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Smart Manufacturability Analysis for Digital Product Development

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Abstract

Cloud-Based Design and Manufacturing is a service-oriented networked product development model in which service consumers are enabled to configure, select and utilize customized product realization services ranging from computer-aided engineering software to reconfigurable manufacturing systems. So far, this paradigm has mainly been tested for digital design and fabrication processes including the usual steps of designing an artefact with a CAD system to then have a prototype manufactured with a 3D printer. Unfortunately, a common mishap that can often be observed is that artefacts that look perfectly fine on the CAD computer screen come out severely misshaped on the 3D printer. In this paper, we first investigate and document this phenomenon and explain its root cause, which concerns a) the data transmitted to the 3D printer, b) inappropriate design features, and c) a mismatch between geometry requirements and printer capabilities. As more and more entrepreneurs, hobbyists in maker communities, and other not always fully trained individuals pursue their design and make ideas, there is a need for smart computer-based support to facilitate a successful design-to-print process. Such a digital DfM assistant might pop up to prompt a designer to modify identified critical areas of the design so that it can be printed with a chosen printer or alternatively propose another type of printer that may have the technical capabilities to accommodate the design in its current form. Acknowledging this need, we propose a two-stage smart manufacturability assistant. The first stage decomposes the digital model into a series of part features; the second stage of the model involved defining the capabilities of the 3D-printer. Finally, we begin to realize this manufacturability assistant by creating and evaluating a bespoke test part which can be used to define a machine-material capability map for an example FDM process.

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1. Introduction

Cloud-Based Design and Manufacturing (CBDM) refers to a service-oriented networked product development model in which consumers are able to configure, select and utilize customized product realization services such as computer aided design (CAD) software and distributed reconfigurable computer aided manufacturing (CAM) platforms [1].

Advantages of CBDM include ubiquitous access to design and manufacturing resources, less maintenance cost and attractive pay-as-you-go price structures. CBDM makes it possible for individuals to develop products which would typically require vast initial capital investment at a comparably low cost.

A further advantage of increasing numbers of cloud-based CAD/CAM platforms is that the barrier to entry for entrepreneurs or hobbyist consumers within the extended maker communities and hence society as a whole decreases. There is also a noticeable general trend toward adopting low-cost desktop 3D printers with currently over 300 companies producing fused deposition modelling (FDM) printers with a consumer spend of $173.3M each year [2].

Whilst additive manufacturing (AM) has many advantages as a manufacturing process including cost being mostly independent of complexity and the ability to manufacture complex hierarchical structures [3], there are still many obstacles to overcome before AM becomes a *'click-and-print'* technology.

Understanding the intricacies of the process is required to optimize print quality and reduce the number of unsuccessful prints. Furthermore, a designer must also understand the limitations of a selected 3D printer to ensure that the features

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that are designed within the CAD environment are producible in the physical world.

In this paper, the use of cloud-based smart manufacturability assistants will be explored as a method of decreasing the knowledge required to produce AM realizable designs, with the hope of reducing the amount of wasted material and associated incurred cost from failed prints.

2. Background Work

In this section, literature on digital manufacturability analysis will be reviewed. Additionally, the limitations associated with the FDM process will be discussed.

2.1. Digital Manufacturability Analysis

Traditional Design for Manufacturing (DfM) methods use feature-based decomposition to analyze the manufacturability of defined features on a CAD part. However, for AM this type of approach is no longer relevant as many 3D prints move away from a feature based definition towards organic geometries.

A number of authors [4–6] have attempted to create design guidelines for the FDM process which aim to guide the user in designing parts that can be manufactured. However, these design guidelines are often cumbersome and require technical expertise to translate them back into the realm of the digital CAD model. They are often process-specific and not detailed enough to cover the intricacies of machine-material combination guidelines. This is a large oversight given that the FDM process covers machines ranging from hundreds to tens-of-thousands of dollars and machine capabilities can vary substantially [2].

Several authors have attempted to transform these guidelines into usable approaches that help assess the manufacturability of a designed part. Kerbrat et al. [7] used an octree decomposition on a CAD model to establish areas of the part which would be challenging to manufacture using both additive and subtractive technologies. Ranjan et al. [8] exploited a graph-based method to develop a manufacturability index for a part based on the geometry of a sliced .STL file input. Nelaturi et al. [9] established a printability map for 3D geometries using techniques from mathematical morphology. This process allowed the authors to specify a print resolution and determine the manufacturability of features such as thin walls, protrusions and holes.

An example of a cloud-based 3D printing assistant was proposed by Rosen et al. [10]. The assistant allowed users to upload .STL files which were subsequently examined for areas with thin regions and small features. If small features were detected, the failed regions were highlighted to the user. Whilst this system provided a good example of a cloud-based manufacturability assistant, it lacked the specificity to analyze prints based on material-machine print data which would cater the manufacturability analysis to individual users.

Further work is required to increase the performance of cloud-based manufacturability assistants that can assess the manufacturability of parts based on machine specific information.

2.2. Errors in the Digital Model

The .STL file format has become the de-facto standard for 3D-printing technologies. This format approximates the surfaces of the CAD model with triangles. With simple part geometries, the .STL file is normally exported in an error-free form suitable for 3D printing. However, if the geometric complexity increases then occasionally the .STL file will require further processing (fixing) before the design can actually be printed.

.STL files exhibit a number of potential issues including missing facets, degenerate facets, overlapping facets, and non-manifold topology conditions [11].

A key requirement of a digital manufacturability assistant therefore must be to ensure the mesh is error-free before providing further insights with respect to the general manufacturability of the design.

2.3. FDM Process Limitations

Due to the nature of the FDM process, there are many reasons why a CAD part is not necessarily representative of the final product. One example of this occurs when the starting and stopping locations of the deposition process occur in the same location. If the start and stop positions are in the exact same (x,y) location for each z-increment, then a 'seam' is created, causing a geometric defect as shown in Figure 1.

All layered manufacturing processes require the digital model to be divided into slices before the part can be manufactured. These slices then form the basis of a material deposition plan for the part [12]. Slices can contribute to several errors that occur when comparing the original CAD model to the printed file. One example, termed the stair-stepping effect occurs when the discretized contours of the 2.5D layers are printed. This phenomenon can significantly reduce the surface quality of the design.

2.4. Geometry Requirement and Printer Capability Mismatch

To generate digital models which can be manufactured, the designer must first understand the capabilities of the target machine. Overhanging faces that occur within the design can be self-supporting if the angle between the feature and the base plate is below a certain limit. This limit is approximately 45° for ABS material however, different materials and machines will have different values. Dimensional accuracy is also an issue with FDM technology. It is typical that tolerance settings selected within the machine software are not always capable of being manufactured.

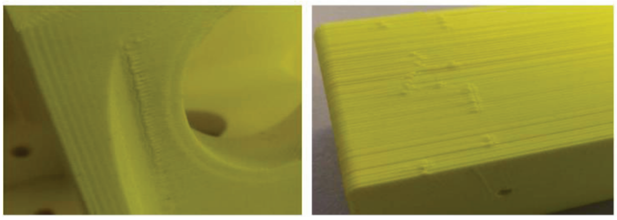

Fig. 1. Seam caused by stop-start error in 3D-Printing.