

Article

Conceptualization and Research Progress on Web-Based Product Co-Design

Xin Kang ^{1,*}, Jian Kang ² and Wenyin Chen ¹

¹ College of Design, National Taipei University of Technology, Taipei 10608, Taiwan; wychen@ntut.edu.tw

² Beijing United Gas Engineering & Technology Co., Ltd., Beijing 100124, China; kangjian@buget.com.cn

* Correspondence: kangxin@pku.edu.cn

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Abstract: Web-based stakeholders' participation in product co-design is an emerging business model for companies. However, research on user's online involvement in product co-design is limited. In this paper, we investigated the three major interdisciplinary academic databases Web of Science, Scopus, and ScienceDirect (data collected in May 2020), with the aim of explaining the meaning, core concepts, historical roots, and research trends of co-design. A total of 39 of the deemed relevant studies were emphatically analyzed, systematically discusses the concept implication and development status of co-design, and the key points of web-based product co-design research, as well as the future research direction.

Keywords: co-design; product design; participatory design; new product development; co-creation

1. Introduction

Based on the huge growth of consumption power brought by the digital age, online product development has become a popular trend for more and more companies. The co-creation strategy has swept the business world, and enterprises have become increasingly community-based and democratic [1], and the concepts of manufacturing on demand (MOD) and demand driven manufacturing (DDM) have emerged [2]. The meaning of value and the process of value creation is rapidly shifting from a product and firm-centric view to personalized consumer experiences. Informed, networked, empowered, and active consumers are increasingly co-creating value with the firm [3]. We are in the middle of a paradigm shift. For decades, our world followed the rules of what we call the "Power Paradigm". Nowadays, the development of new production paradigm is shifting from a manufacturing-active paradigm to a customer-active paradigm [4,5].

E-commerce is growing at an astonishing 18 percent a year [6]; mobile commerce, personalized marketing, and distribution revolution have dramatically changed the way consumers make purchase decisions. The shopping experience begins on the Internet and social media platforms where consumers research products. The user-oriented design has a positive impact on the success of new products. Suppliers' insights and technical skills at all stages of product development help create value, reduce design risk, and gain a competitive advantage in design [7]. Understanding how consumer expectations and the emotional uniqueness of products are changing is more important than ever for retailers [8].

Design is the key to business success, and online communities have become the main way to help companies to involve customers in the new product development process [9]. Online product co-design is growing rapidly. Customer involvement in the design and development of new products leads to better products, which are more effective, efficient, and easier for users to accept and succeed [10], and have been identified as a reliable source of competitive advantage [11]. The online community has changed the rules of the game for retail companies, forcing them to change their business strategies [6]. Many companies or organizations are developing new products by co-designing. Dell was one of

the first companies to launch its own public innovation platform Ideastorm in 2007. Many other companies have followed, like Local Motors, Threadless, Mi Community, Starbucks, Nike, Lego, Nokia, and so on. Local Motors has opened the door to the co-design of the automobile, taking the online customer co-creation process to a new level. Lego's collaborates with customers on the development of its Mindstorms NXT Robot, and the BBC's collaborates with customers who provide program content [12,13]. The global pioneers in co-design or open innovation platforms are Zazzle, Wazoku, Quirky, OpenIDEO, eYeka.net, etc. OpenIdeo.com and Quirky are platforms for social products. The OpenIdeo and MyooCreate platforms address global welfare issues to create positive change through community collaboration. OpenIdeo pledges to remain forever in beta and to design for continuous improvement. These platforms help innovative organizations address their critical technical, scientific, business, AI, and data challenges by connecting them with expert problem solvers on a global network.

A paradigm shift in value creation requires a reassessment of the way new products are developed. The understanding of web-based co-design as a co-creation business model and the basis of innovation impetus is still very scattered in the literature stream, which needs systematic combing and research and points out the future research direction.

1.1. Co-Design: A Brief Overview

Co-design is not a new concept; however, in recent years, with the development of Web 3.0, the application of co-design in social challenge solutions and industrial design has increased significantly. Co-design can be understood as a kind of design thinking or design method, which is based on participatory design, cooperative design, cooperative creation, etc. It can be considered as a step forward in user-centered design and an updated term [14]. Co-design involves all stakeholders in the design process to ensure that the final product meets user needs and has a high adoption rate. The virtues of participatory design are cooperation, curiosity, creativity, empowerment, and reflexivity [15].

Design has always been associated with social change. As a discipline and a recognized practice, design originated from the Bauhaus movement after World War I [16]. The design method originated from the new problem-solving methods developed in the middle of the 20th century and was also a response to industrialization and mass production, which changed the nature of design [17]. The conference on Systematic and Intuitive Methods in Engineering, Industrial Design, Architecture, and Communications held in London in 1962 was considered as an event that marked the beginning of the "design methods movement" [18], which led to the establishment of the design research association, and it has influenced design education and practice. The earliest design methods or methodology books also appeared in this period.

In the 1970s, some opposition parties proposed the rationality of the design method. Some people began to deviate from the rationalization of the design and turn to the problem-solving method, which leads to the user-centered design, participatory design, and design thinking. The research of the engineering system and software design promotes the transformation of the design method from user-centered design to participatory design [19].

Participatory design (originally co-operative design, now often co-design) can be traced back to Scandinavia in the 1970s [20]. The Norwegian Iron and Metal Workers Union (NJMF) project took the first step, from traditional research to working with people to help improve people's working conditions. In the 1970s and 1980s, IBM (New York, NY, USA) introduced a method of user participation in design in the United States and Canada, called joint application design, which is commonly used in the industry. In this method, the user representative becomes a full member of the design team. In the early 1990s, the Scandinavian democratic design approach was adopted and promoted in the form of participatory design within the Man and the Biosphere Programme (MAB) community. The first Participatory Design Conference (PDC) was held in 1990 and held every two years. Since then, the concept of participatory design has been applied to a wide range of sectors and industries, from education to software design to healthcare services and promotion. In 2003, the 1st International

Conference on Hardware/Software Co-design and System Synthesis was held in the United States, bringing together academic research and industrial practice in all aspects related to system-level and hardware/software co-design.

Today, participatory design is more commonly known as co-design. The Internet provides a creative and collaborative environment for user-driven design and innovation. The use of social media in new product development has been widely adopted by companies. Co-design has evolved through practice to be a mature approach to the services and system design [21], and it is becoming an important method to solve complex social, political, environmental, educational, and technological issues [21]. Companies that use social media for product innovation are gaining business benefits, including more and better new product ideas or requirements, faster time to market, faster product adoption, lower product costs, and lower product development costs [22].

1.1.1.1. Defining Co-Design

Co-design has a wide range of definitions. It is also known as generative design, co-creation, participatory design, or cooperative design. Co-design is an approach to design attempting to actively involve all stakeholders in the design process to help ensure that the result meets their needs and is usable. Co-production may also be used, but it is more about the delivery rather than the design aspects of the process. In 2007, a workshop in the United Kingdom clarified the definition which combines definition with principles, as follows [23]. (1) Participation: co-design is a collaboration. (2) Development: co-design is a developmental process. (3) Ownership and power: co-design requires a necessary balance of rights and freedoms between participants. (4) Outcomes and intent: co-design activities are outcome-based; they possess a practical focus, with clarity of vision and direction [24]. Sanders and Stappers define co-design as a process of collective knowledge sharing and knowledge creation [25]. The partner involves those who are likely to be directly or indirectly impacted by or benefit from the process and/or outcome. It can be individual, team, or society [26], including designer, users, customers, consumers, community members, consultants, producers, distributor, detractor, company staff, influencer, researchers, etc. [27]. Different types of participants with different kinds of knowledge involved in the process. Burkett defines co-design as involving consumers and users of products and services in the design process, believing that this will ultimately lead to improvements and innovation [28]. The principles for co-design are respectful, participative, iterative, and outcome-focused [27].

