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Global Design Researchers Academic Research Mapping from the Perspective of Bibliometrics

Xu Jingyu*[a]; Xu Jiang[a, b]; Lu Han[b]; Jiang Zhonggang[b]

[a] Shanghai International College of Design and Innovation, Tongji University, Shanghai, China
[b] College of Design and Innovation, Tongji University, Shanghai, China
* 976098110@qq.com

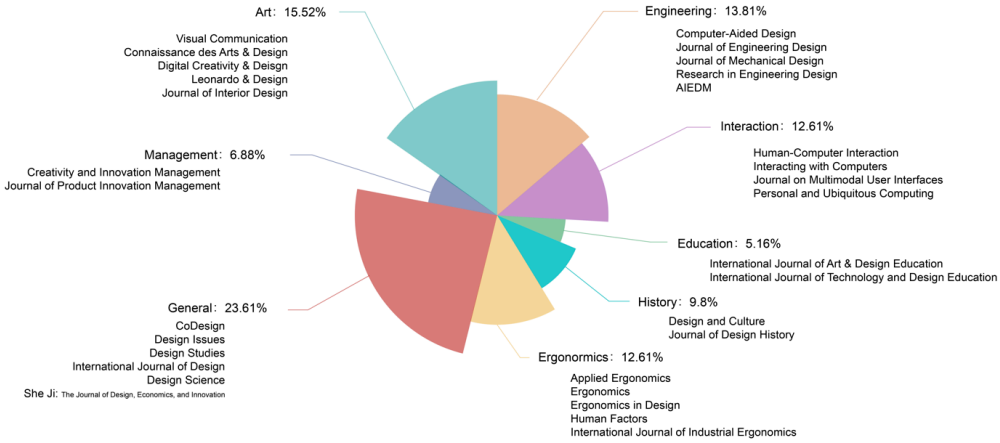
Design discipline has been reborn and developed in the course of multidisciplinary crossover, convection and integration. With the advent of the knowledge networking era, the global design research paradigm actively shifts from experience and theoretical models to data computing thinking. This paper selected 31 international journals as our basic database, using the method of author co-citation analysis from bibliometrics to obtain the knowledge graph of global design researchers. With the help of it, we identified eight research fields of design discipline and high-impact researchers according to total citation frequency. Then we screened out more high-impact researchers from every field, extracting and mapping their original theories in the knowledge graph, which vividly showed the distribution of design research knowledge. Further than that, we take John S. Gero as an example to construct an individual academic research portrait by keyword co-occurrence analysis and literature research, which contributes us to tease out individual research process. Through the above-mentioned analysis of different granularities, we can better understand the core knowledge of design research, the extension of its knowledge and the interaction between them.

Keywords: global design researchers; design discipline structure; researcher portrait; bibliometrics; visualization

1 Introduction

Design discipline has been reborn and developed in the course of multidisciplinary crossover, convection and integration. It has continuously absorbed new ideas, new methods, and new theories from other scientific fields. Its basic kernel has been born in a series of discussions about design research for more than half a century. At the same time, in order to adapt to changing social needs, design science is constantly evolving and transforming itself in the intersection and integration (Lawson & Dorst, 2009). The publication of "Design Expertise" in 2009 marked the beginning of the design study to explore the path of the new research paradigm from following the path of traditional scientific methodology. The academic consensus has reached a trinity design research model: Research About/On Design, Research For Design, and Research Through Design (Jonas, 2007). In the era of knowledge networking, the global design research paradigm actively shifts from experience and theoretical models to data computing thinking.

With the ongoing in-depth cross-discipline innovation in design, the academic achievements of design research output no longer only stay in the domain of practice and innovation, beginning to develop unique academic research and knowledge systems (Cross, 1999). Simon (1996) believes that design is the meta-discipline of all professions. Based on the characteristics of artificial objects, design is concerned with the design process, and it is proposed that design is not an optimal solution, but a satisfactory solution. According to Cross's study (2006) of Designerly Ways of Knowing, the mode of design thinking is the third category of intelligence, which is parallel to the mode of scientific thinking and humanistic



thinking. Lawson (2006) advocates that scientific methods and humanistic thoughts should be put under the designer's special design expertise and designer-style mode of thinking, and the comprehensive application beyond subjects should be carried out.

