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ADDITIVE MANUFACTURING FROM BIOMIMETIC APPROACH

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Abstract: During the past millions of years since the beginning of our world, nature has created structures that are resistant to the various effects of the environment. However, these natural structures are quite complicated, so their production and artificial reproducibility with the tools of traditional manufacturing technology is a very difficult task. However, even complex structures can be produced relatively easily with the help of additive manufacturing. Using topological optimization techniques, lattice structure models with excellent mechanical characteristics can be created, which can be easily manufactured by exploiting the advantages of additive manufacturing. Applying natural structures (biomimetic approach) during topological optimization and produce the solution by additive manufacturing, light and high-strength structural alternatives can be created, any further structural analyses can be done.

Keywords: *additive manufacturing, lattice structures, biomimicry*

1. INTRODUCTION

The recent development of additive manufacturing (AM) techniques makes it possible to manufacture components with complex structures that cannot be produced with traditional manufacturing methods. Nowadays, when sustainability is gaining more and more importance, additive manufacturing also brings advantages such as shortening the production of the component, reducing energy consumption, and minimizing material waste (Tao & Leu, 2016) (Datta, Vyas, Dhara, Chowdhury, & Barui, 2019) (Plocher & Panesar, 2019) (Hoang, Tran, Vu, & Nguyen-Xuan, 2020). This method offers a new perspective to designers and engineers who use additive manufacturing during their work.

The study presents the relevance of lattice structures and topological optimization (Szabó, 2022) in a biomimetic approach, and also mentions the optimization of lattice structures and the relationship between these methods and biomimetic. Fatigue tests are important for examining the fatigue behaviour, but they can only describe the correlations of the topology's fatigue properties phenomenologically. Since the stress distribution within the structure cannot be determined directly by fatigue tests, fatigue tests are also taking a lot of time and work if a large number of samples are used; so its efficiency is not high enough. (Huang, Wang, & Fan, 2023) Due to the limitations mentioned above, fatigue tests must be used in conjunction with other technologies to gain a comprehensive understanding of fatigue behaviour.

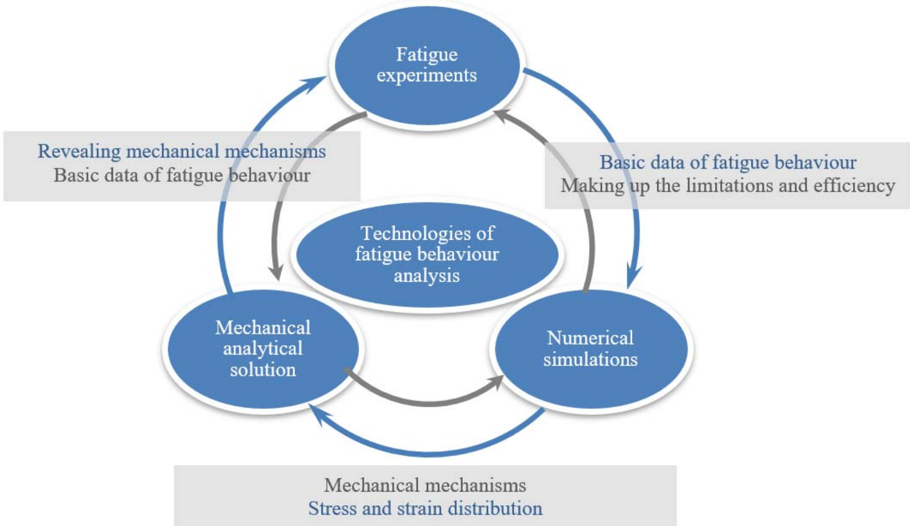


Figure 1. *Analysing methods of fatigue behaviour (Huang, Wang, & Fan, 2023)*

Most traditional manufacturing methods cannot provide the design freedom that AM does, thanks to which theoretical considerations, analytical solutions and computational models are used during design to establish so-called "design-property" relationships, which can be used to predict what topological design is required to achieve a given combination of desired properties. (Alzyod & Ficzere, 2023), (Alzyod, Borbas, & Ficzere, 2023) This often results so complex topological designs that can only be realized with advanced AM techniques.

