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Design for additive manufacturing: Automated build orientation selection and optimization

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Abstract

Additive manufacturing, or 3D printing, is an emerging type of production technology that is seen as the core technology for future high-value engineered products. Due to the additive nature of stacking and unifying individual layers, the part and process design is substantially different from conventional production methods. This paper addresses one of the challenging design aspects for additive manufacturing, namely the determination of the build orientation. The build orientation has a large impact on the final part quality and must therefore be chosen wisely. This paper presents an approach to support the build orientation selection by a feature-based design algorithm. After automated part tessellation and the detection of outer part surfaces, the algorithm determines candidate build orientations through a ray-tracing and convex hull method. Candidate solutions are ranked based on minimizing overhang structures, as this also minimizes the need for additional support structures.

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Keywords: Design tools; Computer aided process planning; CAD/CAM; Additive Manufacturing; 3D printing

1. Introduction

Additive Manufacturing (AM), colloquially known as 3D printing, is positioned as an advanced manufacturing technology and as the future core technology for high-value engineered products in European as well as US research agendas [1, 2]. Due to the additive nature of the manufacturing process, it has great potential for producing parts with complex geometries and integrated functionalities. Also, since it is a Direct Digital Manufacturing (DDM) method, individually customized parts can be made with relative ease [3]. The technology is widely applicable to industries, such as aerospace [4], automotive and healthcare [5], but also more general for logistics and maintenance [6]. The interest in AM has gained considerable impetus over the past decade. The development of AM is provided by the needs of industry to exploit the beneficial effects of these manufacturing techniques. Beneficial effects, or competitive advantages, of AM are geometrical freedom, shortened design-to-product time, reduction in process steps, mass customization and material flexibility [7].

In 2010 the American Society for Testing and Materials (ASTM) has standardized AM technology according to seven categories depending on the method of manufacturing each layer [8]. However, in general, 3D design data is used to build up parts by binding raw material, e.g. a fine powder, layer by layer, stacking layers until the full 3D geometry is ready [9]. This is illustrated in Fig. 1 for a powder-bed technology, in which the powder is fused by means of a laser. After fusing one layer, the unfinished part in the build area moves down and a new layer of powder is rolled on top of the previous one. This process is repeated until the part is finished. The powder is only fused together where needed using the part’s computer model directly.

One of the crucial choices during production is the selection of the build orientation. As the build orientation has a large impact on the final part quality, it must be chosen wisely. At present, the selection, let alone optimization, of the build orientation is ill supported by computer tools. It is usually a manual operation requiring professional craftsmanship and operator skills.

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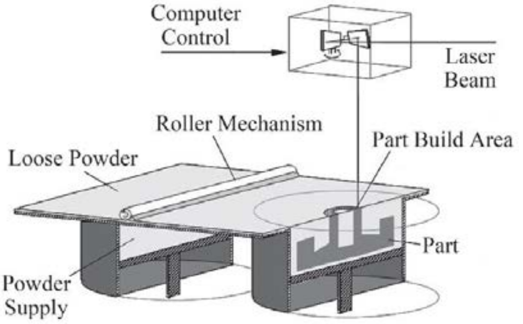

Fig. 1: Layer stacking process for a powder-bed technology [10].

1.1. Design for additive manufacturing

When designing an AM part in general the following 3-step approach is adopted [11]:

1. The part to be produced is modeled on a Computer-Aided Design (CAD) system. The model must be represented as closed surfaces which unambiguously define an enclosed volume. This requirement ensures that all horizontal or vertical cross sections that are essential for AM are closed curves to create the solid object.
2. The computer model is converted to a STereoLithography (STL) file format. This is currently the industry standard for transferring information to AM equipment, although a new Additive Manufacturing File (AMF) format is being promoted. The STL model describes only the surface geometry of a 3D object without any representation of color, material, texture or other common CAD model attributes. The AMF format is indeed capable of handling more than only surface geometry [12].
3. The STL model is prepared to be sent to the AM equipment using a Computer-Aided Manufacturing (CAM) system. This can be a proprietary system and file format, e.g. SLM code. However, some technologies also use an open standard, e.g. G-code. Generally the preparation consists of setting process parameters for the specific AM technology; e.g. build orientation, part slicing, build platform positioning, design of support structures, layer solidification parameters, etc.

In this paper, Step 1 is considered part design and Steps 2-3 are considered process design, and the emphasis is on Step 3 in which amongst others the build orientation is selected.

To exemplify the effects of the build orientation selection Fig. 2 depicts two screw spindles. In both cases the CAD design and STL model of Steps 1-2, respectively, are identical. The only difference is the selection of the build orientation (Step 3). In Fig. 2(a) the build direction was chosen along the axis of rotation. This mend the screw had to be supported underneath the entire rotation. In Fig. 2(b) the build direction was chosen radially. In this case the internal slot, connecting the spindle to the rod, and one side of the screw had to be supported.

These images show that the build orientation selection has an influence on the final part geometry, and thus part quality. Depending on the type of AM technology the exhibited flaws may be different. In this case Fused Deposition Modeling (FDM) was used, causing the first layers to sink in towards the flat bottom plate. This leads to a lower quality of the outer circular shape and internal slot as can be seen in Fig. 2(b). On the other hand, Fig. 2(a) shows the degradation of surface quality on the bottom (supported) side of the screw (see bottom view insert).

a) printed along the axis of spindle b) printed radially

Fig. 2: Effect of build orientation selection for fused deposition modeling.

1.2. Goal and outline

The goal of this paper is to present a framework in which the build orientation selection is automated using a feature-based design algorithm. The developed design tool provides information on the effects of the build orientation. As the algorithm provides relatively quick insights, the tool can be used for build orientation optimization strategies as well. The design tool is capable of ranking candidate solutions based on minimizing overhang structures, as this effect is common among a range of AM technologies. In general, minimizing overhang structures minimizes the need for additional support structures. Consequently better part quality can be attained, as overhang structures typically feature a relatively poor surface quality; e.g. a high surface roughness.

The paper is structures as follows. In Chapter 2, based on a literature study of other researchers in the field, the developed five-step algorithm to support the build orientation selection is presented. In Chapter 3 the algorithm is applied in a case-study example to demonstrate the working principle. In Chapter 4 the design tool is discussed and the future potential of the followed approach are reviewed. Finally, in Chapter 5 the conclusions are presented.

2. Approach

In the last years, a number of authors have proposed different methods for minimizing the amount of support structure by reducing the overall overhang. Allen and Dutta [13] computed the amount of support structure required using a facet normal approach for a given orientation and thus identifying a pool of good candidate orientations. Strano et al. [14] used the same approach but accelerated the computational time by calculating the support at every 5° of rotational angle about x and y axes. This method may not find the optimum orientation, especially when considering very complex structures that typically originate from part topology optimization strategies. Other algorithms use the rendering abilities of GPUs to map the depth value of planes to compute the amount of support volume