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Yuan Lin
University of Auckland

Pai Zheng
University of Auckland

Yuanbin Wang
University of Auckland

Xun Xu
University of Auckland

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VR-based Product Personalization Process for Smart Products

Yuan Lin[a], Shiqiang Yu[a]*, Pai Zheng[a], Liming Qiu[b], Yuanbin Wang[a] and Xun Xu[a]

[a]*Department of Mechanical Engineering, The University of Auckland, 20 Symonds Street, Auckland 1010, New Zealand*
[b]*Department of Electrical and Computer Engineering, The University of Auckland, Building 902, 314-390 Khyber Pass Road, Newmarket, Auckland 1023, New Zealand*

Abstract

Through the synergies of advanced IT technologies in sensor network and hardware infrastructure, both industrial and consumer products are evolving rapidly to carry more smart features. To sharpen competitive edge in global market, manufacturers today ought to enable their customers to personalize their products to meet diversifying customer needs (CNs). However, the increasing complexity of smart product is dramatically expanding the design space due to over-loaded smart features, which results in significant challenges in the personalization of smart products. Typically, manufacturers operating in a configure-to-order (CTO) manner would adopt a mass customization strategy and implement it with a product configuration system (also known as product configurator). The user experience (UX) of personalizing products by conducting product configuration is crucial for encouraging customer retention and loyalty. This project studied the product personalization process for smart products by observing a group of customers conducting a series of product configuration tasks in several types of product configurators we developed for different platforms (web-based and Virtual Reality (VR) based version). By analyzing mental and physical reaction of the customer, a more systematic understanding of user preference has been attained. The proposed VR-based approach for realizing customer-centric product personalization has been proved to be valid and should be a valuable reference in the future development of the product configuration system.

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Keywords: product personalization; smart product, virtual reality, user experience, product configuration

* Corresponding author. Tel.: +64-22-4143072.
E-mail address: syu431@aucklanduni.ac.nz

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1. Introduction

The advancement of technologies are making traditional products smarter [1]. A smart product is commonly outfitted with a wide range of sensors (e.g. smart phone with camera, GPS, gyroscope etc.) to provide various functions, some of which are even running in the background without direct operation of the user (e.g. motion tracking, cloud backup etc.). Albeit products are getting smarter and more powerful, consumers always keep requesting more personalized options to meet their individual requirements. Again, taking smart phone as an example, customer desire personalization from two perspectives: usability (e.g. different memory sizes) and uniqueness (e.g. various colors and finish type). To cope with diversifying customer needs (CNs), mass customization enables offering tailored products with shorter lead time to market by implementing it with a product configuration system (also known as product configurator) [2, 3]. Generally, product configuration system could handle product proliferation caused by an enormous number of product variants. Nevertheless, smart products, filled with over-loaded smart features, may generate excessive options in product configuration process [4]. That will lead to mass confusion in mass customization interaction process [5].

Apart from burdened features, smart products are typically operating in a smart environment which makes the personalization of smart product more difficult. A smart environment, consisting of networked smart products and other service providers, could obtain and apply knowledge about an environment and to adapt to its inhabitants in order to improve their experience in that environment [6]. Nevertheless, all the existing product configuration solutions only can partly demonstrate features of customizable smart product and barely showcase its smart environment. Generally, products are evolving into more multidisciplinary, intelligent and networked products. Traditional product configuration systems therefore are becoming incapable of offering a co-design environment for the customization of smart products.

One of principal purposes of introducing product configuration technologies in product personalization process is showcasing a virtual prototype to boost customer engagement and user experience (UX). A state-of-the-art product configuration system (e.g. Autodesk Configure 360) could provide a co-design toolkit enable customer conducting configuration in parametric graphical way (i.e. manipulating the 2D/3D model of configurable product). Comparing with filling configuration request forms and clicking checkboxes, such a graphical user interface could improve UX in the customers' personalization process. However, the majority of those parametric graphical configuration (PGC) system cannot cope with visualization module well. It is for the reason that there are many technical issues on displaying a 3D real-time rendering model on the webpage. In addition, plug-in installation for PGC system and browser compatibility will greatly wreck UX.

