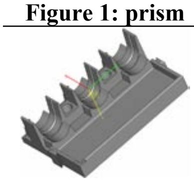
2. STL file format

Our research is based on the three-dimensional CAD model in the STL file format [7, 8]. STL was originally developed for Stereo Lithography [1, 9] rapid prototyping procedure and is supported by majority of CAD software packages. STL is a facet based representation that approximates surface and solid entities only.

3. Test parts

For evaluation of the shape complexity seven various models were chosen (Figure 1-6). They vary from very simple shapes to highly complex parts that are described with over 500 000 triangles in the STL file. Table 1 shows test parts. Block volume represent the minimal block volume that the parts fits into.

Table 1
Test parts

 **Figure 1: prism**	 **Figure 2: rib**	 **Figure 3: plug**
 **Figure 4: housing**	 **Figure 5: holder**	 **Figure 6: wheels**

4. Evaluation of shape complexity based on number of triangles

A very rough evaluation of the parts shape complexity (not considering its size or volume) can be made by examining the parts STL file size, that depends only on the number of triangles used. This size is very closely related to the number of triangles used to describe the part in STL file.

The file size or the number of triangles depend only on parts complexity and exporting resolution, but are not influenced by parts size, and can therefore be used for rough evaluation of shape complexity. Figure 7 shows how STL file size and the number of triangles increases with the parts complexity.

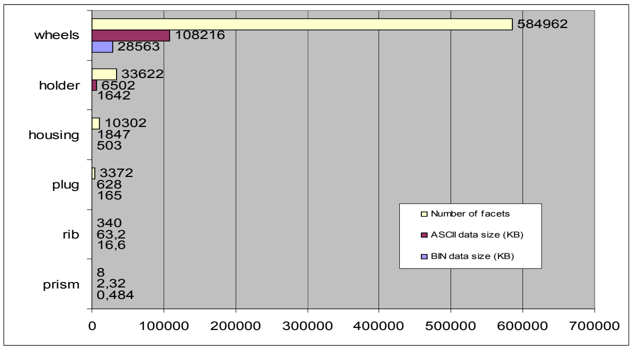


Fig. 7. Comparison between the BIN file size, ASCII file size and number of triangles

5. Evaluation of shape complexity based on ratio between volume and number of triangles

Number of triangles can be established with appropriate software (BIN to ASCII STL converter [10]). Determining the volume can be made in two ways. The precise determination of volume can be made according to the known algorithm [11]. Ratio can also be determined with a rough estimate for volume, based on the minimal block volume that can accommodate the part. When the part is optimally orientated the minimal block volume can be determined by searching for the maximal and minimal values of the triangle coordinates in each axis. Then we can determine the vertexes of the block volume.

This method is much simpler and faster then calculating the real volume, but the estimate is very rough and can lead to significant errors.
Evaluation of shape complexity is:

$$\frac{volume}{number\_of\_facets} \qquad (1)$$

The calculations were made with exact and roughly determined volume. Figure 8 represents the ratio between exact and roughly determined volumes.

Observing Figure 8 and 9, it can be established, that the increase in parts complexity causes the volume/number of triangles ratio to decrease. The ratio difference between the exact and rough volume depends on the shape of the part and increases with thinner parts and free form surfaces.

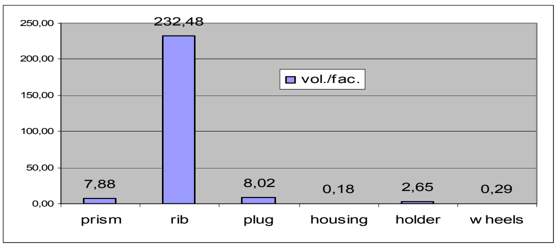


Fig. 8. Comparison between evaluations of shape complexity based on exact volume/number of triangles ratio

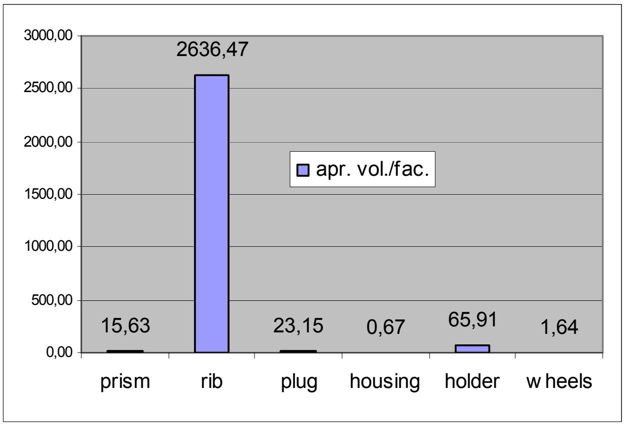


Fig. 9. Comparison between evaluations of shape complexity based on rough volume/number of triangles ratio

