Journal of Building Engineering 5 (2016) 231–238

Contents lists available at ScienceDirect

Journal of Building Engineering

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

Development of a framework for dimensional customization system: A novel method for customer participation

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ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form
1 January 2016
Accepted 4 January 2016
Available online 5 January 2016

Keywords:
Mass customization
Building Information Modeling (BIM)
Parametric design
Constraint-based design
Housing industry

ABSTRACT

Mass customization in the building industry is a relatively new concept. True adaptation of mass customization requires the participation of customers in design to better reflect their expectations. However, architects and homebuilders do not want to deviate from the efficiency of product standardization or selection among products with a standard design. The challenge of customer participation lies mostly in design validation, especially the code compliance checking it involves. This paper presents the conceptual framework for a dimensional customization system that reflects the potential of a constraint-based parametric design. Constraint-based parametric design offers a wide range of variations, while simultaneously complying to design rules.

1. Introduction

The housing industry has been faced with social and cultural challenges that reflect a disparity between customer expectations and building design. Customer demands tend to be heterogeneous, while physical buildings are largely homogenous [1]. The industrialization of housing has been affected by the economy and by individuality [2–4] Shortly after WWII, architects and homebuilders tried to solve the housing shortage by looking at the economies of production from other industries. As a result, they started to pursue a Fordian paradigm that emphasized affordability and promised to rebuild society: mass production. Introducing the Fordian paradigm to the housing industry focused attention on the efficiency and economy of producing in quantity, but as a result housing design suffered from physical homogeneity and failures in variety.

After 1970, customer demand for housing began shifting from affordability to better quality and individuality [2,3] Rather than pursue the economic ideal, architects began applying advanced technologies in design, engineering, manufacturing and assembly to improve quality [3]. Today individuality is widely considered important in the housing industry; in fact, there is an increasing need for variation in architectural designs [4]. The challenge of housing design is getting the best of both worlds: how to meet heterogeneous customer demands without giving up the efficiency of mass-produced industrialized housing. While homebuyers want to purchase homes that are individually customized according to their preferences, homebuilders want to maintain the efficiency of the production process through using standardly designed models [2]. If homebuilders want to obtain customer satisfaction, how should individuality affect efficiency in design? Mass customization—a post-Fordian, 21st-century paradigm—is a trade-off between the profitability of customer satisfaction and the efficiency of mass production.

From a technological perspective, the recognition of disparity between physical homogeneity and cultural heterogeneity compels one to search for a customization system. This paper, as part of ongoing research, puts one forward. It proposes a framework for developing a flexible dimensional customization system that allows customer participation in design of houses. Dimensional customization is a suitable paradigm for the housing industry, because houses essentially reflect the cultural heterogeneity of customers and should be mostly one-of-a-kind products [1]. The novelty of the system lies in two aspects: (i) interactive customization of building geometry, and (ii) automatic design validation. Most systems that support mass customization focus on choosing among existing options, swapping a basic set of features, or adding features onto a basic set based on modular design techniques. These systems are not capable of fully satisfying demands, as will be argued later. None of the current housing customization systems offer dimensional customization as an interactive way to customize building geometry. This is because dimensional customization treats the form as subject to continuous changes—and

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http://dx.doi.org/10.1016/j.jobe.2016.01.001
2352-7102/

when changes occur, errors arise. Due to the number of building rules and regulations (derived from function, manufacturing and design intentions and expressed in the form of constraints), homebuilders hesitate to allow homebuyers to participate in the design process. The complexity inherent in design validation causes technical difficulties, effectively diminishing the market potential of customer participation in mass customization. To overcome this challenge, dimensional customization must ensure that design variations that emerge out of homebuyers' (and other non-expert users') participation are viable. This paper presents a constraint-based design system supported by a flexible computational design technique as a way to ensure the viability of product customization.

To achieve the aforementioned goals, the paper is structured as follows. Section 2 presents what's currently state of the art in the field of mass customization, enhanced with references to the building industry. Section 3 contains a description of the system, namely, the Parametric Design System (PDS) and the User Configuration System (UCS) (Their characteristics along with their implemented interfaces are explained.) Section 4 presents the validity of the system through comprehensive testing in a real design task. Finally, Section 5 draws conclusions, as well as discusses the limitations of the present work and possibilities for its future extension.