To cope with aforementioned issues, a product configuration system for smart product is proposed in this research. The project also introduces virtual reality (VR) technologies into product configuration process to boost UX in product personalization process. At last, an experiment is conducted to study customer preferences over configuration system and validate proposed methods.

2. Research Background

2.1. Product Configuration and Personalization

To conduct product configuration process, manufacturing company usually design a product configuration system (i.e. product configurator) which contains a set of predefined attributes with constraints (rules) for customer to select within the product family scope [7]. The input of the system is the customer's selection of existing attributes and the system output is the recommended or target product derived from the system to fulfill customer requirements. In such a way, it bridges the gap between customer requirements and the end-product by only a series of attribute selection processes in a "configure-to-order" (CTO) model [8]. Also, it benefits the company by reusing existing design elements to provide customer-perceived product variety in the product family [9, 10]. Research on product configuration process mainly focus on two aspects: 1) Configuration reasoning method (e.g. CSP-base approach [11], ontology-based system [12], etc.). 2) Product configurator design for manufacturing models (e.g. mass customization [9, 10], cloud manufacturing [13], etc.). In fact, product configuration technologies have been matured for decades. There are increasingly more technologies being introduced in commercial solutions for product configuration, such as the Internet, AI, cloud technologies, and etc. Today those advanced commercial product configurators support multi-device access (Autodesk Configure 360), integrated CRM (Salesforce CPQ), integrated CAD/CAE (KBMax), and etc.

A part of product configurators has been developed for in-house purpose which means those systems should be carried out by designers or engineers who have sufficient knowledge about the product as well as proper ways to configure it. The in-house solution can significantly reduce the burden of engineers/sales engineers. This configuration scenario commonly happened in capital good industries for two main reasons: 1) Many companies often deliberately hide details of their product design so as to protect their intellectual properties (IPs). 2) Those products do not put emphasize on UX in product design and/or UX in sale and marketing activities. However, the majority of existing product configuration systems are designed without requiring customer's knowledge on detailed design specifications. For average-customer-oriented industries like consumer electronics, automobile, apparel, and etc., a good product configurator must have following features: First of All, it implicitly maps specific design details into apparent indicators or features and allow customer to easily focus on the aspects they want to modify and understand how to change them; In addition, it captures the behaviors of customer during the process and reveal the true intention of each modification; At last, it suggests corresponding adjustments that need to be integrated into design or manufacturing process. Briefly, a product configuration should provide a co-design environment between a manufacturer and its customers to realize product personalization in customer-centric way. User experience therefore should be taken as a priority in the design of product configurator.

2.2. Smart Product and Smart Environment

Driven by the advancement of ICT, computing and AI technologies, traditional products are becoming ever smarter. In comparison with traditional products, smart products with a lot of features could better meet individual customization requirement. Moreover, smart products are typically connected to other devices or networks. Comparing with independent products, networked smart products can realize more personalized functionality for users and enhance UX [6]. The environment that smart product embedded into is referred to as a smart environment [14]. As a same smart product may perform different function when it inhabits differing smart environments [1], customers' usage scenario may affect their purchase. There are product-to-user (p2u) connections and product-to-product (p2p) connections in a smart environment. Sometimes the connection of smart products in smart environment could be complicated. As a result, the personalization process of smart products is more complex than conventional products. Handling of smart environment should be recognized as a key issue in the design of product configuration system for smart products.

2.3. Virtual, Augmented and Mixed Reality

Jayaram et al. [15] have proposed a typical definition of VR as "the use of computer-generated virtual environments and associated hardware to provide the user with the illusion of physical presence within that environment". In addition to immersive display, Burdea and Coiffet [16] addressed the significance of interaction in their definition of VR. They also claimed VR could be implemented by providing various feedbacks including visual, auditory, haptic, smell, and taste feedbacks. Seth et al. [17] mentioned multiple sensations as well. Howard and Vance [18] stressed the direct manipulation of virtual objects facilitated by VR.

