Review | Received 13 December 2023; Accepted 11 March 2024; Published 19 March 2024
https://doi.org/10.55092/am20240004

A framework and implementation of the Customer-to-Manufacturer (C2M) paradigm

Yanglang Yuan[1], Jingke Wang[1], Guyue Zhou[2], Yiming Rong[1,*] and Yongsheng Ma[1,*]

[1] Department of Mechanical and Energy Engineering, Southern University of Science and Technology, Shenzhen, China

[2] Institute for AI Industry Research (AIR), Tsinghua University, Beijing, China

* Correspondence authors; E-mails: rongym@sustech.edu.cn; mays@sustech.edu.cn.

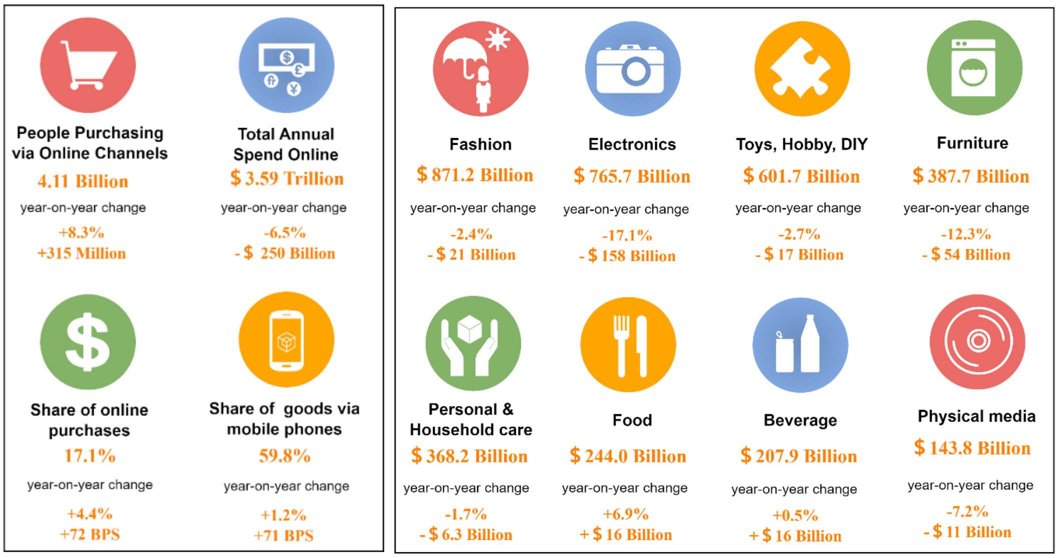
Abstract: With the advancement of pervasive commerce on the Internet, the way to purchase consumer products has been changing to personalized products with preferred individual customization. A new manufacturing paradigm named "Customer-to-Manufacturer (C2M)" has been prevalent in the E-commerce sector and the context of Industry 5.0. It establishes a direct connection between consumers and manufacturers via E-commerce platforms, allowing individual clients to participate in the model design process alongside engineers to fulfill their specific requirements. Moreover, it aims to provide manufacturers with systematic approaches for producing customized products more efficiently, resulting in shorter delivery times, lower inventory costs, and higher customer satisfaction and loyalty. In this paper, the authors briefly review the evolution of the manufacturing paradigm, suggest a structurally well-defined C2M concept, and propose a framework for C2M that utilizes contemporary digital technologies in the context of Industry 5.0 to streamline the manufacturing-to-delivery process through intelligent, human-centric, resilient, and environment-friendly design and manufacturing solutions. Additionally, a case study for the implementation of C2M has been explored. The findings of this study suggest that the C2M paradigm is an effective way to meet the growing demand for customization and personalization in E-commerce. It not only improves customer satisfaction and loyalty but also has the potential to improve supply chain efficiency and reduce costs for both sides. E-commerce retailers or manufacturing enterprises may consider adopting a C2M paradigm for online customization to stay competitive in a rapidly evolving market.

Keywords: Customer-to-Manufacturer (C2M); customization; manufacturing paradigm; Industry 5.0

1. Introduction

With the continuous growth of the Internet and E-commerce worldwide, the advancement of technology, and the improvement of customers' affordability, the increasing demand for customized and personalized products necessitates a new manufacturing paradigm to cater to the demands. Meanwhile, in recent years, there has been a new trend in E-commerce in which the customer provides the manufacturer (or online retailer) with data about what they want in a product, and the manufacturer uses that data to produce customized goods to meet the customer's needs. In this case, the manufacturer becomes a partner in the customer's business and works closely with the customer to understand their needs and develop products that meet their specifications. It begins a new manufacturing paradigm - Customer-to-Manufacturer (C2M) [1].