6. Evaluation of shape complexity based on ratio between parts volume and surface

Another evaluation of shape complexity based on STL data can be made based on the volume/surface ratio. Calculations were made both for exact volume and block volume (Figure 10 and 11). Evaluation of shape complexity is:

$$\frac{volume}{area} \tag{2}$$

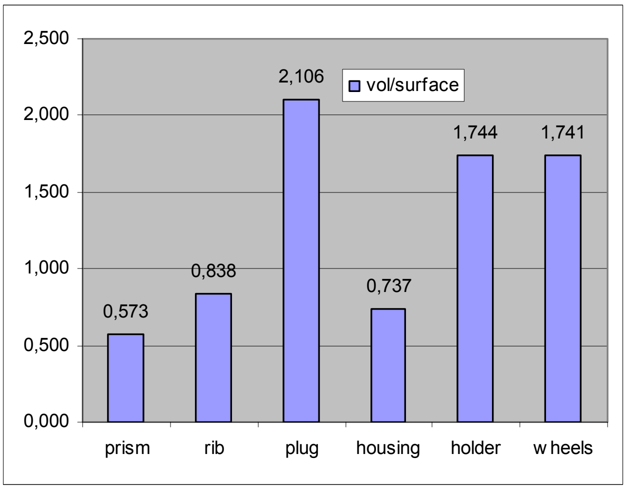


Fig. 10. Comparison between evaluations of the shape complexity based on the volume and surface ratio

Volume/surface ratio basically describes the quantity of curved or free form surfaces in a part. It also points the difference between thin walled and bulk parts.

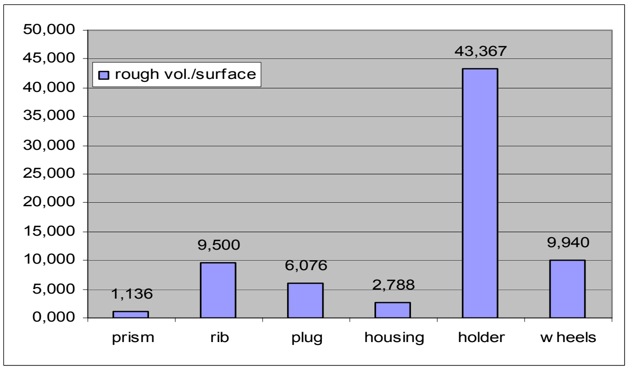


Fig. 11. Comparison between evaluations of the shape complexity based on the rough volume and surface ratio

7. Evaluation of shape complexity based on ratio between a minimal block volume and a parts volume

Block volume/volume ration also shows a difference between simple bulk parts and more complex free form surface parts and can be comparable to volume/surface ration (Figure 12).

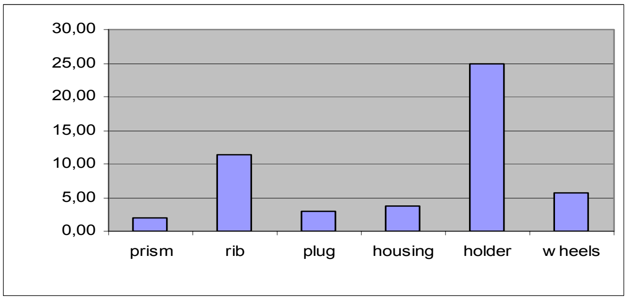


Fig. 12. Comparison between evaluations of the shape complexity based on the minimal bulk volume and volume ratio.

8. Results commentary

Observing the results, two parts can be pointed out. The rib and the holder are both thin walled, with very high minimal block volume/exact volume ratio. The results of those two parts greatly differ from other results for every method except the “number of triangles method”, which is volume independent. In a case of calculations based on minimal block volume the biggest error appears for rib and holder results.

This paper presents four simple methods, based in simple and easily available information acquired from STL CAD data format. The subject of complexity has been investigated by many researchers [12 - 15] but with more complex approach, that is not suitable for STL files.

The methods presented here are using basic geometrical data values available from STL files and the ratios between those values. First and the simplest method, based only on number of triangles, can be a very objective estimate, because the number of triangles in a parts STL file is not dependant on parts volume but only on the export resolution. A very accurate estimate can by made by volume/number of triangles method described in second method. Last two methods are very similar and the results are very close to experience based evaluation.

But all methods presented are unable to determine the convexity or concavity and similar geometrical properties of parts that can be a key factor when considering classical machining.

9. Application of methods

Fast development in the area of manufacturing technologies choosing the optimal manufacturing procedure can be a difficult but crucial decision. Nowadays, the previous experiences are the key factor in determining the optimal manufacturing procedure for a certain part. Usually this method produces goods results, but sometimes can lead to cost increase and reduced economic efficiency.

As already mentioned in introduction, the complexity from the manufacturing point of view, depends largely on the manufacturing procedure used. Every manufacturing procedure has its properties and limitations that must be taken into consideration, when evaluation a certain parts complexity.

10. Conclusions

For methods presented are only small inroads into the subject of evaluating shape complexity. Their advantage lies in mathematical simplicity in intuitive use. On the other hand that simplicity can also lead to some significant errors, especially when complex thin walled parts are in question.

Some new methods are being developed that could lead to greater accuracy. One of these methods is based in the size of individual triangles of the parts STL file, enabling the slicing of certain part on layers of different complexity. The other method is based on the difference of angle between normals of adjacent triangles, greatly enhancing the possibility of determining edges, convexity and concavity. It also enables the evaluation of some small features in a certain part that can present a mayor problem for manufacturing. Combining the existing methods with those currently in development should give a relatively accurate evaluation of shape complexity and would also serve as a guideline for choosing an appropriate manufacturing procedure regarding to that evaluation.

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