Augmented Reality (AR) is frequently mentioned as the next technical revolution stage of VR. While VR isolates user from reality, AR imposes digital objects into physical surroundings. Since AR could display virtual and real objects at same time, it is suitable for a comparatively broader range of applications than VR. However, it has more challenging issues (e.g. registration and tracking) in implementation. AR is merely a subset of Mixed Reality (MR), which blends virtual and realty. To be specific, MR also includes methods to present real objects in Virtual Environments (VEs).

Although methods like Augmented Reality (AR) or Mixed Reality (MR) may provide more fancy experience than VR, VR is still the best choice for developing product configurator at current stage. It is for the reason that VR is the easiest one for customers to get access to. Nowadays, there are plenty choices of VR goggles in consumer market, such as HTC Vive, Oculus and Gear VR, let alone the cheapest solutions like all variants of Google Cardboard. As for AR, typical devices like Microsoft Hololens, META 2 and ODG R9 are still quite costly. Moreover, none of them have been released to the consumer market. Companies like Alibaba are still trying to promote their VR applications. Thus, VR still represents the main trend for now and even near future.

3. Product configuration for Personalizing Smart Product

As mentioned above, there are two main issues in the product configuration process of smart product, including overloaded features of smart products and the complexity of its smart environment. In this research, smart product and its smart environment are integrated as configurable instances in proposed product configuration architecture.

For those may not have sufficient knowledge about a smart product, if they are offered too many configurable options, their desired configuration may not be generated and the UX of configuration process will be significantly affected. Therefore, a product configuration system should offer proper configuration solution scope which could adapt users' cognition of the product. Especially for products with many smart features, determining the scope of configuration solution is critical before performing product configuration. To make the range of configurable options adaptable, product configurator users should be provided a variety of customization degree of freedom (DOF). If an expert customer is given high customization freedom, he/she need to fulfill a relatively complex configuration process by making more decisions and even assigning specific design parameters. In contrast, user with less knowledge on the product will cope with less configurable items which means the given customization DOF is lower. As for the smart environment, the configuration system need to figure out the potential p2p and p2u connections in the usage scenario.

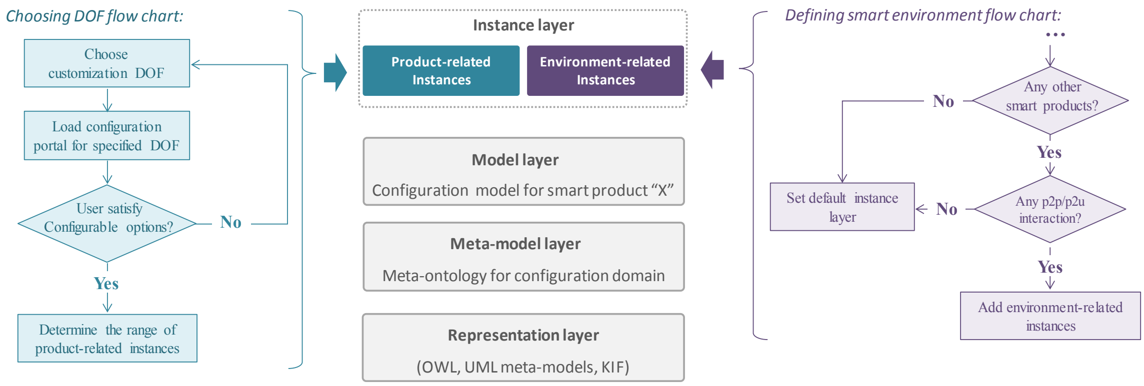

Fig. 1. Smart environment in product configurator

As mentioned in 2.1, various configuration reasoning methods have been researched. In this paper, ontology-based approach is adopted as it perfectly supports knowledge sharing and reuse which could make product configurator adaptable in updating configuration models and instances [12]. The architecture of an ontology-based product configuration system is typically consisting of four layers as Fig. 1 shown. The model layer contains models of a product. In Fig. 1, we take Smart product "x" as an example. In the product configuration process, a customer need to choose customization DOF before beginning configuration task (see the flow chart on the let in Fig. 1). Then the system will offer the customer corresponding configuration solution scope in accordance with specified customization DOF. If the customer does not satisfy the chosen DOF, he/she can jump back and select higher or lower DOF. Similarly, the usage scenario of each customer is varying, so the instance layer will keep updated according to specified environment-related instances (see the flow chart on the right in Fig. 1). To predefine the smart environment, a customer need to finish a questionnaire before conducting product configuration.