The C2M manufacturing paradigm refers to a new approach in the manufacturing industry that leverages cutting-edge technologies such as big data, cloud computing, and artificial intelligence within the context of the Internet and E-commerce. This approach aims to streamline the entire product production process from design to delivery by integrating intelligent, personalized, flexible, and energy-efficient practices. This paradigm drives innovation toward meeting customers' expectations for cost-effective, personalized, and differentiated products by prioritizing customer preferences and demands.



(a) (b)

Figure 1. Overview of E-commerce around the world. (a) Overview of Spend and shares; (b) Cottagers of consumer goods in 2022. (Data adopted from [2].)

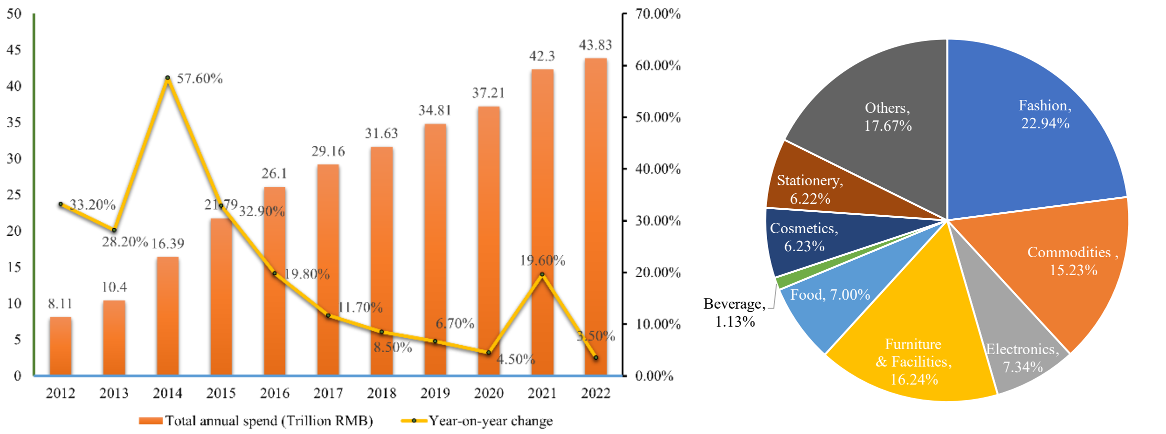
People worldwide are increasingly inclined to use E-commerce in the domain of consumer products. As shown in Figure 1, Data from "datareport.com" illustrates that in 2022, 4.11 billion people around the world purchased consumer goods via the Internet, with a year-on-year change of 8.3%; and the total online annual spend on consumer goods purchases is

USD 3.59 trillion, with a share of 17.1% and an annual growth rate of 4.4%. Figure 1 briefly reviews E-commerce and its main shares in different categories[2]. Fashion, electronics, toys, hobbies, and DIY products have taken the main shares, which are in a high value of customization.

Specifically, in China, the total amount of online transactions has continued to grow; from 2012 to 2022, the E-commerce transaction volume increased from 8.11 to 43.83 trillion RMB yuan, with an average annual growth rate of 20.6% [3,4]. According to Figure 2, the trend of E-commerce in China in the past decade has been illustrated in (a) the total transactions increased yearly, even with the impact of COVID-19. Moreover, (b) has demonstrated the shares of different categories of online consumer goods in 2021, similar to the global market. Judging from these data, the still-expanding trend of online consumption will bring huge space to E-commerce, which is the soil for C2M to grow.

The broad use of steam, electricity, computers, and Internet-based information and communication technologies led to four industrial revolutions. Recently, the concept of "Industry 5.0", which emphasizes human-centricity, resilience, and sustainability in industry, has been proposed [5]. The virtue of the spreading application of Industry 5.0 technologies and advocating the paradigm there is the emerging manufacturing paradigm, i.e., Customer-to-Manufacturer (C2M). It is possible to explore a systematic solution to create a more efficient supply chain, reduce waste, and provide customers with products tailored to their specific requirements.

The structure of this article is organized as follows: This section, i.e., Section 1, has given a brief review of the development of E-commerce and introduced the concept of C2M. Section 2 illustrates the evolution of manufacturing paradigms from Craft Production to C2M. The features of C2M and the main principles of Industry 5.0 are also presented in this section. Then, Section 3 proposes a prospective framework of the C2M paradigm in E-commerce based on the principles of Industry 5.0. Section 4 explores a typical in-progress C2M project from a lab. Finally, in Section 5, the conclusion and perspective of this article are presented.



