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Design for manufacturing to design for Additive Manufacturing: Analysis of implications for design optimality and product sustainability

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Abstract

In response to the development of new materials, improved design methods, and increased societal demands to manufactured products, Design for Manufacturing (DfM) concept has paved the way to incorporate these demands into the development of more sustainable products. However, the emergence of Additive Manufacturing (AM) techniques has brought new manufacturing capabilities that are beyond the conventional DfM concept. For this reasons there is a need to rethink design considering the capabilities of these technologies and make smooth transition from design for manufacturing to design for Additive manufacturing (DfAM). In this paper, the possible paradigm shift from DfM to DfAM is analyzed, the impacts on the realization of optimum design, and accommodation of the requirements for product sustainability is assessed. The role that DfM played in previous approaches to product development process and the factors that are the drivers of the DfAM approach are also discussed.

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Keywords: design for manufacturing; design for additive manufacturing; design optimization; topology optimization; product sustainability

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1. Introduction

The development of new materials, improved design methodologies and knowledge based societal demands that appeared in the last decades have enabled the concept of Design for Manufacturing (DfM) to pave the way to incorporate the above-mentioned concepts in the product development or design process. The DfM concept can be defined as design of a product with consideration of manufacturing knowledge throughout the product development process. The main goal of DfM is reducing manufacturing cost and improving product quality [1] by addressing the manufacturing constraints. Parallel with the DfM efforts, designers should also address the issue of optimum design that is demanded by diverse applications. This can be considered as one of the design engineers' paradox. Optimum design is a design process of searching a compromise between the size, shape or topology of a part and utilization of as minimum as possible material while ensuring the overall performance of the part. Optimum design is not fully realized in conventional manufacturing techniques such as turning and milling as they have limitations on manufacturing of complex part geometries [2]. Contrary to the conflict between DfM and design optimization in the conventional manufacturing approach, where not all optimized features can be manufactured, the AM approach, in a way, realizes design optimization. Additive manufacturing is a process of joining materials to make objects from 3D model data, usually in a layer-by-layer process opposed to subtractive manufacturing [3, 4].

Nowadays, a global effort is emerging to implement AM technology in both fabrication of diverse consumable materials and other sectors such as medicine [5, 6]. Among others, this move is expected to remove the huge manufacturability constraint because complex geometry is no longer an issue of the design engineer. In addition to its capability of building complex geometries, it also has other potentials such as building hierarchically structured parts, multi-materials in a single part manufacturing and functionally integrated objects [7]. These capabilities of additive manufacturing makes further move from the conventional optimization for manufacturability to optimization for functionality, enabling parts to have higher performance. Furthermore, the need of the customers for long lasting and environmentally friendly product is dramatically increasing, as the concern of sustainability in all products and services is a current worldwide concern. To cope with this issue, designers are developing and using different approaches to account for product sustainability into the product development process. Sustainable product can be defined as 'a product that gives as little impact on the environment as possible during its life cycle' [8]. Thus, sustainable product design is the product development process in which the environmental issues are accounted for at all stages of the product development phase.

This review article will focus on assessing the possible natural paradigm shift from design for manufacturing to design for additive manufacturing (i.e. transition from DfM to DfAM). It also analyses the implication of design optimality and product sustainability in product development process in the conventional DfM concept and in the emerging DfAM concept. This kind of analysis simplifies the transition from DfM to DfAM for the design engineers and for the product development team at large so that they can benefit from the unique capabilities of additive manufacturing technologies.

The paper is organized as follows: first general information about design for manufacturing concept and its role in product development process are discussed in Section 2, which emphasizes the past and current developments. In Section 3, the need for transition from DfM to DfAM is elaborated followed by Section 4 that discusses the implication of design optimality and then product sustainability in design for additive manufacturing is presented in Section 5. Finally, concluding remarks are given in Section 6.

2. Design for manufacturing

For a long time in the history of product development process, the two broad concepts design and manufacturing were thought separately. As a result, it was very expensive to correct the failure encountered during the product development process later in the manufacturing phase. However, with the introduction of computer-based technologies and the emergence of concurrent engineering approach in the field, design and manufacturing are no longer separate but interrelated in one way or the other, as one cannot sustain alone. In order to ease and make the manufacturing process sustainable, the knowledge and experience of different manufacturing concepts and techniques should be incorporated in the product development process and this is done with design for manufacturing approach. To get the maximum benefit from DfM concept, general guidelines [9] with consideration of conventional