Due to the features of ontology-based configuration reasoning engine, the configuration system can get evolved after a customer specify a certain customization DOF and smart environment. The proposed product configurator with adaptability could handle feature laden products and satisfy differing customer types. This project developed a webpage-based product configuration system which can offer three different levels of customization DOF (as Fig. 2 shown). Higher DOF means a larger range of configurable features will be offered in the product configuration process. The case product in this research is a smart respirator with configurable components. The user of product configurator can choose a customization DOF to start a personalization process and switch to other customization DOF at any time until they get a desired product configuration.

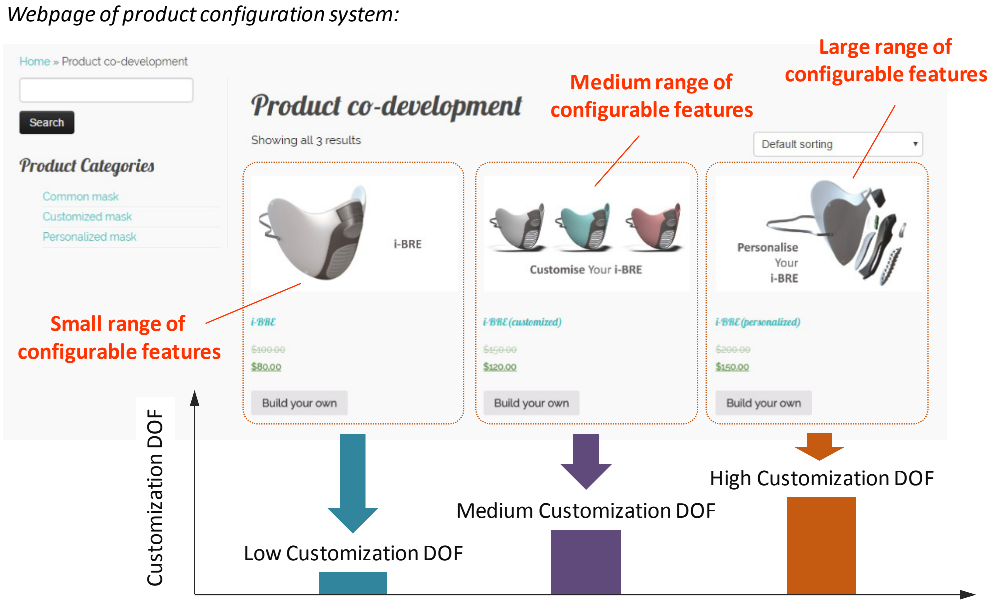

Fig. 2. Different customization DOF in configuration process

4. Introducing of VR technologies

As the visualization is very essential for virtual prototype, most of commercial product configurator vendors are striving to develop more visual product configurator functionality, such as generating rendered photo-realistic 3D images, exporting lightweight 3D VRML model, and etc. Although a lot of efforts have been made, visualization is still a weak spot of existing product configurators.

Aforementioned VP is a good approach to improve visualization issues in product configuration. First, using virtual prototypes for evaluation, companies could reduce the cost (e.g. for material, equipment, salary and postage), time and efforts required for physical prototyping. Second, the modification made by user could be more consistent with their true intention because the interface is intuitive and they could experience the outcome of their adjustment in real-time. Third, the adjustment made by user could be easily integrated into design since entire workflow is in digital form. Besides, using virtual prototype, companies could easily hide some design details since the virtual prototype is not subject to physical rules that cannot be violated in physical prototyping. In this research, VP is introduced to improve product configuration process for better UX. To achieve that, the configurable product must be brought in VR world.