(a) (b)

Figure 2. Overview of E-commerce in China. **(a)** Yearly growth (2012-2022). **(b)** Cottagers and shares of consumer goods in 2021. (Data adopted from [3,4])

2. C2M and Industry 5.0

2.1. Key features of C2M

Consumer demand is inexhaustible and specific individually. Continuous new manufacturing methods and technologies have been developed to cater to the demand. It allows every ordinary customer to purchase goods at an affordable price, such as cars, household appliances, mobile phones, etc. Meanwhile, the manufacturing paradigm has evolved over four generations, i.e., from Craft Production, Mass Production, Mass Customization to Personal Customization. Each generation of the manufacturing paradigm was adopted due to the continuous change of new market demands[6,7]. Figure 3 illustrates the evolution of the manufacturing paradigm, and a brief review is given next:

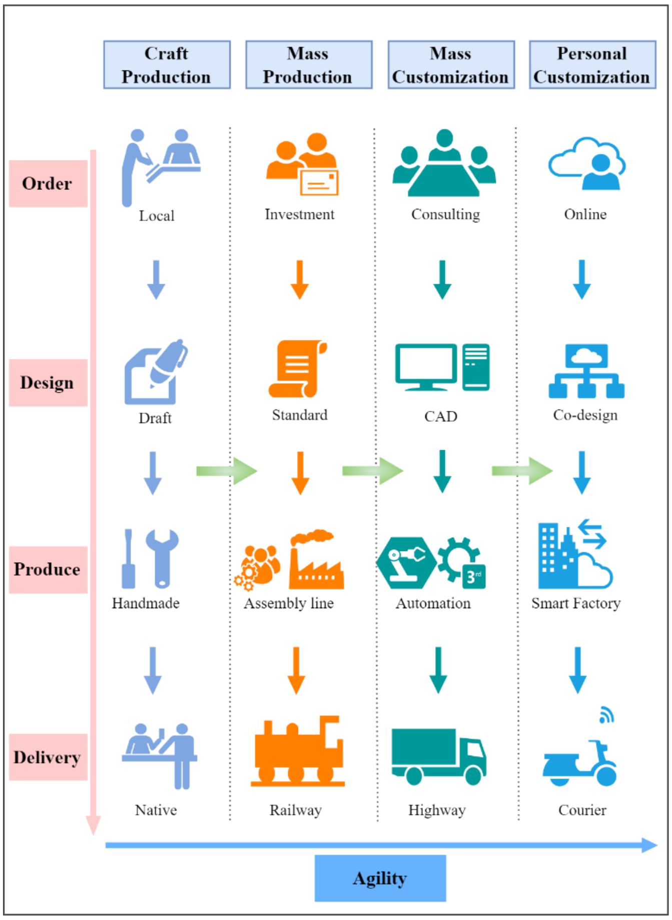


Figure 3. Evolution of manufacturing paradigms.

- Craft Production: It was the earliest paradigm of manufacturing, in which goods were produced by skilled artisans using hand tools and simple machinery. The focus was on quality and customization, and each product was unique. It was the dominant form of manufacturing until the first industrial revolution [8,9].
- Mass Production**:** With the advent of steam power and mass-produced machinery, manufacturers could produce goods on a much larger scale. Assembly line

production, interchangeable parts, and high volumes of standardized products characterized mass production. The focus was on efficiency and cost reduction, and products were designed to be identical and interchangeable [6,10].

- Mass Customization: As consumers become more sophisticated and demanding, manufacturers begin to look for ways to offer more personalized products without sacrificing mass production efficiency. Mass customization combines mass production's economies of scale with custom manufacturing's flexibility. Manufacturers use advanced technologies like computer-aided design and computer-aided manufacturing to produce customized products on demand while still benefiting from the efficiencies of mass production [11–13].
- Personal Customization: It is an umbrella term for several concepts which has been proposed as “Mass Personalization”[7], “Mass Individualization”[14], “On-Demand Manufacturing” [15], “Design-Manufacturing Integration” [16], smart, connected open architecture product (SCOAP) [17], etc. These concepts focus on providing customized goods for individual clients instead of batch orders from company users such as mass customization, with the supporting technologies of Industry 4.0, such as artificial intelligence (AI), big data, simulation, optimization, digital twin, etc. Since implementing these technologies, the boundaries between the physical and cyber worlds have been pushed, almost overlapping.

Manufacturing paradigms have evolved in pursuit of balancing efficiency and customization. Craft production provided quality but was constrained by artisans' skills, while mass production focused on efficiency at the expense of personalization. Mass customization emerged to combine these strengths, offering personalized goods at scale. Furthermore, personal customization empowers individual consumers to play a more active role in shaping goods' design and production processes.