Co-design builds on engagement processes such as social democracy and community development, in which all critical stakeholders, from experts to end-users are encouraged to participate and are respected as equal partners, sharing expertise in services and product design. It is using creative and participatory methods and principles that respond to shared challenges in an iterative process. The key components of the co-design process should involve: intentionally involving the target users in designing the solutions, postponing design decisions until feedback is gathered, synthesizing feedback from target users into insights, developing solutions based on feedback [29], and the key steps in the co-design process are to engage, understand, ideate, and validate [26].

1.1.1.2. Co-Design, Co-Production, and Co-Creation

Co-design, co-creation, and co-production, these terms have different histories and come from different disciplines, but their basis is the same, namely, a collaborative, cooperative, and community-centric approach to creating social good. At the beginning of the 21st century, the term co-creation came into being, and companies began to adopt a user-centered approach [30], where users were regarded as partners, and participatory design methods emerged [25]. Prahalad and Ramaswamy describe it as a consumer-centric view, as a way of thinking about the value [31]. Aric Rindfleisch and Matt O'Hern define co-creation as a collaborative NPD (new product development) activity in which customers actively contribute and/or select the content of a new product offering [32]. They categorize four types of co-creation. (1) Collaborating: open contribution, customer-led selection. (2) Tinkering: open contribution,

firm-led selection. (3) Co-designing: fixed contribution, customer-led selection. (4) Submitting: fixed contribution, firm-led selection.

Co-design is a type of co-creation process in which a number of customers, known as “co-designers”, submit product designs to the company, and a larger group of customers select which design the company will produce. Maarten Pieters and Stefanie Jansen describe co-design as part of a complete co-creation process [33]. Co-production is a practice of providing public services, and citizens participate in the creation of public policies and services. In contrast to traditional civic participation, citizens are not only consulted, but also part of the concept, design, steering, and management of services [34]. Co-production: Working out what to do is design; doing it is production [3]. Co-design covers all stages of a development process [33]. Many designers often use the term co-creation to encompass the entire process of design and production.

McDougall explained the difference between co-design, co-creation, and co-production [3]: Co-design is an attempt to define a problem and then define a solution; co-production is an attempt to implement the proposed solution; co-creation is the process by which people do both. Table 1 shows the interpretation of “co-design”, “co-creation”, and “co-production” in different literature.

Table 1. Summarize the interpretation of the terms “co-design”, “co-production”, “and co-creation” in the literature.

Terms	Definition	Implication and Difference
Co-design	An approach to design that involves all stakeholders [33].	Co-design defines a problem and a solution [3]. A plan or method for doing something. A type of co-creation process [33].
Co-production	Co-production refers to the practice of providing public services, while emphasizing user involvement in the management and delivery process. Citizens are part of the concept, design, steering, and management of services [34].	An attempt to implement the proposed solution [3]. Co-production includes [35]: co-management, co-governance, co-design, co-delivery, and co-assessment.
Co-creation	A way of thinking about the value [31]. A collaborative new product development (NPD) activity process [32].	The process of co-design and co-production [3]. Four types of co-creation: collaborating, tinkering, co-designing, and submitting.

1.1.3. Web-Based Product Co-Design

Web-based co-design means applying social media tools or collaboration platforms in designing new products or services together with users. It includes early ideation, active participation by users, and systematic design process and methods. David, Sabiescu, and Cantoni identified five key themes closely associated with the concept of co-design with communities: stakeholders, context, ownership, social learning, and sustainability [36].

We combined the product design process [37], co-design process [27], and co-creation framework [38] to gain the web-based product co-design framework. As mentioned above, the concepts of co-design, co-production, and co-creation have many commonalities, and the terms “co-design” and “co-creation” are often used mutually. In the following, we will use this framework and combine the five basic elements of co-creation: what (content or task), how (process/tools), whom (partner), why (motivation), and who (personal characteristics), to help clarify the most fundamental set of issues in the concept of co-design (Figure 1). It is open and iterative and will help us understand the essence of co-design and serve as a framework for follow-up literature investigation and analysis. Web-based product co-design projects should consider issues such as user integration, organization and communication, data sharing, evaluation, visualization, management, and delivery, etc.

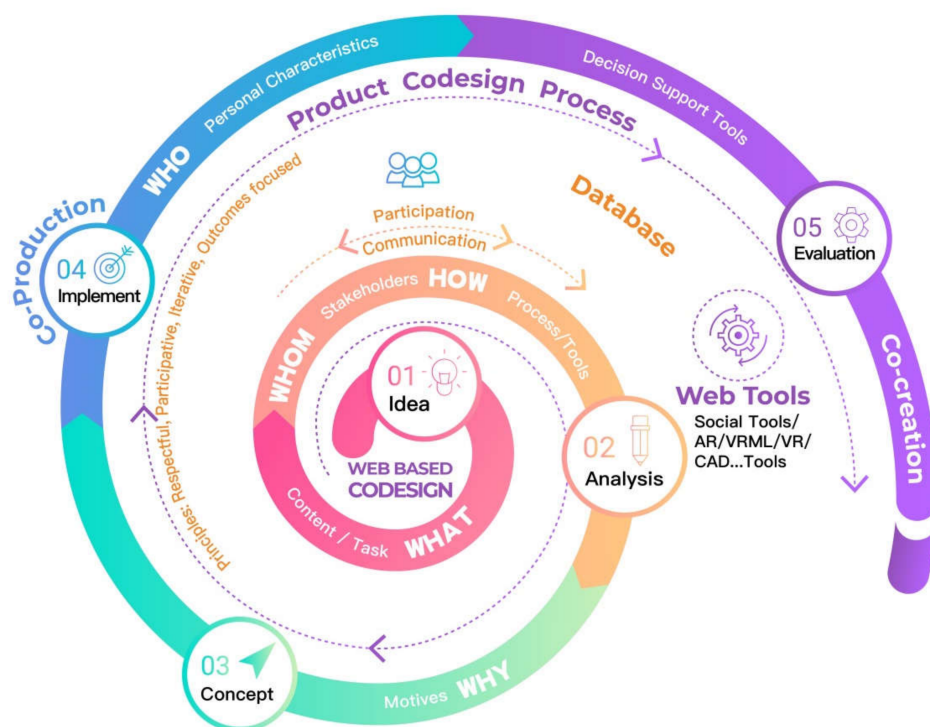


Figure 1. The framework of web-based co-design.

An online co-design project usually starts with the submission of an idea. The online product co-design process is divided into five main steps:

- (1) **Idea:** An individual, team, or society comes up with an idea;
- (2) **Analysis:** Co-planning and developing product strategies, gathering the general and specific materials, and conduct data mining and social diffusion research;
- (3) **Concept:** Open-innovation collaborative design, understanding and clearly defining the issue;
- (4) **Implement:** Build prototypes and implement plans. It is enabled by digital production technologies. This step involves the management and delivery process of co-production;
- (5) **Evaluate:** Testing the idea and improvements. Evaluation is not limited to the final product but is based on iterative and participatory relational processes.

