Enhancing parametric design through non-manifold topology

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This paper aims to build a theoretical foundation for parametric design thinking by exploring its cognitive roots, unfolding its basic tenets, expanding its definition through new concepts, and exemplifying its potential through a use-case scenario. The paper focuses on a specific type of topological parameter, called non-manifold topology as a novel approach to thinking about designing cellular spaces and voids. The approach is illustrated within the context of additive manufacturing of non-conformal cellular structures. The paper concludes that parametric design thinking that omits a definition of topological relationships risks brittleness and failure in later design stages while a consideration of topology can create enhanced and smarter solutions as it can modify parameters based on an accommodation of the design context.

Keywords: digital design, parametric design, computational models, modelling, non-manifold topology

Parametric design is both misunderstood and over-used. Many who hear or read the term associate it with complex and curved works of architecture. Others may even associate it with a style of architecture or work produced by an architectural office. While many have used the concepts of parametric design thinking to create a certain style of architecture, from a research point of view, parametric design thinking is separate from the outcome that we are witnessing in built works. One can build simple and subtle geometries that have complex parametric relationships among their parts or indeed build very complex solutions based on very simple parametric relationships. Furthermore, one can build works that appear to use parametric design methods, but do not. Given this state of confusion, the larger aim of this paper is to establish a solid theoretical foundation for parametric design thinking and enhance our understanding of it by exploring its cognitive roots, unfolding its basic tenets, expanding its definition through new concepts, and exemplifying its potential through a use-case scenario.

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To achieve this aim, we offer our definition of parametric design as a rigorous and mostly systematic method that requires a fundamentally different approach to design thinking. The paper starts by providing a background on the cognitive roots of parametric design based on the work of the Swiss clinical psychologist Jean Piaget and proceeds to introduce a taxonomy of parametric design elements based on previous published work (Jabi, 2013). We then focus on one element of this hierarchical taxonomy: topology (the study of properties of entities that are not normally affected by changes due to transformations) for its potential to enhance and expand parametric design thinking. To explore the implications of integrating topology into parametric design thinking, we explore the concept of non-manifold topology (NMT) (Aish & Pratap, 2013; Jabi, 2015). While most current Building Information Modelling (BIM) approaches are successful in representing and parametrizing the physical components of the building's fabric through 3D solid boundary representations, the mathematical concept of NMT is proposed as a different approach to thinking about space/void. Solids within BIM systems strictly divide the world into the void of the exterior and the solid material of the interior of the solid itself. In contrast, NMT representations allow consistent internal division of complex volumes into cellular spaces using zero-thickness internal surfaces. In addition, NMT maintains topological consistency so that a user can query cellular spaces and surfaces regarding their topological data (e.g. adjacency information).

While computational methods are not essential to parametric design thinking, they are the most effective tools for exploring the complex relationships within a design solution space. Thus, the paper reports on a use-case scenario of a software system using NMT for the design and additive manufacturing of conformal cellular structures. The paper concludes with a reflection on the role of topology in influencing parametric design thinking, the limitations and advantages of the proposed approach and the future potential of additive manufacturing of conformal cellular structures using non-manifold topologies. One of the major findings in this paper is that the ability to consistently define topological structures and query the system for topological data enhances parametric investigations and creates more efficient solutions that take better consideration of the design context.

1 Background – cognitive roots of parametric design

"Parametric design is about change" (Woodbury, Gün, Peters, & Sheikholeslami, 2010). This simple and fundamental idea is the most compelling and seductive attribute of parametric systems. The largely static system of design that involved drawing or building analogue representations can now be amplified, enhanced, and extended with fluid and interactive representations that change (almost) instantly as the designer operates a set of controls. As our hands and fingers move sliders, type new numbers, or press buttons, our