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Evolution and Emerging Trends of Kansei Engineering: A Visual Analysis Based on CiteSpace

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ABSTRACT Today's development focuses on the integration of affective meaning into products and services. Kansei Engineering (KE) is a technology that establishes the relationship between customers' kansei and design elements to optimize the design for customers. This study aims to identify the research status and emerging trends in KE research by using visualization analysis with CiteSpace. We retrieve 2830 articles from the core collection of the Web of Science (1995–2021). First, based on the chronological distribution and background of research institutions, journals, literatures, countries and core authors, this study analyzes the main contributions, knowledge sources, interdisciplinary characteristics and major research domains of KE. Second, the research hotspots and cutting-edge technologies are intuitively presented and analyzed to reveal the knowledge structure and research frontier. Finally, this research expounds upon the evolution and developmental process of each stage and proposes the emerging trends of KE research, which are the use of big data in the Internet era, multidisciplinary cooperation, and the integration of multiple mathematical algorithms to serve multiapplication practice. This is also the orientation for further research on KE in the succeeding stages.

INDEX TERMS Kansei engineering, CiteSpace, design, emotion.

I. INTRODUCTION

Kansei is a Japanese term meaning sensibility, subjective impressions, and emotion [1]. KE is a powerful product development methodology proposed by Nagamachi (1995) that aims to translate consumers' feelings, images, and requirements for existing products or concepts into product design elements [2], [3]. KE is mainly a catalyst for the systematic development of new and innovative solutions [1], [4], but can also be used as an assessment tool to improve existing products and concepts [5]. It has been applied successfully to the physical product design field such as for automobiles [2], mobile phones [6], [7], costumes [3], cosmetic products and packages [3], house design, kitchen interiors and faucets [8]. Besides, it has been widely expected that KE research on service design will be conducted [9]. For example, a KE-based approach to enable cross-border e-commerce [1] providers to be closer to customers in e-banking systems [10], luxury hotel services [11], real estate services [12], and logistics services [13], [14] help them improve existing services and inspire new service design concepts, thus improving customer satisfaction and stickiness and even develop a new customer base. KE is recognized as the driving force for meeting consumers' feelings and demands. KE is a creative and practical way to improve existing products and services and enact new innovation. As the concept of KE is introduced to promote customer satisfaction, related researchers have considerably discussed and formed different research branches.

The boom in KE has allured researchers from various disciplines, including mathematics, computers, artificial intelligence, engineering, psychology, cognitive science, neuroscience, sociology, management and psychophysiology [15]. Thus far, several research directions have been formed. First, scholars concentrate on approaches to capture,

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analyze and understand project customers' needs. The gray relational analysis model [16], gray system theory [17], semantic difference method [18], and Kano model [6], [19] are helpful to grasp customers' needs. Some mathematical models, such as neural networks [20], fuzzy logic [20], the multiple linear regression [21], the support vector regression [22], genetic algorithms [20], [23] and others, have been proposed to enhance the inference between kansei words and design elements in kansei design systems. Second, since the last century, KE researchers have devoted themselves to collecting and establishing massive user databases [24], which not only have the functions of storage and query but also provide data visualization, virtual product design, design scheme evaluation, and other functions [25]. Furthermore, feedback and evaluation methods of design schemes are commonly used by researchers and are continuously released to the public [26].

Evaluation differences among evaluators are analyzed as characteristic records, from which the needs of users are analyzed. Although KE originated from the field of industrial design in Japan, its application value has now spread to different fields in various countries worldwide [27]. However, most of the literature reviews on KE remain at the microlevel study of the interdisciplinary knowledge of a certain product or a certain industry and focus on the method of capturing consumers' kansei needs and constructing and optimizing the model for translating kansei images into design elements. These studies help us better understand the internal mechanism of KE, but efforts to investigate the comprehensive intellectual landscape of KE have seldom been systematically conducted in the scientific studies mentioned above.

The intellectual landscape of a scientific field that takes knowledge mappings as the object is an emerging approach to literature analysis [28]. It provides holistic and comprehensive depictions of the intellectual landscape of evolving scientific fields by visualizing various networks, such as cocited references, keyword clusters, and co-occurring keywords, with contributions to comprehend the disciplinary knowledge structure, intellectual collaborations, research progress, hotspot fronts, disciplinary development trends, and dynamic evolutionary relationships. Therefore, this paper proposes objectively revealing the hot spots and evolutionary process of KE research using the CiteSpace software [28]. In addition, this research aims to grasp the trend of the theory of this research as a whole and propose future research prospects so as to provide a useful reference for subsequent research. The main contributions of this study are as follows:

(1) to understand the main KE research workforces at the individual, institutional and country levels

(2) to explore the classical theory of KE and the evolution of the research

(3) to analyze the main research topics and methods to identify the cutting-edge technology of KE

(4) to discover the burst keywords and the research hotspots and to forecast the future research on KE

TABLE 1. Summary of the search for details.

Search Settings	Content
Database	SCIE, SSCI, A&HCI, CPI-S and CPI-SSH
Search term	TS= ("kansei engineering") OR TS=("kansei ergonomics")
Literature type	Proceeding paper, article, review, and editorial material
Years	1995-2021
Search time	2021-4-28
Records	710
Sample size= citing articles	2830

II. RESEARCH DESIGN

A. DATA SOURCES

The data sources for this study were collected from the core collection of the Web of Science (WOS), which has been considered the most authoritative scientific and technical literature indexing tool [29] and an ideal data source for bibliometric investigations [30]. KE is an interdisciplinary subject, and KE researchers have different academic backgrounds. In order to comprehensively understand and master the research content and development of KE, our study uses unique data sources. First, the data sources were mainly from the citation indexes of the SCIE, SSCI, A&HCI, CPI-S, and CPI-SSH in the core collection of the WOS to ensure the diversity and intersection of disciplines. Second, we use a citation index-based expansion to construct our dataset, which is more robust than defining a rapidly growing field with a list of predefined keywords [28]. Third, we intended to collect all data related to KE as long as possible because we did not know the clear period of KE publications in WOS [30]. The initial topic research on "kansei engineering" or "kansei ergonomics" resulted in 715 records published during 1995-2021. We used this time period as the analysis interval later. After filtering out meeting abstracts and corrections, the data were reduced to 710 records. If the term "kansei engineering" or "kansei ergonomics" did not explicitly appear in the titles, abstracts or index terms, the records are not relevant publications. We expanded the data set using citation indexing. If an article cites at least one of the 708 records, then the article will be included in the expanded dataset based on the assumption that citing a KE article makes the citing article relevant to the topic. The citation index-based expansion resulted in 2834 records. The time period remains 1995-2021, and less representative record types are filtered out. This method of data collection comes from Chen *et al.* [28]. Thus, the record was reduced to a data set of 2830 articles for subsequent analysis. The data was retrieved on April 28, 2021. Tab 1 shows the retrieval strategies in detail.

B. RESEARCH METHODS AND TOOLS

Knowledge mapping is a newly evolving interdisciplinary area of science for charting, mining, analyzing, sorting, and displaying knowledge [31], [32]. Knowledge mapping is one

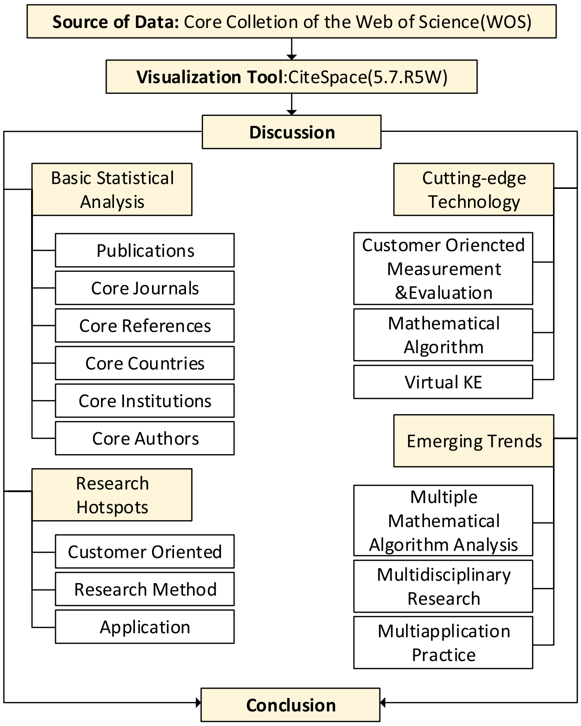

FIGURE 1. Research framework.

of the most important steps in knowledge management and can present concepts, knowledge and links in visual/graphic formats [33]. Science mapping tools such as VOSviewer, CiteSpace, HistCite, SciMAT, and Sci2 are currently used widely [34]. We used the CiteSpace software as the tool for analyzing and visualizing cocitation networks [34]. CiteSpace combines citation analysis and cocitation analysis to transform literature data from abstract data into visual and intuitive maps of scientific knowledge through information visualization [35]. CiteSpace detects emerging trends, identifies and visualizes bursts, labels cocitation clusters, conducts bibliographic analysis, and helps researchers find research hotspots and frontiers in a scientific field [36]. Thus, we used CiteSpace (5.7.R5W) to visualize and analyze the knowledge maps of the KE research literature in this study. Fig 1 shows the research framework and main analysis contents.

III. BASIC STATISTICAL ANALYSIS OF KANSEI ENGINEERING LITERATURES

A. PUBLICATIONS AND RESEARCH STAGES

Publications are very suitable sources of data that can be used to investigate the growth rates of scientific research [37]. The number of publications is an important index to measure the development trend of a certain field in a specific period [38]. The number of publications can also more intuitively illustrate the change of the popularity of the research in this field, which is of great significance to analyze the developmental trend of a certain field and predict its future developmental trend. In this paper, Excel tools are

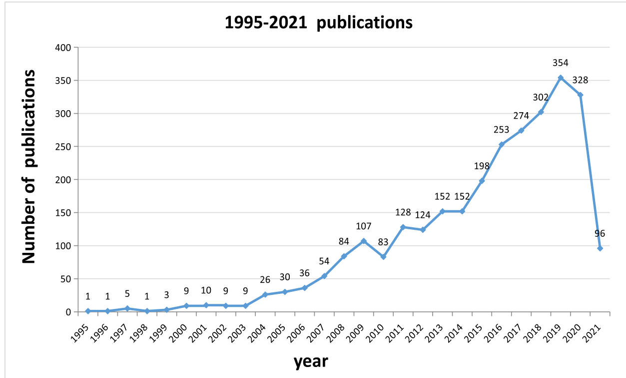

FIGURE 2. Number of publications in 1995–2021.

used to calculate the statistics of the sample documents. Fig 2 is a summary of the KE research articles published in 1995–2021. Some researchers have been involved in KE since the 1970s [39], but the first paper on KE that appeared in the WOS was from Mitsuo Nagamachi in 1995 [2], [15]. Since then, KE research has been widely conducted in academic and business fields. Regarding the most recent 20 years of development, the number of articles published on KE is also very considerable. Three stages can be identified from the track of the change of the number of publications in Fig 2. These stages are the embryonic development stage (1995-2003), the steady development stage (2004-2014) and the rapid development stage (2015-present).