2. State of the art

Mass customization is an emerging domain that considers the heterogeneity of individual needs with regard to efficiency in design and production processes. The roots of mass customization date back to 1970, when futurist Alvin Toffler described the future systems and technologies as capable of product variety and individuality with almost no extra costs [5]. The term was originally coined by Stan Davis in 1987 as a business strategy in which "the same large number of customers can be reached as in mass markets of the industrial economy, and simultaneously […] be treated individually as in the customized markets of pre-industrial economies" ([6]: p. 169). Pine [7] defines the goal of mass customization as providing enough variety in products and services at reasonable prices. Following that definition, Mourtzis and Doukas [8] point out that changes in the market landscape from the Craftsmanship Era to the Era of Customization are driving manufacturing systems to offer variations with maximum production efficiency ([8]: p. 3). They outline the goal of mass customization as "supplying varied products that fit a specific customer's needs in order to increase his interests with maintaining low prices" ([8]: p. 17). According to Duray et al. [9], the profitability of mass customization is achieved through product variety in the volume-related economies. Focusing on the economies of scope and scale, mass customization aims at offering customers the possibility of specifying products or services, which can be supplied at prices close to those of mass-produced ones. Since the trade-off between product variety and operational performance determines the efficiency of a system, how could individual products be produced as they are in the mass production strategy? For mass customization, achieving efficiency at or near that of mass production is dependent on various managerial and technical aspects. These strategies, means and methods can be enhanced by digital and information technologies.

Mass customization is customer-centric design; the customer plays a key role in product customization. Mass customization determines a new relationship between customers and producers. In *Future Shock*, Alvin Toffler introduces the term "prosumer" to describe the producing and consuming role of the customer [5] . It is the customer who defines, produces and uses products. As design tasks change, producers and customers become involved in design and production processes together; customers become co-designers. Unlike mass production, in which producers offer products without customer involvement in design or production processes, mass customization deals significantly with decision-making in product specification to meet customer needs [9]. Salvador et al. [10] identify three fundamental capabilities for successful adaptation of mass customization: solution space development, which refers to the design of product attributes with customer needs; robust process design, which refers to the ability to re-use organizational resources; and choice navigation, in which customers can identify their individual solutions with minimum complexity and burden of choices. Active participation in customization requires solution space development, which is characterized by "stable but still flexible and responsive processes" ([11]: p. 631) Solution space development identifies product attributes with respect to customer needs, nevertheless, in the housing industry the viability of housing design is vulnerable to numerous rules and regulations. Therefore, to maintain the relationship and coherence between building elements, customization of building geometry could be supported by digital design and flexible manufacturing systems.

The flexibility of solution space is bounded by the point of customer involvement and determines the level of customization to which customers can create products that fit their needs. Mourtzis and Doukas [8] identify four business strategies for mass customization ranging from low to high degrees of product customization: off-the-shelf product variety (selection among finished products), intense option of products (ordering personalized characteristics of products), point-of-delivery personalization, and personalized products (design option sets). The amount of product customization is highly dependent on the moment the customer enters the production process. Lampel and Mintzberg [12] develop five types of mass customization: pure standardization (no involvement), segmented standardization, customized standardization, tailored customization and pure customization. Both tailored customization and customized standardization deal with customizing standard products, but in different degrees and with different methods. Tailored customization deals with an earlier point of customer involvement and therefore offers a higher degree of customization than that of customized standardization. Piller [13] points out that customization can occur on three levels: style, fit and functionality. Mishra et al. [14] also identify three levels of customization in the building industry which can be offered together or separately: variation, permutation, and configuration. Variation refers to the interior fit-ups and building appliances. Cabinetry and kitchen companies such as IKEA offer that possibility. Permutation refers to the customization of building elevations. Both variation and permutation produce customized solutions based on modular techniques. Configuration refers to changes in building geometry through floor plan changes. The point of customer involvement is bounded by the method of customization, which determines the level of customization. The earlier the customer is involved, the higher the level of customization [9].

Supported by digital and information technologies, a configuration toolkit (online or via app) could provide a new form of interaction that enables customers to participate in the design process [15–17]. As a design interface, a toolkit should support customer-driven product innovation through trial-error experimentation and deliver feedback on the outcome [18]. Based on exploratory studies, von Hippel [18] proposes five important elements of a toolkit: enabling trial-and-error experimentation in order to allow customers learn their preferences iteratively until creating their individual designs; offering a solution space that supports diverse design possibilities; allowing customers to simply