C2M represents a novel phase in personal customization, leveraging digital and intelligent technologies to enable consumers to interact directly with manufacturers in product design and ordering. Figure 4 illustrates the major processes of C2M, including demand definition, analyzing customer demands and matching the attributes, design of products, verification of design with customer, manufacturing, and delivery of the final products. By circumventing traditional intermediaries such as retailers and wholesalers, this approach not only streamlines the supply chain but also facilitates the production of bespoke items at a diminished expense [18,19]. In addition, C2M empowers manufacturers to collect and analyze consumer preferences and behavior data, facilitating product enhancement and the development of novel marketing strategies. The key features of C2M are shown below:

- Direct interaction**:** C2M provides a communication channel for consumers to interact directly with manufacturers, eliminating the need for intermediaries. This direct interaction allows for more personalized products and faster response times to consumer needs[20].

- Customization: C2M allows consumers to personalize products to their needs and preferences. This level of customization is possible due to the digital technologies in production.
- Data-driven production: It is efficient for manufacturers to gather consumer preferences and behavior data, which can be used to improve products and create new marketing strategies. This data can help manufacturers to better understand their customers and create products that meet their needs[21].
- Cost efficiency and maximize profit: It eliminates the need for intermediaries, reducing costs for consumers and manufacturers. Consumers can often get customized products at a lower cost than they would from a traditional retailer, while manufacturers can reduce costs by producing products only when they are ordered. Compared to traditional cases, the C2M model adopts a customer-centric collaborative framework, where the supply chain can be flexibly adjusted to meet the personalized needs of customers and maximize profits[22].

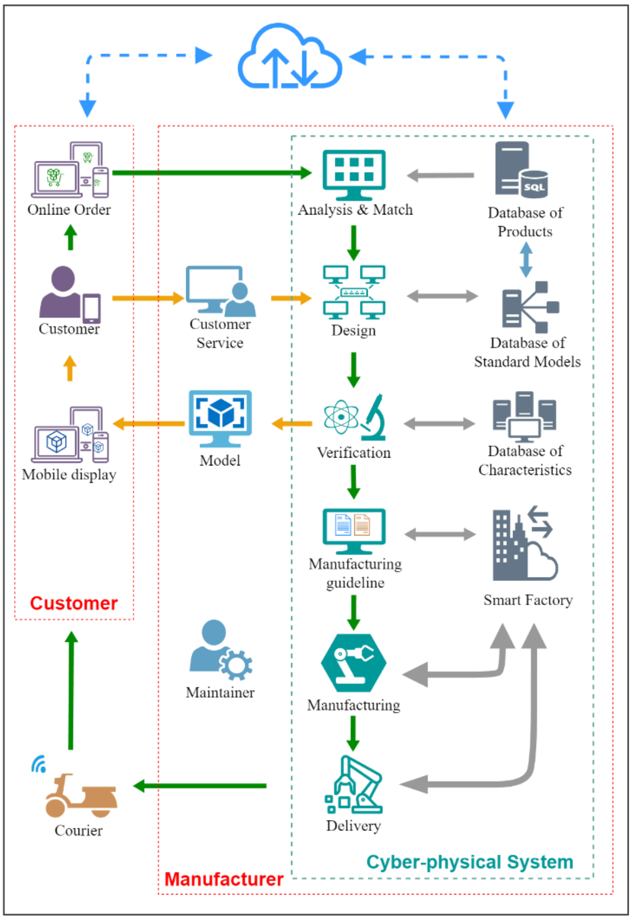


Figure 4. Major processes of C2M.

- Faster time to market: It can reduce the time it takes for new products to reach the market. Traditional manufacturing would take months or even years to develop and launch a new product. With C2M, manufacturers can quickly produce new products based on consumer demand[23].

In summary, C2M, as a new trend, allows for direct interaction between consumers and manufacturers. It could provide customized products with data-driven manufacturing solutions, cost efficiency, and faster time to market.

2.2. Industry 5.0

As more factories and businesses started to embrace the era of Industry 4.0 in recent years, the idea of "Industry 5.0" has been proposed since 2017, which focuses more on human issues of engineering and the cooperation between operators and machines rather than manufacturing technologies as before [24]. This transition aims to establish a resilient foundation for prosperity by promoting sustainable production practices that prioritize both planetary boundaries and the well-being of industrial workers. Accordingly, a paradigm shift from isolated technological advancements to a comprehensive, systemic approach is imperative, offering wide-ranging benefits to the global industry landscape [25].

Industry 5.0 is currently nascent in academia and is widely recognized for its foundational principles centered around human-centricity, resilience, and sustainability[26–28]. Figure 5 illustrates the core values of Industry 5.0.