It can be seen that scholars are crucial parts of knowledge production and impartation. Focusing on scholars' knowledge system research can help to conduct interdisciplinary, collaborative, and comprehensive research. This paper aims to explore the disciplinary structure of design through author co-citation analysis, extract core theories contributed by scholars in various fields, draw a map of global design scholars' academic research, further track their respective study history and construct scholars' individual academic research portraits.

2 Structural exploration of design discipline

According to the deep research (Gemser, de Bont, Hekkert, & Friedman, 2012; Nie & Sun, 2017; Gemser & de Bont, 2016) in the text mining analysis of active journals, high-quality journal quality index analysis and journal impact analysis, and publication patterns in design journals, we did the further quality evaluation of these journals. Then combining with our research orientation, expert evaluation, two iterative analyses and verification of co-citation analysis were conducted. Finally, 31 international journals were selected as the source of our research data, as shown in Figure 1. Based on these 31 international journals, we screened out the data published after 2000 to construct the author co-citation knowledge graph because of the characteristics of large proportion and high timeliness. Furthermore, in order to balance the number of literatures in respective research fields, we filtered the original data of ergonomics field and human-computer interaction field, which had overwhelming advantages in the size of the raw data. And we selected 900 literature data from each field to achieve an optimized database.

Figure 1. The Source of Data

The content of this paper relied on VOSviewer for data analysis and visualization. Based on the SLM (Smart Local Moving) algorithm, VOSviewer uses the Majorized algorithm for the layout of nodes, which can effectively represent the relative position of each data in two-dimensional space and reflect the inherent logical relationship and hierarchical structure of the data. It is more suitable for presenting the main information of large-scale sample data sets (Liao, 2011).

Due to the authors co-citation analysis can reflect the disciplinary structure and characteristics of the scientific system on a macro level, and it is possible to explain the interactions and dependencies among disciplines from the micro level (Chen & Wang, 2017). We used VOSviewer to conduct co-citation analysis of about 8000 journal literature data, selected 1000 scholar nodes to draw, and obtained the author co-citation network, as shown in Figure 2. According to the strength of links between nodes, all scholars' nodes have been clustered into several different groups with respective colors by the software. Then we consulted with field experts, decided to divide nodes into eight research fields, and denominate them as "Design Cognition", "Design History", "Design Art Theory", "Design Education", "Design Engineering", "Human-Computer Interaction", "Ergonomics" and " Design Management ". Essential theories proposed by scholars in these fields can reflect the core knowledge of design research.

