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Process types of customisation and personalisation in design for additive manufacturing applied to vascular models

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Abstract

Manufacturing companies face high demand for products that fulfil individual customer desires. Recent improvements in additive manufacturing (AM) enable the fabrication of customer-specific components of a product.
This paper presents a categorisation of design processes for customised and personalised products through the use of AM in three process types: special design, specific adaptation, and standardised individualisation. The characteristics of design processes are examined in medical development of vascular models integrated into a modular neurovascular training setup. The paper considers how initial customer involvement and preplanning of customer-specification influence the design process for varying degrees of individualisation enabled by additive manufacturing.

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Keywords: Design for additive manufacturing; Customised product development; Personalisation; Design method

1. Introduction

Manufacturing companies are confronted with demand for products fulfilling individual customer needs. Additive manufacturing (AM), as a collective term for layer manufacturing methods, facilitates the fabrication of customer-specific products because of the elimination of tooling, which enables production directly from computer-aided design data [1]. Compared to conventional manufacturing, such as subtractive, joining, and formative processes, additive manufacturing is generally recommended for fabricating products with higher degrees of customisation and/or higher levels of geometrical complexity [2].

The object of this work is the impact of AM in product design when offering customer-specific products and in the resulting design processes. The capabilities of AM are well known and AM is already used for customisation and personalisation, e.g. 17 million customer-specific orthodontic aligners annually fabricated in the dental industry [3]. However, there is a lack of knowledge and methods in design for AM [4] and the potential remains unrealised, particularly in custom part production [3]. The aim of this paper is to present the AM-specific influences on design processes for customisation and personalisation and to present three main process types of individualisation in design for AM. Based on an overview of AM and individualised design, the processes of individualisation in design for AM are described and applied to medical design of individualised vascular models showing the distinct design effort for individualisation.

2. Background

2.1. Additive manufacturing and its applications

Tool-less fabrication, due to the layer-by-layer fabrication of AM, has various possibilities in the product engineering process. Beside Rapid Prototyping and Rapid Tooling, AM is used more for direct manufacturing of end-use parts [1] with three main areas of application [1, 5]:

- High design freedom to either improve functionality and performance through the adoption of internal and external forms or to offer more aesthetics and design features
- Integration of functions and part consolidation to reduce the overall number of parts

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- Individualisation and user-fit requirement to adopt unique shapes and to fabricate small lot sizes economically.

Principles of design for AM are summarized by Rosen, including design ideas that cannot be produced using conventional fabrication methods [6]. The various AM technologies offer their own material and geometry properties [7], with diverse restrictions [5], so that each requires different construction guidelines and design knowledge. It is assumed that the effects of different AM technologies on the design process are comparable, so this work assesses the implications of direct additive production of AM in design without focussing on one specific AM technology.

2.2. Customised and personalised product design

In a buyer's market there is a demand for products that fulfil individual customer needs. Manufacturing companies face the conflict of increasing the external variety demanded by the market while offering competitive prices [8].

The business strategy Mass Customisation aims to fulfil individual customer needs at a cost level that satisfies a large part of the market [9]. Common strategies for Mass Customisation present a compromise between standardisation and pure individuality. Product family design aims for sufficient external product variants combined with manageable internal variety to obtain economies of scale at the component level and to reduce complexity in the development and manufacturing capabilities [8]. It profits from reuse of design elements and modules that are specifically configured for the customer and assembled within a pre-defined product family [10]. One attribute of a modular product structure is "function binding" of each product function implemented within a specific component [11]. A variety-oriented product structure should obtain one-to-one mapping between differentiating properties and variant components, and a minimal degree of coupling of variant components to other components [8].

While the current Mass Customisation strategies have passive and limited customer participation, Mass Personalisation strategies aim to satisfy each customer as an individual with implicit needs [12]. Personalisation is enabled through a high degree of product change, user experience and co-creation, so that the final product as well as the basic design and product structure are changeable, adaptable, configurable [10] and consequently less predictable [12].

As per [10, 12], the term (mass) customisation is used in this work for a design for market segments and (mass) personalisation for regarding each customer as an individual. The term individualisation is further used in this work as a generic term of customisation and personalisation for customer-specific products that satisfy customer needs. It differs from other definitions, where individualisation is equated with personalisation [13]. It is particularly used for products not easily classifiable as one of the two terms. The degree of individualisation increases with early initial involvement of the customer, but has negative effects on delivery time and efficiency [9].

2.3. Design for customisation and personalisation through additive manufacturing

Flexible production technologies support the customer-task-oriented parts of production in allocating high performance and geometric complexity. Thus, AM is an enabler of customised product design [14]. There are multiple applications of AM in customer-specific products, such as patient-specific Aligners in the dental industry and plastic shells for custom in-the-ear hearing aids [3]. The potential of direct AM can be graded by lot size effects and the degree of customisation [15]. Most AM-facilitated customisations are based on user information for body-fitting or for user-relevant geometries [16], as in the customised design of protective face masks [17] and in the design method for the production of body-fitting customised seat profiles using three-dimensional laser scanning, reverse engineering and direct additive manufacturing [18]. Ko et al. argued that personalisation through AM needs to consider design requirements that include customer satisfaction. They proposed a formal framework for a design process for AM-facilitated personalisation that systematically categorises preferable affordances and user behaviours in a numerical way [16]. In another publication, Ko et al. introduced a new representation of design knowledge of Customized Design for Additive Manufacturing [19].

3. Process types of customisation and personalisation in design for additive manufacturing

Additive manufacturing is an enabler of customer-specific product design. The make-to-order environment is the main application of AM for individualisation containing high potential for companies [20]. AM makes it possible to offer high external variety while the internal processes remain lean and standardised. The self-customisation of components in the stock-to-order environment exists as a further personalised design. The customer designs components and fabricates them using AM [21]. The increased number of home-based machines and AM distributors enables the self-customisation of components, which is interesting for consumer products but only has minor influence on the design process.

In the make-to-order environment the levels of individualisation and customer involvement in product processes differs [20]. Three types of design processes are identified through the use of AM in make-to-order individualisation: (1) special design, (2) specific adaptation, and (3) standardised individualisation. The types of individualisation processes differ in degree of customer integration, preplanning of individualisation, and influence on the design process.

In *special design* as a one-off production, a single product is designed and fabricated bases on customer desire. The special design presents the implications of AM in customer-specific design, for example in lamps or medical modelling [21]. Special design is only slightly suitable for Mass Customisation as it is truly custom-made. It has the highest