In this process, a large amount of meta-data will be generated, and this will contribute to decision making. The process is web-based, with online social tools as the foundation and many design tools such as CAD (computer-aided design), AR (augmented reality), VR (virtual reality), VRML (virtual reality modeling language), and decision support tool being used. Co-design is an experimental process aiming at innovation. The process is cyclical, not sequential, and may be required to be reevaluated or changed at any point in the process. It is full of a continuum of engagement, feedback loops, learning, iteration, trial, and error. Co-design activities are complicated and interlocking, stakeholders can participate at any time. The principles for co-design are respectful, participative, iterative, and outcomes focused [27].

2. Methodology

Co-design is highly interdisciplinary and cross-disciplinary. In order to reveal the current research status of co-design from a macro perspective, the data sources of this paper are from three major interdisciplinary databases, Web of Science (WOS), Scopus, and ScienceDirect (data collection date: May 2020); two main source journals, *CoDesign—International Journal of CoCreation in Design and the Arts* (since 2005) and *Design Studies*; and two international conferences, *Participatory Design Conference* (PDC) (since 1990) and *(PIN-C) Participatory Innovation Conference* (since 2011).

The purpose of this paper is to first study the current research status of co-design from a historical and comprehensive perspective. Then, extract the most relevant papers related to web-based product co-design to analyze its research status. The literature extraction according to the combined keywords of “participatory design”, “co-design” or “co-creation”, and “product design”, as well as “web-based”, “online”, or “social media”, respectively.

As the term co-design is often mixed with participatory design, cooperative design or co-creation, the literature search was divided into two parts. In the first part, a hierarchical search was performed on the keywords “participatory design”, “collaborative design”, “co-design”, “co-design*”, or “co-creation” to investigate the research status of co-design through meta-analysis. In the second part, we selected 39 papers that were the most relevant to online or web-based product co-design from 2010 to May 2020 for microanalysis to figure out the current research status and problems that need to be solved. Literature types include journal articles, conference proceedings, literature reviews, books, and doctoral dissertations. In order to find the most relevant literature, the search strategies are as follows:

TITLE-ABS-KEY (Title, Abstract and Keywords).

Part 1: The keyword search combined “participatory design”, “cooperative design”, “co-design”, “co-design*” or “co-creation” with “product design” respectively. Timespan = All years.

- (TITLE-ABS-KEY (“participatory design”) OR (“cooperative design”)) AND (“product design”);
- (TITLE-ABS-KEY (“co-design*”) OR (codesign)) AND (“product design”);
- (TITLE-ABS-KEY (co-creation)) AND (“product design”);

Part 2: The keyword search combined “participatory design”, “co-design” or “co-creation” and “product design”, as well as “web-based”, “online” or “Social media”, respectively. Timespan = 2010–2020.

- (TITLE-ABS-KEY (“Participatory Design”) OR (“cooperative design”)) AND (“product design”) AND ((web-based) OR (online) OR (“Social media”));
- (TITLE-ABS-KEY (“Co-design*”) OR (Codesign)) AND (“product design”) AND ((web-based) OR (online) OR (“Social media”));
- (TITLE-ABS-KEY (co-creation)) AND (“product design”) AND ((web-based) OR (online) OR (“Social media”)).

3. Results

3.1. Research Status of Co-Design

The publication timeline of co-design related articles can clearly reflect the development trend of co-design research. Co-design research began approximately in 2008 and has grown at a rate of 2–8% per year in the past ten years, with the fastest growth in 2019 (data collected in May 2020). This also reflects that the previously mentioned co-design is considered an updated term for participatory design and user-centered design and is a relatively new concept (Figure 2), (Table 2).

In the three databases, research on participatory design, co-design, and co-creation first appeared in 1976, 1990, and 1979, respectively. Among them, research on product design began in 2000, 2004, and 1995, while research on web-based or online product design was first published in 2006, 2007, and 2008 (Table 2).

Figure 3 shows that in the three academic databases, research on participatory design and co-design increased significantly since the mid-1990s. The main literature on participatory design comes from ScienceDirect, which has grown since 1995, and the research on co-design is minimal.

In the past ten years, research on product participatory design has increased significantly, and in the past five years, research on product co-design has also begun to increase. It can be seen that research on product co-design has only begun to emerge in the last few years (Figure 4).

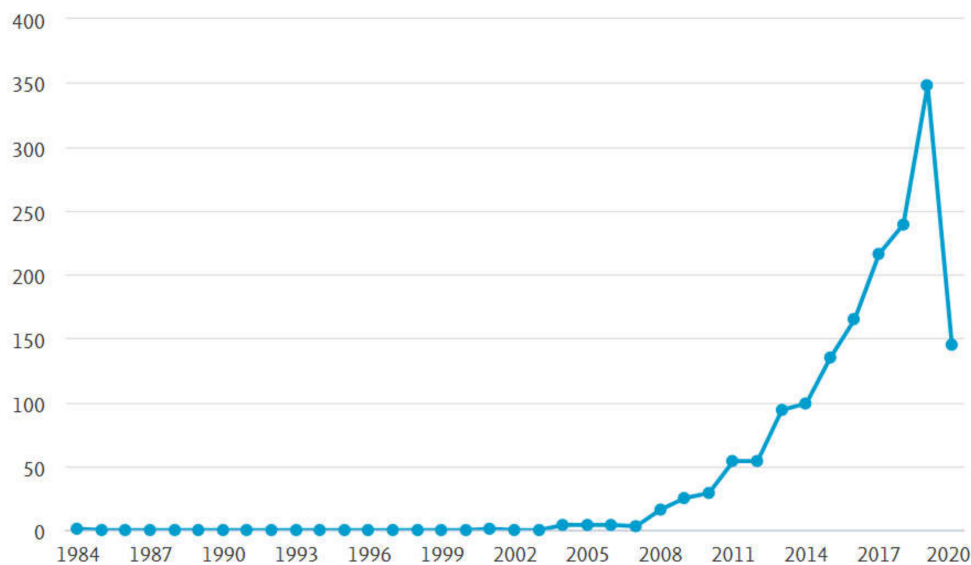


Figure 2. Timeline and number of publications related to co-design.

Table 2. Use of different keyword combination search strategies to get the earliest years of relevant literature in the three databases.