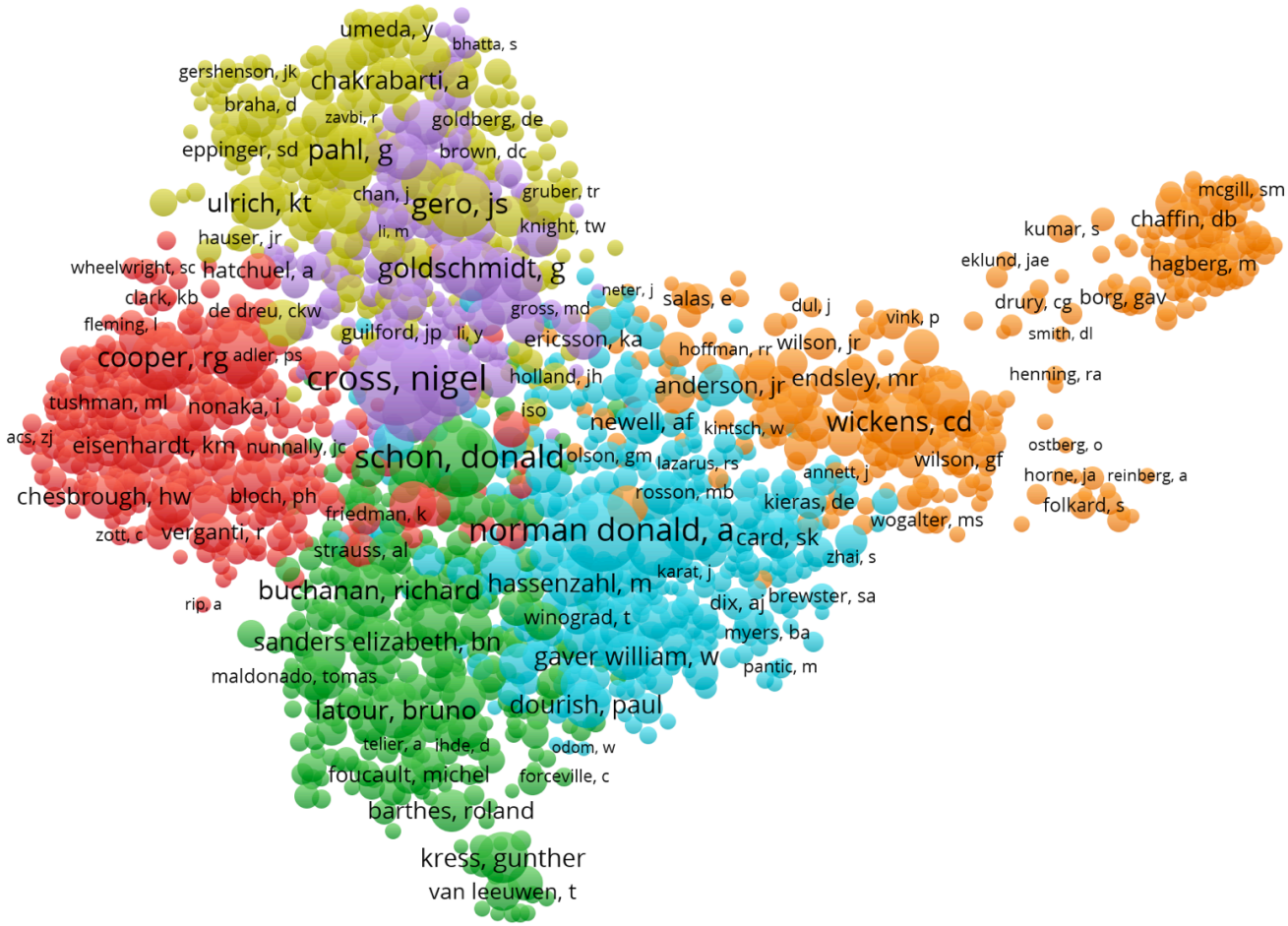


Figure 2. Author Co-Citation Network of Global Design Research

3 The influence of design researchers

3.1 High-impact design researchers

Total citation frequency refers to total citations of the papers published by researchers. It's an important indicator to evaluate the academic influence of a researcher, which reflects the real-name comments of peers on research results worldwide (Wang, Guo & Zhang, 2015). Therefore, through the author co-citation analysis, 20 high-impact researchers with high citation frequency in the global design research field were shown in Figure 3, whose academic contributions in respective fields have promoted the derivation and development of design research.