- **Human-centricity:** It places human needs and interests at the center of the manufacturing system and takes more care of operators' physical health, mental health, well-being, and protection of their fundamental rights.
- **Resilience:** It advocates manufacturers to be more robust, better able to withstand disruptions, and capable of providing and maintaining essential infrastructure in times of emergency, like the COVID-19 pandemic and some geopolitical upheavals.
- **Sustainability:** It entails lowering energy use, reducing greenhouse gas emissions, avoiding resource depletion and degradation, and meeting the needs of the present without endangering the needs of future generations.

Figure 5. Core values of Industry 5.0 (Information adopted from [5,28,29]).

In the domain of Industry 5.0, Xu Xun, *et al*. [5] have summarized Industry 5.0 as a value-driven revolution rather than Industry 4.0 as technology-driven. Therefore, C2M, as a value-driven manufacturing paradigm, naturally matches the theme of Industry 5.0. Research efforts combining the characteristics of Industry 5.0 with C2M as a systematic program for customized products in E-commerce will support the continuous development and implementation of C2M and Industry 5.0.

3. A framework of C2M

The preceding section has introduced and examined the pertinent concepts of C2M and Industry 5.0. A conceptual framework integrating C2M and Industry 5.0 within the realm of

Figure 6. A framework of C2M in the context of Industry 5.0.

E-commerce is delineated in Figure 6. In this case, customers and manufacturers are value-driven and centered on human effects. Interactions between them are facilitated through online platforms and streamlined delivery systems enabled by Internet services. Customers could access ubiquitous services, enabling them to convey their specific requirements to manufacturers spanning local and global markets. Subsequently, upon placing an order, they are engaged in the iterative processes of prototyping, providing feedback, verifying product simulations, and awaiting product delivery via courier services.

Regarding the manufacturers, they occupy a central position within dual-layered concentric circles, each comprising several nested sub-circles. The outer sub-circles in the first circle with a green backdrop encompass infrastructural components essential for optimizing manufacturing operations. These include cutting-edge technologies such as artificial intelligence (AI) [30,31], smart factories leveraging big data analytics, virtual modeling, digital twins alongside diverse databases, and human-centric policies promoting workforce well-being and skill development initiatives [32–34].

In contrast, the inner sub-circles in the second circle with a yellow background are the main processes for the C2M manufacturing system, encompassing activities such as analysis and matching (such as shape, material, size, function, etc.), product design, verification, manufacturing guidelines, production execution, and order fulfillment (as shown with details in figure 4). With the supplement of the outer infrastructures, advanced technologies such as collaborative design [35], supply chain management [36], sustainable and intelligent manufacturing [37,38], intelligent sorting systems[39], and express delivery systems [40], *et al*. have made each process from demand definition to the final products within the C2M paradigm intelligent and customizable.

In the realm of E-commerce, the application of the C2M framework appears highly viable for industrial implementation. Previous research has verified that advanced manufacturing technologies and methods, such as digital twins, big data, virtual modeling, etc., could play important roles in product design, simulation, and production in smart factories[41]. Subsequently, the adoption of innovative technologies and strategies has the capacity to revolutionize traditional practices, thereby catalyzing improvements in product development, exchange mechanisms, and distribution channels. Thus, there is an urgent need for technologies and methods to support future societal values. With the advent of changes and questions deeply related to technological innovation and social crisis, it is necessary to rethink the position and role of industry in society. For example, during the COVID-19 crisis, many firms had to rethink their existing manufacturing technologies and methods and aim to make their factories human-centric, sustainable, resilient, and more future-proof [28,42,43]. Therefore, the concept and attempt of Industry 5.0 are necessary to meet these requirements.

Moreover, consumers have been encouraged to think of personalization through E-commerce and live-streaming shopping in recent years [44,45]. With escalating consumer demands, there is a discernible shift away from standardized products as they no longer meet universal customer preferences. The study and development of new materials and technologies have also led to an ongoing increase in the variety of customized goods. Thus, the burgeoning demand for personalized offerings within the E-commerce landscape underscores the substantial growth prospects for C2M initiatives.

Therefore, the implementation of the C2M in E-commerce is promising for the future society. This framework could provide a basic guideline or feasible solution for the following research and industrial application.

4. Lab case

As previously mentioned, the C2M paradigm entails leveraging data and customer input to shape the design and production of goods. Within this framework, consumers play an active role in manufacturing by offering feedback on product attributes and customization options.

This approach is gaining traction in various sectors, notably electronics and everyday consumer interactions.