Keywords Search Strategy	Scopus	Web of Science	ScienceDirect
"Participatory Design"	1976	1991	1996
"Participatory Design" AND "Product design"	2002	2004	1995
"Participatory Design" AND "Product design" AND "online" OR "web-based"	2010	2009	2008
"Co-design"	1990	1996	1996
"Co-design" AND "Product design"	2000	2012	2012
"Co-design" AND "Product design" AND "online" OR "web-based"	2011	2017	2014
"Co-creation"	1979	1992	1997
"Co-creation" AND "Product design"	2004	2004	2003
"Co-creation" AND "Product design" AND "online" OR "web-based"	2006	2007	2014

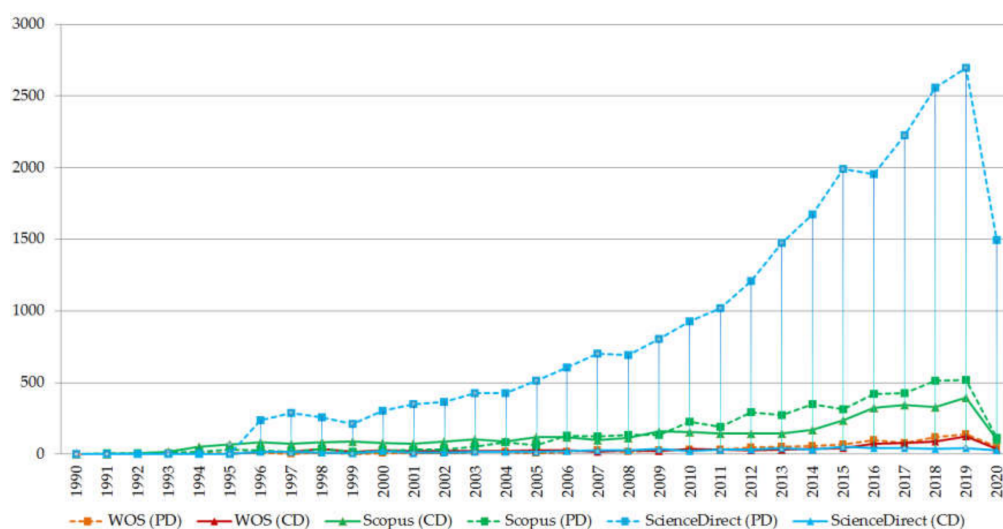


Figure 3. The timeline and amount of literature related to participatory design (PD) and co-design (CD) in the three databases.

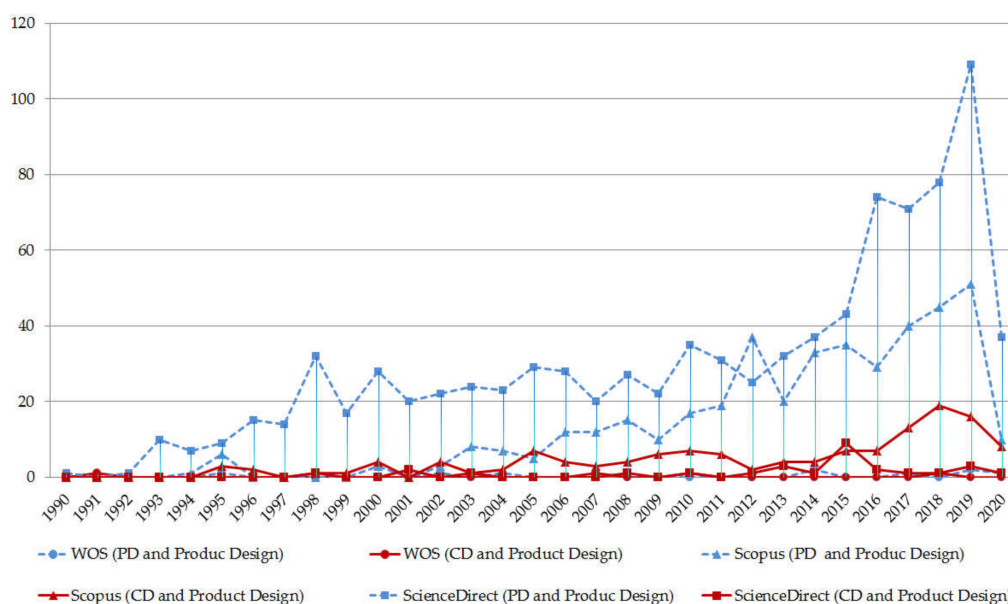


Figure 4. The timeline and number of articles related to product design in participatory design (PD) and co-design (CD) literature.

3.1.1. Research Areas

Table 3 shows the research areas, countries, and source publications of the literature that contains the keywords to participatory design, co-design, and co-creation. Participatory design has grown rapidly in the past few decades, and people all over the world are increasingly participating in various participatory design projects. Co-design provides an opportunity for governments, the private sector, and community services organizations to comprehensively review and overhaul how they do business. The research areas of participatory design and co-design cover most disciplines, including computer science, engineering, health care, public environmental, education, business economics, psychology, social sciences, science technology, etc., and each research direction presents different understandings of co-design.

Research areas covered by the literature including the keywords product design and participatory design include manufacturing, ergonomics, social and behavioral sciences, evaluation and program planning, and agricultural systems. Co-design research mainly focused on hardware and software design and is also the most cited. In addition, research in the communication and arts and humanities field has begun to emerge. The common point of online products' participatory design or co-design is communication. Compared with participatory design and co-design, the source publications included *Computers in Human Behavior*, *International Journal of Human-Computer Studies*, *Information Communication Society*, and *Journal of Product Innovation Management*. Overall, in recent years, the research of co-design has shifted from the initial software and hardware design to a broader field.

From the perspective of publications source, research related to co-creation focuses on the following disciplines: business, marketing, management, and innovation. For example, the research topic involves business research, industrial marketing management, services marketing, product innovation management, innovation organization management, product and brand management, sustainability, etc. Obviously, co-creation is more related to co-design than participatory design. Although co-design evolved from participatory design, as an important method of co-creation, co-design is commonly used with co-creation (Table 3).

The main geographic provenance of participatory design, co-design, and co-creation research in America (United States, Canada, Brazil, etc.), Europe (United Kingdom, France, Germany, Italy, Finland, Netherlands, Spain, Belgium, Denmark, Italy, Sweden, Estonia, etc.), Asia (China, India, Japan, South Korea, etc.), Oceania (Australia, New Zealand), and Africa (South Africa). Research on web-based product co-design is mainly conducted in the United States, the United Kingdom, and China (Table 3).

Table 3. Research area, country, and source publications of the literature that contains the keywords “participatory design”, “co-design”, and “co-creation”.

