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Multi-objective Optimisation in Additive Manufacturing

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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Abstract

Additive Manufacturing (AM) has demonstrated great potential to advance product design and manufacturing, and has showed higher flexibility than conventional manufacturing techniques for the production of small volume, complex and customised components. In an economy focused on the need to develop customised and hi-tech products, there is increasing interest in establishing AM technologies as a more efficient production approach for high value products such as aerospace and biomedical products.

Nevertheless, the use of AM processes, for even small to medium volume production faces a number of issues in the current state of the technology. AM production is normally used for making parts with complex geometry which implicates the assessment of numerous processing options or choices; the wrong choice of process parameters can result in poor surface quality, onerous manufacturing time and energy waste, and thus increased production costs and resources. A few commonly used AM processes require the presence of cellular support structures for the production of overhanging parts. Depending on the object complexity their removal can be impossible or very time (and resources) consuming.

Currently, there is a lack of tools to advise the AM operator on the optimal choice of process parameters. This prevents the diffusion of AM as an efficient production process for enterprises, and as affordable access to democratic product development for individual users.

Research in literature has focused mainly on the optimisation of single criteria for AM production. An integrated predictive modelling and optimisation technique has not yet been well established for identifying an efficient process set up for complicated

products which often involve critical building requirements. For instance, there are no robust methods for the optimal design of complex cellular support structures, and most of the software commercially available today does not provide adequate guidance on how to optimally orientate the part into the machine bed, or which particular combination of cellular structures need to be used as support. The choice of wrong support and orientation can degenerate into structure collapse during an AM process such as Selective Laser Melting (SLM), due to the high thermal stress in the junctions between fillets of different cells.

Another issue of AM production is the limited parts' surface quality typically generated by the discrete deposition and fusion of material. This research has focused on the formation of surface morphology of AM parts. Analysis of SLM parts showed that roughness measured was different from that predicted through a classic model based on pure geometrical consideration on the stair step profile. Experiments also revealed the presence of partially bonded particles on the surface; an explanation of this phenomenon has been proposed. Results have been integrated into a novel mathematical model for the prediction of surface roughness of SLM parts. The model formulated correctly describes the observed trend of the experimental data, and thus provides an accurate prediction of surface roughness.

This thesis aims to deliver an effective computational methodology for the multi-objective optimisation of the main building conditions that affect process efficiency of AM production. For this purpose, mathematical models have been formulated for the determination of parts' surface quality, manufacturing time and energy consumption, and for the design of optimal cellular support structures.

All the predictive models have been used to evaluate multiple performance and costs objectives; all the objectives are typically contrasting; and all greatly affected by the part's build orientation.

A multi-objective optimisation technique has been developed to visualise and identify optimal trade-offs between all the contrastive objectives for the most efficient AM production. Hence, this thesis has delivered a decision support system to assist the operator in the "process planning" stage, in order to achieve optimal efficiency and sustainability in AM production through maximum material, time and energy savings.

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