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METODOLOGY FOR INTEGRATING PARAMETRIC DESIGN IN THE DESIGN FOR ADDITIVE MANUFACTURING

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Abstract Additive Manufacturing (AM) refers to a group of processes that experienced rapid development over the last decade. This enabled their applicability in various areas. Their specific manner of functioning through adding material is the reason why they are so versatile. Still, at the same time, this specific manner of functioning demands a different approach in the design process, the so-called design for additive manufacturing (DfAM). DfAM is an approach based on the principle of the well-known DFM (Design for Manufacturing) and DFMA (Design for Manufacturing and Assembly). The aim of the DfAM is to help designers to adapt more easily to AM and fully exploit its possibilities. One of the most important AM advantages is the fabrication of complex geometries, which is particularly interesting to designers. Regardless of all the advantages, there are some restrictions to the AM processes that need to be taken into consideration in the design process. In this paper, we propose integrating parametric design for designing unique models with complex geometries. Through designing the parameters, we can implement the AM restrictions in the early stages of the design process without affecting the complexity of the shape. Another advantage of the parametric design is the possibility of easy manipulation of the CAD model and a change of the parameters, so that a whole collection of unique products can be created.

Keywords: Design for additive manufacturing (DfAM); parametric design; design process.

1. INTRODUCTION

All Additive manufacturing is a group of processes in which the model is built by adding material in layers [1]. This manner of functioning is completely opposite to the traditional manufacturing processes. One of the key opportunities stands in the AM's flexibility potential [2, 3]. While other technologies impose strict technological or economic constraints on the production of variants, AM offers an unprecedented level of freedom in this regard [4, 5]. AM processes are well-suited to customized products and small-series production down to lot size one [6], and, at the same time, they lower the overall manufacturing cost. AM's main capabilities and advantages include the following: shape complexity, hierarchical complexity, material complexity and functional complexity [4]. This creates new opportunities, but also, at the same time, poses challenges when designing for AM.

1.1. Design for Additive Manufacturing (DFAM)

Freedom offered by AM can be treated as a threat for the industrial design, caused by the lack of structured procedures and tools to easily adapt the new technologies [6]. When it comes to these structured procedures and tools, few studies were published concerning the breakthrough into the designing process [7]. Bourell et al. [8] suggest developing new design methodologies dedicated to additive manufacturing and inspired by the Design for Manufacturing and Design for Assembly; they call it DFAM. DFAM is a methodology which tends to maximize product performance through the

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synthesis of shapes, sizes, hierarchical structures, and material compositions, enabled by the AM technologies [4]. Laverne et al. [9] suggest an extension of this definition to the tools that support the DFAM methodologies. According to them, DFAM is a set of methodology and tools that help the designer to take into account the specificities of additive manufacturing during the design process.

1.2. CAD modelling

The opportunities occur in the form of freedom for complex shapes creation, allowing the designers to set their imagination free in the design process. The first steps in the concept generation phase are the most creative; the designer imagination is at the highest level and there are no obstacles. In the next step, sketches need to be transferred to CAD software. This is the moment when designers usually encounter difficulties. The reason is that the available CAD software packages are designed to address the needs and requirements, but also restrictions of the traditional manufacturing processes. This means that the working principle should be changed, but, more importantly, flexibility in the form creation should be enabled [4]. The challenges that the user encounters with CAD can be stated as: geometric complexity, physically based material representations and physically based property representations [4].