2. LATTICE STRUCTURES

The development of additive manufacturing techniques has liberated the design of lattice structures by enabling the manufacturability of lattice structures (Voicu, Hadăr, & Vlăs, 2021). Lattice structures are primarily made up of nodes and stiffening elements, which significantly contribute to reducing mass and at the same time maintaining structural integrity (Gibson & Ashby, 1997), (Seharing, Azman, & Abdullah, 2020).

2.1. Mechanical properties of lattice structures

Since the properties of lattice structures depend directly on the shape and structure of the unit cell, each unit cell has different mechanical properties (Libonati, Graziosi, Ballo, Mognato, & Sala, 2023).

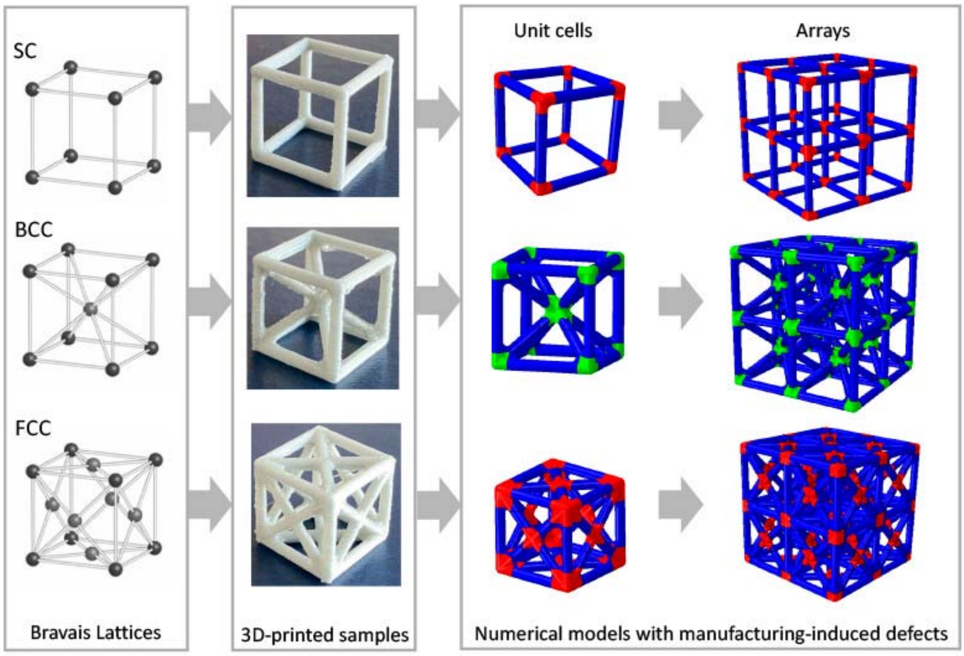
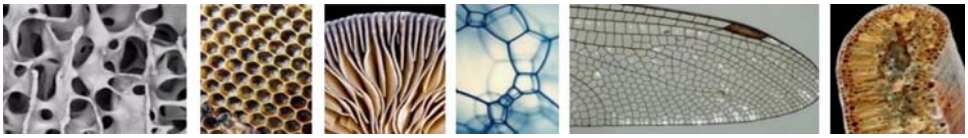


Figure 2. *Examples for building up lattice structures and unit cells (Libonati, Graziosi, Ballo, Mognato, & Sala, 2023)*

2.2. Advantages and disadvantages of grids

Traditionally, lattice structures can be made by casting and sheet forming, however, the manufacturing limitations of these methods greatly affect the complexity of the designed lattice structures. Therefore, with these methods, only a few lattice structures with a simple unit cell topology can be produced, in contrast to the possibilities of AM. The most important challenge for the designer in a construction is the selection of the appropriate variables. The material of the lattice, the cell type and the volume ratio play an important role in determining the structural stiffness and strength. The same applies to other mechanical properties. Since the size affects the mechanical performance, the mechanical characteristics of lattice structures, the smaller the relative density, the greater the size effect (Kladovasilakis, Tsongas, & Tzetzis, 2020).



