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Analysis of Design Guidelines for Automated Order Acceptance in Additive Manufacturing

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Abstract

Additive manufacturing (AM) is increasingly used in industrial production. Compared to conventional manufacturing technologies, such as milling and casting, AM offers a high degree of design freedom. Nevertheless, still some manufacturing restrictions and design guidelines have to be considered to ensure a flawless production. Therefore, a checking of design guidelines is a necessary step in order acceptance. Addressing this need, this paper presents an integrated analysis of design guidelines for an automated order acceptance.

In recent times, guideline catalogs for the design of additively manufactured parts have been developed. However, the analysis of a part's geometry with regard to these guidelines still requires a lot of manual work and expert knowledge. This paper introduces different algorithmic approaches, which automate the analysis and assessment of a part's geometry. Based on a preselection of guidelines from existing design catalogs for selective laser melting and sintering, this paper presents algorithms to automatically check the manufacturability of a part. The algorithms use the triangulated surface geometry (STL) of a part. They are implemented within a web-based platform for the automated order acceptance of additive manufactured parts. The evaluation compares the different algorithms regarding their efficiency and effectiveness.

Keywords: design guidelines, manufacturing restrictions, automation, order acceptance, design for manufacturing (DFM), additive manufacturing (AM), STL

1. Introduction and Background

Additive manufacturing (AM) technologies are increasingly used in the industrial production of plastic and metallic parts. This leads to the fact that more and more 3D printing service providers establish on the market. In recent times, the first service providers offer the option to place orders online [1]. AM builds up parts layer by layer based on given 3D geometry data [2,3]. Although AM offers a high degree of design freedom, still some manufacturing restrictions remain to ensure a flawless generation process [4,5].

In this paper, we present an approach for an integrated check of manufacturing restrictions and design guidelines as part of an automated order acceptance, with focus on selective laser melting (SLM) and selective laser sintering (SLS). Based on the results, parts can immediately be accepted and go into production (see Fig. 1) or rejected, if they cannot be produced.

Fig. 1. Integration of a web-based order acceptance into the AM process chain

The presented algorithms are prototypically implemented in a web-based platform, which simplifies the process of order acceptance. The customer can upload the geometry data of a part via an online form (see Fig. 2). Subsequently, the geometry is checked and critical areas are marked.

The paper is structured as follows: Section 2 presents the selected manufacturing restrictions and design guidelines, which are considered for an automated checking and are implemented within this paper. Section 3 describes the algorithms for checking a part's size. Section 4 introduces the algorithms for checking design guidelines for walls, gaps, cylinders, and boreholes. Section 5 evaluates and compares the different approaches. Section 6 gives a conclusion and outlook.

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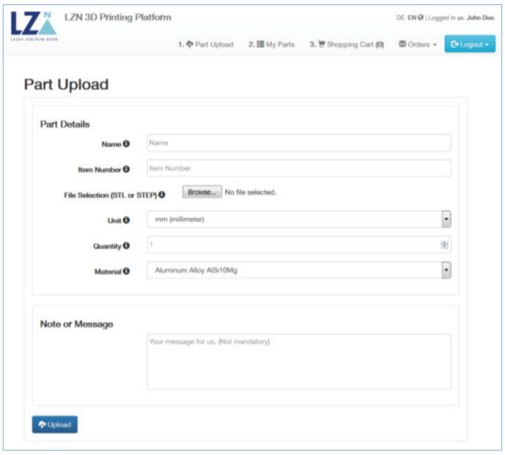


Fig. 2. Part upload via the implemented web platform

2. Preselection of Manufacturing Restrictions and Design Guidelines

In order to ensure a fault-free AM process and provide required qualities (e.g. shape and positional tolerances), certain manufacturing restrictions and design guidelines have to be considered. In recent research, process- and material-specific guideline catalogs have been developed [5–9].