A typical C2M project was set up by a team from Southern University of Science and Technology (SUSTech) in cooperation with Shenzhen Sewing Technique and Shenzhen Fudakin Technique. The Shenzhen Sewing Technique is trying to focus on robots, digital twins, AI, and other technologies to tailor personalized clothing for consumers based on their physiques and preferences. Meanwhile, Shenzhen Fudakin Technique aims to provide smart mirrors that guide customers in choosing the right clothes through virtual image displays. The key point of this project is combining those two companies' advantages to establish a C2M model in clothes customization in the context of E-commerce and Industrial 5.0.

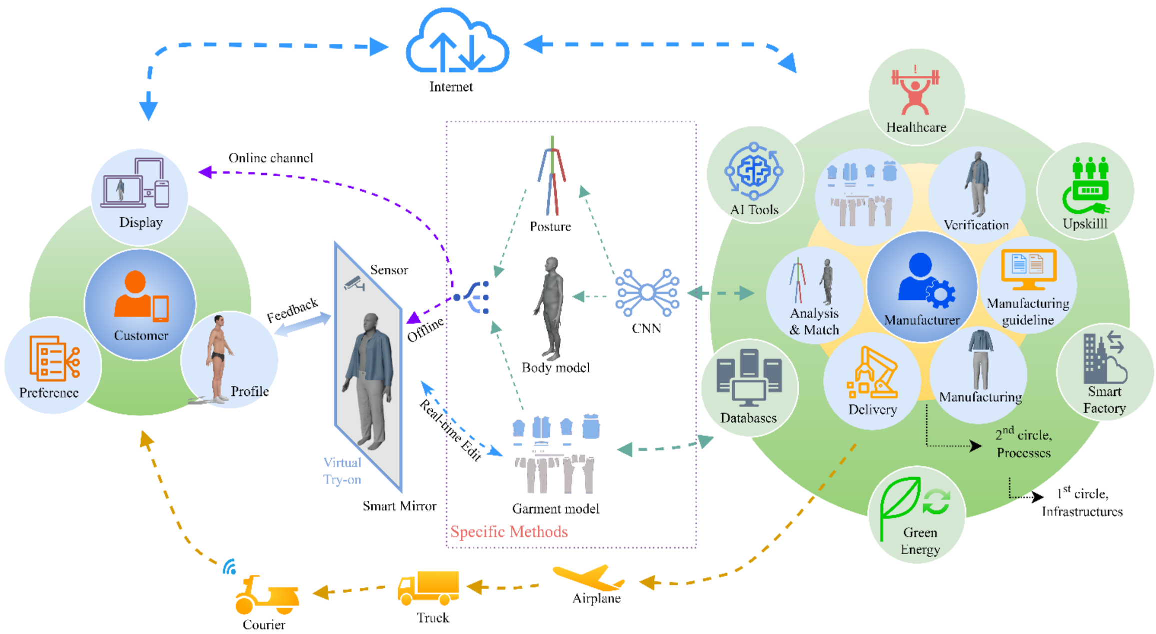
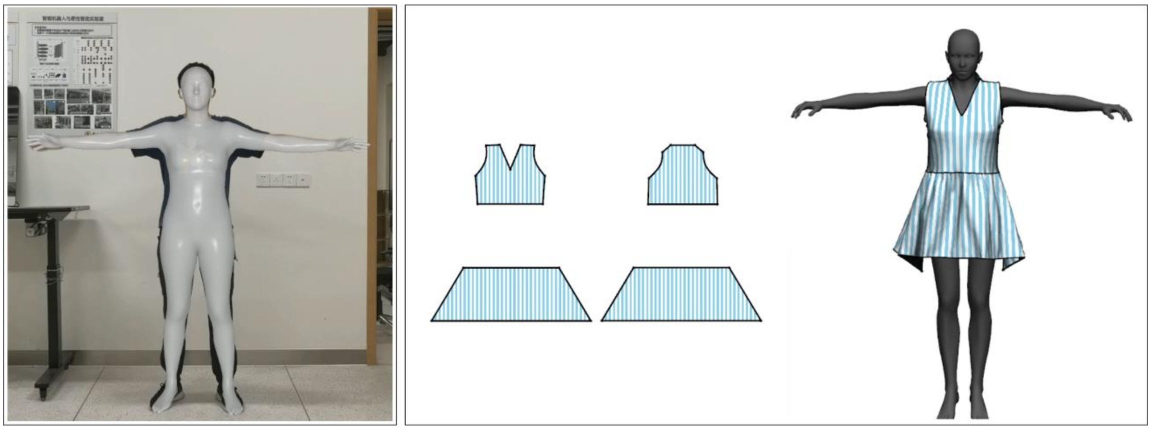


Figure 7. An example of C2M. Real-time garment order taking and showcase of manufacturing.

