Renewable and Sustainable Energy Reviews 73 (2017) 1086–1103

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Parametric design and daylighting: A literature review

Ahmad Eltaweel*, Yuehong SU*

Department of Architecture and Build Environment, University of Nottingham, Nottingham NG7 2RD, UK

ARTICLE INFO

Keywords:
Parametric design
Daylighting
Solar radiation
Energy saving

ABSTRACT

In the history, architecture was exploited to the human being to protect him from unsteady environmental conditions. In the past centuries, architecture was pioneer art which has special features such as; simplicity, organization, clear style, accurate decoration, material assembly, and so on. However, modern buildings become complex products that have so many parts which have to fulfil different functions. Therefore, new computational ways and techniques have been developed to facilitate the design of modern complicated buildings and to create a convenient quantitative relationship between the environment and the envelope, putting into consideration the obstacles which influence on the building design. This has therefore formed the concept of parametric design in architecture, in order to deal with complex designs and gain more accurate results. Modern architects claim that parametric design is the most creative way to understand the development and complexity of the new era of architectural trends [1]. Meanwhile, it is really hard to deal with sophisticated details in buildings using our brains to imagine, or conventional ways to design [2]. In addition, building technologies nowadays are integrated and containing many disciplines in the same time, and each discipline is dependent on the other disciplines in a very complex vast connections. Hence, they should be organized in a database container, and this container could be managed parametrically using parametric design as an advanced way to explore and understand these sophisticated relations [3]. This paper hence presents a literature review on parametric design in architecture practice and put a focus on its applications in daylighting and solar radiation, which can have an essential impact on improving daylight availability and energy saving.

1. Introduction

In the general architectural design, all design aspects and their dimensions can be considered as parameters, such as location, orientation, shape, solar radiation and so on. In the conventional way of design, once an initial model has been created, and if the designer wants to change any parameter, the whole process has to be repeated, which is quite time-consuming. In contrast, the so-called parametric design employs a certain software such as Grasshopper to efficiently amend and improve design by integrating and coordinating design components simultaneously. Therefore, any change of parameters like editing or developing will be automatically and immediately updated in the model, which is like a “short cut” to the final model. A graphical comparison between the conventional approach and the parametric design is shown in Fig. 1.

Generally, the process of conventional design with a simple project is known for people as a design and coordinating process, where the idea of change, edit or develop is a usual process, and this process could be iterated till achieving the optimum design and best solution. However, for a company, this process will be more sophisticated according to different disciplines and project magnitude, in addition to the other design aspects. Accordingly, dealing with these complicated relations will be very difficult, complex, time-consuming and feasibility risky. Therefore, these complicated relations should be integrated using parametric methods. As mentioned in the previous diagram, parametric method can work with complex projects as a coordination tool, in order to facilitate the relation between different disciplines, moreover, dealing with modifications smoothly. These modifications will influence on the whole project disciplines with no need to iterate the whole project process [4], because, all parameters, disciplines and elements are connected parametrically.

2. The origins of parametric term

Daniel Davis, a researcher in the technology of the building industry, RMIT University, his PhD was about computational design; wrote a thesis about Parametric Origins titled as “A History of Parametric” [1]. According to his thesis, he claimed that the term parametric originates from mathematics, and the beginning of using this word is not known. Another researcher, David Gerber [5] claimed

* Corresponding authors.
E-mail addresses: ahmad.eltaweel@nottingham.ac.uk (A. Eltaweel), yuehong.su@nottingham.ac.uk (Y. SU).

http://dx.doi.org/10.1016/j.rser.2017.02.011
Received 16 October 2016; Received in revised form 27 December 2016; Accepted 2 February 2017
Available online 11 February 2017
1364-0321/