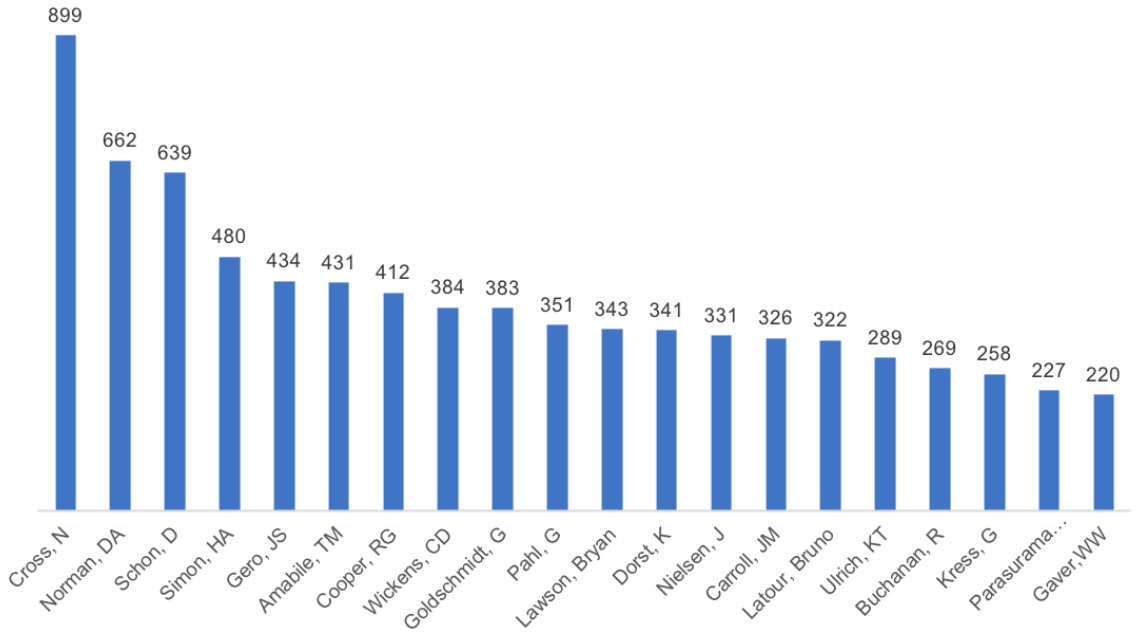


Figure 3. Top 20 High-Impact Design Researchers

Among them, Herbert A. Simon, Nigel Cross, Don Norman, Donald Schon, Teresa M. Amabile and John S. Gero have made significant contributions in fields of design cognition, design education and intelligent design. Herbert A. Simon, as a famous American computer scientist and psychologist, has committed to research intelligent representations in problem-solving and decision-making, and explored the use of computer and artificial intelligence as tools to simulate and enhance human thinking. *The sciences of the artificial* (Simon, 1996) is one of his representative works. Nigel Cross focused on the research in design methods early, and he published *Engineering Design Methods*. Subsequently, his research interests were turned to design cognition and design thinking, and his thoughts in *Designerly ways of knowing* (Cross, 2006) were widely diffused. Concentrated on the research into cognitive science and ergonomics in USA, Don Norman is renowned in the domains of industrial design and interaction design for his book, *The Design of Everyday Things* (Norman, 2013). Donald Schon is a well-known scholar because of the proposal of reflective practitioner theory. He has probed into the nature of the learning system and the significance of learning in a continuously changing society. His paper *The Reflective Practitioner: How professionals think in action* (Schon & DeSanctis, 1986) has obtained the highest citations. Teresa M. Amabile proposed the componential theory of organizational creativity and innovation, which demonstrated the impact of factors, such as internal motivation, working environment, on

individual creativity. Her highly cited article is *Motivating Creativity in Organizations:* On doing what you love and loving what you do (Amabile, 1997).

In addition, Christopher D. Wickens and Gerhard Pahl also play a prominent role in the field of ergonomics. Christopher D. Wickens specializes in the research into application cognition, attention, decision-making, human factors and so on. His interests are mainly taken in the control of aviation vehicles, crossing the intersection of psychology and human factors engineering, interpreting the human behaviour in these complex systems. He has written the book called *Engineering Psychology and Human Performance* (Wickens, Hollands, Banbury, & Parasuraman, 2015), and his high-impact papers consist of *A model for types and levels of human interaction with automation* (Parasuraman, Sheridan, & Wickens, 2000). Gerhard Pahl pays attention to the design process, including computer-aided design, safety and cost issues, modular systems and psychoanalysis of human creativity, whose representative work is *Engineering Design: Systematic Approach* (Pahl & Beitz, 2013).

3.2 Distribution of design researchers from different sub-domains

In order to find out the theoretical cornerstone of design research, this paper analyzed the author co-citation graph and sought for high-impact scholars and their core theories in eight sub-domains of design research, as shown in Figure 4. These authoritative researchers all have significant impacts on design research from various perspectives and levels, whose classical theories constitute the knowledge structure bases and theoretical sources of design research.

In the field of design history, Papanek (1995) presented the design principle of From Cradle to Cradle, which holds that the designer is not only the designer of individual products but also production relationships between the product and the environment. Later Margolin (2002) proposed The Politics of the Artificial, which elaborated on reflective design and multiple ways of engaging in design practices. He also approved of creating an international and interdisciplinary attitude to design research.

In the field of design art theory, there have been quite a few academic achievements such as Actor-Network-Theory (Latour, 2005), Semiological Analysis (Bathers, 1977), Art as Experience (Dewey, 1934) and Metaphors (Lakoff & Johnson, 2008) establishing a solid foundation for the prosperity of design art theories. Different from traditional visual semiotics, The Grammar of Visual Design presented by Kress (1996), concentrates on ‘grammar’, the way in which these depicted people, places, and things are combined into a meaningful whole, rather than on the ‘vocabulary’.