Figure 7 illustrates the main principles of this C2M project. The first step is to estimate individual human models with poses. In offline cases, the sensor on the smart mirror is able to scan the body shapes and sizes and then input the data to establish 3D body models of customers synchronously. For online cases, clients could upload a frame image or video with poses to reconstruct their 3D models. Then, customers could select clothes on the mirror's screen and pose in different postures to appreciate the virtual dressing (including size, material, shape, graphics, etc.).

The virtual images could change in real time to match the movement of customers. Once they get their favorite styles and take the orders, the 3D clothes could be interpreted into 2D parts with production information (size, material, shape, graphics, etc.) in the system. Then, the customized clothes will be automatically done by cutting the fabrics and sewing them up. Finally, the customers could receive their unique dresses according to the courier systems.



(a) (b)

Figure 8. Case study of C2M. **(a)** Estimation of an individual 3D human model; **(b)** Lab demo of real-time garment design.

For the estimation of individual 3D models with specific postures, Jiefeng Li *et al*. [46] have proposed the HybrIK (Hybrid Analytical-Neural Inverse Kinematics) solution. It combined the 3D keypoint estimation methods and body mesh estimation method to reconstruct a 3D human model with body pose from a single frame image or a video quickly and accurately. This could partially meet the needs of the dynamic human model showcased in this case. However, the generated human model does not include size information. In this project, we absorbed this solution to lay out the human model with realistic scale and specific poses for virtual try-on (As shown in Figure 8(a) and Figure 9).

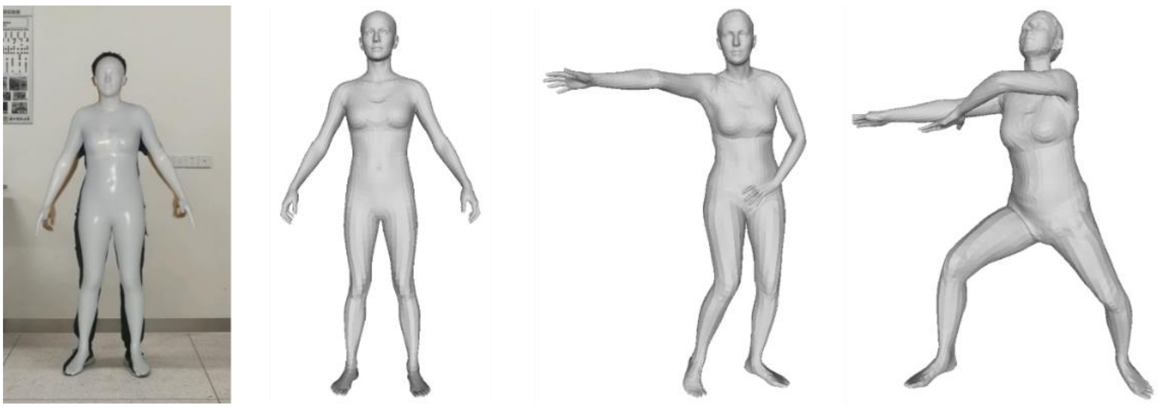


Figure 9. Customized 3D human model with specific poses.

The construction of clothing models is typically classified into two main categories: three-dimensional design, which utilizes 3D clothing modeling techniques on a human body model to create 3D meshes that are then unfolded into 2D garment pieces [47], and two-dimensional design based on 2D garment pieces [48]. While machine learning tools can enhance realism and virtual fitting effects, challenges remain in accurately translating 3D garments into 2D representations and virtual effects[49]. Three-dimensional design is commonly used in gaming, AR, VR, and related fields [50]. Two-dimensional design streamlines garment production by directly incorporating sizing information from 2D sketches, ensuring pattern precision and broadening its utility in manufacturing. This project adopted the DelFEM library and sensitivity analysis method proposed by Nobuyuki *et al*. [51,52] to address the real-time interactivity issue of transforming clothing from 2D patterns to 3D effects. Clothing effects on different body models are available in this solution, and when editing the 2D patterns, the real-time changes in virtual clothing effects can be showcased.