1) EMBRYONIC DEVELOPMENT STAGE (1995–2003)

During the first stage (1995–2003), KE research was just starting, and the number of published papers was relatively small, with an annual average of approximately 5. In 1997, the Japanese Society of KE (www.jske.org) was established, and the journal KE, which is one of the highest-level research journals on KE in Japan, was founded. The publication of this journal brought scholars from outside Japan into contact with KE [40]–[42]. Fig 3 shows the number of publications in different countries during 1995-2003. The articles published in this stage mainly came from Japan, and only a small number of researchers from South Korea, Taiwan, the United States, and other countries began to contact and study KE and apply it in the field of existing product design [43], [44].

2) STEADY DEVELOPMENT STAGE (2004–2014)

In the second stage (2004–2014), the number of publications developed rapidly. The amount of publications is close to 1000. Many research results emerged during this phase. Approaches for the optimal combination of product design, kansei mining systems for affective design, and mathematical models for mediating the kansei database and design database have also steadily developed [4], [45]–[47]. The average annual number of publications exceeded 100 since 2009. Besides, international conferences such as the ASME International Design Engineering Technical Conference, the

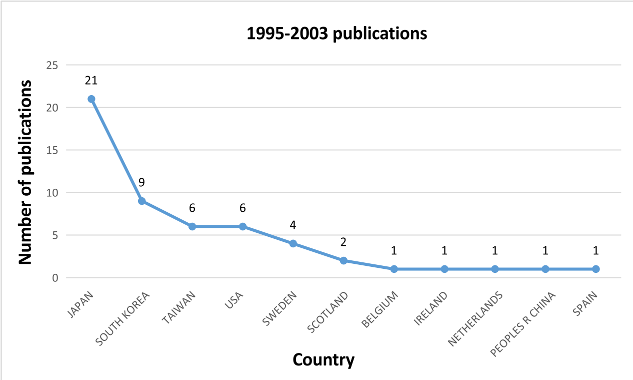

FIGURE 3. Publications of countries in 1995–2003.

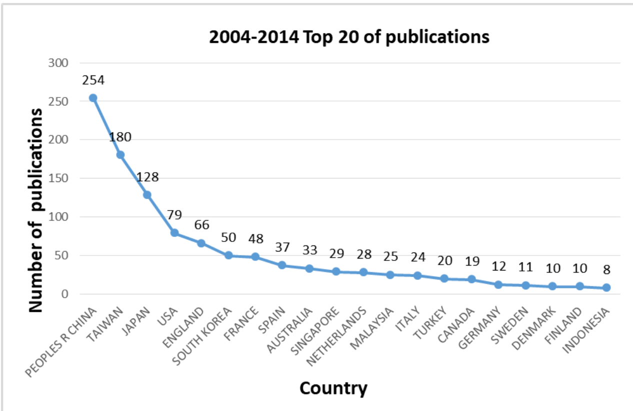

FIGURE 4. Publications of countries in 2004–2014.

Computers and Information in Engineering Conference and the IEEE International Conference on Computer-aided Industrial Design and Conceptual Design were held yearly to promote the cross between KE and other disciplines and the application and development of KE and to accelerate the exchange and cooperation of KE research among countries. Fig 4 shows that the publications in different countries changed dramatically from that in Fig 3. In general, the number of publications from each country and region, especially from the PR China and Taiwan, has increased greatly.

3) RAPID DEVELOPMENT STAGE (2015-PRESENT)

In the third stage (2015–present), KE research continued to increase until it reaches its peak in 2019 with 354 publications. The total number of publications reached 1807 during this stage; and the top six countries with published articles were consistent with the second stage, namely, the PR China, Taiwan, Japan, South Korea, the USA and England. However, the KE research in India has undergone dramatic changes from 5 publications in the second stage to 72 publications in this stage, as shown in Fig 4 & Fig 5. Quality function deployment (QFD) and the Kano model were integrated to prioritize the aesthetic attributes of car profiles [48], [49] and to optimize the online game experience [50]. In summary,

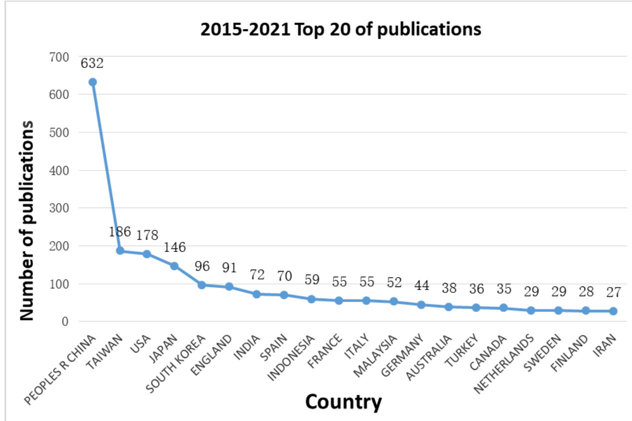

FIGURE 5. Publications of countries in 2015–2021.

KE has been studied by many countries in recent years, and KE research will still be a key field in the future.

B. CORE JOURNAL ANALYSIS

Core journals include a large amount of professional information and are high quality, and thus core journals can represent the developmental level of professional disciplines and be valued by readers of these disciplines [51]. A dual-map overlay of the mapping of the scientific literature represents the entire dataset in the context of a global map of science generated from over 10,000 journals indexed in the Web of Science [52]. The dual-map overlay shows that the mapped scientific papers are published in almost all major disciplines [34]. Publications on KE (shown in the map as curves in cyan and red) occur in at least four disciplines (mathematics, psychology, economics, and computer science) in the map (Fig 6).

Usually, core journals refer to the most important journals with higher citation counts [53]. Tab 2 lists the top ten journals with higher citation counts and illustrates the distribution of the core journals in KE studies with counts, cited journals, 2019 impact factors, and subject coverage ranked by count in 1995-2021. From the list, we can divide the core journals on KE into three research subjects.

1) ERGONOMICS-CENTERED SUBJECT COVERAGE

The International Journal Of Industrial Ergonomics, Applied Ergonomics and Ergonomics are all ergonomics engineering-centered, but the different journals have different themes and emphasize different contents [54]. For instance, the International Journal of Industrial Ergonomics pays more attention to the theoretical and practical research of human factors in the industrial field and tends to proposed various methods to evaluate these factors in order to achieve better designs for human beings. While the Journal of Applied Ergonomics prefers applications, the application scope of ergonomics is not limited to industrial fields but also includes construction, food processing, transportation and medical fields [55]–[57]. Drawing upon human biology, psychology, engineering and design, the Journal of Ergonomics aims to develop and apply

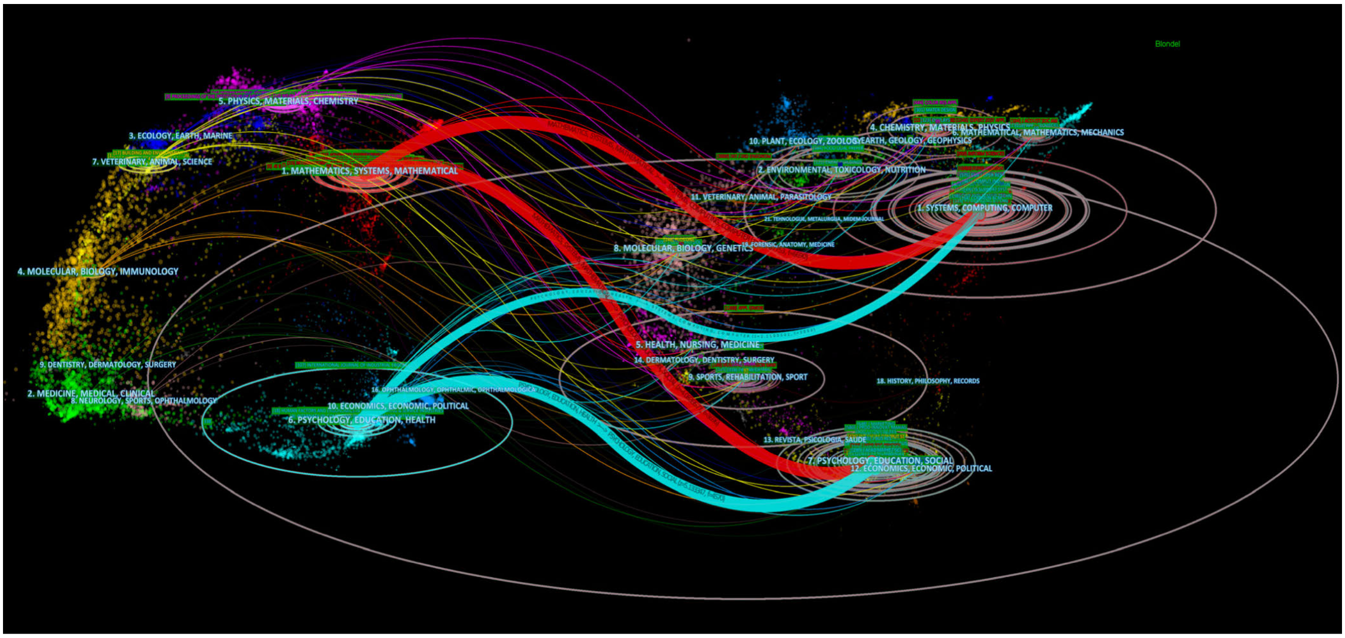

FIGURE 6. **A dual-map overlay of the mapping of the scientific literature.**

knowledge and techniques to optimize system performance while protecting the health, safety and well-being of the individuals involved, closely linking psychology and sociology, thus laying a foundation for the multidisciplinary development of KE.

2) DESIGN-CENTERED SUBJECT COVERAGE

The Journal of Design Studies is a leading international academic journal focused on developing an understanding of design processes. It studies design activity across all domains of application, including engineering and product design, architectural and urban design, computer artifacts and systems design. The subject coverage of the Journal of Engineering Design is similar to that of the Journal of Design Studies. However, the Journal of Engineering Design only focuses on the field of engineering products and system design. Nevertheless, both journals provide an interdisciplinary perspective for analyzing, developing and discussing the fundamental aspects of design activities, ranging from cognition and methodology to values and philosophy. Regarding KE, both journals attach great importance to analyzing the methods and processes of mapping kansei words and design elements from multidisciplinary fields.

3) COMPUTER SCIENCE-CENTERED AND ECONOMICS-CENTERED SUBJECT COVERAGE

With the development of computer science and artificial intelligence, KE is also closely connected with computers [58]. Virtual reality, mathematical algorithms, perceptual databases and design element databases are all inseparable from computer science in the era of big data. These articles in the Journal of Expert Systems with Applications, Information Sciences and Computers & Industrial Engineering are all good at using fuzzy algorithms, neural networks, gray system theory, multiple linear regressions and other mathematical algorithms to develop systems for mining consumers' emotional factors, evaluating consumers' preferences and establishing models of consumers' affective responses to product form elements [46], [46], [59]. Besides, journals such as the International Journal of Production Economics and the Journal of Marketing emphasize user-oriented design for the optimal combination of product design that can effectively enhance customer satisfaction and purchasing power and increase profits for companies [4], [6].

As analyzed above, eight core journals had an impact factor of >2 in Tab 2, suggesting that the quality of core journals is overall high to some extent. Core journals provide the distribution of key knowledge sources of KE research, which can help us determine which journals are cited in large numbers; determine the subject categories of KE; and identify the algorithms, methods and applications of KE research. Furthermore, the research results reveal the strong interdisciplinary nature of KE research, not only in the field of engineering but also in the fields of design, psychology, computer science and economics. Therefore, no single discipline field can fully reflect the wide distribution of disciplines in KE research.