To select these guidelines, which allow an automated checking based on a part's STL file, existing design catalogs are analyzed. Main selection criteria are the available and required input information for a design check. Thus, design guidelines, which are based on a fixed orientation of the part in the build chamber, are not taken into account, since the orientation is not known at the time of the online upload. Table 1 gives an overview of the selected restrictions and guidelines. The developed checking algorithms for these guidelines are presented in Section 3 and 4.

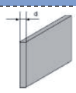
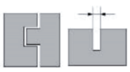
Restriction or guideline	Figure	Description
Part dimensions		
Part dimensions		The part has to fit into the build chamber of the generating machine. If necessary, the part must be oriented appropriately.
Walls and gaps		
Wall thicknesses		Wall thicknesses should not be below a certain limit to ensure a reliable and clean generation. The limit can depend on the orientation (angle to the build platform).
Gap dimensions		In order to avoid powder accumulations, merging of opposite areas within the part and facilitating removal of powder in the post-processing, gap dimensions should not fall below certain limits.
Cylinders and boreholes		
Cylinder diameters		The diameter of cylindrical structures should not be below a certain limit for a reliable and clean generation process.
Borehole diameters		In order to avoid powder adhesion, borehole diameters should not fall below a certain diameter.

Table 1. Overview of the selected manufacturing restrictions and design guidelines for an automated checking (example figures by [5])

The limits or thresholds, which decide whether a part can be produced or not, are implemented as configurable parameters of the developed checking routines. Therefore, the algorithms are applicable on different materials and manufacturing processes. Exemplary for the materials polyamide PA12 (SLS) and titanium alloy TiAl6V4 (SLM), the limits, which can be found in the literature, are shown in Table 2.

Restriction or guideline	Polyamide (PA12)	Titanium (TiAl6V4)
Part dimensions		
Part dimensions	depends on build chamber of machine	depends on build chamber of machine
Walls and gaps		
Wall thicknesses	0.5 – 0.7 mm	0.3 – 0.4 mm
Gap widths	0.4 – 0.9 mm	0.2 mm
Cylinders and boreholes		
Cylinder diameters	1.4 mm	0.5 mm
Borehole diameters	1.2 – 1.4 mm	2 mm

Table 2. Limits for PA12 and TiAl6V4 (values taken from [5,6])

As already introduced, the algorithms expect the STL data of a part as an input. The STL format (Standard Triangulation Language) has established as a de facto industry standard in AM [10,11]. This is also the reason why the presented algorithms are based on the STL format. In order to execute the algorithms on CAD data (e.g. STEP), the input data of a part must be converted into STL previously. The algorithms are implemented in Java. A visualization, which shows the part and its critical areas, is written in JavaScript and WebGL.

3. Check of Part Size

The size of a part (or its dimensions) is a fundamental manufacturing restriction, which decides whether a part can be produced. In order to check whether a part fits spatially in a given build chamber of a generating machine, three approaches have been developed. All algorithms get the STL data of a part as an input. In the worst case the algorithms show a linear behavior, and thereby have a computational complexity of $O(n)$.

3.1. Complete Point Cloud

This algorithm uses the complete point cloud, which is given by the STL. This point cloud is systematically rotated until a suitable orientation (spatial limits of the build chamber are not exceeded) is found. The algorithm follows the sequence shown in Fig. 3. The preprocessing eliminates duplicate points, which can occur in STL files [11]. Due to the centering of the part and the build chamber, rotations in the range of 0° to 90° are sufficient. The accuracy of the solution depends on the configurable angular step size α.

The execution time of the algorithm mainly depends on the number of rotations to be performed as well as on the number of points to be checked per rotation. In the worst case all rotation combinations are traversed and per rotation all points are checked. The following two approaches (*bounding box* and *surrounding sphere*) try to reduce the execution time.

3.2. Bounding Box

Based on the basic algorithm, shown in Fig. 3, this approach reduces the number of tested points in the preprocessing. The aim is a reduction of the execution time. Instead of checking all points, the bounding box of the part is