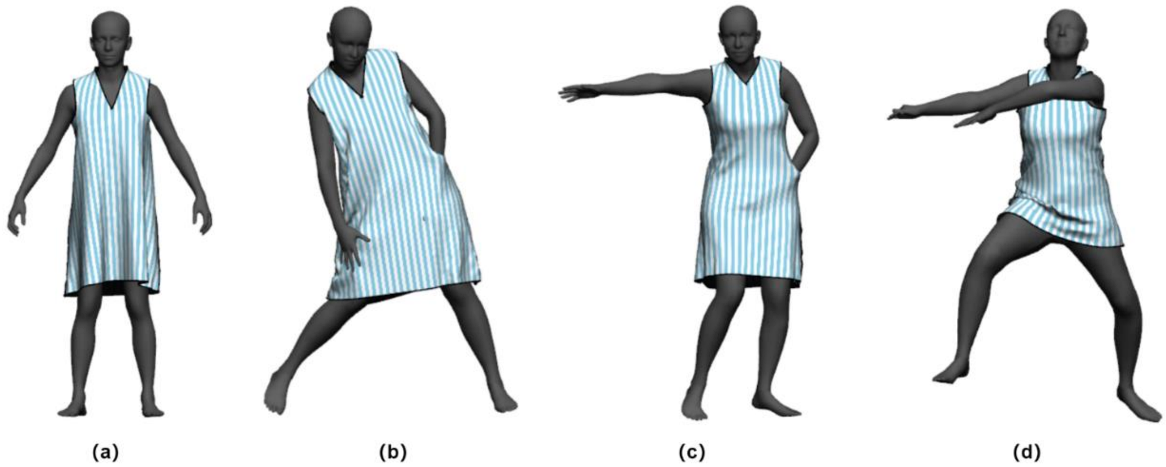


Figure 10. Virtual try-on of customized 3D models with specific poses.

To enhance the realism of virtual try-on scenarios, customized human body models in various poses derived through the enhanced HybrIK method are utilized, and feature matching techniques are employed to simulate the virtual try-on effects of the same garment on different pose human body models. Figure 10 illustrates the virtual try-on of customized 3D models with specific poses.

After editing the 2D patterns and getting a satisfactory virtual try-on, the drafts of 2D patterns could be downloaded for manufacturing process. As shown in Figure7, the implementation of a human-centric and sustainable solution in this case could meet the core value of Industry 5.0.

This lab case exemplifies a typical C2M case in E-commerce, emphasizing the customization of products tailored to individual consumers. This approach underscores adopting of a systematic and human-machine integrated strategy aligning with the core values upheld in Industry 5.0, specifically those of human-centricity and resilience. From the manufacturers' perspective, this methodology enhances competitiveness by offering customers an efficient avenue for acquiring personalized apparel in the realm of E-commerce, thereby heightening customer satisfaction and fostering brand loyalty. Production is determined according to firm demands, which means the inventory time for raw materials and products is under control, reducing manufacturers' storage expenses. Moreover, scanning customers' scales by sensors and showing the virtual 3D models in real-time is much more efficient than by hand, not only for customers but also for manufacturers. While this case study is solely conducted in a laboratory setting, it serves as a testament to the viability of C2M applications within E-commerce.

5. Conclusion and perspective

With the advancement of technology, the continuous growth of E-commerce around the world, and the improvement of customers' affordability, the increasing demand for customized and personalized products necessitates a new manufacturing paradigm, i.e., C2M, which drives a new trend of further optimized and personalized production. This paper has reviewed the trend of E-commerce and the evolution of manufacturing paradigms, and it has introduced the concept of C2M and its key features. The main characteristics of Industry 5.0 have been reviewed. Then, a C2M framework in the context of Industry 5.0 has been proposed and discussed. The authors have also showcased a typical in-progress C2M project from the laboratory.

This research is still in the initial stage. For application purposes, there are many types of products that need to be studied specifically. Besides, there are also many challenges that need more research, including technologies to integrate data sources and associations consistently among older generation, payment acceptance, designing, manufacturing, shipping, and customer support smoothly as a systematic solution:

- Three hindrance factors for C2M are observed: (1) Resistance to manufacturing efficiency; (2) Lack of products and resources for C2M; (3) Need for more high-tech trained employees.
- General models for analyzing the profitability of C2M to keep the customers' demands and manufacturers' business objectives in balance.
- Customers' data management and analysis to make the most use of data and to keep its privacy and security.

Acknowledgments

The authors acknowledge the financial support from SUSTech, Shenzhen Fudakin Technique, and Sewing Technique. Many thanks to the Sewing Technique, especially for those organized workshops and visits in the investigation phase.

Authors' contribution

Yanglang Yuan: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Visualization, Writing - Original Draft, Writing - Review & Editing; Jingke Wang: Data Curation, Formal Analysis, Investigation, Resources, Visualization, Writing - Original Draft; Guyue Zhou: Conceptualization, Funding Acquisition, Validation; Yiming Rong: Supervision, Validation, Writing - Review & Editing; Yongsheng Ma: Funding Acquisition, Supervision, Validation, Writing - Review & Editing.

Conflicts of Interest

This article has been partially accepted for oral presentation in the "2023 NSFC-RGC Conference on Frontiers of Industrial Big Data and Intelligent Systems, Hong Kong SAR, China", but it has not been published. The authors declare no conflict of interest.

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