C. CORE REFERENCE ANALYSIS

References represent a critical repository of knowledge. Reference cocitation analysis selects some representative studies as the analysis subject, which can be a crucial means to reveal the knowledge structure of one field and reflect the important scholars and classical literature of a specific domain. We export the top 50 references with

TABLE 2. Top 10 journals in Kansei engineering.

Ranking	Count	Cited Journal	2019 impact factor	Subject Coverage
1	1394	International Journal Of Industrial Ergonomics	1.662	E and I
2	672	Expert Systems With Applications	5.452	CS & AI, MS, EN, and EL
3	659	Applied Ergonomics	3.145	E and I
4	399	International Journal of Production Economics	5.134	MS, E, and I
5	344	Computers & Industrial Engineering	4.135	CS, E, and I
6	342	Design Studies	2.791	E and Multi
7	341	Journal Of Engineering Design	1.95	E and Multi
8	329	Journal Of Marketing	5.266	B
9	329	Ergonomics	2.19	PSY, E, and I
10	313	Information Sciences	5.91	CS and IS

the strongest citation bursts from CiteSpace. Major milestones in the development of KE can be identified from the list of references that have strong citation bursts between 1995 and 2021 (Table 3). References with strong values in the strength column tend to be significant milestones for KE research. We label such references with high-level concepts. For example, the first milestone paper in the field is a landmark customer-oriented technology of KE for product development [2], [3]. The next milestone is a major measurement and assessment of customer kansei needs in the early design phase, and the semantic differential method is the main method [5], [43]. The third major milestone is a technique studying the relationship between customer kansei needs and product properties. These techniques include Quantification Theory Type I (QTTI) & Neural Networks (NNs) [4], the kansei mining system [46], Grey Relational Analysis (GRA) & Neural Networks (NNs) [7], fuzzy logic [45], and Kano models [6]. In recent years, the application of KE has changed as the scope of design has expanded with the popularization of design. Another milestone in the field of KE is service design [1], which makes services more useful, available, efficient, effective and needed.

D. CORE INSTITUTIONS/COUNTRIES ANALYSIS

The number of published articles reflects the research levels and field contributions of different countries, regions, and scientific research institutions [54]. We can quickly understand the distribution of the main research forces by analyzing the cooperating institutions and countries in a certain field.

1) CORE INSTITUTION ANALYSIS

When we import the sample data into CiteSpace, the node type is set to "institution", and the rest of the parameters are set to their default values when running CiteSpace. Fig 7 shows the academic collaboration among institutions. The size of nodes represents the number of papers that institutions published. The color and thickness of the links between

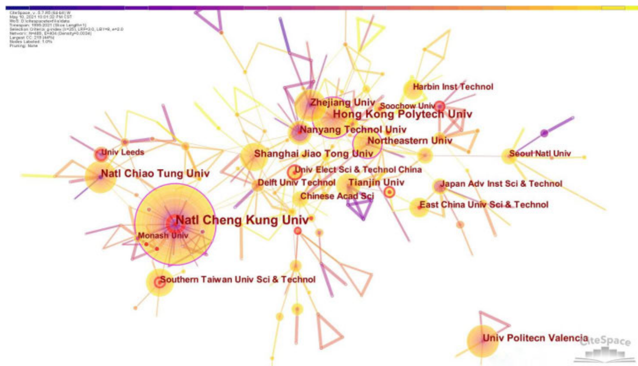

FIGURE 7. Map of coinstitution network.

the nodes denote the year and level of cooperation among institutions, respectively. Institutions with 18 or more papers are labeled in Fig 7.

The distances among the networks are relatively close except at Politecn Valencia University in Spain, which is far from the subnetworks, suggesting minimal communication between them. The largest subnetwork is comprised of 32 institutions centered around Natl Cheng Kung University, which has published 105 articles. As shown in Tab 4, Natl Chiao Tung University in Taiwan ranked third with 41 articles. Combining the lines of the two university nodes, we can identify that these two universities are closely related, which shows that they have made the greatest contributions to the field of KE in the world as the top international scientific research institutions.

Next, Hong Kong Polytech University and Nanyang Technology University were ranked 2 and 6 with 52 and 37 articles published, respectively. In addition to the abovementioned institutions, 869 articles from China accounted for 30.7% of the total number of articles (2830), which is the country with the largest number of articles published. Institutions such as Zhejiang University, Northeastern University, Shanghai Jiao

TABLE 3. Top 50 references with the strongest citation bursts.

	References	Year	Strength	Begin	End	1995 - 2021
Consumer-oriented technology	NAGAMACHI M, 1995, INT J IND ERGONOM, V15, P3, DOI	1995	15.62	**1996**	2003	
	Matsubara Y, 1997, INT J IND ERGONOM, V19, P81, DOI	1997	7.54	**1999**	2005	
	Nakada K, 1997, INT J IND ERGONOM, V19, P129, DOI	1997	8.23	**2000**	2005	
Product development	Nagamachi M, 2002, APPL ERGON, V33, P289, DOI	2002	38.76	**2004**	2010	
Semantic differential method	Hsu SH, 2000, INT J IND ERGONOM, V25, P375, DOI	2000	22.31	**2004**	2008	
	Chuang MC, 2001, INT J IND ERGONOM, V27, P247, DOI	2001	16.18	**2004**	2009	
	Chuang MC, 2001, INT J IND ERGONOM, V27, P233, DOI	2001	11.46	**2004**	2009	
	HSIAO SW, 2002, DESIGN STUDIES, V23, P67	2002	7.74	**2004**	2010	
Assessment of product semantic	Petiot JF, 2004, INT J IND ERGONOM, V33, P507, DOI	2004	24.05	**2005**	2012	
	Crilly N, 2004, DESIGN STUD, V25, P547, DOI	2004	11.17	**2005**	2012	
	Barnes CJ, 2004, WEAR, V257, P740, DOI	2004	8.85	**2005**	2012	
QTTI & NNs	Lai HH, 2006, INT J PROD ECON, V100, P253, DOI	2006	22.4	**2007**	2014	
Kansei mining system	Jiao JX, 2006, EXPERT SYST APPL, V30, P658, DOI	2006	20.56	**2007**	2014	
GRA & NNs	Lai HH, 2005, COMPUT OPER RES, V32, P2689, DOI	2005	20.49	**2007**	2013	
	Lai HH, 2005, INT J IND ERGONOM, V35, P445, DOI	2005	13.96	**2007**	2013	
	Park J, 2004, INT J IND ERGONOM, V34, P31, DOI	2004	9.63	**2007**	2012	
	Schutte S, 2005, APPL ERGON, V36, P557,DOI	2005	9.21	**2007**	2012	
	Norman D A, 2004, EMOTIONAL DESIGN WHY, V0, P0	2004	14.75	**2008**	2012	
	Hsiao KA, 2006, INT J IND ERGONOM, V36, P553, DOI	2006	12.46	**2008**	2014	
	Chang HC, 2006, INT J IND ERGONOM, V36, P3, DOI	2006	8.37	**2008**	2012	
	Han SH, 2004, HUM FACTOR ERGON MAN, V14, P15,DOI	2004	8.02	**2008**	2012	
	Desmet P, 2007, INT J DES, V1, P57	2007	7.99	**2008**	2015	
Fuzzy logic	Lin YC, 2007, INT J IND ERGONOM, V37, P531, DOI	2007	17.84	**2009**	2015	
	Hsiao SW, 2005, INT J IND ERGONOM, V35, P411, DOI	2005	10.77	**2009**	2013	
	Chen X, 2009, MATER DESIGN, V30, P4299, DOI	2009	9.77	**2010**	2017	
	Zhai LY, 2009, EXPERT SYST APPL, V36, P393, DOI	2009	8.82	**2010**	2016	
	Hsiao SW, 2010, INT J IND ERGONOM, V40, P237, DOI	2010	8.37	**2011**	2016	
	Leon N, 2009, COMPUT IND, V60, P539, DOI	2009	7.48	**2011**	2016	
Kano model	Chen CC, 2008, INT J PROD ECON, V114, P667,DOI	2008	23.12	**2012**	2016	
	Zhai LY, 2009, INT J IND ERGONOM, V39, P295, DOI	2009	9.78	**2012**	2015	
	Yamaguchi D, 2007, INFORM SCIENCES, V177, P4727, DOI	2007	9.55	**2012**	2015	
	Yang CC, 2011, COMPUT IND ENG, V60, P760, DOI	2011	11.77	**2014**	2019	
	Wang KC, 2011, EXPERT SYST APPL, V38, P8738, DOI	2011	11.52	**2014**	2019	
	Chen KH, 2012, INTERNET RES, V22, P467, DOI	2012	8.54	**2014**	2018	
	Yang CC, 2010, COMPUT IND ENG, V59, P682, DOI	2010	8.29	**2014**	2017	
	Yang CC, 2011, EXPERT SYST APPL, V38, P11382, DOI	2011	7.92	**2014**	2016	
Robots & exoskeletons	Sankai Y, 2010, SPRINGER TRAC ADV RO, V66, P25	2010	39.48	**2015**	2018	
	Llinares C, 2011, INT J IND ERGONOM, V41, P233, DOI	2011	10.11	**2015**	2019	
	Esquenazi A, 2012, AM J PHYS MED REHAB, V91, P911, DOI	2012	8.81	**2015**	2019	
	Guo F, 2014, J ENG DESIGN, V25, P194, DOI	2014	10.64	**2017**	2021	
	Chen MC, 2015, INT J IND ERGONOM, V48, P46, DOI	2015	7.73	**2017**	2021	
Service design	Hsiao YH, 2017, TELEMAT INFORM, V34, P284, DOI	2017	17.95	**2018**	2021	
	Vieira J, 2017, APPL ERGON, V61, P1, DOI	2017	10.81	**2018**	2021	
	Chou JR, 2016, ADV ENG INFORM, V30, P1, DOI	2016	9.97	**2018**	2021	
	Shieh MD, 2016, J AMB INTEL HUM COMP, V7, P107, DOI	2016	9.57	**2018**	2021	
	Castilla N, 2017, BUILD ENVIRON, V122, P72, DOI	2017	9.14	**2018**	2021	
	Wang WM, 2018, ENG APPL ARTIF INTEL, V73, P149, DOI	2018	9.39	**2019**	2021	
	Chang YM, 2016, INT J IND ERGONOM, V56, P97, DOI	2016	8.39	**2019**	2021	
	Yan TF, 2015, ROBOT AUTON SYST, V64, P120, DOI	2015	8.13	**2019**	2021	
	Hsu CC, 2017, DISPLAYS, V50, P21, DOI	2017	7.7	**2019**	2021	

Tong University, Tianjin University and Chinese Academy of Sciences have made great contributions to the field of KE.

However, the institutions researching KE are mainly universities, and there is mainly one type of research institution, which shows that universities are the main force in the field of KE. Besides, the average number of connections between these institutions is 10. As shown in Fig 7, there are 489 institution nodes and 404 connections between institutions, and the density of the institutional cooperation network is only 0.0034. Therefore, together with the number of links in each subnetwork and the entire network used for further analysis, the results show that the cooperation between different organizations via internal subnetworks is insufficient, and scientific research cooperation needs to be further improved.

