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Review

A review on hybrid optimization algorithms to coalesce computational morphogenesis with interactive energy consumption forecasting

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ABSTRACT

The present review paper focuses on the exploration and qualitative evaluation of hybrid optimization methods applied to architectural design, computational morphogenesis and energy consumption problems. After introducing the computational morphogenesis notion and the novel institutional framework of nZEB labeling, we define here computational morphogenesis as a design procedure where the environmental qualities of the envelope and especially thermal storage and load shifting have the potential to guide an automation process of shape creation in the building scale. For this reason we focus on reviewing the well-cited literature on scale that introduced novel hybrid optimization tools especially developed for thermal load, energy consumption optimization and/or computational morphogenesis optimization issues. Different approaches and methods are reported in this review paper, while at the end of the paper an exhaustive list of conclusions and potential perspectives of these approaches is explicitly presented. Inexorably, we seek to review here hybrid optimization tools that are (or could be) applied on computational morphogenesis problems with the aim to optimize, facilitate and encourage a creative architectural design in relation to innovative envelope conception to promote interdisciplinary research coupling the fields of architectural design and building physics.

Contents

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1. Introduction and general context

In a context where the building sector is responsible for 42% of final energy consumption, 35% of greenhouse gas emissions and 50% of material resources consumption, the European Union introduced a new label to characterize the energy performance of buildings [1–5]. More precisely, in the general framework of *climate change*, the re-cast Energy Performance of Buildings Directive (EPBD) requires that from 2019 onwards "*all the new buildings occupied and owned by public authorities are nearly zero-energy buildings*" (nZEB) and by the end of 2020 "*all new buildings are nearly zero-energy buildings*" [6–11]. In other words, this European Directive on energy efficiency of buildings (EPBD) requires member states to ensure that on 1st January 2021, all new buildings have an energy "*almost zero*" consumption in order to obtain the nZEB label [12,13]. The aim of this directive is to enhance interdisciplinary research on building applications sharing knowledge about products, systems, conceptual methods and innovative techniques that combine low energy consumption, renewable energy and industrialization [14–21]. Hence, as we understand, the first step, to achieve nZEB levels of energy consumption consists in designing buildings with high thermal storage and load shifting potential. And at this stage we understand that we have to enter in the equation the building form optimization at early design stages in order to achieve high standards of sustainability.

When we deal with a classic building design problem we work simultaneously during two distinct phases: the shape conception and the ex nihilo post conceptual phase where the geometry of the problem is defined in detail and engineering accomplishes the tasks of constructability and sustainability. In general we remark that the shape conception stage remains an integral artistic procedure while energy performance issues are not entered in the equation of form creation. Even if the building research community has been always using building performance simulation tools [22–29], this kind of research is not coupled with the architectural design process at early design stages. As it is well-argued elsewhere, there are many reasons for this delay, starting from the difficulty of using complex sophisticated simulation tools to describe complex physical phenomena [26,28,30–32], the augmented calculation time needed for such operations, the uncertainty in the results and the general impression that the designer is restricted by the limitations of the tools [33,34]. Architectural discourse has always included a reflection on providing a high quality and comfortable interior environment via an equilibrated architectural project, albeit the use of computer-aided building energy simulation software in the decision-making process for building form optimization at early conceptual stages is limited. In architectural design, regarding the sustainability of the created space, intuition played the most important role, and the fact that traditional architecture has always sought to use local materials and adapt building forms, systems and space organization to precise climatic conditions optimizing their thermal storage capacity, reinforced a kind of discourse among architects and designers, which generally concludes that the use of thermal simulation tools at an early design stage is inessential.

However, the use of procedural, parametric and generative computer-supported techniques in combination with mass customization and automated fabrication is not new in architectural design and consists an alternative way for building form conception. Such tools are the main numerical procedures currently used in contemporary architecture to enable holistic manipulation and the subsequent production of increasingly complex architectural arrangements. In this paper we will try to link the currently employed generative computer-supported techniques and concepts with the sustainable dimension of architecture in order to propose the main elements to reinvent computational morphogenesis in the climate change era.

1.1. Definition of computational morphogenesis in architecture

In recent architectural discourses, the approaches to conceive and design original architectural forms from scratch have been described as morphogenesis or more precisely computational or digital morphogenesis. By definition, computational morphogenesis is a process of shape development enabled by computation. Although the concept is applicable in many scientific fields, the term computational morphogenesis was first used in architecture and engineering. Ergo, in architectural design, computational morphogenesis is a group of methods that employ digital media and numerical techniques to shape the form and adapt it in a specific context rather than simply expressing an individual's inspiration offering an original representation. According to Roudavski, in this inclusive perspective, computational morphogenesis in architecture bears a largely analogous or metaphorical relationship with morphogenetic processes in nature, expressing the dependence of progressive development; nevertheless it not necessarily refers to the adaptation of the current mechanisms of growth [35]. Meanwhile, recent speeches have linked computational morphogenesis in architecture at a number of concepts such as emergence, self-organization and sustainable or ecological design. According to Roudavski [35]:

> "*A better understanding of biological morphogenesis can usefully inform architectural designing because: 1) architectural designing aims to resolve challenges that have often already been resolved by nature; 2) architectural designing increasingly seeks to incorporate concepts and techniques, such as growth or adaptation, that have parallels in nature; 3) architecture and biology share a common language because both attempt to model growth and adaptation (or morphogenesis) in silico*." [35, p. 34]

1.2. Aims and scopes of the present review article

Auxiliary, since architectural production is nowadays commercialized and industrialized in a general context where *climate change* consists the major challenge of our era, the research for innovative architectural forms that reach nZEB levels of energy consumption aims to couple optimization techniques with *computational morphogenesis*. That means that an optimized shape conception could significantly improve thermal storage and load shifting in a given climatic and topographic context. Henceforth, the first question that arises when we deal with a space creation problem is the volumetric characteristics and the materiality of the form. That means that when the architect conceives a building form he deals indirectly with the creation of a building envelope. Every form is conceived on the basis of material choices while the thermophysical properties of these materials will play decisive role on the thermal behavior of the form as well as on thermal storage and load shifting of the future building. Thermal engineering research showed that safe sophisticated no toxic materials, with low energy content and low environmental impact is a very important question that should be investigated at an early design stage, since optimum utilization of such materials could significantly influence on the geometry of the envelope [27,36–42].

Besides, numerical thermal engineering studies in building scale showed that the control of building forms at an early design stage could eventually lead to the use of local materials (wood, stone, metal...) and to the building form optimization through the regeneration of a contemporary iconic architecture born from the necessity of the reduction of the environmental impact of buildings