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Design Strategies for the Process of Additive Manufacturing

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Abstract

Additive manufacturing (AM) is a cyclic manufacturing process to create three-dimensional objects layer-by-layer directly from a 3D CAD model. Today AM processes like SLM and SLS are already suitable for direct part production. The processes have little restrictions regarding the shape of the object. The challenge to a designer is to use the unique characteristics of additive manufacturing in the development process to create an added value for the manufacturer and the user of a product. This paper presents two design strategies to use additive manufacturing's benefits in product development. A manufacturing driven design strategy allows a substitution of manufacturing processes at a later stage of the product life cycle, while a function driven design strategy increases the performance of a product. The choice of strategy has great impact on the development process and the design of components. Two cases are presented to explain and illustrate these design strategies.

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1. Introduction

Additive Manufacturing (AM), or 3D printing as it is referred to in the media, is a group of manufacturing technologies which are capable to produce complex, three-dimensional objects without the need for individual tooling. Since the beginning of the 1980s additive manufacturing evolved from the first processes for the rapid production of prototypes into a number of different processes of which some are capable of direct part production. Today processes like selective laser melting (SLM), selective laser sintering (SLS) and with some limitations fused deposition modelling (FDM) are capable to produce direct parts in end-user quality out of metal or thermoplastics. Additive manufacturing processes are technologically mature for industrial production and due to a rising competition between service providers additive manufacturing becomes economically feasible for a growing number of industrial and end-user applications [1]. From a design perspective the challenge of additive manufacturing is to understanding the limitations and opportunities of these new processes and to use them in the right applications. This paper supports the designer to select a suitable design strategy for the development of new products and the improvement of existing ones.

2. Additive manufacturing processes

Before a designer is able to create a truly additive design he needs to understand the characteristics of additive manufacturing. The common standard of ASTM and ISO defines additive manufacturing as a manufacturing process to produce three-dimensional objects by adding material layer-by-layer. The production is based on a 3D model which is digitally sliced into layers. [2]

There is a growing number of AM processes available with different processes to join material. Each process is limited to one type of material and only few are able to process more than one material e.g. thermoplastics of different color [3,4]. In the last decade the maturity of these processes was largely increased due to research on new materials, development of better equipment and a deeper understanding of the processes which led to robust and stable processes [4]. From an industrial perspective processes capable of producing robust parts with high strength and long-term stability are most

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relevant, because they allow the direct production of end-user parts.

Two processes which meet this requirement are Selective Laser Melting (SLM) for metallic parts and Selective Laser Sintering (SLS) for thermoplastics. Both processes are based on the principle of powder-bed fusion. Figure 1 depicts the cyclic process consisting of applying a layer of powder, solidifying the powder with the energy of a laser beam and lowering the powder-bed for the next layer to be applied.

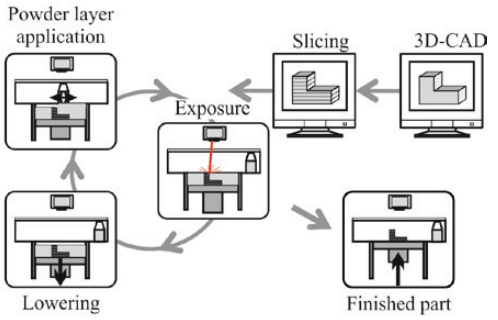

Fig. 1. Additive manufacturing by laser-based powder-bed fusion [5]

Parts produced by SLS and SLM have similar material properties compared to conventional parts of the same material. There is a slight anisotropy between the strength in build direction and the ones in perpendicular directions, but this is usually neglected in design. [6, 7]

Fused Deposition Modelling (FDM) follows a different principle. A thermoplastic filament is extruded through a heated nozzle and placed on the previously build portion of the part. The mechanical properties of FDM parts are highly anisotropic and this should be respected in design. [8, 9]

3. Benefits of Additive manufacturing

The advantages of additive manufacturing as a manufacturing technology mainly derive from the basic principle of adding material in a cyclic process based on a 3D CAD-model without the need for any tools or fixtures. This basic principle has two effects on manufacturing costs.

First of all a complex three-dimensional object is broken down into simple two-dimensional manufacturing steps. Therefore the complexity of the part no longer dominates manufacturing time and costs. The complexity has some influence on the amount of support structures required in SLM and FDM, but it is not as dominant as in conventional processes. This is commonly referred to by the term *complexity for free*.

The second major difference between AM and conventional processes is the limited impact of lot size on manufacturing cost and lead time. Additive Manufacturing is a CAD driven process without the need for individual tooling or CAM programming. Without this upfront investment in production means producing a number of identical parts or the same amount of individual items takes the same effort. This *cost advantage at small lot sizes* allows the production of single parts and mass customization at reasonable costs.

Great expectations were raised in the past on how additive manufacturing will change the landscape of manufacturing [10]. Despite the quality of the produced parts and the growing productivity of the equipment it is unlikely for additive manufacturing to substitute traditional manufacturing processes in general [11]. Instead additive manufacturing is already a valuable extension to existing production technologies. The processes offer an almost unlimited freedom in design and an economic production of individual parts and by this AM helps to overcome the limitations of conventional processes. At the same time additive manufacturing is often more expensive compared to the costs per part volume of conventional processes. The challenge for a designer is to identify parts and assemblies where using the freedom of design creates an added value and by this justifying the additional costs of additive manufacturing.

A literature review reveals a number of different approaches to describe and cluster the benefits of additive manufacturing. Based on example of end products Gebhard (2013) demonstrates the larger freedom in design, which enables the integration of functions and the use of innovative design elements, a simple way of mass customization as well as a way to create novel materials and innovative manufacturing strategies [3]. Wohlers (2013) clusters direct part production into reduction of tooling, agile manufacturing operations, reduction in inventory, decentralized manufacturing, part consolidation, light weighting und lattice structures. He derives these clusters from case studies which also demonstrate that additive manufacturing is already capable to produce industrial goods [4]. Other publications, like Gausemeier et al. (2012) and Uglow et al. (2013), further distinguish the potential benefits of additive manufacturing between different applications or industries[11, 12].

4. From AM benefits to selection criteria

To use the benefits of additive manufacturing it is necessary to identify parts in a product where additive manufacturing's benefits create the most value to the customer. Companies continuously develop their products in order to maintain their market position. The objective behind product improvements or optimizations may vary. Typical examples are an increase of performance, a better efficiency or the reduction of costs.

One possible route to an improved product is a change of production technology. Additive Manufacturing is a young production technology which is deemed to offer new ways in product development. Today additive manufacturing processes are proven manufacturing technologies for serial products for industrial and end user applications [11]. Designers should consider using the advantages of additive manufacturing to create an added value for the user of their product.

Studying cases of successful AM parts and reading about its benefits might inspire designers for new designs, but it doesn't provide guidance in finding the right applications for additive manufacturing within the product portfolio of a company. A designer might even feel swamped by the multitude of possibilities and it clearly is difficult for him to