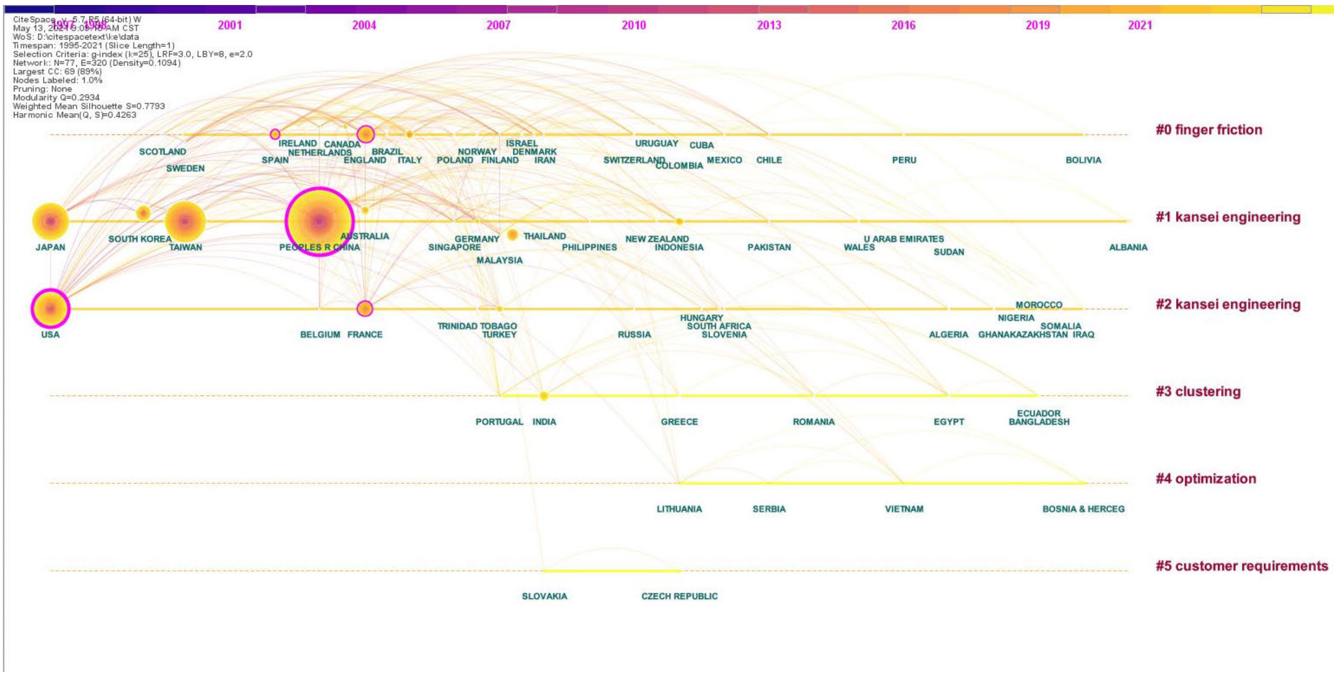

FIGURE 8. Timelines of cocountry network.

TABLE 4. Top 10 institutions in Kansei engineering.

Ranking	Count	Institution	Year
1	105	Natl Cheng Kung Univ	2002
2	52	Hong Kong Polytech Univ	2009
3	41	Natl Chiao Tung Univ	2000
4	39	Zhejiang Univ	2004
5	39	Univ Politecn Valencia	2005
6	37	Nanyang Technol Univ	2006
7	36	Northeastern Univ	2006
8	35	Shanghai Jiao Tong Univ	2005
9	30	Tianjin Univ	2003
10	27	Chinese Acad Sci	2009

2) CORE COUNTRY/REGION ANALYSIS

When we import the sample data into CiteSpace, the node type is set to ‘‘country’’, and the rest of the parameters are set to their default values when running CiteSpace. Fig 8 shows a timeline visualization of the cooperating countries by clusters of 6 keywords. The timeline map focuses on describing the time when a country’s related scientific research started and the historical span of the cooperation with different countries. The size of the nodes represents the number of papers that countries published. The lines between the two nodes represent the collaborative links. The figure intuitively shows the cooperation and migration of popular keywords in KE research between different countries.

As shown in Fig 8, 78 nodes and 321 links were found in the partner countries. There are two timelines with KE as the keyword. Timeline #1 of KE, which is cooperation among Asian countries, is the main timeline. The earliest research originated in Japan and spread to various Asian countries, such as South Korea, Taiwan, PR China, Singapore, Malaysia, Thailand and other countries, over time. Another timeline, #2 of KE, which was led by the USA, also had close cooperative relations among European countries, followed by Belgium, France, Trinidad and Russia. However, some countries cooperate across continents. For example, the USA cooperates frequently with South Korea, Taiwan and PR China in Asia, as does France. Nevertheless, the cooperation between countries and other countries on timelines #3, #4 and #5 is very weak, indicating that the cooperation between countries needs to be strengthened.

Table 5 shows the top ten productive countries sorted by the quantities of their published articles in descending order in KE. PR China contributed 869 papers, followed by Taiwan (370), Japan (286), the USA (258), South Korea (153), England (152), Spain (106), France (101), Malaysia (77), and Italy (76).

As analyzed above, one main distribution research on KE is around Asian countries. Their research focuses on kansei quantification, transforming the results of human kansei into physical elements of products. For instance, the PR China and Taiwan not only account for the largest proportions in the number of published articles but also have the most citations, which indicates that their strength and application of KE research in different industries have been accepted and recognized by international academic journals. Another main research distribution is around European countries dominated by the USA, where the experimental methods and tools of

TABLE 5. Top 10 countries in Kansei engineering.

Count	Degree	Country	Year
869	34	PEOPLES R CHINA	2003
370	13	TAIWAN	2000
286	21	JAPAN	1997
258	34	USA	1997
153	13	SOUTH KOREA	1999
152	31	ENGLAND	2004
106	22	SPAIN	2002
101	25	FRANCE	2004
77	14	MALAYSIA	2007
76	21	ITALY	2005

emotion/affective response are at the forefront of the world and are widely used.

E. CORE AUTHOR ANALYSIS

Prolific authors are the core force of research work in a field [60]. Highly cited authors have an important influence in this field. Furthermore, coauthors can reveal the connection of different authors' research in a certain field in the cooperative network map of authors. In order to determine the core strength in the field of KE research, core author analysis depends on the combination of coauthorship and cited authorship maps generated by CiteSpace.

1) COAUTHORSHIP ANALYSIS

After importing the sample data onto CiteSpace, the node type is set to "author", and the remaining parameters are set to their default values when running CiteSpace. Fig 9 is generated by selecting the unit of analysis and setting the appropriate thresholds. The size of nodes represents the number of articles published by authors, and the colors of nodes represent the years of publication. The more prominent nodes are, the greater the number of articles published. The darker the color is, the earlier the year of publication. The distance between the nodes and the thickness of the links denotes the level of cooperation among authors. The map of the coauthorship network shows that there are several larger subnetworks and quantities of isolated smaller subnetworks, which show that the KE research strength is relatively dispersed around the world.

As shown in Fig 9, there are academic cooperation groups across regions and institutions, which indicates that the strength of each research institution is scattered in this field. Cooperation among scholars is generally conducted the same region and the same institution, and a relatively large research group has not yet been established. Combined with the above analysis of research institutions, Japan is the birthplace of KE research with academic cooperation groups formed in the early days. South Korea and Taiwan followed closely and developed very rapidly. Chinese scholars started theoretical and practical research in this field in the last decade. A large number of influential articles by Chinese scholars emerged in excellent international journals.

From the purple-colored links and nodes, we can identify that M. Nagamachi from Hiroshima University was the most frequent contributing author to the field of KE in the embryonic development stage. He began to study KE in 1970 and has published 89 books and 200 articles [13]. The team headed by him, with the members of Y. Matsubara, M. Ichitsubo, S. Ishihara, T. Tsuchiya et al, is the largest thus far. Another early research team comprised SH. Han, J. Kim, Hong. SW and MH. Yun. Following their pace, a large number of coauthor networks appeared and formed in the steady development stage. For instance, one team with the members HungYun Chen, YangChen Lin, ChiChieh Yang and ChuangSing Yeh formed. The next research team included Hongbin Yan, Yoshiteru Nakamori and Vannam Huynh. The third team comprised CK. Kwong, HuiMin Jiang, K Y Chan *et al.* The main members of the fourth team were Anitawati Mohd Lokman, Ana Hadiana, Azara Abdul Aziz and others. In recent years, the kansei research has attracted many researchers learning and communicating with each other, forming several cooperative network teams with Fu Guo, Shihwen Hsiao, Myung Hwan Yun and Jianxin Cheng as the core members, respectively. Overall, the relationship between KE researchers is not close. Most of them study as individuals or groups that are relatively scattered and have not yet formed a large scientific research team.

2) CITED AUTHOR ANALYSIS

We set the years per slice to 5 and set the pruning as pathfinder when running CiteSpace. We plotted the results in Fig 10. The cited authors' analysis can not only identify influential authors in this field but also obtain the research topics of similar authors in a certain field. Each node represents an author, and the link between two authors represents their cocitation relationship. The darker the color of a node is, the earlier the node appears. In addition, the size of each node represents the authors' citation counts; and the larger a node is, the greater the author's influence. The distance between two nodes represents the cocitation frequency of the two authors. The smaller the distance is, the higher the cocitation frequency and the closer their research directions.

The authors with citation counts equal to or greater than 100 are labeled in Fig 10. The largest node corresponds to Nagamachi M, cocited with Hsiao SW and other authors (Jshihara S, Jindo T, Chuang Mc, Schutte S, and others), who is the founder of KE. His research focused on making more scholars understand the types, procedures, technique and application cases of KE and enabling product development to be performed anytime by referring to the research, thus resulting in more industries applying KE and benefitting from it. The second large node is represented by Osgood CE, with the cocitation relationship of Hsu SH and Sankai Y. They focused on the problem of measuring meaning and considered the Semantic Difference scale (SD scale) as a central pillar, which measures the way a person feels about a certain object on