Yang and Zhao [10] classify contemporary design tools (different modelling software) for AM into four groups, depending on their main characteristics. The first group consists of systems (i.e., Geomagic Design [11] and Meshlab [12]) intended for point cloud (received from 3D scanning) editing. The second group consists of solid based CAD systems (Solidworks, CATIA), which, although they use parametric modelling, still follow the rules of modelling for traditional manufacturing. The third group contains systems that are intended for process-oriented design (i.e., Magics). These kinds of systems are mainly used to check the model's manufacturability; they are not intended for modelling. These three types of design systems enable modelling, visualization, mesh, and converting of the 3D model into STL files, which is important for the transformation from conceptual ideas to implementable files for AM systems. Nevertheless, with the growth in the number of physical features and the increase in the hierarchical order of magnitude, conventional solid-modelling-based systems run slowly and consume too much memory. Another problem is the difficulty in manipulating the interior volume to form internal structures in the AM design. Since the possibilities of software's part of the presented three groups do not satisfy the needs of designers when designing for AM, new design tools have emerged in recent years. The design tools of the fourth group come across the problems that the tools from the first three groups cannot solve. They propose a new way of designing which exploits the AM's advantages. In this group, two main courses can be identified: topology optimization (i.e. HyperWorks's Altair [13]) and lattice structure. The topology optimization solutions are based on the finite element analysis in order to optimize the use of material and final design output. In spite of that, the lattice structure software or modules generate cellular structures in the predefined model shape. These design tools change the design process and the design approach involving the designers in the early stages to think about the AM considerations and manufacturing. This is an appropriate approach when designing for AM, as stated previously. However, one key ingredient is absent in the working process with these tools and that is designer's creativity. These tools do not help the designer in the modelling phases of creating more complex and organic shapes. Friesike et al. [6] have an interesting approach in the design for additive manufacturing in order to increase creativity and productivity. At the moment, designers are left to their own devices in CAD modelling to find alternatives. They often use CAD software intended for animation since it allows for better surface modelling but that can result in an inappropriate STL file

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(not closed boundaries). Hence, this kind of software should be used with caution and the file should be verified before slicing and sending it to the machine. At Loughborough University, researchers work on the development of new software as an appropriate answer to the AM development [14], [15] and its opportunities for application in customization and personalization [16].

In this paper, we propose the use of software for parametric or algorithmic software for the design in AM. With parametric modelling, the designer can combine mathematical equations in order to create rhythmic and complex shapes. This offers multiple possibilities: with parametric models, a whole series of unique models can be created without the need of additional modelling.

2. METHODOLOGY

The research methodology proposed by Gibson et al. [4] is used in the paper. The methodology is designed so that it can be applied for designing various products for AM. As implied by [4], the proposed DFAM methodology includes the design process, concept generation, solid modelling and process planning. All the elements have the same level of importance and all of them should be taken into consideration. The most important characteristic of this methodology is that process planning should be a part of the design process. The design process starts with problem synthesis, using an existing problem template. According to the problem definition, different interconnections of elements are made. Figure 1 presents the model that we propose for the implementation of parametric design in the DFAM.

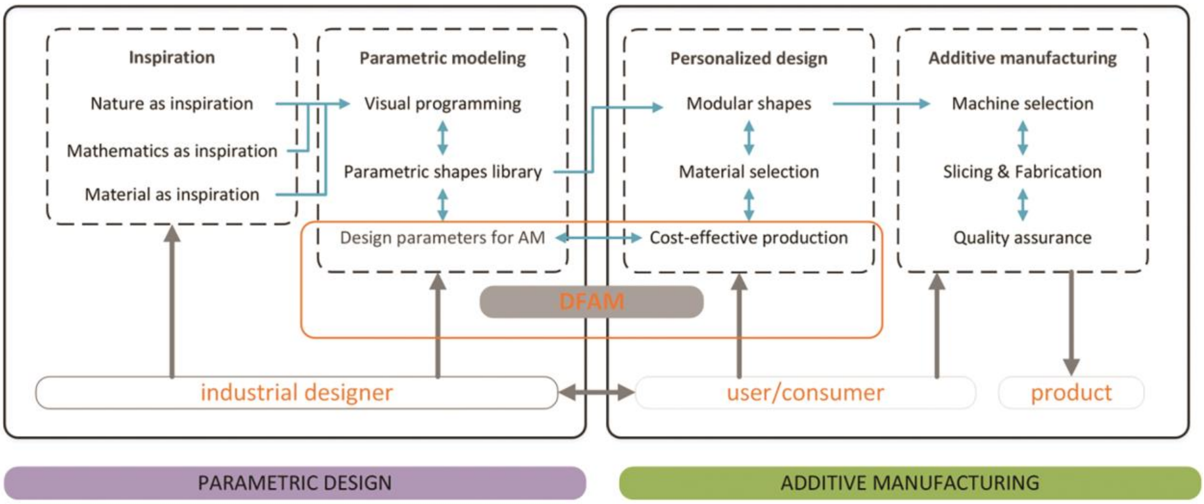

Figure 1. The proposed model for the integration of parametric design in the DFAM.

