

AI-enhanced design for additive manufacturing of bioinspired, smart and living materials and devices

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Historically, design processes have pursued simplicity of shapes and a certain clarity in the functional structure of all types of products, fundamentally seeking geometries that are easy to obtain through mass-production processes. Thus, the use of geometries with rotational symmetry for turning processes, the design of moldable surfaces with uniform thickness for thermoplastic and metal injection processes, or the use of Eulerian geometries and Boolean operations processable with the more classical computer-aided design (CAD) software toward numerical-control machining, among others, have given rise to multiple design tools focused on simple geometries. Evidently, simplicity is desirable and often leads to safer and more durable products, generally facilitating mass production and offering notable benefits in terms of manufacturing costs and sales prices.

However, additive manufacturing (AM) technologies have emerged radically changing the *statu quo*, enabling the direct fabrication of geometries with an unprecedented degree of complexity thanks to their layer-by-layer processes. When properly leveraged, such geometrical complexity allows for a highly rewarding functional integration and enhances the mechanical, dynamic, thermal, fluidic, and even aesthetic performance of the products under development. AM, through functional integration, can even reduce the number of manufacturing, assembly, and other post-processing steps. In this way, AM -by embracing geometric complexity- can significantly simplify the functional structure and production cycle of all types of products.

Still, since classical design tools have been oriented toward geometrical simplicity, it is necessary to investigate and develop innovative engineering design approaches that facilitate the discovery, creation, design and additive manufacturing of complex geometries, materials and devices, to fully exploit the transformative potential of AM techniques. Due to the complexity of geometries and phenomena involved in the design and additive processing of intricate multifunctional materials and devices, bridging the gap between AI and AM constitutes a promising strategy [1].

Accordingly, this talk aims to systematically present the current and expected synergies between AI and AM for advancing materials and devices with a special focus on the AI-enhanced design and AM of bioinspired geometries, smart or multifunctional materials and engineered living systems. Recent advances from ongoing projects from our team, especially the METALIA and BIOMET4D projects, are showcased.

First, the talk presents the development of a conceptual engineering design methodology based on “constructive dialogues with generative AI” for creativity promotion in connection with AM [2]. This methodology is intended to support the exploration of geometric concepts across different industries by employing the capabilities of new generative AI tools (starting from ChatGPT-4 versions that allow the use of images as complementary inputs to the provided instructions or prompts). It has been demonstrated that using the images obtained by processing self-development CAD designs is helpful for guiding and controlling the generative process to enable more applicable results for designing and crafting novel materials and devices [1].

Second, the implementation and use of taxonomies and ontologies for describing complex geometries and the functionalities of smart [2] and engineered living materials [3] is explained, as well as their applicability to taming generative AI tools for supporting materials discovery and the ideation of biomimetic devices and technologies. Connections with their materialization through additive methods are also explored and discussed. Besides, between the complex AI-generated concepts following *ad hoc* taxonomies, ontologies and codes, and the creation of printable designs (i.e. in standard tessellation language or in additive manufacturing file formats) it is also necessary to put forward advances in “text-to-3D” and “image-to-3D” resources, whose usability for AM is analyzed and compared to algorithmic and generative design approaches.

Third, the development and application of AI tools for predicting & controlling AM and post-processing results, with a clear focus on error minimization, is presented. Usually, AM processes are challenging to simulate because of being intrinsically anisotropic, involving multiple materials, whose properties dramatically change during processing, entailing extreme thermal gradients in the components during crafting, and working with geometries changing along their processing, to cite a few. Furthermore, defects like warping, curling, differential shrinking, delamination or the presence of pores and cracks, among others, are also difficult to predict due to the variety of processing conditions and factors of influence involved. Precisely for these types of problems AI-based strategies may prove successful when classical methods fail. Consequently, a set of algorithms for predicting volumetric and surface defects of additively obtained materials and devices are presented and their initial results examined.

Finally, trends related to the automated generation and (bio)mechanical evaluation of bioinspired geometries and biomaterials for personalized, high-performance and smart or multifunctional medical devices are addressed. While AI may importantly enhance AM-based solutions and lead to more efficient product development processes in a variety of industries, including the medical industry, in which AI methods are expected to contribute to the 3Rs principles [5] and to minimize eco-impacts, it is also essential to present an ethical discussion on AI for AM. For this purpose, the four ethical principles in biomedical ethics [6] (beneficence, nonmaleficence, respect for autonomy and justice) are examined in detail as regards AI for AM and medical devices.

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Figures

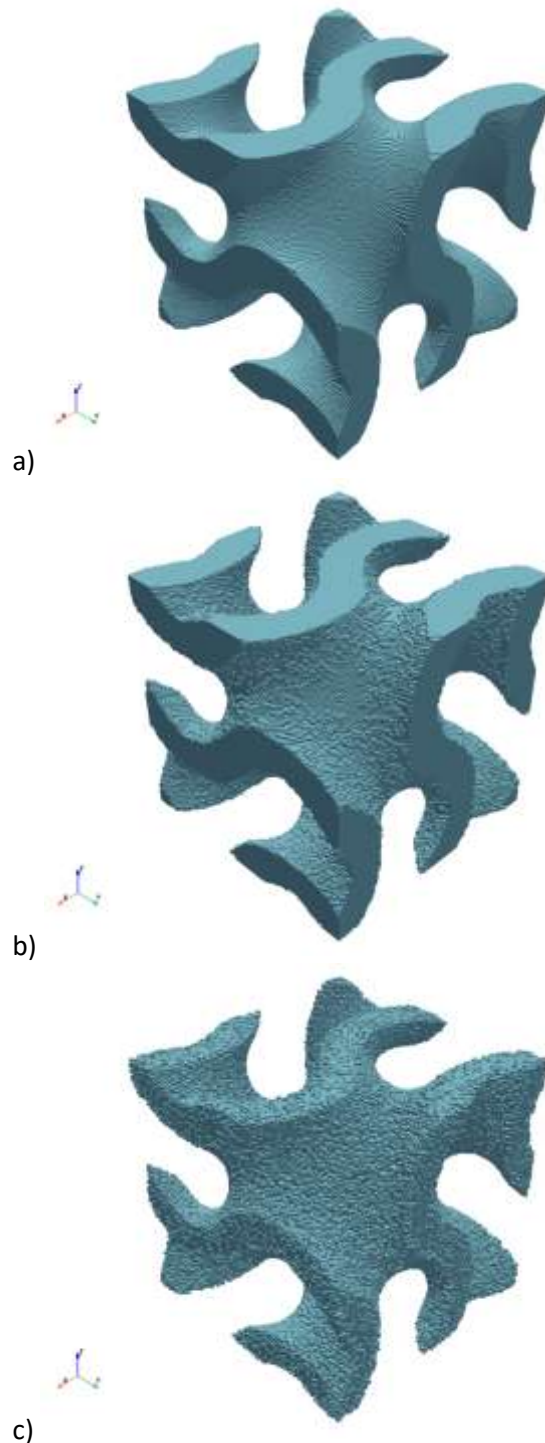


Figure 1. AI-aided prediction of AM defects including: a) voxelated CAD model of the original triply periodic minimal surface unit cell (upper image), b) prediction of increased surface roughness due to adhered powder in laser powder bed fusion (central image), and c) prediction of the effects of a chemical etching as post-process (lower image).