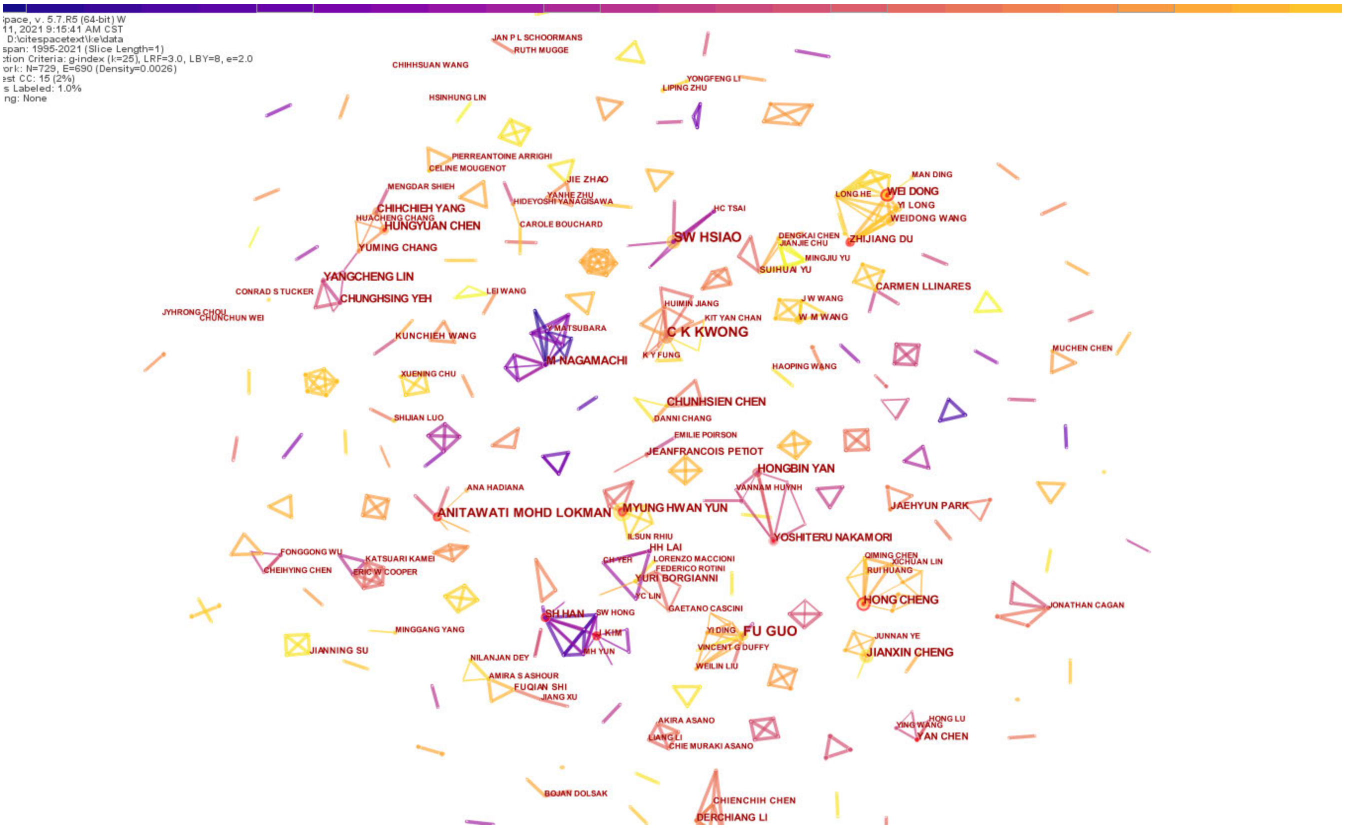

FIGURE 9. Map of coauthorship network.

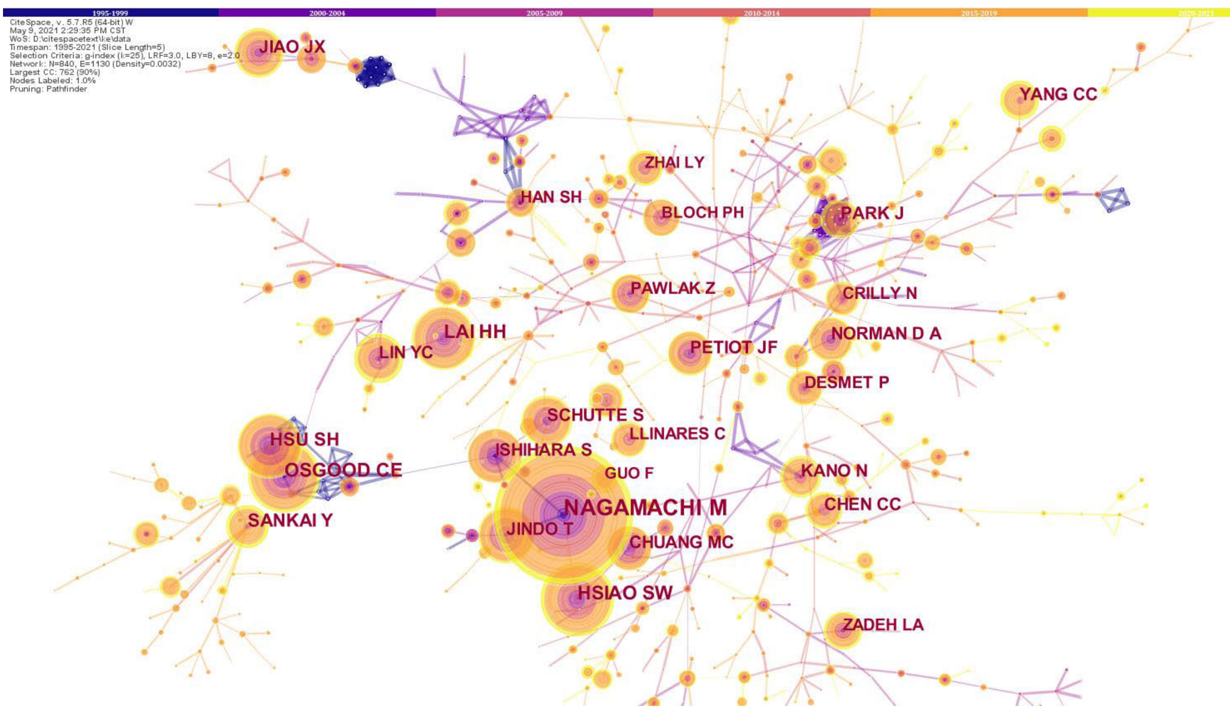

FIGURE 10. Map of cited authorship network.

TABLE 6. Top 10 most productive authors in Kansei engineering.

Count	Author	Year	From	Research Subjects
31	Li n YC	2004	National Cheng Kung University, Taiwan	Neural network, gray relational analysis, fuzzy logic, and consumer oriented product form
25	Hsiao SW	2002	National Cheng Kung University, Taiwan	Fuzzy neural network, genetic algorithm, gray system, and user experience
24	Yun MH	2011	Seoul National University, South Korea	Product usability, usability evaluation, user satisfaction, and user experience
23	Guo F	2006	Northeastern University, China	Physiological measurement (eye tracking, EEG, EMG, and ECG), product design, and webpage design
23	Kwong CK	2009	The Hong Kong Polytechnic University, Hong Kong	Big data, artificial intelligence, intelligence technology, and mine consumers' emotions
21	Chen CH	2006	Nanyang Technological University, Singapore	Artificial intelligence, artificial neural network, data mining, and dynamic customer demand
21	Han SH	1999	Pohang University of Science and Technology, South Korea	Evaluate product usability, systematic method for magnitude estimation data, and user experience
21	Nagamachi M	1995	Hiroshima International University, Japan	Concepts, methods, tools in KE; consumer product design; and rough set model
20	Yeh CH	2006	Monash University, Australia	Fuzzy logical analysis, grey relational analysis, neural network, and evaluation
19	Lokman AM	2009	Universiti Teknologi MARA (UiTM), Malaysia	Kansei affinity cluster, mobile learning, online learning, and webpage design

a 5-point scale. The data can be treated using, for example, factor analysis; and the underlying patterns of how the object is perceived can be extracted. This information is then used to improve the perception of the project [61], [62]. Besides, there are two other cocitation groups represented by Lai HH and Norman D A, respectively. The former emphasized the approaches of optimizing user-oriented design to transform users' perceptions into product elements [63]. The latter asserts that the emotional side of design may be more critical to a product's success than its practical elements. He provides a unified theory of product design by incorporating three levels, namely, the "visceral" level, "behavioral" level and "reflective" level, to cater to consumers' emotions [64]. In addition, many authors have been cited and made great contributions to KE research.

3) CORE AUTHORS AND RESEARCH SUBJECT ANALYSIS

In order to understand the core authors more objectively, Tab 6 lists the top productive authors of their research subjects, and Tab 7 lists the top 10 most cited authors with their representative articles. As shown in Tab 6, the most productive author is Lin YC(31), and the other top productive authors are Hsiao SW (25), Yun MH(24), Guo F (23), Kwong CK (23), Chen CH (21), Han SH (21), Nagamachi M (21), Yeh CH (20), and Lokman AM (19). As shown in Tab 7, the most cited author is Nagamachi M (928), followed by Osgood CE (289), Hsiao SW (284), Lai HH (261), Hsu (215), Jindo T (174), Lin YC (173), Ishihara S (168), Jiao JX (156) and Kano N (155). According to the above analysis, the authors appearing in both tables at the same time are as follows: Nagamachi M, Hsiao SW and Lin YC. All three of them are outstanding contributors to KE research, and the last two are both from National Cheng Kung University, China Taiwan. Their research focuses on neural networks, gray relational analysis and genetic algorithms for consumer-oriented product form or color. The results show that the top 10 most productive authors and the top 10 most cited authors are all from Asia. Besides, Osgood CE, Jiao JX of the USA and Yeh CH of Australia have great influence in the field of customers' affective design [46]. This proves once again that Asian scholars and teams are keen to KE research and have made great contributions to KE research. In turn, the results show that the field of design and enterprises in Asia benefit from the promotion and application of KE.

As shown and analyzed above, the core authors have published a large number of papers or their papers have been cited by a large number of people in the field of KE. They have their research directions and research teams in their research fields. In this paper, we classify their research subjects into the following categories based on Tab 6 and Tab 7:

(1) Basic theoretical background. The types of KE, a framework of kansei systems [65], procedures, experimental methods and applications of KE have been widely studied in commercial product design.

(2) Techniques and tools. In establishing an intelligent system, techniques related to computer science such as expert systems, fuzzy logic, neural networks, genetic algorithms, and computer graphics are used to link consumers' kansei and product/service design elements.

(3) Computer intelligence technology. Big data and artificial intelligence are used to mine users' emotional design. Based on the experimental evaluations, surveys, or designers' skill, various kansei databases and product design databases for consumers have been established.

IV. RESEARCH HOTSPOTS AND CUTTING-EDGE TECHNOLOGIES

A. RESEARCH HOTSPOTS

Keywords generalize an article's theme and highly refine an author's research focus. The analysis of keywords with high

TABLE 7. Top 10 most cited authors in Kansei engineering.

Count	Author	Year	From	Articles
928	Nagamachi M	1995	Hiroshima International University, Japan	Kansei engineering: A new consumer-oriented technology for product development[2]
289	Osgood CE	1995	University of Illinois, USA	The Measurement of Meaning[63]
284	Hsiao SW	2004	National Cheng Kung University, Taiwan	A neural network based approach for product form design[67]
261	Lai HH	2006	National Cheng Kung University, Taiwan	User-oriented design for the optimal combination on product design[4]
215	Hsu SH	2004	National Chiao Tung University, Taiwan	A semantic differential study of designers' and users' product form perception[43]
174	Jindo T	1995	Nissan Motor Co., Lid, Japan	Application studies to car interior of Kansei engineering[68]
173	Lin YC	2004	National Cheng Kung University, Taiwan	Consumer-oriented product form design based on fuzzy logic: A case study of mobile phones[45]
168	Ishihara S	1996	Onomichi Junior College, Japan	An automatic builder for a Kansei engineering expert system using self-organizing[69]
156	Jiao JX	2007	Georgia Institute of Technology, USA	A kansei mining system for affective design[46]
155	Kano N	2004	Tokyo University of Science, Japan	Attractive quality and must-be quality[70]

TABLE 8. Frequency and centrality of high frequency keywords.