3. PARAMETRIC DESIGN

Abdullah and Kamara [17] propose the procedures for parametric design in order to increase the idea generation in the conceptual phase. Dean [18], [19] uses parametric and generative modelling to fully exploit the AM's possibilities and to offer personalized products to users. The design studio Nervous Systems offers an interesting approach, by applying parametric and generative design to their products inspired by nature [20].

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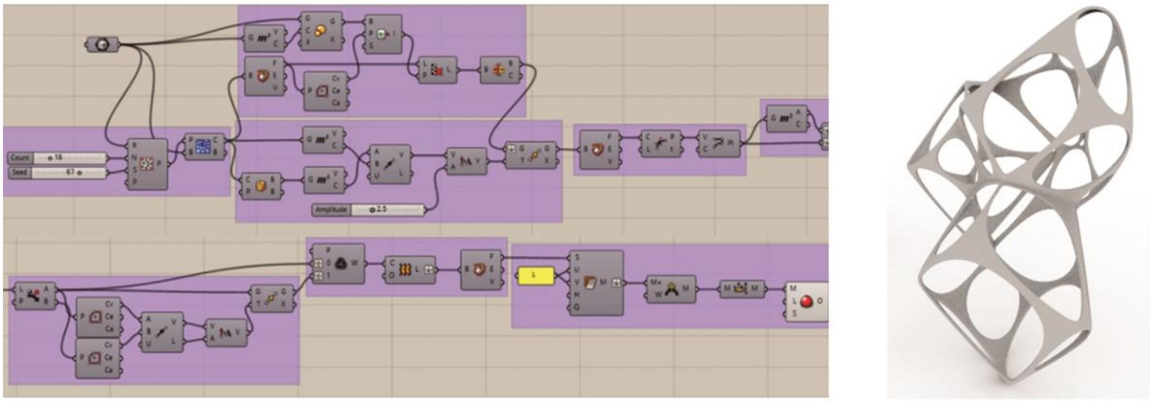
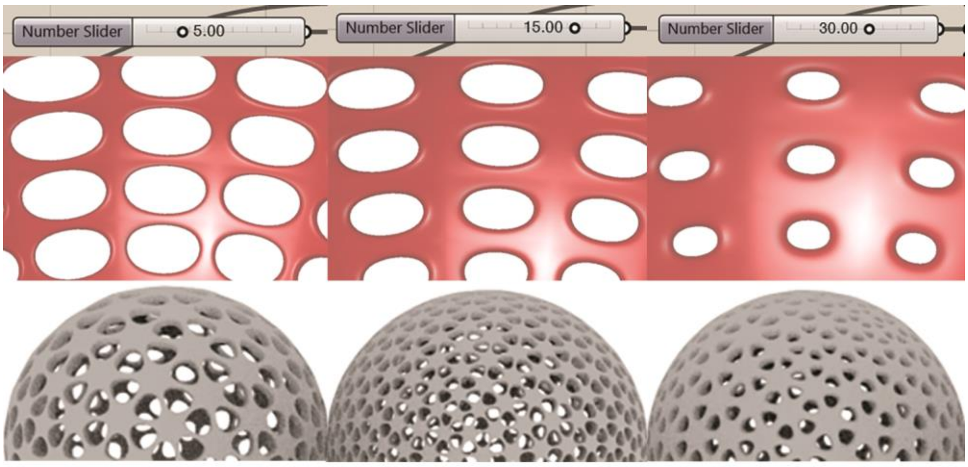
Rhinoceros and its visual editor Grasshopper were used for parametric modelling. The possibilities offered by the combination of Rhino and the Grasshopper provide an adequate response to AM requirements [21]. Rhino is used for modelling complex freeform shapes, while Grasshopper is utilized for additional mathematical modelling or even programming [22]. Still, Grasshopper on its own can be used for the modelling of the whole part. Rhino offers more subtle and straightforward options for freeform modelling. In Figure 2-a, the algorithm for one model is presented. With simple manipulation of the already created algorithm, multiple variation of the initial model can be created. In Figure 2-b, one variation of the model is presented.



a) the Grasshopper algorithm b) one variation of the model

Figure 2 (a,b). The algorithm created in Grasshopper for complex voronoi structure [23].

Figure 3 presents the sphere model so as to demonstrate the creation of different variations with the change of one parameter. In order to create variance with less resemblance, several parameters can be varied. In the example shown in Figure 3, the parameter for the space between the holes has been varied.



a) variation #1 b) variation #2 c) variation #3

Figure 3 (a-c). Variation in output depending on one parameter of the sphere model.