In the field of design education, Buchanan (1998) put forward the Four Orders of Design, including these four perspectives of symbols, physical objects, activities and services, systems, environments and organizations, which inspires educators to rethink the curriculum design of talent cultivation. Besides, the Reflective Practitioner (Schon & DeSanctis, 1986), Social Innovation Design (Manzini, 2015) and Situated Learning (Lave & Wenger, 1991) also have maintained the continuous improvement in the design education system.

In the field of design management, Verganti (2009) raised Design-Driven Innovation, a third way distinct from market-driven or technology-driven. He analysed the essence of design innovation and mentioned the constructive elements of design innovation capabilities. In addition, there are many theories absorbed from management science and other disciplines, such as New Product Portfolio Management (Cooper, Edgett, & Kleinschmidt, 1999), Open Innovation (Chesbrough, 2004), Flow Experience (Csikszentmihalyi, 1996).

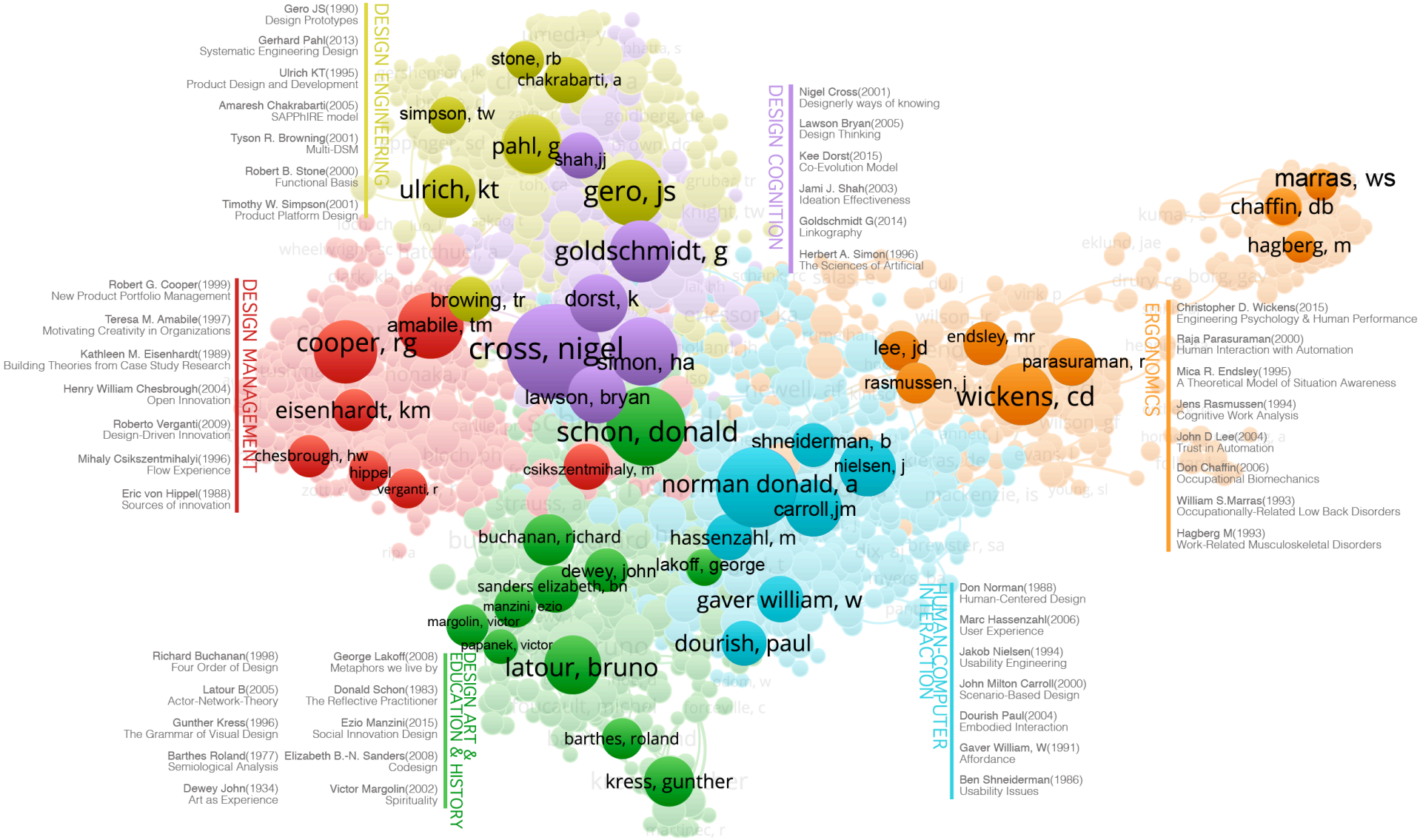


Figure 4. The Theoretical Cornerstone of Design Research

In the field of human-computer interaction, Nielsen (1994) put forward the concept of Usability Engineering, emphasizing user-centered development, which can effectively evaluate and enhance the usability quality of products. Other concepts such as Human-Centered Design (Norman, 1988), User Experience (Hassenzahl & Tractinsky, 2006), Embodied Interaction (Paul, 2004), Technology Affordance (Gaver, 1991) have guided the design practice into further explorations in this field.

In the field of design engineering, Browning (2001) reviewed four applications of the two design structure matrices, static and time-based DSMs, and discussed research directions of the new Multi-DSM. Additionally, Design Prototypes proposed by Gero (1990), Systematic Engineering Design proposed by Pahl (2013) and Product Platform Design proposed by Simpson (2001) have stimulated the optimization and innovation of research methods and product development technology to meet all kinds of requirements of design processes.

In the field of design cognition, Goldschmidt (2014) developed a method for the notation and analysis of the design process, Linkography, which is designed to describe how designers think, generate ideas, put them to the test and combine them into something meaningful. Designerly Ways of Knowing (Cross, 2006), Design Thinking (Lawson, 2006), Co-Evolution Model (Dorst, 2015) and Ideation Effectiveness (Shah, Smith & Varges-Hernandez ,2003) have enriched our cognition of design process and design thinking.