Frequency	Centrality	Keywords	Frequency	Centrality	Keyword
448	0.10	design	76	0.01	Kano model
309	0.13	kansei engineering	74	0.04	preference
307	0.07	model	68	0.04	classification
270	0.13	system	68	0.07	aesthetics
194	0.09	product design	66	0.09	genetic algorithm
191	0.04	customer satisfaction	58	0.02	quality function deployment
88	0.06	perception	58	0.02	impact
166	0.03	management	56	0.03	support
121	0.05	quality	56	0.01	exoskeleton
115	0.02	user experience	55	0.04	information
110	0.03	consumer oriented technology	55	0.02	selection
85	0.03	technology	52	0.07	algorithm
84	0.05	emotion	50	0.01	QFD
84	0.04	framework	49	0.04	kansei
82	0.05	neural network	48	0.06	conjoint analysis
81	0.05	form	47	0.02	affective design
80	0.04	optimization	45	0.01	emotional design
79	0.06	usability	44	0.02	methodology
79	0.06	performance	43	0.03	product form
79	0.08	product development	43	0.05	dimension

frequency and centrality can help to show the knowledge structure and research paradigm of KE and reveal a hot topic in the research field by mining the core knowledge nodes in KE research. The higher the centrality is, the stronger the central position of the keyword in the co-occurrence network. The following landscape map was generated based on the keyword network of 2830 publications and clustered with keywords by CiteSpace (Fig 11). The map consists of 729 nodes and 4854 links with a network density of 0.0183, a Q of 0.3908 and an S of 0.7171, which show that the clustering results are good. The keyword data and clustering data in CiteSpace are exported to Tab 8 and Tab 9, respectively. Tab 8 lists the high frequency and high centrality keywords, and Tab 9 lists the 10 clusters with keywords as the topics.

By analyzing the keywords with high frequency and high centrality in Tab 8 and keyword clusters in Fig 11, the three main hot KE research topics are as follows:

1) CUSTOMER ORIENTED ANALYSIS

Customers are the ultimate users and service objects of design. Clusters #0 user experience, #1 kansei engineering, #6 trust and #9 comfort are keywords related to customers. The high-frequency keywords in clusters about customers are as follows: customer satisfaction, perception,

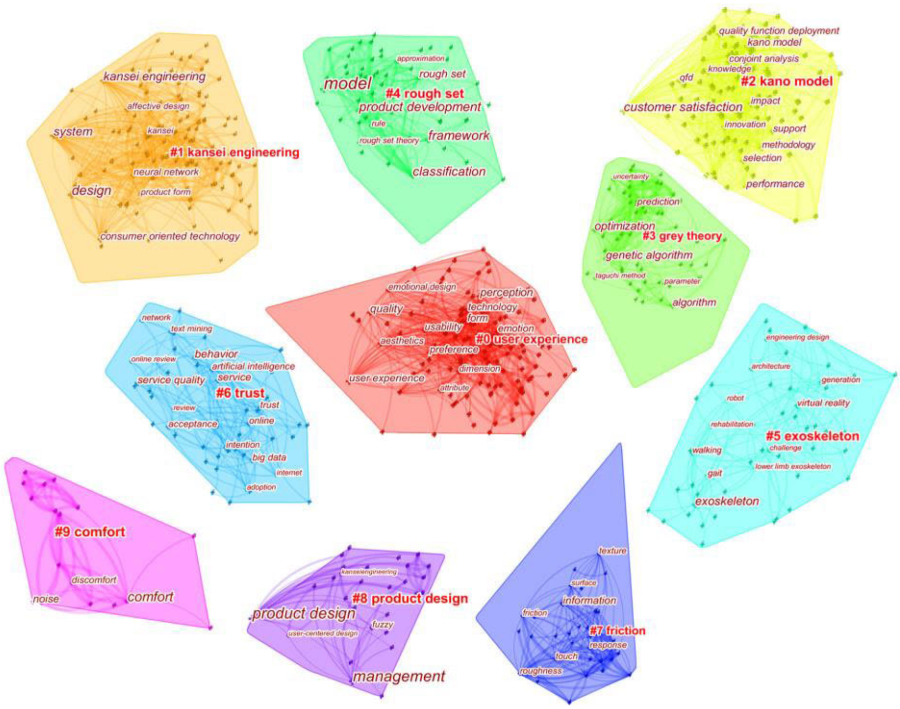

FIGURE 11. Map of cited authorship network.

TABLE 9. Frequency and centrality of high frequency keywords.

ID	Cluster	Size	Silhouette	Year
0	user experience	128	0.592	2009
1	kansei engineering	122	0.685	2006
2	Kano model	111	0.647	2012
3	gray theory	60	0.874	2010
4	rough set	59	0.761	2010
5	exoskeleton	57	0.69	2016
6	trust	55	0.764	2016
7	friction	38	0.871	2012
8	product design	31	0.759	2007
9	comfort	17	0.934	2003

user experience, emotion, preference, and selection. Therefore, customers' perceptions, preferences, emotions/affective responses, kansei and feelings regarding products are all research hot spots. Therefore, customer requirement management [70] and customer relationship management [71], such as customer attributes [72], customer behavior [64], [73], customer identification, customer attraction and customer loyalty [74], have become parts of KE research. Besides, many researchers are interested in analyzing the affective factors of customer purchases [75], [76], the technology for mining customer satisfaction data [71], and the value of user experience and service quality [72].

2) RESEARCH METHOD ANALYSIS

The development of KE is inseparable from various research methods and techniques such as for clusters #2 Kano model, #3 gray theory, and #4 rough set. The high frequency keywords in clusters are as follows: model, system, technology, framework, neural network, Kano model, genetic algorithm, QFD, conjoint analysis, and methodology. Most of the keywords are mathematical quantification methods. Combined with the characteristics of high-frequency keywords, the procedures of KE are reviewed. First, We obtain consumers' feelings/kansei about products by evaluating and testing products from multiple aspects of ergonomics or psychology (mainly the semantic difference scale). Then, we obtain data with mathematical model methods, such as multivariate linear regression analysis, quantification theory type I, genetic algorithms, BP neural network models, gray systems, fuzzy logic analysis, rough set theory, etc. All these methods are used to determine the relationship between the design purpose and design point so as to establish a perceptual engineering system. Finally, data should be supplemented and adjusted to update the kansei database according to current social trends or personal preferences.

3) DESIGN AND APPLICATION ANALYSIS

KE is a technology that unites kansei with the engineering discipline. The application of KE and product design has been related to various places and situations and a myriad of fields in daily life. The high-frequency keywords in clusters are as follows: design, product design, form, usability, performance, product development, quality function deployment, exoskeleton, affective design, emotional design, and product form. These keywords mainly develop products around the dimensions of product form, color and materials. In addition, KE has been extended to fields including architecture, housing, transportation, urban design, industrial products, daily goods, and information technology. In recent years, KE has attracted considerable attention in the fields of interface design (such as web page design and mobile phone interactive interfaces), services (real estate, aviation, tourism, website shopping services, and logistics service [77]), and regional culture inheritance (cultural and creative product design).

B. CUTTING-EDGE TECHNOLOGY

As shown in Tab 8, Tab 9 and Fig 11, the most common keyword hotspots are techniques and methods, which are the frontier force of KE research. Combined with the above research contents, this paper further analyzes the literature contents and expounds the most commonly used methods of KE research to determine the research frontier in this field. The research methods can be divided into three categories:

1) CUSTOMER-ORIENTED MEASUREMENT AND EVALUATION TECHNIQUES

In today's competitive environment, customers' affective needs must be considered. Most methodologies consist of accurately measuring and analyzing human reactions to affective design and subsequently evaluating the corresponding affective design features. According to the keywords and clusters, this paper summarizes the characteristics and defects of three popular customer-oriented measurements and evaluation techniques, as shown in Table 10.

(1) Semantic Differential Scales (SD scales): The KE methodology is, in particular, specialized in the translation of affective values into concrete product design parameters. To achieve this, KE uses Semantic Differential scales (SD scales) as a central pillar. This special type of scale was developed by Charles E. Osgood in the 1940s/50s and measures the way a person feels about a certain object on a 5-point scale [60]. Taking positive and negative adjective pairs instead of single positive adjectives makes it easier for subjects to understand and answer questions, which reduces reaction errors. However, 10-30 adjective pairs are better than too many pairs, which can easily cause boredom and affect the test results. Although the method was originally used for political research, the same technique can be slightly modified and used for consumer products, housing assessment [76], webpage design [78], and tourism service [79]. Most KE researches are based on this method, and the perceptual cognitive value of customers is obtained before the mapping model is established.

(2) Analytic Hierarchy Process (AHP): The AHP is a decision-making method developed by T.L. Saaty in 1971, and the method is mainly applied in uncertain situations and decision-making problems with several evaluation criteria.

TABLE 10. Customer-oriented measurement and evaluation techniques.

Technique	Characteristics	Defect
SD Scales	Simple and easy to understand and operate for the subjects taking the questionnaire.	Lack of standardization
AHP	Systematic analysis and concise and practical decision-making method that requires less quantitative data and information.	Data statistics are large and it is difficult to determine the weights and provide new solutions for decision-making
Kano Model	Nonlinear relationship between product function and customer satisfaction.	Not fixed and changes with time (product life cycle)

The AHP conducts quantitative analysis of qualitative problems, which can simplify complex problems into systematic hierarchical elements. Then, the weight value of each element is obtained in terms of the evaluation of experts and scholars' comparison of the importance of elements at different levels so as to identify the priority of each scheme. This method can break down a complex multidecision problem from a higher-level project into several lower levels. The user preference order can be evaluated, and the relative weight of the evaluation criteria can be determined in the end. This method is widely used to determine the elements and weights in research on human meals [80], hematology analyzers [81], e-books [82], etc. However, it is sometimes difficult to compare the hierarchical elements in pairs when using this method. Moreover, when there are many elements, the consistency test may fail, so the number of elements is generally reduced to 7.

(3) Kano model: Customer demand for "good feeling" products or services is related to overall satisfaction. Kano proposed a customer satisfaction model, the Kano model, for the investigation and study of consumer demand in 1984 [69]. Kano emphasizes nonlinear two-dimensional scales to interpret the relationship between product quality and overall customer satisfaction. In the Kano model, the relationship between product properties and customer satisfaction can be clearly understood by attractive quality, performance quality and must-be quality. In recent years, the Kano model has been widely used in product design, real estate sales [12], hotel services [83] and other fields due to its attractive quality, which will make customers have unexpected surprises and pleasant feelings. Hence, one "good feeling" product can trigger the final purchase design.

In the research of customer-oriented measurement and evaluation techniques, in addition to the techniques listed in this paper, there are also questionnaires, focus interviews, ethnography, expert system methods, factor analysis, cluster analysis, data mining and other methods and technologies. These methods have been widely used to collect users' information and rate design elements. However, these mature methods and techniques in KE have their own advantages

TABLE 11. Mathematical algorithm techniques.

Technique	Characteristics	Defect
QTTI	QTTI is convenient to use to understand items, categories and their weights.	Insufficient to express the kansei nature of nonlinearity
GST	GST is effective at handling incomplete known information; and the results are more objective, true and accurate.	The model established is not based on the original data and has no predictability for design development.
RST	RST has analytical power in handling imprecision, uncertainty, ambiguity and nonlinearity data. RST is highly complementary to other methods for handling uncertain problems.	Poor fault tolerant ability during data processing and classification
NNs	They have a strong association ability, strong adaptability, strong fault tolerance and self-organization ability.	Long prediction time, difficult convergence and easy to fall into local minimum
GA	A GA is comparatively more effective at searching the entire solution space.	Poor local search ability
FL	FL can handle nonlinear problems and has strong real-time performance.	It is difficult to handle the dynamic changes of the system.

for users' physiology and psychological analysis. Therefore, when measuring and evaluating customers and customer-oriented products/services, we should choose the appropriate method instead of purely adopting the technology using ''new methods and new concepts''.