Keywords	Research Areas	Countries	Source Titles
Participatory Design			
Participatory Design	Public Environmental Occupational Health, Environmental Sciences Ecology, Engineering, Health Care Sciences Services, Computer Science, Education Educational Research, Psychology, Business Economics, Social Sciences Other Topics, Science Technology Other Topics, etc.	USA, Australia, United Kingdom, Canada, Germany, Sweden, France, Netherlands, Denmark, Italy, etc.	BMC Public Health, Sustainability, Progress in Community Health, Partnerships Research Education and Action, BMJ Open, International Journal of Environmental Research and Public Health, Work a Journal of Prevention Assessment Rehabilitation, Ecology and Society, Journal of Environmental Management, Health Expectations, Agricultural Systems, etc.
Participatory Design AND Product design	Engineering, Environmental Sciences Ecology, Public Environmental Occupational Health, Computer Science, Business Economics, Science Technology Other Topics, Health Care Sciences Services, Education Educational Research, Social Sciences Other Topics, Agriculture, etc.	USA, United Kingdom, Finland, France, Australia, Germany, Spain, South Korea, Canada, China, etc.	Journal of Cleaner Production, Design Studies, Procedia CIRP, International Journal of Industrial Ergonomics, Applied Ergonomics, Procedia Manufacturing, Procedia—Social and Behavioral Sciences, Futures, Evaluation and Program Planning, Agricultural Systems, etc.
Participatory Design AND Product design AND online OR web-based	Computer Science, Education, Educational Research, Engineering, Health Care Sciences Services, Psychology, Public Environmental Occupational Health, Medical Informatics, Communication, Environmental Sciences Ecology, General Internal Medicine, etc.	USA, United Kingdom, Finland, Germany, South Korea, China, France, Netherlands, South Africa, Finland, etc.	Computers in Human Behavior, International Journal of Human-Computer Studies, Procedia—Social and Behavioral Sciences, Value in Health, International Journal of Medical, Informatics, Applied Ergonomics, Interacting with Computers, Journal of Retailing and Consumer Services, Journal of Cleaner Production, Futures, etc.
Co-design			
Co-design	Engineering, Computer Science, Telecommunications, Automation Control Systems, Physics, Health Care Sciences Services, General Internal Medicine, Materials Science, Mathematics, Science Technology Other Topics, Public Environmental Occupational Health, Education Educational Research, etc.	USA, China, United Kingdom, France, Germany, Australia, Italy, Canada, Spain, Austria, etc.	IEEE Transactions on very Large Scale Integration VLSI Systems, Lecture Notes in Computer Science, Computer, Design Automation for Embedded Systems, IEEE Transaction on Computer Aided Design of Integrated Circuits and Systems, ACM Transactions on Design Automation of Electronic Systems, BMJ Open, IEEE Design test of computers, IEEE Transactions on Microwave Theory and Techniques, IEEE Micro, etc.
Co-design AND product design	Computer Science, Engineering, Business Economics, Operations Research Management Science, Automation Control Systems, Materials Science, Communication, Instruments Instrumentation, Arts Humanities Other Topics, General Internal Medicine, etc.	USA, China, Germany, Spain, United Kingdom, Australia, Brazil, Italy, Finland, India, etc.	IEEE Transactions on very Large Scale Integration VLSI Systems, ACM Transactions on Design Automation of Electronic Systems, Journal of Service Research, Proceedings of the IEEE, Design Automation for Embedded Systems, IEEE Design Test of Computers, IEEE Transactions on Advanced Packaging, IEEE Transactions on Computers, IEEE Transactions on Industrial Electronics, Journal of Product Innovation Management, etc.

Table 3. Cont.

Keywords	Research Areas	Countries	Source Titles
Participatory Design			
Co-design AND product design AND online OR web-based	Business Economics, Communication, Computer Science, General Internal Medicine, Sociology	USA, New Zealand, Australia, Belgium, Brazil, Germany, India, Israel, Japan, South Korea, etc.	Secure Computing, Information Communication Society.
Co-creation			
Co-creation	Business, Management, Hospitality leisure sport tourism, Environmental sciences, Environmental studies, Green sustainable science technology, Information science library science, Computer science information systems, Engineering industrial, Education educational research, etc.	USA, England, Australia, China, Finland, Sweden, Netherlands, Italy, Germany, Spain, etc.	Journal of Business Research, Industrial Marketing Management, Journal of Service Management, Sustainability, Journal of Services Marketing, Journal of Service Theory and Practice, International Journal of Contemporary, Hospitality Management, Journal of Business Industrial Marketing, European Journal of Marketing, Marketing Theory, etc.
Co-creation AND product design	Business economics, Engineering, Computer science, Social sciences other topics, Environmental sciences ecology, Science technology other topics, Operations research management science, Information science, library science, Psychology, Public administration, etc.	USA, England, China, Finland, Sweden, Germany, Italy, Australia, Netherlands, Spain, etc.	Industrial Marketing Management, Journal of Business Research, Sustainability, Journal of Business Industrial Marketing, Creativity and Innovation Management, European Journal of Marketing, Journal of Product Innovation Management, Technological Forecasting and Social Change, Journal of Product and Brand Management, Journal of Service Management, etc.
Co-creation AND product design AND online OR web-based	Business economics, Computer science, Engineering, Health care sciences services, Medical informatics, Operations research management science, Psychiatry, Psychology, Social sciences other topics, etc.	Finland, England, Sweden, Brazil, Estonia, Guatemala, Italy, Netherlands, Norway, Oman, etc.	Business Horizons, European Journal of Marketing, Innovation Organization Management, International Journal of Electronic Commerce, Internet Interventions the Application of Information Technology in Mental and Behavioural Health, Journal of Service Management, Leisure Studies, Production Planning Control, Service Business, Supply Chain Management an International Journal, etc.

3.1.2. Research Topics of Participatory Design Conference (PDC) (2010–2020)

The Participatory Design Conference (PDC) brings together research related to people's direct involvement in co-design, development, implementation, and funding activities around technology, space, art, and services. In this part, we selected 319 papers or reports from the 2010–2020 Participatory Design Conference (PDC) to analyze the themes of participatory design research. As shown in Figure 5, the methodology has been the leading topic of participatory design research, and other research topics include social services, health care, urban planning, education, etc. Among the 319 papers, only nine papers related to product design and five papers related to social media (Figure 5).

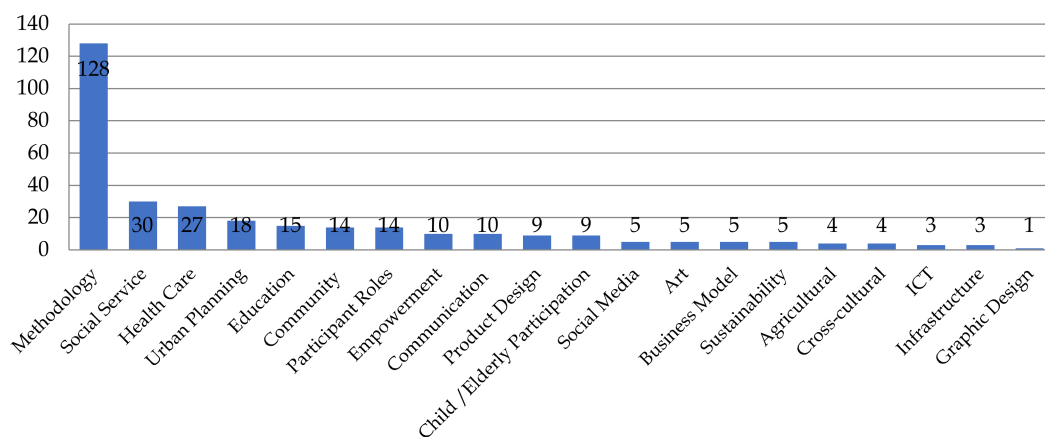


Figure 5. The research topics of the Participatory Design Conference (PDC) proceedings (2010–2020).