In the field of ergonomics, Parasuraman (2000) created a model for types and levels of Human Interaction with Automation, which provides a framework and an objective basis for deciding which system functions should be automated and to what extent. Engineering Psychology & Human Performance proposed by Wickens (2015), Theoretical Model of Situation Awareness proposed by Endsley (1995), Cognitive Work Analysis proposed by Rasmussen (1994), Occupational Biomechanics proposed by Chaffin (2006) have propelled the research from initial ‘human-machine’ to systematic ‘human-machine-environment’.

3.3 Academic Research Portrait Analysis of Design Researchers

Based on the distribution of researchers in various fields, we further narrowed the granularity of research objects. Different from the traditional citation subjects, analyses used to investigate an author’s influence by Wania (2015), and qualitative citation content analyses used to understand an author’s intellectual legacy by Beck & Chiapello (2018), we combined the literature research with keywords co-occurrence analysis, teased out the research processes of individual researchers and constructed the academic research portraits of researchers in a micro level.

In this paper, we take John S. Gero for example, a research professor in computer science and architecture at the University of North Carolina. He conducts extensive design research in the fields of design science, design computing, artificial intelligence, computer-aided design, design cognition and cognitive science. He is also the author or editor of 53 books and over 700 papers and book chapters. His academic achievements have obtained over 20,000 citations with a h-index of 65 and in i10-index of 314. He is on the editorial boards of numerous journals, such as AIEDAM, and the chair of the international conference series *Design Computing and Cognition.*

This paper screened out the literature data of John S. Gero collected in Web of Science, and then imported them into VOSviewer for keywords co-occurrence analysis. As presented in Figure 5, the node in this keywords co-occurrence graph represents a corresponding keyword. The color of the node indicates the average year when the keyword is mentioned

in his literature, the size of node refers to the total frequency of occurrence, and the edge between two nodes means their co-occurrence in the same paper.