2) MATHEMATICAL ALGORITHM TECHNIQUES

Adjective words and kansei words from the early stages of kansei engineering research were evaluated and rated so as to determine the criterion for inclusion in the database. Multivariate analyses have been widely employed to analyze statistical data. As Fig 11 shows, gray theory and rough sets are the key methods to treat the data that connect kansei words to product properties. Quantification theory type I is still the most popular multivariate analysis method as it has much merit. Besides, many cutting-edge technologies are mainly based on intelligent computer systems and are able to sort and find similarities in the data. BP neural networks, gray theory, fuzzy systems, genetic algorithms and rough sets have been used as effective tools to connect kansei words and design properties. According to the keywords and clusters, this paper summarizes the characteristics and defects of common popular mathematical algorithm techniques, as shown in Table 11.

(1) Quantification Theory Type I (QTTI): Quantification theory type I is widely used in KE. Designers identify customer kansei evaluations as characteristic values (objective variables or external criteria) and design elements as explanatory variables. According to the application of quantitative theory type I in KE, the mathematical model between product sensibility and design elements can be obtained as follows:

$$y\ kansei\ value = f(\text{design elements})$$

By analyzing and studying the model, the design elements that affect kansei and the degree of its effect could be identified. In addition, the positive and negative effects of subdesign elements could be captured via kansei evaluation. Then, the relationship between the two variables is established by a regression equation, which guides designers and engineers to cooperate in design. Based on quantification theory type I, scholars analyze data, i.e., affective customer needs for luxuriousness in product design attributes [84]; customers' perceptions of products and their preferences for certain shapes, colors and styles [23]; and The functional and usable appeal of Facebook SNS games [85].

(2) Gray System Theory (GST): According to Fig 11, gray theory is an independent cluster, which indicates that this method is a common method in KE. GST has been developed to check the relationships among factors in an observable system in which the information available is uncertain and incomplete [17], [86]. It has been successfully used in a wide range of fields, including some recent application results highlighting its effective handling of incomplete known information to explore unknown information [7], [6]. GST sets each random variable as a gray quantity that changes within a given range. It does not rely on statistical methods to address gray quantities. It directly addresses the original data and searches the intrinsic regularity of the data. Grey Relational Analysis (GRA), in GST, measures the relationship between factors based on the degree of similarity of their developmental trends [86]. The GRA method is widely applied in KE systems because it effectively solves complicated interrelationships between multiple performance characteristics.

(3) Rough Set Theory (RST): As shown in Fig 11, rough set is another independent cluster, which means that this method has been a hot spot in KE research. The relationship between customer kansei needs and product attributes is not linear. Since the emergence of KE, researchers have realized that there is a nonlinear relationship and uncertainty between customer kansei needs and product attributes, and they have been studying various mathematical algorithm techniques to solve this problem. Rough set theory is an effective and systematic method to handle any type of data, irrespective of the linear or nonlinear characteristics of the data [87]. Rough set theory is one of the most promising alternatives

for solving KE problems as a systematic and effective knowledge discovery means with analytical power in handling imprecision, uncertainty, ambiguity and nonlinear data [88]. Generally, rough set theory seeks to find the highest approximation and the lowest approximation of decision information from fuzzy kansei data, which can help designers modify and improve product designs and meet the objective kansei demand. Rough set theory can enhance consumer-oriented product research and development and can be widely used in more complex situations, including various classification design elements and more consumer evaluations [88], [89]. It has made affective design a promising alternative for kansei knowledge acquisition [90].

(4) Neural Networks (NNs): NNs are frequently used in the field of design because of their superiority in handling nonlinear data [20], [66]. NNs have been used to construct a kansei prediction system focusing on variations in the appearance or form of product properties [21]. However, too many or too few neurons affect the accuracy of the system. Faced with many interrelated product design attributes and factors, NNs have been used to construct kansei predictive models, which provide greater complexity for hidden layers, learning speed parameter settings and the waste parameter setting time [21]. Therefore, preliminary data reduction dimensional reduction based on factor analysis or cluster analysis before NNs construct learning and training logic rules for optimization or performing predictions are necessary.

Back Propagation Neural Networks (BPNNs) are the most commonly used and popular neural networks due to their excellent nonlinear approximation ability. A BPNN was conducted to identify quantitative relations between key design factors and emotional dimensions [78]. Although the BPNN has some shortcomings, such as its slow convergence speed and falling into the local extremum, it can achieve a better convergence speed and overcome the local extremum phenomenon. BPNNs are widely used to construct prediction models for webpages [78], mobile phones [22] and product form codesign systems [91] due to its simplicity, easy implementation, low computational costs and strong parallelism.

(5) Genetic Algorithm (GA): A GA simulates the evolutionary processes of organisms in the natural world [23]. The natural selection process of the GA extracts the useful design items from a multitude of design attributes. The GA is capable of solving the difficulty of treating numerous independent variables concurrently in a very short computation time. Unlike other optimization methods, the GA does not perform random searches [92]. When searching the next generation according to a specified criterion that can be applied to continuous or discontinuous cases, the GA usually functions according to the experience of the previous generation. The GA is comparatively more effective at searching the entire solution space [78]. In addition, the GA has been employed to search for a near-optimal design. Therefore, the GA can be used to improve the efficiency in the data search process and ultimately optimize the design of tangibles and intangibles [20], [22], [55]. However, a single GA coding cannot fully express the constraints of optimization problems. Hence, the GA is often used in combination with other mathematical algorithm techniques in KE.

(6) Fuzzy Logic (FL): Fuzzy logic has been developed to examine the relationships between the variables in an observable system where the information available is subjective and imprecise. Fuzzy logic provides an effective framework for modeling humans' feelings regarding words for decision making due to its effective handling of imprecise known information when exploring unknown information. Therefore, fuzzy logic is suitable for modeling the product design process to describe the relationship between the product form (as an input variable) and the consumer perception of a product's image (as output variable), where the consumer perception is often expressed subjectively and imprecisely [45]. Fuzzy logic is often integrated with other methods to build kansei models of product development and design optimization. The fuzzy rule-based model [92], fuzzy neural networks [20], the fuzzy KE and Kano model [93], and fuzzy-based the Taguchi method [94] have better prediction performance for multiresponse optimization of product form design in KE than single methods.

3) VIRTUAL KANSEI ENGINEERING

In cluster #6, the keywords related to virtual KE are artificial intelligence, big data, online, etc., which mean that virtual reality is already a cutting-edge technology in KE [94]. Virtual KE is a technology combining virtual reality and KE. AI and VR are very useful and effective technologies to construct a computer system for helping a customer select a good design. This system consists of an emotion database, reference engine and design database. First, the customer describes his or her family, lifestyle, preferences, and feelings/likes regarding goods. Second, the system calculates the relationship between emotion and design speculation and outputs a good design that is in line with customers' emotions [73]. Automatically, the computer uses his or her data to display the created design picture to them.

In a virtual KE system, users can blend into the image in 3D space, move their hands on the data, and control the image according to customers' preferences. Any dissatisfaction can be corrected in the computer. A virtual reality system enables people to participate in virtual reality. Therefore, this system can truly be called a participatory design system, and it can be combined with virtual reality to achieve customer satisfaction, which will become the standard of future product development and the research focus in the future.

V. EMERGING TRENDS OF KANSEI ENGINEERING

Visualization of the time zone can clearly show the evolutionary process of knowledge over time. Fig 12 shows the high-frequency keywords in KE studies in different periods and presents the research emphases of scholars, which varied from stage to stage. In each time zone, the font size denotes the frequency of keywords. That is, the larger the font size is, the higher the frequency of keywords. The connections

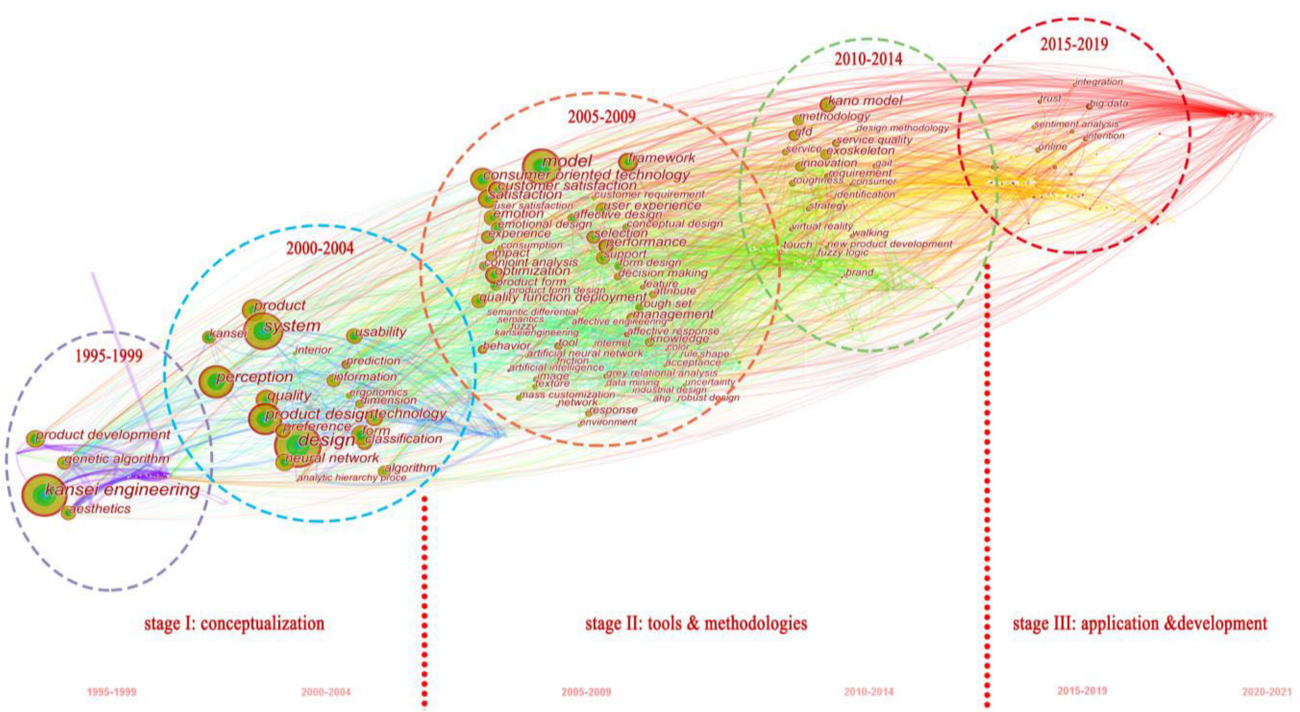

FIGURE 12. Time zone view of keywords.

of nodes between time zones indicate the inheritance of research. Besides, burst keywords (keywords that are cited frequently over a period of time) represent research hotspots in a certain period and can also represent frontier topics. Tab 12 lists the top 35 keywords with the strongest citation bursts in 1995-2021. Combined with the above division of research stages, the evolution and development process of each stage and the possible research trends in the field of KE will be established in the next part through Fig 12 and Table 12.