3.2. Research Progress of Product Co-Design

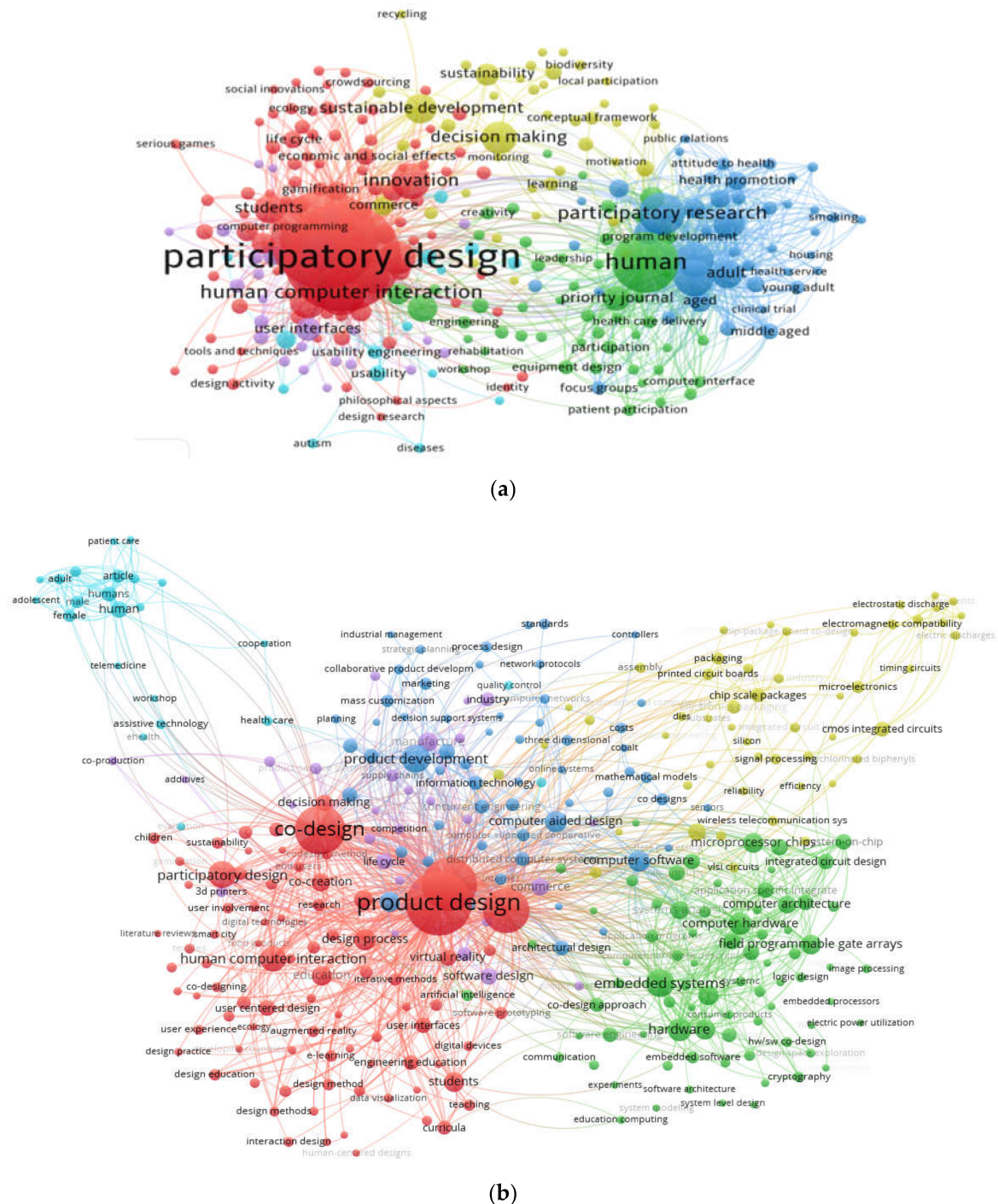
Table 4 shows the main distribution of keywords related to participatory design, co-design, and co-creation. The literature related to participatory design mostly focuses on participatory approaches, organization and management, decision-making, etc., while the literature related to co-design is almost all about computers and embedded systems. Software and hardware co-design is the main research direction. Among them, the same research topic of participatory design and co-design is human computer interaction (HCI). Co-creation is almost equivalent to open innovation, and its research directions mainly include innovation, service, sales, information, social media, management, etc. As mentioned above, co-design is often shared use with co-creation, and the keywords bear this out. The literature on product co-creation mainly focuses on open innovation, customer satisfaction, information systems, commerce, manufacturing, crowdsourcing, social networking, product service systems, knowledge management, sustainable development, etc. (Table 4).

Table 4. The distribution of the top10 keywords related to participatory design, co-design, and co-creation.

Participatory design	participatory approach, community-based participatory, human–computer interaction (HCI), organization and management, decision making, health care, information processing, education, human engineering, psychology, etc.
Co-design	embedded systems, hardware/software co-design, field programmable gate array (FPGA), computer architecture, algorithms, integrated circuit design, systems analysis, computer simulation, human–computer interaction (HCI), computer aided design, etc.
Co-creation	open innovation, human, service-dominant logic, sales, information systems, social media, knowledge management, sustainability, human computer interaction (HCI), decision making, etc.
Product participatory design	human computer interaction (HCI), human, user interfaces, human engineering, design process, children, education, user experience, information systems, decision making, etc.
Product co-design	embedded systems, hardware–software codesign, field programmable gate arrays (FPGA), human, human computer interaction (HCI), integrated circuit design, computer architecture, computer aided design, design process, computer simulation, etc.
Product co-creation	open innovation, customer satisfaction, information systems, commerce, manufacture, crowdsourcing, social networking, product-service systems, knowledge management, sustainable development, etc.

Figure 6 shows the keyword clustering network related to the product design of participatory design, co-design, and co-creation in the literature so that we can intuitively get the research key points

of the literature. The research of product co-design is concentrated in the field of computer-related product design. However, product participatory design and product co-creation are more focuses on interaction with people. Co-creation, as an important value creation method combined with social media, is more widely used in business and has more research focuses on interaction with people (Figure 6).



