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Development of software tool for cellular structure integration for additive manufacturing

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Abstract

Cellular structure is one of the solutions for producing parts in a more resource efficient way by reduction of material and time used. Recent advances in Additive Manufacturing (AM) have enabled these complex structures to be built while it is almost impossible by subtractive manufacturing. However, modelling process is resource intensive and time consuming due the geometrical complexity. This article presents development of a software tool for rapidly modelling the structures with prefabrication hybrid geometric modelling (P-HGM) method based on a hybrid B-Rep approach. The structure will be integrated to the specified volume in the base 3D model with polygonal approach. Open-source libraries, including OpenCascade Technology (OCCT) and Visualization Toolkits (VTK), are used.

Keywords: Cellular Structure; Additive Manufacturing; Sustainable Manufacturing; Rapid Prototyping; CAD; Hybrid B-Rep; Geometry modelling

1. Introduction

1.1. Cellular structures and additive manufacturing

Resource efficiency is one of the key considerations in sustainable manufacturing. Additive Manufacturing (AM) is considered a possible option that is able to build parts which optimal designs. Due the manufacturability, complex geometry can be built as the AM builds parts by adding material layer by layer. The design can be optimised in many ways. These days, cellular structures have been brought into attention due to the manufacturing capability of AM. Cellular structures are one of the solutions for reducing material and energy usage. According to the geometry of unit cells and space between them, material usage can be reduced while the parts remain functional.

Cellular structures are complex geometries consisting of a large number of *unit cells* joining with a repetitive pattern. The properties of the structure are determined by the geometry of the unit cell. Cellular structures are generally used as support structures in additive manufacturing. They can also be used to modify certain parts of models to achieve specific properties - namely *stiffness*, *strength*, *compliance*, *thermal*, *dynamic*, and *visual* - which can be determined by the geometry, dimension, and arrangement of the cells [1].

1.2. Problem in modelling and design

According to 3D modelling and representation, two types of techniques, namely *Boundary Representation* (B-Rep) and *Stereo Lithography* (STL), are involved.

B-Rep is a well-established technique for solid geometry modelling that is commonly used in Computer Aided Design (CAD) software. The geometry and topology of the model can be formulated by defining mathematical functions with limits and constraints. For STL, it is known as a standard format for AM. STL represents a model with a surface geometry which is a collection of polygons connected to each other.

The problems in design and modelling arise due to the complexity of the structures regarding the following aspects, *size, parameterisation, manufacturability, precision and validity* [2, 3]. B-Rep can be modified and parameterised easier than STL. However, STL is capable of handling highly

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complex geometry more efficiently than B-Rep. [4] proposed Hybrid Geometry Modelling (HGM) method that resolves those problems. The unit cell of the model can be parameterised with B-Rep technique before constructing the entire structure and storing as STL. For generating structures with a large number of cells, the performance is improved in Prefabrication Hybrid Geometric Modelling (P-HGM) method [2] (see Section 3.1).

1.3. Cellular structure integration techniques

Much research focuses on the cellular structure generation methods transforming entire base models to cellular structure. [2] used P-HGM to generate uniform large scale uniform structure. [5] used HGM to generate the structure conforming with the base part that is limited to parametric models. [6] used Genetic Algorithm to generate the cellular structure over the entire base part. [7] proposed hierarchy computational models that pack cells along the hosting surface.

Little research has been conducted on the integration process. None of them worked on the automatic approach that integrates the structure to selected areas. Modelling parts with cellular structure integrated in B-Rep and convert to STL is achievable but expensive. Software tools [8-11] that work with polygonal or mesh models directly are more suitable. The structures can be generated automatically but the integration process still needs to be done manually with a number of steps (see Fig. 2(a)).

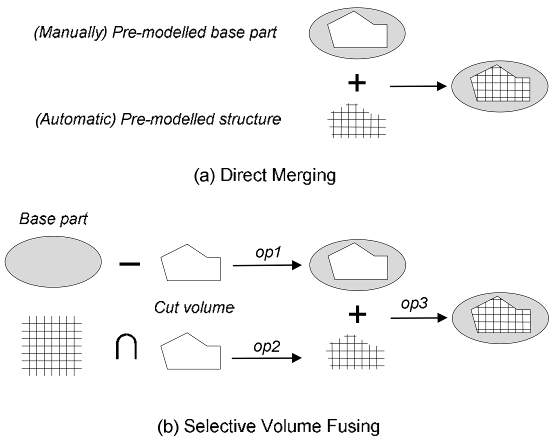

Fig. 1 Surface Boolean operation for part integration

The parts need to be pre-modelled separately and then merged. The volume that will be substituted by cellular structure is manually removed; while the part cellular structure volume can be defined and automatically generated.

1.4. Scope and overview

In this research, the ultimate aim is to develop design software that is able to optimise the design by using cellular structure considering the functional requirement and resource efficiency. The research consists of three development parts; *Phase (1)* - methodology for efficiently generating cellular structure; *Phase (2)* - methodology for automatic integration; *Phase (3)* - methodology for physical properties analysis of the cellular structure integrated parts.

This article focuses the development in Phase (2). An advanced and automatic integration method based on Selective Volume Fusing (SVF) [12], a procedure that facilitates the automatic integration, is presented. A software tool for generating cellular structures and integrating them to the base geometry is developed without considering physical properties of the resultant parts.

This article is organised as follows. The framework of the software tool is presented in Section 2, the methodology in Section 3, implementation and case-study in Section 4, and discussion and conclusion in Section 5.

2. System framework

2.1. Software and libraries

Free Form Design^{TM} (FFD) is a 3D modelling software tool designed for non-experienced CAD users [13]. The cell *cellular structure integration* (CSI) module is developed on FFD platform that is developed in C++ with two libraries. (1) *Visualization Toolkits* (VTK 6.0) [14] is a computer graphic library used for visualisation and modifying surface models, *vtkPolyData*, that can be directly converted to *STL*. (2) *Open Cascade Technology* (OCCT 6.7.1) [15] is a software development kit for solid modelling. The functions are used for geometry modelling in B-Rep. In FFD, B-Rep and STL formats are interchangeable in order to integrate OCCT with VTK (see overview, Fig. 2(e)).

2.2. Cellular structure generation module (CSM)

CSM generate a cellular structure with particular unit cell. The structure is generated rapidly with *P-HGM* [2] (see Section 3.1). The unit cell is modelled in B-Rep with OCCT. The entire structure is created by populating the unit cell by using VTK with polygonal surface model.

2.3. Cellular structure integration (CSI)

CSI integrates the cellular structure generated by CSM with a base part. The proposed method, SVF (see Section 3.2), is used to replace specified volume of the base part with the cellular structure. This process is based on surface Boolean operation of polygon model performed by VTK that can be exported to STL.

3. Methodology

3.1. P-GHM

This section presents a 3D modelling method, P-HGM, hybrid B-Rep – polygonal surface modelling technique that rapidly generates cellular structures. Performance of P-HGM regarding the generation speed is higher in comparison to HGM [4]. The key advantages of HGM are the flexibility in modelling and the minimal computation resources needed in cells joining process that is used for constructing the complete structure. Regarding the joining process, instead of using surface Boolean operation which is a resource intensive