A. STAGE I: CONCEPTULIZATION OF KANSEI ENGINEERING

From 1995-2003, the keyword with the highest strength of 8.23 was ''interior'' in Tab 12; and the most cited keywords were ''kansei engineering'', ''design'', ''product design'', ''system'' and ''perception'', which corresponded to the first and second stages of the concept of KE in the evolutionary path(Fig 12). At this stage, the research object is established, and the object of KE is the tangible objects used by users in their daily lives. Academic circles and business circles in Japan have been seeking perceptual quantification methods for a long time. From a certain point of view, KE is an ergonomic technology, but it is quite different from ergonomics. For example, KE focuses on positive pleasure. Researchers at Hiroshima University in Japan fully considered residents' emotions and desires in residential design and sought to introduce perceptual analysis into the engineering research field to produce the first batch of ''perceptual goods'' in the automobile industry. The interior designs of the Mazda Miata MX 5, Nissan and Mitsubishi introduced KE into automobile development and achieved success, which aroused the interest and concern of European and American car manufacturers in the application of KE in automobiles. In addition, in the 1990s, the technology and ideas of KE were fully introduced into Japanese industry and applied to the research and development of new products such as residences, clothing, automobiles, electrical products, sporting goods, women's care products and decorations, which formed a new situation of the KE boom and a new academic concept of KE. The Japanese Society of KE (www.jske.org) was established in 1997. To date, academic conferences have been regularly held twice a year, laying the foundation for the conceptualization and development of KE.

B. STAGE II: TOOLS & METHODOLOGIES OF KANSEI ENGINEERING

During 2004-2014, the keyword with the highest strength of 7.43 (Tab 12) was ''conjoint analysis'', which corresponded to the third and fourth stages in the evolutionary path (Fig 12), indicating that scholars established the relationship between design elements and kansei image at this stage. The most cited keywords were ''model'', ''Kano model'', ''customer-oriented technology'', ''customer satisfaction'' and ''optimization''. These keywords are closely related to the research tools and methods of KE development. Although researchers continue to use the tools, methods and systems developed in the previous stage, customers' perceptual responses to the same product will change over time, and perceptual measurement and evaluation must inevitably evolve. Therefore, the above analysis of a large number of developmental research tools and technologies enables researchers to study unknown phenomena. This is a productive stage because many results have been produced, and the understanding of KE research has been greatly improved. In addition, the development of these tools and methodologies may contribute to the development of other disciplines.

C. STAGE III: APPLICATIONS OF KANSEI ENGINEERING

After 2015, the keywords with the highest strength were ''sentiment analysis'' and ''trust'', which corresponded to the fifth stage in the evolutionary path (Fig 12). As shown in Figure 12, the most cited keywords also include ''emotional analysis'', ''trust'', ''big data'', ''online'', ''integration'' and ''intention'', indicating that KE has a steady development trend. The study of KE is no longer limited to methods and tools. Researchers study the output of KE. The applications of KE are both tangible and intangible. As long as the products and services related to users can be applied, from the design of a daily mobile phone user interface to real estate sales services, the process of KE is also closely integrated with the development of science and technology. That is, first, we use KE to analyze the users' emotions. Second, we obtain the users' preferences and build a database for big data analysis. In addition, the users participate in the experience of product/service, improve the design, and thus improve the satisfaction and trust of the users. Finally, the brand image of the enterprise will be enhanced, the purchase rate will be increased, and more profits will be created for the enterprise. Overall, regarding the application scope of the research, the emphasis of KE is shifting from tangible objects to intangible services. From a technical point of view, big data and artificial intelligence are of greater concern.

D. EMERGING TRENDS OF KANSEI ENGINEERING

As shown in Tab 12, besides the burst strength, considering that the burst keywords begin in 1999 together with their corresponding red lines, the three emerging trends of KE research are as follows:

1) MULTIPLE MATHEMATICAL ALGORITHM ANALYSIS

Since the last century, Japan, South Korea, Taiwan and European and American countries have established databases to collect massive amounts of user data. The databases have the functions of storage and query and provide the functions of data visualization, virtual product design and design scheme evaluation. Commonly used design scheme feedback and evaluation methods are continuously being released, and the evaluation differences among evaluators are analyzed as characteristic records to analyze user needs. However, databases are generally analyzed using a single mathematical model, and there are some defects. Researchers also found that integrating various methods can allow data to be more accurately and effectively analyzed and evaluated because these combined methods can compensate for their own deficiencies. Therefore, multiple mathematical algorithm analysis is more comprehensive, which will be a new trend in the KE research in the future.

2) MULTIDISCPLINARY RESEARCH

In recent years, with the rapid popularization of the internet, customer-oriented big data have emerged. KE, emotional design and artificial psychology were all born in different countries' industrial backgrounds. The research fields spanned by them have their own emphasis, but some cross each other. They have some commonalities, and they are horizontally complementary. KE researchers mainly come from four fields (psychology, engineering, economics, and computers), with different emphases; however, regardless of their field, they all have the same goal of improving user satisfaction. Therefore, based on the development of the internet and databases, how to make effective use of big data and realize a multidisciplinary research method of users' perceived value in the internet age will be a trend of KE research.

3) MULTIAPPLICATION FIELD PRACTICE

After the success of KE in Japan's automobile industry, combined with university research institutions, KE has been fully introduced into various industrial fields covering a wide range of products. KE has been applied to the development and research of new products including residential products, clothing, household appliances, public design, media advertising design, ceramics, lacquerware and other regional cultural products. KE is widely used not only in Japan but also in other countries. For example, the PR China, Taiwan, Korea, Malaysia and India all use KE to develop products. With the products and services brought by technology and the internet, increasingly more tangible and intangible services have been introduced to people. KE has a wider range of applications. The small applications include interface design, web page design, social media, online shopping services and other. The large applications include the interface and service design of e-commerce systems and banking systems, hotel services, tourism services, the housing design of real estate development projects, and reception and procurement services. During the COVID-19 pandemic, the application of KE in humanitarian logistics and in cold food chains improved customer satisfaction and loyalty [14], [77]. In recent years, countries have begun to recognize traditional culture and began to protect and inherit cultural heritage. Sustainable development has been applied to cultural fields, such as the development of cultural products. The image of a regional urban environment cannot be separated from sustainable development. Sustainable development also plays an important role in the sustainable development of social culture. Therefore, multiple applications is also a trend in KE research.

TABLE 12. Top 35 keywords with the strongest citation bursts.

Keywords	Year	Strength	Begin	End	1995 - 2021
interior	1995	8.23	**2000**	2012	
kansei	1995	5.64	**2000**	2014	
usability	1995	4.45	**2001**	2009	
product design	1995	6.16	**2003**	2009	
system	1995	4.24	**2004**	2008	
product form	1995	5.78	**2005**	2012	
neural network	1995	4.79	**2005**	2012	
image	1995	4.04	**2005**	2009	
conjoint analysis	1995	7.43	**2006**	2009	
affective design	1995	5.7	**2006**	2014	
product development	1995	5.67	**2007**	2012	
consumer oriented technology	1995	5.14	**2007**	2009	
mobile phone	1995	4.47	**2007**	2013	
semantics	1995	4.41	**2008**	2014	
rule	1995	6	**2009**	2014	
rough set	1995	4.59	**2009**	2014	
artificial neural network	1995	4.33	**2012**	2016	
quality function deployment	1995	4.84	**2013**	2015	
rough set theory	1995	4.72	**2013**	2014	
methodology	1995	4.1	**2013**	2017	
innovation	1995	4.69	**2015**	2016	
triz	1995	4.23	**2015**	2017	
exoskeleton	1995	4.99	**2017**	2019	
sentiment analysis	1995	6.45	**2018**	2021	
service quality	1995	5.65	**2018**	2021	
set	1995	4.41	**2018**	2021	
trust	1995	6.08	**2019**	2021	
big data	1995	5.29	**2019**	2021	
online	1995	5.19	**2019**	2021	
performance	1995	4.79	**2019**	2021	
online review	1995	4.45	**2019**	2021	
review	1995	4.45	**2019**	2021	
artificial intelligence	1995	4.43	**2019**	2021	
social media	1995	4.00	**2019**	2021	
sustainability	1995	4.00	**2019**	2021	

VI. CONCLUSION

In this paper, all the KE related articles published in WOS are reviewed in detail by using visualization and scientific metrology methods. Some useful results with the statistical information of various items (e.g., journals, references, countries/regions, institutions, authors and keywords) are shown.

Regarding the core journals, most have high qualities, such as the International Journal of Industrial Ergonomics, Expert Systems with Applications, Design Studies and the International Journal of Production Economics. The distribution of core journals shows the interdisciplinary characteristics of KE research and provides important knowledge sources and three research topics: (1) ergonomics-centered topics, (2) design-centered topics, and (3) computer science-centered topics and economics-centered topics.

Regarding the main contributing forces of KE research, at the macro (country) level, several countries (the PR China, Taiwan, and South Korea) have formed an academic circle centering on Japan. Europe has formed an academic circle of emotional design centered on the USA. They are prolific countries, and the number of articles for the PR China is also much larger than those of other countries. At the meso (institution) level, the core research forces were mainly from universities; and Natl Cheng Kung Univ, Hong Kong Polytech Univ, Natl Chiao Tung Univ, and Zhejiang Univ are prolific institutions. At the micro (author) level, the prolific authors are Lin YC, Hsiao SW, Yun MH, Guo F, Kwong CK, Han SH, Nagamachi M, and Lokman AM. The most cited authors are Nagamachi M, Osgood CE, Hsiao SW, Lai HH, Lin YC, Ishihara S, and Kano N; among which Nagamachi M, Hsiao SW and Lin YC are both prolific and highly cited authors.

Regarding hot research topics, there are three main hot research topics: (1) customer oriented analysis, (2) research method analysis, and (3) design and application analysis. Regarding cutting-edge technology, (1) customer-oriented measurement and evaluation methodology, (2) mathematical algorithm techniques to combine customer kansei and design elements, and (3) virtual KE techniques are the most popular and widely used technology.

Regarding the emerging trends, the evolution and developmental process of each stage are expounded according to the time zone view and burst strength of keywords. KE in the embryonic development stage mostly stays at the theoretical level and basic concepts; and in the steady development stage, KE pays more attention to the methods and tools, and its application is mostly concentrated in the rapid development stage.

According to the above analysis, there are still some problems in the KE research: (1) Customers are the subjects of experiments, and their feelings will change and become more subjective as the environment and time change. At present, the premise of kansei evaluation is limited to adjective pairs, which may not completely reflect customers' feelings. (2) There are many researches on the single method of associating customers' kansei with design elements, and they generally aim to solve an explicit problem of a project. (3) Both the kansei database and design database are insufficient to be used in various fields and need to be updated in real time.

Therefore, the paper provides the emerging trends of KE research: (1) multiple mathematical algorithm analysis, (2) multidisciplinary research, and (3) multiapplication field practice. First, the Internet is used to collect and store big data on kansei and design elements. Second, computers are used to integrate multiple mathematical algorithms to determine the relationships between variables, establish models and databases, and improve the operating efficiency and accuracy. Finally, combined with many disciplines, KE is applied to all fields of daily life to meet customers' needs and improve customers' satisfaction. Research on intelligent KE can serve the sustainable innovation of society and is also a research direction that should be vigorously developed in the future.

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