4.1. VR Hardware

For decades, research groups worldwide have proposed various VR platforms attempting to work on different senses of users. However, providing stereo visual feedback is always the most fundamental and effective approach to create immersive experience. The stereoscopy has been facilitated by several types of equipment including desktop monitors [17], projector-based systems [19] and Head-Mounted Displays (HMDs) [20]. The first two types of platforms often need polarized glasses or shutter glasses as companion. Desktop monitor could reproduce depth information but cannot provide immersive experience. Such experience is achievable with system consists of multiple projectors, but that is unaffordable for customers and is very complex to undertake. Judging from cost and experience, HMD is the best choice for this project.

Generally, there are two types of HMD which could be distinguished by computer-dependency. HTC Vive and Oculus CV1 are both typical HMD that relies on external PC for graphic computations. Such systems could present better rendering results by utilizing a high performance PC. Considering the smartphones today are equipped with more advanced computation units, more accurate motion sensors and higher resolution screens, a lot of enterprises are focusing on the development of smartphone-based HMD. Such devices only need a simple structure for containing two sets of lenses and leave smartphone screen in charge of the content display. In general, smartphone-based HMD, like Google Daydream and Samsung Gear VR, are the most approachable VR solution for average customers. Thus, this project chose Samsung Gear VR and Galaxy S7 Edge to display VP model and operate configuration process.

4.2. Data Format

In this project, we used aforementioned smart respiratory equipment as a case product for conducting personalization. The 3D model of parts and assembly were designed in SolidWorks. Initially, the original CAD models were exported as STL files, which afterwards were converted into FBX files and then imported into Unity 3D as assets. Then, the VP model of case product is established (as Fig. 3 shown).

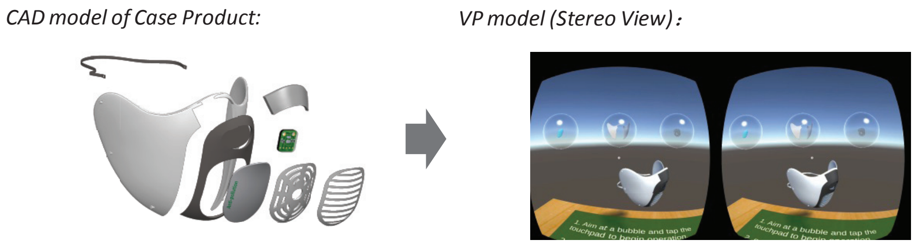

Fig. 3. From CAD model to VP model

4.3. Workflow

Once the program is launched, a 3D model of assembly with default configuration would be presented in front of the user (see the VP model in Fig. 3). Above the assembly, there are a few bubbles surrounding the user. Each bubble stands for a configurable component and the item shown inside each bubble indicates current decision for each component. The assembly will update in real-time when any changes are made in the product configuration process.

Two control methods have been provided in this system for users to conduct the personalization process, specifically gaze control and tapping on touchpad of headset. At the beginning, as shown in Fig. 4(a), user would found a green note on the virtual table, which explains how to use this system. After reading this instruction, user could commence the following procedure. As displayed in Fig. 4(b), a white reticle at the center of view indicates user's gaze point. When user aims at a bubble, the reticle would enlarge and suggest this is a configurable component. If user tap on the center of touchpad at this moment, all available options of this component would be listed as in Fig. 4(b). By scrolling up and down, user could move another option into the bubble and tap again to confirm the change. Fig. 4(b), together with Fig. 4(c), are showing the process of changing mask body from black to pink.

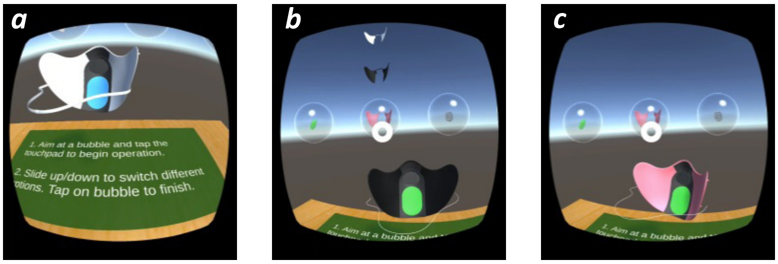

Fig. 4. (a) Introduction; (b) Choose a Component; (c) Change the Configuration.

