Guest editorial

Special issue: topology optimisation in additive manufacturing

Additive manufacturing (AM) can be defined as the manufacturing layer by layer of parts from digital models. This new route of material processing has gained an increasing attention because of the ability to design complex three-dimensional parts without modifying the processing tool. The growing research activity on AM technologies stands from the viewpoint that several aspects are still not known for engineers and scientific communities from both the technical and scientific sides. Some of these aspects are the qualification of the parts according to standards, the link between the processing and the performance, the optimization procedures for both processing conditions and in-service properties, the response of the additively manufactured parts under severe working conditions, the development of 4 D printed architectures, etc. There is no doubt that AM is now viewed as a new revolution in material processing because it combines a high degree of freedom in design and manufacturability from digital models. AM ranks as one of the major research fronts in engineering and materials science. The exponential growth trend of citations especially since the last two decades and the numerous worldwide events reveal a need to reach a mature state for the technology and to build a comprehensive vision of what AM can achieve. By opposition to traditional ways of manufacturing such as injection molding *(*Pons *et al.)*, the unique step standing between the real part and the computer-aided design (CAD) model is the conversion of the digital model to a set of machine instructions. This is, however, a critical step on which the part performance and the quality of the product depend. By only changing the model orientation or the toolpath strategy, the properties of the printed structure such as its finishing state (roughness, flatness) differ significantly (Han *et al.*).

Among the most promising research routes in AM is the use of automated optimization procedures to improve the functionalities of the AM-based parts (Liu *et al.*). Most of the research effort did not come from scratch as optimization procedures do exist for traditional processing routes *(*Pons *et al.)*. They just make more sense with AM technologies because the digital models that are used to build the AM-based parts can be also exploited to produce numerical models for performance predictions or process optimization (Langelaar *et al.*; Wei *et al. Fundamentals*[...]). This is a strong route in AM development that is, unfortunately, disseminated in a sparsely way within the huge amount of research papers dedicated to AM technologies. This special issues aims at giving it a better focus through a collection of papers that tackles, in its diversity, several challenges related to AM optimization. One of these challenges is the improvement of the performance of technical parts manufactured by AM using numerical models based on finite element (FE) approach (Alshare *et al.*). This type of approaches is generally privileged in many engineering processes to evaluate the performance of technical parts (Alshare *et al.*; Liu *et al.*) and understand the link to the process parameters (Wei *et. al Fundamentals.*). If an FE model is used as a predictor in a direct scheme (i.e. no feedback to the design), the optimization route ends up to manually comparing the performance of several hypothetical designs. Another way of achieving an optimal design without manually tuning the design variables is through the concept of topology optimization. This approach allows the exploration of the design space using gradient-based or stochastic-based algorithms to find the optimal solutions that satisfy the constrains imposed to the design geometry (Rezayat *et al.*; Zhao *et al.*). This approach has a huge success in several applications because the update of the geometry is done automatically based on the result of the FE computation for several virtual designs without the need for manufacturing of the intermediate designs. This concept has a key significance for AM (Vaverka *et al.*; Zhao *et al.*) as there is, hypothetically, no need to modify the constrains to satisfy the criterion of manufacturability. Indeed, the manufacturability of complex designs is not a serious concern for AM because digital models on which the FE model relies are anyway convertible to a set of machine instructions for AM processing. Therefore, the term hypothetically means that topology optimization algorithms have to adapt to some of the specificities of the AM process to be more robust. For instance, complex designs containing overhang structures need a support material to avoid part collapsing during AM processing. Overhang criteria can be added to the list of constrains when building the topology optimization scheme to produce realistic designs of the technical parts (Rezayat *et al.*). Without these added constrains, the prediction of the part performance leads justifiably to an inaccurate result because the modification operated on the CAD model during the slicing step is ignored in the FE model. This inaccuracy amplifies with the increase of geometrical complexity as the weight of the support structure becomes significant and the subsequent load transfer within the part deviates from the result of the prediction.

Speaking of the weight of the support structures, optimization strategies can be complementarily applied to decrease the influence of the support material. This is a subject of mathematical development for topology optimization to achieve a light-weight support structures (Zhu *et al.*; Wei *et al.* (1) Generating Support [...]), to create self-supporting architectures (Wu *et al.*; Zhao *et al.*), or to optimize simultaneously both the targeted design and support material (Langelaar *et al.*). Also, the filling of the solid part itself can be controlled to achieve light-weight structures and this can be performed by adopting the concept of channel design *(*Wei *et al.* (2) Channel design [...]). This is a feasible strategy thanks to the ability of AM to control point by point the core of the part allowing for hollow structures to be designed irrespective of shape complexity. Another topic of interest is handling the uncertainty, which originates from inaccuracies in defining the

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Rapid Prototyping Journal
25/9 (2019) 1453–1454

[DOI 10.1108/RPJ-10-2019-317]

Rapid Prototyping Journal
Volume 25 · Number 9 · 2019 · 1453–1454

loading conditions or material properties (Wang *et al.*). The last ones are primarily driven by the type of the microstructural arrangement generated by AM and the related microstructural defects. If a cellular geometry is taken as an example, the relevant scale is not the beam element size but it is rather the size of sintered powder particles (Wei *et al. Fundamentals* [...]; Liu *et al.*) for SLS (Selective Laser Sintering) or the filament diameter (Zhu *et al.*, Rezayat *et al.*) for FDM (fused deposition modelling).

As a conclusion, the implementation of specific aspects of AM technologies in optimization strategies such as the integration of support material is the bold line that can be understood from the contributions in this special issue. However, much effort is still to be done to improve the development of mathematical models such as for topology optimization. One of the aspects that is to be considered is the use of the slicing models as a basis for the FE computation instead of the CAD models. Such a consideration will allow several key factors to be handled in the prediction such as material anisotropy, discontinuities and defects. Of course, this shift to more realistic models comes at a higher cost. More complexity in FE modelling would mean large computation resources involved and as the related predictions need to be available several times before reaching the optimality, the computation cost becomes a concern.

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