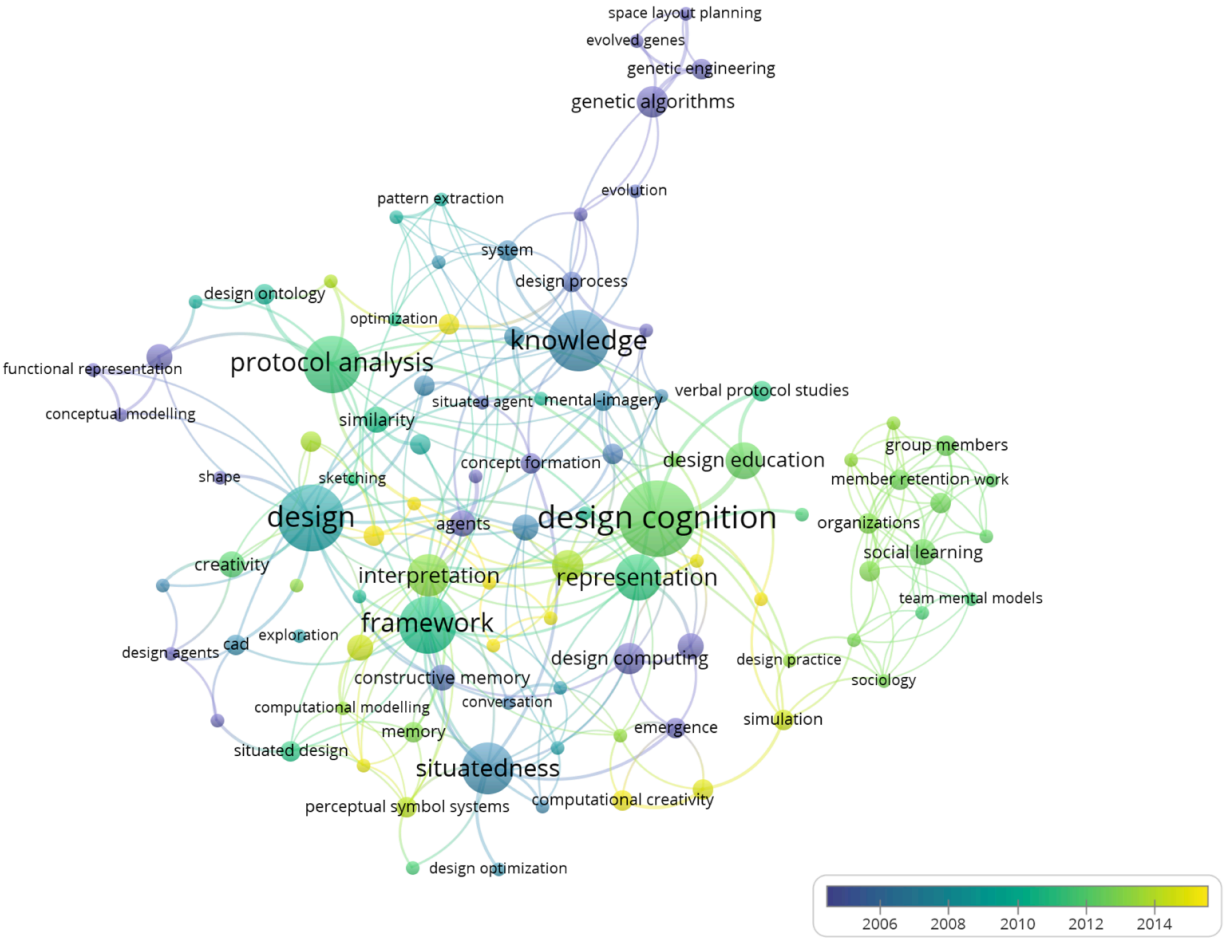


Figure 5. Keywords Co-Occurrence Network of John S. Gero's Research Subjects

Therefore, we interpreted and analyzed keywords shown in Figure 5. It can be identified that he devotes himself to the research into three main fields covering design cognition, design computing and design education. Then we attempted to follow the time sequence to understand the evolution of his research subjects.

From the 1980s to the 1990s, John S. Gero cooperated closely with Coyne RD, Radford AD, Rosenman MA, Murthy NS, Oxman RE and so on. Initially, his research focused on the optimization of computer-aided design, the application of knowledge engineering in computer-aided design, and the optimization of CAD decision-making process. Later, his research began to focus on artificial intelligence in engineering, and he thought that the prototype was the basis of knowledge-based design, and then explored the design creativity applying a prototype method. Subsequently, he introduced a knowledge representation schema for design, called design prototypes in *Design prototypes: a knowledge representation schema for design* (1990). This schema can support the initiation and continuation of the act of designing, and employ design prototypes to distinguish routine, innovative and creative design.