5. Experiment and Validation

In order to analyze the user experience about product configurators, 39 volunteers were recruited in this project to conduct an evaluation. At the beginning, all volunteers are required to complete a survey about their education background, design experience and knowledge on smart wearable products. This survey is conducted before experiment to exclude those who have professional knowledge on product development. Among the subjects, only a quarter of them have ever used online customization tools and merely 10 people have purchased customized products. Meanwhile, none of participants have tried any VR device before this test. Afterwards, the subjects were asked to operate both web-page based configuration system and VR-based configuration system. After each session of personalization, corresponding questions were presented to the volunteer immediately to ensure their answers are more consistent with their actual experience rather than blurry impression.

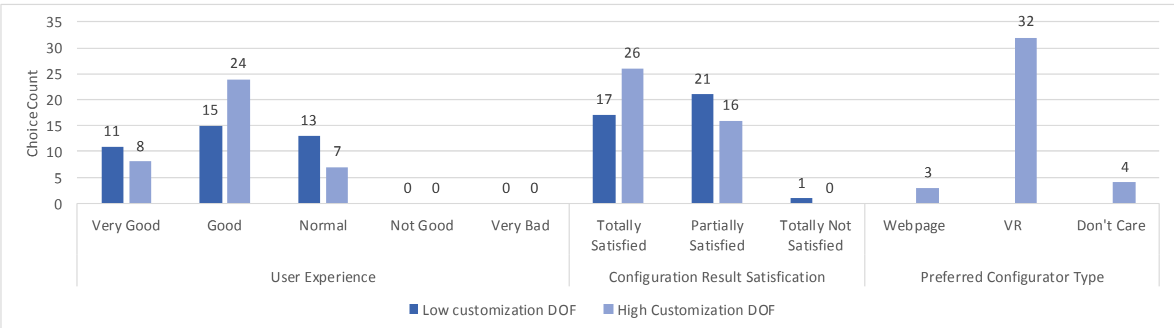

Fig. 5. Experiment results

In the experiment, all the subjects were first asked to conduct two webpage-based configuration tasks which cover low and high customization DOF (the system could allow users to switch between three kinds of customization DOF, however in this session subjects can only follow assigned DOF in this session). The customization DOF is fixed because, in this session, the authors try to figure out how the customization DOF affects users' satisfaction on configuration results. Only two kinds of DOF are chosen for time saving concerns. According to experiment results (see “Configuration Result Satisfaction” in Fig. 5), more people were satisfied with the results of high customization DOF but the results of UX are varying (see “User Experience” in Fig. 5). In the question “Whether you would like to have multi-customization-DOF choices in a single product configuration process?”, almost 75% people’s answer are affirmative. The experiment results, to some extent, imply that adaptable customization DOF have a positive effect on UX improvement.

Around 80% of subjects prefer the VR-based system rather than web-based ones (see “Preferred Configuration Type” in Fig. 5). Only three participants voted against VR-based system. One of them felt dizzy and the other two complains that the goggle is not so comfortable to wear. According to questionnaire results, all participants agree that VR-based system has the best performance in visualization of product. In view of the popularity of VR-based product configuration, VR may be a significant milestone for the evolvement of product configuration technologies.

6. Conclusion and Future Work

The market of smart products is growing rapidly. Considering these products are carrying more and more smart features, the manufactures today need to provide proper tools for customers to personalize their products to satisfy diversifying CNs. To extend traditional product configuration systems compatible with smart products with overloaded features, adaptable customization DOF is introduced to reduce mass confusion. The proposed system also works for smart environment by updating environment-related instances in accordance with user data. For better user experience in configuration process, this research utilizes VR technologies to generate VP model and offer users immersive personalization environment. According to the experiment results, applying VR in product configuration area has a lot of potential.

