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ScienceDirect

Procedia CIRP 50 (2016) 408 – 413

www.elsevier.com/locate/procedia

26th CIRP Design Conference

Considering Part Orientation in Design for Additive Manufacturing

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Abstract

Additive Manufacturing (AM) is established not only in prototyping, but also in serial production of end-use products. To use the full potential of the production technology the restrictions of current additive manufacturing processes (like support structures in Selective Laser Melting) must be considered in the design process. Especially the compliance with design rules from early design stages on is important in AM serial production, due to production quantities and the resulting scale effect. The part orientation in the build space has a strong influence on many quality characteristics. In order to use the full potential and to consider the restrictions from the start, a design guideline is necessary to support the whole design process.

For this purpose, this paper presents a framework for design guidelines. The framework distinguishes between process characteristics, design principles and design rules; each supporting the designer during different stages of the design process. Furthermore, the paper examines the influence of part orientation in existing design rules and elaborates its importance. Based on this result, the design principle "early determination of part orientation" is presented, which includes a process for determining the part orientation in early stage of the design process.

In addition, a design process for additive manufactured parts is demonstrated on an extensive showcase, following the guideline framework and including the principle for early determination of part orientation. The presented framework proved to be helpful in the design process and will be used in the future to collect more process characteristics, design principles and rules.

Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference

Keywords: Part Orientation; Additive Manufacturing; Design Process; Design for Additive Manufacturing

1. Introduction

Additive Manufacturing (AM), or 3D printing - as it is referred to in the media, is a group of manufacturing technologies which produces three-dimensional objects by adding material, usually in a layer by layer process. In the beginning of the manufacturing technologies in the 1980th, the first applications were the production of prototypes. During the following decades the manufacturing technology and materials evolved and nowadays, new fields of application are possible.

Additive Manufacturing processes are technologically mature for industrial production and due to a sufficient process stability and a rising competition between service providers [1] Additive Manufacturing becomes economically feasible for a growing number of industrial and end-user applications [2]. Today there are many different Additive Manufacturing processes available, some of which are capable of serial direct part production. Nowadays, processes like Selective Laser Melting (SLM), Selective Laser Sintering (SLS) and, with some limitations, Fused Deposition Modeling (FDM) are used to produce end-user parts.

The possibility for serial direct part production brought new challenges for industries. To implement new production technologies, companies have to identify suitable parts for AM [3]. Furthermore, the new production process created new possibilities but also new restrictions to the design. Unlocking the design potential of AM is a big challenge, because of the tradition and fixed mind-sets of experienced designers and of course due to the lack of knowledge on the new technology [4,5].

Introducing a new way of thinking to designers can be achieved through design guidelines and training. In particular, it is difficult to obtain support for the designers in terms of design guidelines and design rules of AM. At the moment design rules are mostly presented in academic publications for an academic target audience. There is a challenge to develop a design guideline for AM which can be used in industry and is based on industrial experience.

2. Design Guideline

The knowledge needed for a good design for a specific application is complex and multi-facetted. The different publications of design rules for AM are usually driven scientifically [5] and follow a systematic scientific structure which doesn't necessarily match the workflow of practitioners.

To implement AM Design in the industry, a user-centered structure of the design guideline is necessary to assist the de-

Peer-review under responsibility of the organizing committee of the 26th CIRP Design Conference
doi:10.1016/j.procir.2016.05.016

signer in product development and to overcome reservations against novel production methods. Therefore, the presented design guideline follows product development respectively design process.

A design process can be roughly divided into the stages of task clarification, conceptual design, embodiment design and final design [6,7]. The tasks in each of these stages require a different kind of guidelines to support designers. Based on the needs along the process, the design guideline is divided into three areas: *process characteristics*, *design principles* and *design rules*. These are not exclusively assigned to the individual stages but are rather aligned with the developer's needs.

The multitude of AM processes and materials makes the development of a generic design guideline for all feasible combinations of processes and materials an impossible task, if it is intended to have any practical use [5]. Therefore, the presented design guidelines primarily focus on AM processes for the production of end-user parts, especially on SLS, SLM and FDM. The presented process characteristics, design principles and design rules can be applied to individual processes or even to Additive Manufacturing in general. For reasons of simplicity, this publication focuses primarily on SLM processes.

2.1. Process Characteristics

The process characteristics summarize the basic knowledge on the working principle of a process for the design and should be known to the designer if he wants to design AM components. They describe the characteristics conditioned by the process which have an impact on the design, and, therefore, must be taken into account for the design of AM components. They illustrate the specifics of the process. Thus, for example, the stair-step effect is explained and the need for support structures. The basics on process features of different AM technologies are already available in the literature and can be derived respectively prepared therefrom [2,8].

2.2. Design Principles

Design principles support the designer to transfer a principle solution into a specific, manufacturable design. They enable the developer to exploit AM's freedom of design and to circumvent existing AM constraints creatively. The design principles can range from simple notes to cut costs to recommendations which largely impact the design of parts. They also give instructions to increase part quality or to reduce manufacturing costs respectively post processing effort.

Like in design principles for conventional manufacturing a trade-off between conflicting principles may be needed [9]. In such a case, the designer has to rate the impact and decide which principle is more important to the overall objective of the design.

Design principles are rarely found in literature as they are often based on experiences of developers. There are a few case studies on good AM designs, but those usually don't provide enough background information to extract and refine the experience of the designer from the part design.

2.3. Design Rules

The design rules cover the necessary characteristic facts and figures for designers to design manufacturable components for the AM process. These design rules depend on the chosen manufacturing process, material, machine and machine parameters. Initial reference values for designing parts can be taken from the literature. However for a specific design the characteristic values of the chosen production system are necessary and a communication with the workshop is essential. The design rules includes such values as minimum wall thickness or roughness information which depend on the machine and process parameters.

3. Part Orientation

Part orientation describes the rotation of the part in the build space around the axes of the machine's coordinate system [10]. The term excludes a translation of the part along the coordinate axes of the machine's coordinate system during part positioning [10].

3.1. Significance of Part Orientation for Design

Based on the layer by layer manufacturing process there is a difference between the part geometry in building direction (typically the z-direction of the machine's coordinate system) and the geometry orthogonal to the building direction. The orthogonal shape is produced almost continuous while the part production in build direction is discontinuous in discrete steps of one layer thickness. Furthermore some AM processes require support structures in build direction and the design has influence on the component warping. Therefore the impact of part orientation on the design of the part is significant.

The importance of part orientation is reflected in an analysis of already published design rules. Adam published a design rule catalog to support suitable designs for AM with 55 design rules [11]. The design rules are developed for SLS, FDM and SLM based on a process independent method for developing design rules for AM [12].

In preparation of this contribution we analyzed and classified the design rules of Adam for direct, indirect or no dependence of the part orientation. Design rules with direct request for orientation are added to the direct dependence design rules. The design rules which need a specific orientation to be applicable are classified as indirect dependence design rules. For example the rule on inner radius in simple curved elements provides no instruction how to orientate the inner radius, but it states the minimal radius to build up horizontal holes without support structure in SLM an FDM. Strictly speaking, this is no direct instruction to orientate the element but a dependence on the orientation is clearly stated. Therefore this rule is added to the indirect dependent design rules.

The design rule analysis of Selective Laser Sintering (SLS) shows that over 55% are direct or indirect dependent on the orientation. For SLM and FDM 70% of the design rules depend on part orientation, see Fig. 1.