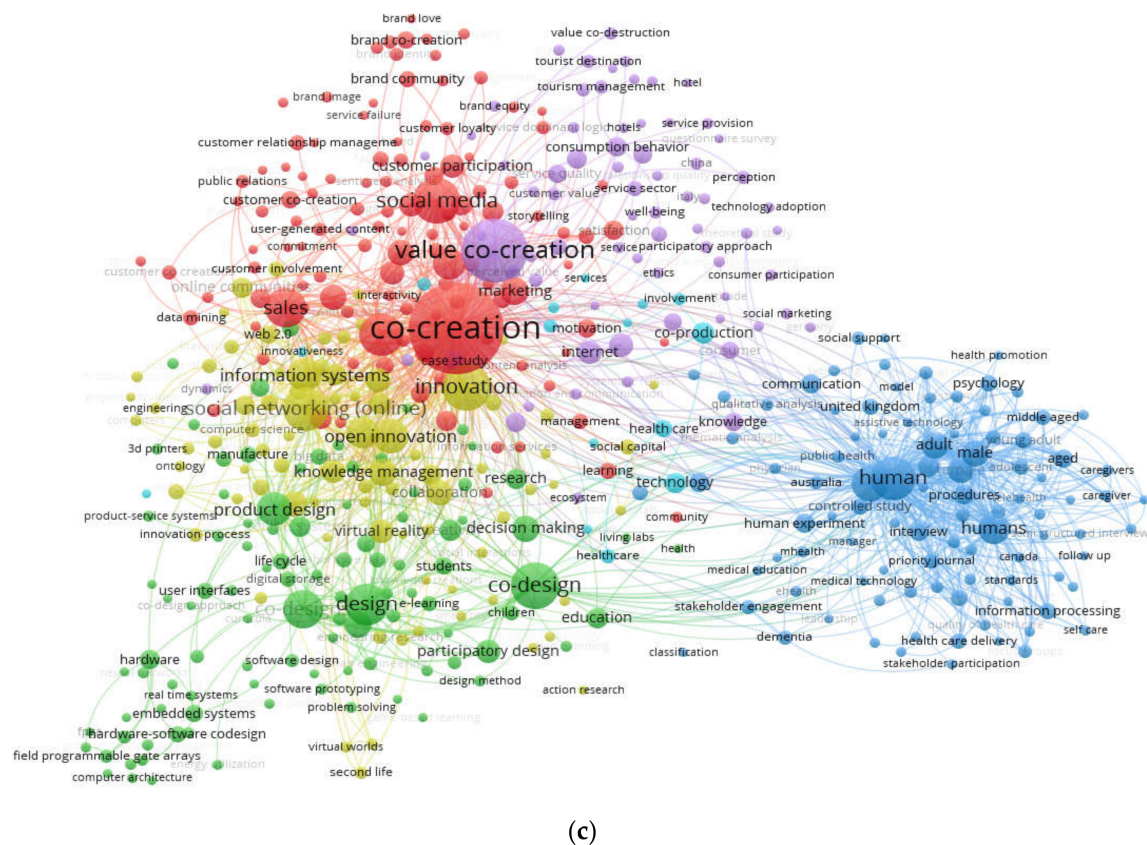


Figure 6. Network visualization of keywords clustering in product participatory design, co-design, and co-creation literature. (a) Keywords of product participatory design. (b) Keywords of product co-design. (c) Keywords of product co-creation.

We cleaned up the keywords in Figure 6 to get Figure 7. Through keyword cloud analysis, the research emphases of web-based product design can be intuitively compared (Figure 7):

- The top ten keywords of web-based product participatory design:
- Human computer interaction (HCI), education, design process, online systems, social networking, students, user interfaces, children, collaborative development, decision-making.
- The top ten keywords of web-based product co-design:

Online systems, co-creation, Human computer interaction (HCI), social networking, design process, new product development, computer aided design, customer satisfaction, information and communication technologies (ICT), customization, e-health.

The top ten keywords of web-based product co-creation:

Open innovation, sales, Facebook, commerce, consumer behavior, customer satisfaction, economic and social effects, human resource management, information systems, innovation management.

Product design includes virtual and physical product design [39]; this paper is focused on physical product design. Through the above analysis, the research on web-based product co-design is very limited.

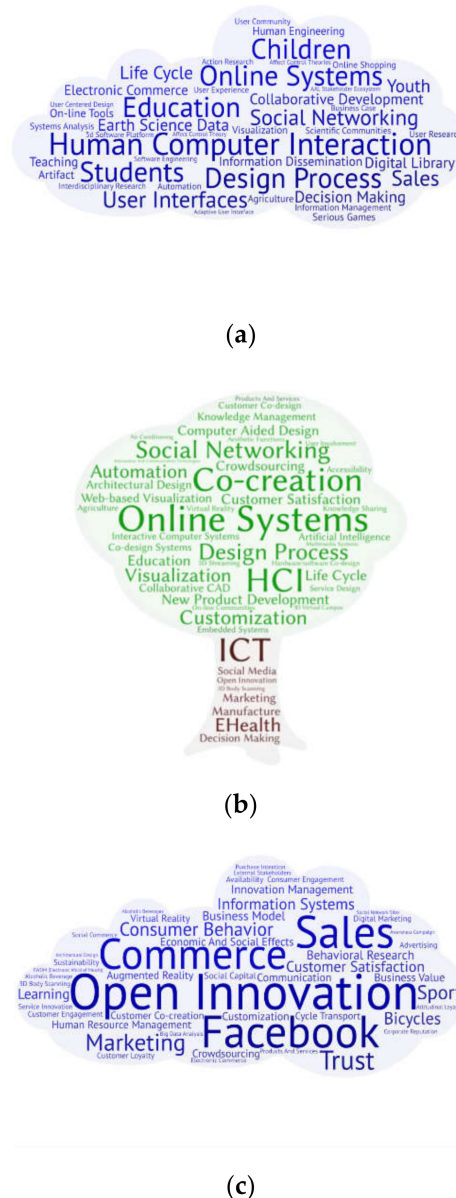


Figure 7. The word cloud of main keywords related to web-based and product design in participatory design, co-design, and co-creation. (a) Keywords of web-based product participatory design. (b) Keywords of web-based product co-design. (c) Keywords of web-based product co-creation.

3.3. Research Progress of Web-Based Product Co-Design

We selected 47 publications that are the most relevant to web-based product co-design, based on the above search strategy that is: (TITLE-ABS-KEY (“Participatory Design”) OR (“cooperative design”) OR (“Co-design*”) OR (Codesign) OR (“co-creation”)) AND (“product design”)) AND ((web-based) OR (online) OR (“Social media”)). The selected publications include 32 journal articles, seven conference proceedings, seven books, and one master’s thesis (Published 2010–2020). Of the selected books, five are related to social media, one is sustainability research, and the other is about virtual environment systems research. For example, Pirjo Friedrich studied how to use social media tools to support user participation in the design and innovation process, and how social media influences user participation, in his book *Web-based co-design: Social media tools to enhance user-centered design and innovation processes* [40]. The master’s thesis is about the utilization of social media within the product development of SMEs.

Journal articles and conference proceedings can timely reflect the development trend of co-design and problems that need to be solved, so further analysis is conducted below. Figure 8 shows the web-based product co-design research topics of the selected 39 Journal articles and conference papers.

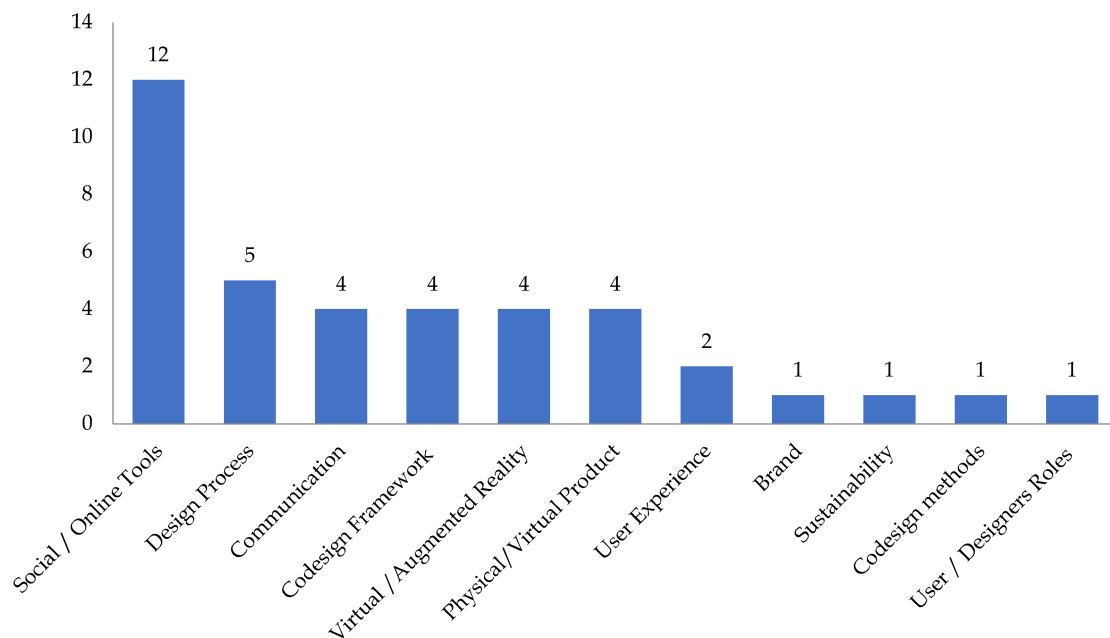


Figure 8. Web-based product co-design research topics (2010–2020).