a) b) c) d) e) f)

Figure 3. *Lattice structure examples in nature*
a) microscopic photon of human bone, b) honeycomb structure, c) fungal mycelium, d) Voronoi structure in bubbles, e) wing of a dragonfly, f) cross section structure of a leaf (Nazir, Abate, Kumar, & Jeng, 2019)

2.3. Manufacturing lattice structures

The development of additive manufacturing techniques, such as 3D printing, has made it possible to create more complex structures when designing lattice structures. Thus, lattices created by AM methods can mimic biomaterials such as bone (Briguiet & Egan, 2020). While 2D extruded fabric-like gratings can be produced by conventional manufacturing methods such as casting, forging, and extrusion, 3D shell/sheet structures can be produced by the AM method, as it enables even complex structural structures to be produced (Nguyen, 2019).

3. BIOMIMICRY

Ideas derived from the biological structures of nature's optimized complex structures have spread widely in the field of additive manufacturing thanks to the latest developments. These structures, which occur frequently in nature, are a source of inspiration for the design of various cell structures that can be used in engineering applications (du Plessis, et al., 2019), (Dömötör, 2005), (Dömötör & Péter, 2012), (Dömötör, 2014). Natural structures are often complex systems of several repeating structural elements. These biological structures can be listed as filamentous, helical, gradient, layered, tubular, cellular, sutural, and overlapping structures, as shown in Figure 3. Nature offers many effective solutions, e.g.: mineralized tubular skeletons from one such species, Euplectella aspergillum (Fernandes, et al., 2021) show very high strength, which results from the hierarchical arrangement of the porous light structure and different geometric structures.

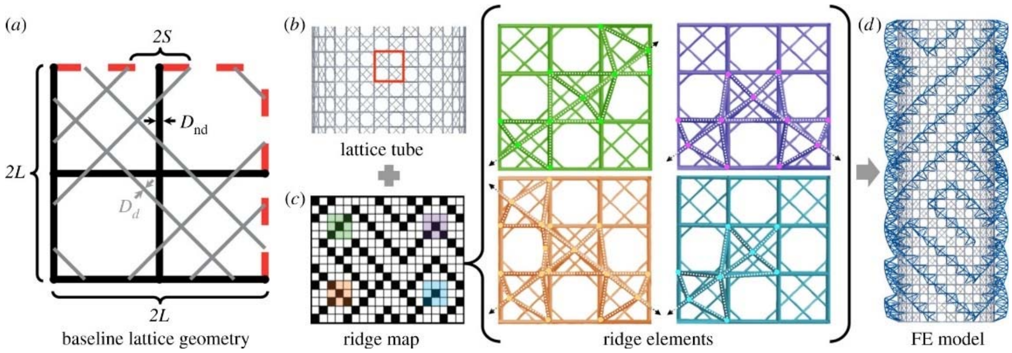


***Figure 4.** Workflow for creating structural models of Euplectella aspergillum:*

(a) schematic drawing of diagonally reinforced square unit cell geometry, to create the tubular grid shown in the figure (b), then (c) mapping of the schemes that make up the different elements used to create the complete lattice structure, and finally (d) modelling the pattern of the FEM model (Fernandes, et al., 2021)

The complex structures found in nature exceed conventional design and manufacturing technologies, hindering the progress of biomimetic studies and their use in engineering applications. AM has created new possibilities for the production of multifunctional structures made of several materials, and the integration of biomimicry will enable breakthroughs in the development of engineering technology in the coming decades (Yang, et al., 2018).

4. CONCLUSION

The mechanisms of natural synthesis need to be further studied to design usable bio-inspired structures in engineering systems. For this, AM manufacturing must be developed together with other technologies so that the mechanisms behind the properties of manufactured parts and the phenomena observed in nature can be explored. It is also important to understand and identify the growth processes that shape matter in nature, which can inspire the search for alternative methods to mimic the natural growth process on a shorter time scale. This way, 3D printing can best approach the growth process and at the same time meet the production timescale in an engineering environment. By understanding these materials and structures, research can provide further insight into methods for replicating these natural structures rather than simply replicating biological structures.

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