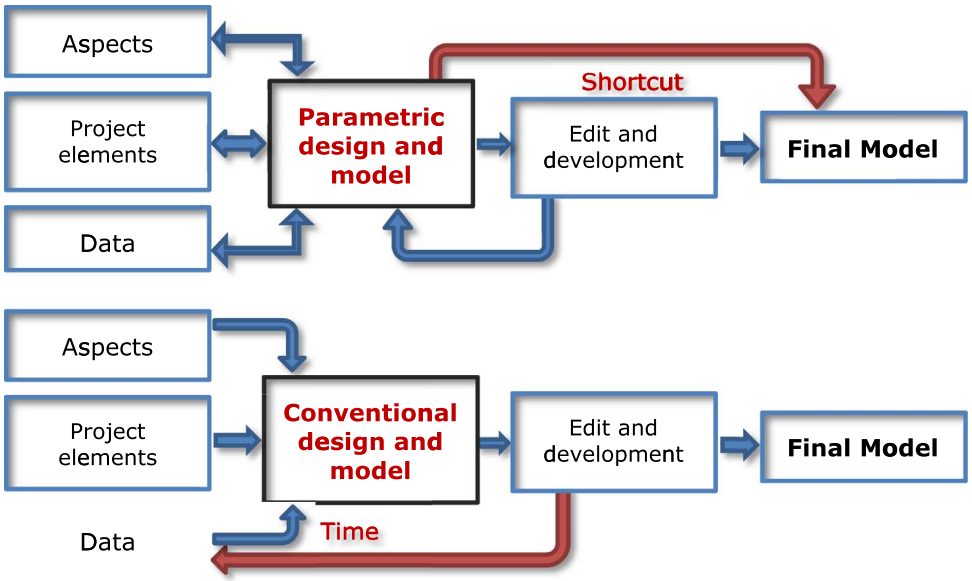

Fig. 1. Comparison diagram between Parametric design process, and conventional ones, showing the difference in time consuming.

in his thesis *Parametric Practices* that Maurice Ruiter who is the first using this term in his book in 1988 which tilted as *Advances in Computer Graphics III* [6]. In the same year (1988) mathematician Professor Samuel Geisberg founded the PTC (Parametric Technology Corporation) [7] and created the first parametric modelling software called as Pro/ENGINEER, which is an integrated CAD/CAM/CAE solution, and was the first rule-based constraint applied software used nowadays in mechanical design in many companies [8]. In 1978, Hillyard and Braid [9] created a system which can combine between two parameters such as dimensions and tolerances in order to design a mechanical components, which could be considered as a parametric approach. On the other hand, Robert Stiles argued that the first appearance of parametric concept was earlier in the 1940 by Luigi Moretti in his book *Writings of Architect* [10] who wrote extensively about parametric architecture. However, Daniel [11] investigated in his thesis that there was also an earlier example; James Dana 1888 who was using the language of parameters, variables and ratios to define general steps to draw a range of crystals, which explained in his paper *On the Drawing of Figures of Crystals* [12].

Moretti defined parametric architecture as the study of architecture systems aiming to "defining the relationships between the dimensions' dependent upon the various parameters". He used a stadium as an example to explain how the stadium's form can be divided into nineteen parameters, concerning things like viewing angles and economical cost of concrete as shown in Fig. 2. His parametric stadium was presented as part of his *Parametric Architecture* exhibition at the Twelfth Milan Triennial in 1960 [1,11].

3. The principle and implementation of parametric design

Basically, the term parametric originates from mathematics, and refers to using certain parameters or variables, which can be amended in order to manipulate with the equation results [2]. Accordingly, the principle of parametric design can be defined as mathematical design, where the relationship between the design elements are shown as parameters which could be reformulated to generate complex geometries, these geometries are based on the elements' parameters, by changing these parameters; new shapes are created simultaneously.

For example, if we need to draw an integrated model consist of venetian blinds, and these blinds have specific rotation angles responding to sun movement. Accordingly, a mathematical equation should be created for these blinds in order to get the required rotation angle. Indeed, we have to substitute in the created equation every time the sun change its position, however, this process will be very long and time-consuming. In order to simplify this complex process; this mathematical equation can be gently done in a parametric formula using specific software, then the substitution will done automatically or in better words "parametrically". Accordingly, any changes in the data or parameters will influence on all the other parameters in the equation, which can appear in the final model, as shown in Fig. 3.

where; δ is the opposing two angles over the slat, Ω is the solar profile angle, θ is the angle between reflected light and ceiling, u is the distance from the Point c to the Point a, v is the distance from the Point a to the target Point b, and β is the slat tilt angle, see Fig. 4.

There are previous examples of using integrated modern systems in designing, such as Antoni Gaudi, who studied the design space using analogue models [2]. Recently, there are an obvious relation between

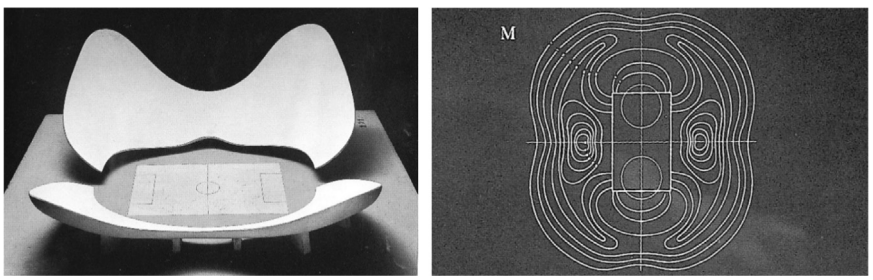

Fig. 2. A model of stadium by Luigi Moretti. Exhibited at the 1960 Parametric Architecture exhibition at the Twelfth Milan Triennial. The stadium derives from a parametric model consisting of nineteen parameters (left). The plans for the stadium (right) [10].