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4. RESULTS AND DISCUSSION

It has been proved over time that parametric modelling is a great opportunity to create complex shapes. Additionally, it is a very powerful tool in the concept generation phase. In this paper, we have aimed at proving that it is also an appropriate solution when designing for AM.

Figure 4. Example of shape modification on one model.

Using parametric modelling, dsigners create the initial shape of the parameterized model, which can be modified using the parameters in order to explore the options (Fig. 3, Fig. 4). The first model from Figure 4 was manufactured using the machine for fused filament fabrication (FFF) in order to check the quality of the model and manufacturability. FFF is one of the most often used AM processes. The models are designed as polygonal mesh, which is the most suitable for STL conversion. The STL file is the universal file format needed for the AM processes. The parts are fabricated using different methods, as shown in Figure 5. Different methods and process parameters are applied in order to find the most suitable one.

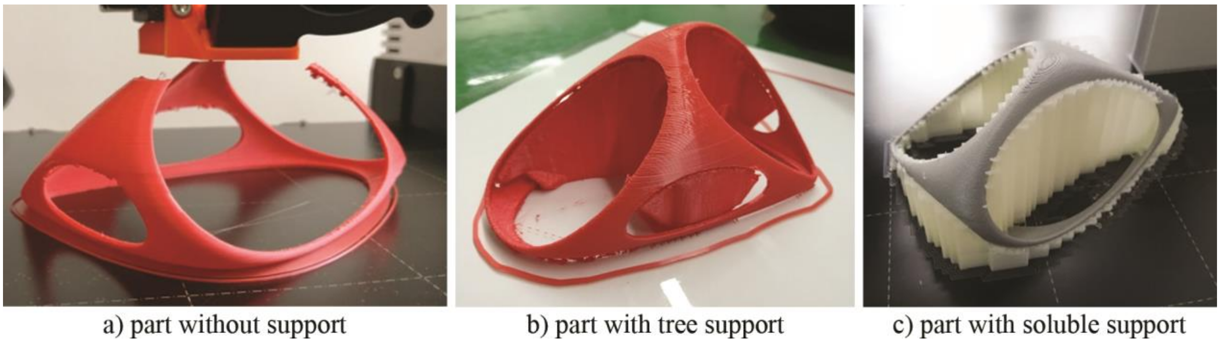

Figure 5 (a-c). Different fabrication methods using the FFF machine [23].

The changes in the suppot material options affect printing time and the used material, but, at the same time, surface quality as well. In Figure 5-a, the model was manufactured without the support material and printing time was four hours. In comparison, printing time of the second option, with three supports (Figure 5-b), is eight hours, which is double. In the last option, fabrication with the soluble support material, printing time is 12 hours. It is important to mention that the parts were fabricated using the FFF machine with one extruder. If there had been two extruders, printing time would have been decreased.

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a) part without support b) part with tree support c) part with soluble support

Figure 6 (a-c). Manufactured outputs using different parameters [23].

In Figure 6, outputs of the fabricated parts obtained by using differet methods are presented. All models were manufactured on the same machine, using the same material – only working parameters were modified. The results are satisfactory, although the best results regarding surface quality are achieved with the use of the soluble support material.

Still, the main purpose of this paper has been to check whether the parametrically designed model is suitable for this purpose to be manufactured using AM. Based on Figure 6, it can be concluded that the models designed parametrically as a polygonal mesh are an appropriate solution for AM and the printed result is fully satisfactory.

5. CONCLUSION

On the basis of the findings presented above, it can be concluded that parametric modelling is an appropriate tool for the designers to use when designing forms in AM. This kind of modelling gives the designer the freedom that he/she needs and, at the same time, exploits the possibilities of the AM technologies. As stated previously, there are other software solutions that exploit the possibilities of AM, like topology optimization software or lattice structure modelling, but they restrict designer's creativity.

In this paper, we used Rhino's Grasshopper, since if offers multiple modelling techniques. At the same time, openness of the plug-in allows for the creation of individual modules and components or the use of the third party components. This flexibility enables numerous different applications for any type of design or product.

Additionally, there is always an option to use multiple software solutions for one model. This means that the initial shape of the model or one component can be designed in one software package and the more complex operations, such as panelling or morphing, can be done in the software for parametric design.

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