However, due to the small sample size (39), more experiment should be performed to reinforce the conclusion. Moreover, the results may vary if the authors change the case products, so more smart product types should be tested in future. Also, this project is working on reflecting existing smart environment in VR world to perfect the personalization process of smart products.

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References

[1] Mühlhäuser, M., "Smart products: An introduction," Proc. European Conference on Ambient Intelligence, Springer, pp. 158-164.
[2] Pine, B. J., 1993, Mass customization: the new frontier in business competition, Harvard Business Press.
[3] Salvador, F., and Forza, C., 2004, "Configuring products to address the customization-responsiveness squeeze: A survey of management issues and opportunities," International journal of production economics, 91(3), pp. 273-291.
[4] Piller, F., Schubert, P., Koch, M., and Möslein, K., 2005, "Overcoming mass confusion: collaborative customer co‐design in online communities," Journal of Computer‐Mediated Communication, 10(4), pp. 00-00.
[5] Chen, Z., and Wang, L., 2010, "Personalized product configuration rules with dual formulations: A method to proactively leverage mass confusion," Expert Systems with Applications, 37(1), pp. 383-392.
[6] Das, S. K., and Cook, D. J., "Designing smart environments: A paradigm based on learning and prediction," Proc. International Conference on Pattern Recognition and Machine Intelligence, Springer, pp. 80-90.
[7] Xie, H., Henderson, P., and Kernahan, M., 2005, "Modelling and solving engineering product configuration problems by constraint satisfaction," International Journal of Production Research, 43(20), pp. 4455-4469.
[8] Wang, Y., and Tseng, M. M., 2011, "Adaptive attribute selection for configurator design via Shapley value," Ai Edam-Artificial Intelligence for Engineering Design Analysis and Manufacturing, 25(2), pp. 185-195.
[9] Wang, Y., and Tseng, M., 2014, "Attribute selection for product configurator design based on Gini index," International Journal of Production Research, 52(20), pp. 6136-6145.
[10] Chen, C., and Wang, L., 2008, "Product platform design through clustering analysis and information theoretical approach," International Journal of Production Research, 46(15), pp. 4259-4284.
[11] Xie*, H., Henderson, P., and Kernahan, M., 2005, "Modelling and solving engineering product configuration problems by constraint satisfaction," International Journal of Production Research, 43(20), pp. 4455-4469.

[12] Yang, D., Dong, M., and Miao, R., 2008, "Development of a product configuration system with an ontology-based approach," Computer-Aided Design, 40(8), pp. 863-878.
[13] Yu, S., and Xu, X., "Development of a Product Configuration System for Cloud Manufacturing," Proc. IFIP International Conference on Advances in Production Management Systems, Springer, pp. 436-443.
[14] Cook, D., and Das, S. K., 2004, Smart environments: Technology, protocols and applications, John Wiley & Sons.
[15] Jayaram, S., Connacher, H. I., and Lyons, K. W., 1997, "Virtual assembly using virtual reality techniques," Computer-aided design, 29(8), pp. 575-584.
[16] Burdea, G. C., and Coiffet, P., 2003, Virtual reality technology, John Wiley & Sons.
[17] Seth, A., Su, H.-J., and Vance, J. M., "A desktop networked haptic VR interface for mechanical assembly," Proc. ASME 2005 international mechanical engineering congress and exposition, American Society of Mechanical Engineers, pp. 173-180.
[18] Howard, B. M., and Vance, J. M., 2007, "Desktop haptic virtual assembly using physically based modelling," Virtual Reality, 11(4), pp. 207-215.
[19] Wan, H., Gao, S., Peng, Q., Dai, G., and Zhang, F., "MIVAS: a multi-modal immersive virtual assembly system," Proc. ASME 2004 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers, pp. 113-122.
[20] Jayaram, S., Jayaram, U., Wang, Y., Tirumali, H., Lyons, K., and Hart, P., 1999, "VADE: A virtual assembly design environment," IEEE Computer Graphics and Applications, 19(6), pp. 44-50.