Among these 39 papers, social/online tools, design process and communication are the most studied areas. Below, we will analyze the research status of web-based product co-design from the five aspects as we discussed in 1.1.3 above, that is, what, how, who, why, and who.

3.3.1. What: Content/Task

The web-based co-design usually starts with an idea from a member of the co-design platform community, which can be a product or an innovative task. The literature reviewed above includes two case studies of physical products co-design: bra product innovations [41] and an active wheelchair [42].

3.3.2. How: Process/Tools

How can we get there? “How” is the major phase of co-design including processes and tools. The web-based co-design activities involve stakeholder integration, organization, and communication; modeling, review, evaluation, and presentation; data sharing, management and visualization (VR/AR/VRML tools), and a range of integrated tools for different phases.

As mentioned above, we divide the web-based product co-design process into five main steps: idea, analysis, concept, implement, and evaluate. A distributed design project management environment [43] is a must, and relevant studies include information management, task management, activity scheduling, resource sharing, social tools, CAD tools, and decision-making [44] tools, etc. The research related to the collaborative design environment is divided into the following five parts.

Design Concept

Collaborative conceptual design has always been the main area of research work. The key to conceptual design activities is to understand and clearly define the problem and requires the participation of people from multidisciplinary backgrounds. Many frameworks have been proposed for web-based co-design systems. Maher et al. propose a conceptual space to model how technology supports the transition from individual design to team design and then to collective design [45]. Framework

research in the selected papers include consumers co-creating conceptual frameworks [46–48], analysis framework [49], commercial product development framework [38], continuous innovation design framework [50], framework for online data analysis and reduction [51], and a comprehensive approach to sustainability and holistic life cycle assessment during product development [52]. AI plays a pivotal role in conceptual design. It can learn new concepts, deduce design problems and draw useful conclusions, perceive and understand a visual scene, etc.

Design Process

Research on design process includes user innovation in social network service [53], the collaborative product design process of industrial design and engineering design [54], the co-creation process of social media [55,56], and the co-creative process management system [57].

Social Tools

Web 3.0 is about creating value based on user collaboration [58–60]. Web 3.0, the semantic Web, is about mass production and precise consumption. Social platform interactive enables internal and external interconnections and collaboration from all over the world and promotes the value creation process of organizations [61,62]. Research on social platforms in co-design has emerged in recent years, such as a web-based platform for collaborative product design, review, and evaluation [63]; the impact of social media on co-creation of innovation [55]; online communities for commercial software development [60,61]; social tools and technology research [40,64]; and customer integration in social media-based product and service development [65].

The operation and success of the new product development process depend on user engagement, solutions, and communication [38]. Via online tools, users can participate anytime. Shared user diaries and real-time chat sessions can be used to quickly gather user feedback [64]. Some studies cover the interaction and communication of stakeholders in the development of new products [7,66]; dialogue-labs methods [67]; diffusion [68]; the transparency-enhancing toolset for encouraging citizen participation [69]; and the incentives, intensity, and extent of participation [52].

CAD Tools

Shared product visualization and collaborative design review is another major research area. Methods of sharing product representations over the virtual environment and a number of CAD-integrated shared workspaces have been presented in the scientific literature for distributed design review [70,71]. Other relevant studies include virtual and augmented reality, haptics working principles and their advantage towards product evaluation [72,73], web 3D-based collaborative design research [74], etc.

Evaluation and Delivery

Research on supervision, management, and evaluation includes virtual reality evaluation platforms [75], ICT-based solution approach for collaborative delivery [76], collaborative product design decision-making research [44], etc.

3.3.3. Whom: Partner

“Whom” refers to the type and role of partners. The spread and development of information and communication technologies have resulted in a redistribution of roles and tasks among value creation participants. Social media platforms are fueling a new era of customer empowerment [61]. Users also become designers, even participating in decision making, and designers become facilitators of the co-design process. The role of researchers is to provide users with lightweight tasks and guidance to help them analyze their needs and participate in the design process.

The customer plays a central role in the company's process of creating new value. [46]. Guo et al. identified six user roles that emerged during the NPD process: project leader, active designer, generalist, communicator, passive designer, and observer [77]. Other studies involve the types and roles of participants, including consumers' attitudes toward online mass customization [78,79], the impact of supplier involvement on product innovation [80], users' roles and contributions during the new product development process [79,80], and user experience [81,82].

3.3.4. Why: Motivation for Participation

Motivations for stakeholder participation usually include curiosity, dissatisfaction with existing products, intrinsic interest in innovation, to gain knowledge, to show ideas, to get monetary rewards [38].

3.3.5. Who: Personal Characteristics

The personal characteristics of the partners such as the participant's domain-specific skills, involvement in innovation activities, internet-specific innovation task involvement, adoption and innovativeness, novelty seeking, exploratory behavior, web usage, previous innovation activities, etc. The relevant studies include the exploitation of designers and customers' skills and creativity in product design and engineering [83] and youth co-design [84].

4. Conclusions

The charm of co-design has been increasingly demonstrated in the development of the Internet. The application of co-design is spreading to every corner of society, and the academic research on co-design is also being explored from different disciplines. We have discussed the historical roots of co-design, and the survey highlighted five aspects most closely related to co-design: what, whom, how, why, and who. Our study complements the literature on web-based product co-design and attempts to theoretically improve the research framework of co-design to help researchers discover and explore future research topics.

The future research of co-design still has a great space to figure out. First of all, knowledge management in design has been cited as an important area of future research. The challenge here is to capture and reuse the existing designs, help them adapt to new requirements, and maintain the design knowledge as a corporate asset. Second, the future of innovation is open, social, environmentally driven, faster, and more global. Web-based co-design goes beyond previous participatory community design and may involve participants from all over the world. As more and more firms engage in co-creation creative activities, innovative customers may become a new aspect of companies' competition. Third, hidden customer needs, advanced evaluation tools, a huge amount of information, and corporate absorptive capacity all pose challenges to the use of social media [56]. The challenges of the future digital factory frameworks, such as using more intelligent product/process models, provides predictive capabilities to further reduce the need for physical prototyping. In addition, the shift in value creation paradigm requires the assessment of co-creation and participation in the new product development cycle. Finally, social media does not always lead to the success of NPD. In the context of luxury fashion brands, putting user-designed labels on products can backfire [85]. Individual contributions on social media tend to be small and purposeful, or genuinely active people may come to dominate the co-design process. If the goals of co-design are too open, too large a task will have no incentive for users who volunteer to participate in network collaborative design. Online co-design presents some challenges for companies, such as secrecy concerns, sharing of intellectual property, information overload, and production infeasibility, etc. Too many standardized creative processes may after all hamper creativity, and too much involvement leads to slow down the speed of innovation.

Co-design enables the full implementation of the potential associated with development and production engineering. Social entrepreneurship is on the rise [86], 5G will promote the growth of participatory spaces and immersive experience, and the research areas of co-design will become more

diversified. It seems that we should look beyond individual approaches, methods, and achievements towards building greater collaborative design capacity in society.

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