As for the research on design cognition, he worked with Purcell T, Ding L, Tang HH, Smith GJ and other people in the early stage. He began to pay attention to this field in 1997,

proposing a situated agent-based learning method to discover and acquire beneficial knowledge and recognize the situation from multiple representation of the knowledge. Then he (2001) continued to explore the differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process. During the years between 2008 and 2012, he conducted diversiform research with his partners including Kannengiesser U, Sosa R, Kan JWT, Saunders R and so on. The contents of his research incorporated information acquisition from the linkography of designers' protocol studies, measurement of cognitive design activity changes during team brainstorming sessions, and design education cognitive research, extended to the fixation and commitment in the design process further, social learning in team and affordance in association-based systems. Since 2018, his interests have turned to the cognitive neuroscience of designing, beginning to utilize quantitative research methods, such as EEG (Electroencephalo-graph), fNIRS (Functional near-infrared spectroscopy) and fMRI (Functional magnetic resonance imaging), to seek for the unique brain behaviours during design processes.

In the field of evolutionary design and function-behaviour-structural model, his research involved the application of genetic algorithm in spatial reasoning, and also discussed the role of function-behaviour-structure model in design. In 2004, John S. Gero and Kannengiesser U extended the FBS framework in *the situated function–behaviour–structure framework*, in conjunction with a model of constructive memory, and proposed a situated functional-behaviour-structural framework. In 2007, they two explored the further application of function-behaviour-structural ontology in design, design objects and design processes.

In general, it is obvious that we can better and faster grasp main research subjects of researchers by applying the keywords co-occurrence method. All of the above results derived from research on researchers form pictorial portraits of their research processes.

4 Conclusion

In this paper, we utilized the method of bibliometrics, and visualization intended to depict an academic research map of global design researchers from several different levels.

Firstly, we screened out 31 international journals of high quality, chose about 8,000 literatures published at the high-credibility period after 2000 as our database. Based on the clear results of network visualization and analyses, it turned out to be reliable and comprehensive, so we will regard it as our standard database and optimize it further.

Secondly, we performed the author co-citation analysis among design researchers, aimed to identify the knowledge structure of design discipline. According to the outcome of cluster analysis, we found that the design discipline consisted of eight fields including design history, design art, design education, design cognition, design engineering, ergonomics, human-computer interaction and design management, which also reflects that design now is characterized by multidisciplinarity after integrating itself with natural and social science.

Thirdly, we pay more attention to every node in the author co-citation network. We elaborated on the high-impact researchers and their achievements and summarized classical theories of prominent researchers from every field. As a result, we found that researchers have played a crucial role in promote the development of design discipline and design education, and their theories laid the core of design knowledge. Based on this paper, we will try to standardize the research system of design discipline from a view of meta knowledge later, which will advance the interdisciplinary design research.

Fourthly, we keep furthering our research into a micro level of one specific author by the same method of bibliometrics. From the keywords co-occurrence graph of John S. Gero's research, we can track his research subject dynamically. Combining with the corresponding literature research, we create his academic portraits through this new way, which can clearly and meticulously depict their research processes.

Fifthly, different from listing the boring literature data by showing the simple information orderly, our visualization results facilitate scholars and students better and easier to understand the situations and distributions of global design research researchers systematically from a macro perspective to a micro one.

At last, we are trying to establish a design scholar knowledge service platform based on methods mentioned in this paper, which aims to help design scholars to acquire knowledge, find cooperative scholars, and understand research trends easily.

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About the Authors:

Xu Jingyu: Xu Jingyu is currently studying for her master's degree in Shanghai International College of Design and Innovation, Tongji University. Her main research interests include design strategy and design computing.

Xu Jiang: Xu Jiang is the professor and vice dean of Shanghai International College of Design and Innovation and College of Design and Innovation, Tongji University. He received the Ph.D. degree in computer science and technology from Zhejiang University of China. His major research interests include Design Science Knowledge Graph, Design Cognition and Computing, Emotion Engineering. He was appointed as the deputy secretary-general of the Industrial Design Branch of the Chinese Mechanical Engineering Society. He has published nearly 30 papers in related journals.

Lu Han: Lu Han is studying for his PhD in College of Design and Innovation, Tongji University. He has attended the 2019 Tongji-Cambridge-London Research Student Conference on Design-Engineering-Making. His main research direction is design cognition. He has published many professional papers retrieved by EI, CSSCI and CSCD.

Jiang Zhonggang: Jiang Zhonggang is studying for his master's degree in College of Design and Innovation, Tongji University. His main research interests are design theory and design innovation