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TOPICAL REVIEW

User Experience: A Bibliometric Review of the Literature

WUHENG ZUO[1], BAIJUN MU[1], HUI FANG[2,3], AND YUEHUA WAN[2,3]

[1]College of Educational Science and Technology, Zhejiang University of Technology, Hangzhou, Zhejiang 310023, China
[2]Library, Zhejiang University of Technology, Hangzhou, Zhejiang 310023, China
[3]Institute of Information Resource, Zhejiang University of Technology, Hangzhou, Zhejiang 310023, China

Corresponding author: Hui Fang (fanghui@zjut.edu.cn)

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ABSTRACT User experience is a well-discussed topic in the field of human–computer interaction. To describe the status of research on this topic, a bibliometric analysis of publications concerning user experience from 2011 to 2021 was conducted using the Web of Science database. The main functions of Derwent Data Analyzer software include data cleaning, mining, and visualization. The historical trends of the year, leading countries, leading institutions, major contributors, and leading research fields and journals were investigated, and a keyword analysis of the highly cited literature was performed. The key findings are as follows. The United States, China, and Britain are the three most productive countries. Tsinghua University in China is the most productive organization, and Sungkyunkwan University in South Korea has the highest average citations per publication. User experience has attracted the attention of numerous scholars in 204 research fields, and computer science information systems is the main field. ''Usability,'' ''virtual reality,'' ''human–computer interaction,'' and ''augmented reality'' are the most used keywords. A recent trend is the focus on molecular biology.

INDEX TERMS User experience, virtual reality, human-computer interaction, bibliometric, keyword analysis.

I. INTRODUCTION

User experience (UX) is a catchphrase in the field of human–computer interaction (HCI) and design, and the focus of academia and the industry [1]. ISO9241-210 defines UX as all reactions of people to the products, systems, or services they use or expect to use, including spirits, beliefs, preferences, cognitive impressions, physiological and psychological reactions, behaviors, and achievements [2]. This is currently the most influential definition of UX. With people's increasing interest in this field, research on UX is expanding to the fields of computer science [3], [4], [5], communication [6], [7], [8], medicine [9], [10], [11], biology [12], [13], [14], the Internet of Things(IoT) [15], [16], [17], virtual reality [18], [19], [20], augmented reality [21], [22], [23], education [24], [25], [26], automobile industry [27], [28], [29], [30], robots [31], [32], [33], and others.

The concept of UX was put forward by Donald Norman, the world's first UX designer appointed by Apple in the 1990s. He believes that UX should meet the customers' needs, and a product's design should be simple and generous, such that it makes users happy with the product and brings them additional surprises [34]. With the increasing interest in this area, the content of UX research continues to expand, and the framework continues to improve. Alben [35] believes that ''experience'' refers to all aspects of people's use of interactive products: the feeling of the product in their hands, their understanding of the working principle of the product, their feeling when using the product, how the product meets their purpose, and the fit of the product with the whole environment in which they use the product. Nielsen et al. [36] believed that UX includes all interaction factors between end users and enterprises, their products, and services. Garret [37] put forward a UX model in the elements

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of UX: a user-centered design (UCD) for the web composed of ''elements'' existing in the ''plane'' of the development process. Each website develops at five levels from the bottom to the top: strategy, scope, structure, framework, and surface. Hassenzahl and Tractinsky [1] highlighted that UX is the result of the user's internal state (tendency, expectation, demand, motivation, emotion, etc.), the features of the design system (e.g., complexity, purpose, availability, functionality, etc.) and the interaction environment (or environment; e.g., organizational or social environment, significance of activities, voluntary use, etc.). Partala and Kallinen [38] emphasize that the main structure of UX should include experience emotion, satisfaction of psychological needs, and contextual factors. The UX model widely used at present is mainly the UX cellular model proposed by Peter Morville [39], [40].

A UX evaluation method can be used for product design and development processing. It is mainly divided into 1) User methods, including interviews [41], [42], [43], questionnaires [44], [45], [46], experiments [47], [48], [49], focus groups [50], [51], [52], and biophysiological measurements [53], [54], [55]; 2) Expert-oriented methods such as heuristic evaluation [56], [57], [58]; and 3) Automated methods such as telemetry analysis [59], [60], [61].

At present, some reviews have summarized the research results concerning UX, but they merely offer a review of the development of UX in a specific field and lack a comprehensive analysis of UX in various fields. For example, Kim et al. [62] believe that the virtual reality (VR) system presents extensive interaction with users, and new types of interactions are constantly being developed. Therefore, it is necessary to keep eyes on the UX of the VR system. To determine the current research status and future research direction, the UX research of VR has been systematically reviewed. Hornbaek and Hertzum [63] reviewed papers on the intersection of the technology acceptance and UX models to explore the experience component of HCI. In order to evaluate the user satisfaction of different types of computer games, Phan et al. [64] designed and developed a scale called ''Game User Experience Satisfaction Scale'' Brajnik and Gabrielli [65] reviewed studies on how online display advertising affects website usability and UX quality in the past decade. Clearly, the current overview in the field of UX is not comprehensive enough to systematically describe the research situation of UX from a global perspective, nor to judge the research hotspots and trends. As the first survey using bibliometrics on the topic of UX, this paper systematically summarizes the current status of UX research worldwide, focuses on the research hotspots, and predicts future research directions through a keyword analysis.

Bibliometrics is commonly known as statistical document analysis, in which statistical methods are applied to make a simple statistical analysis of the characteristics of relevant documents containing strategic intelligence, and data are analyzed to describe or explain the data characteristics and the change rules of the documents, to achieve the purpose of a strategic intelligence research. Many fields of research use bibliometrics to explore the effect of papers in specific research areas and to determine the influence of specific research areas or researchers [66]. It is widely used in research and evaluation in many fields [67] such as humanities [68], management [69], social sciences [70], tourism [71], economics [72], biomedicine [73], information technology [74], chemical engineering [75], architecture [76], psychology [77], machinery [78], education [79], and artificial intelligence [80].

II. MATERIALS AND METHODS

Bibliometrics is an interdisciplinary science that quantitatively analyzes all knowledge carriers using mathematical and statistical methods. Unlike a systematic review of papers, bibliometrics allows the analysis of numerous papers to show the overall research situation of a given topic, such as UX, based on the literature. This study analyzes ''user experience-related'' literature published between 2011 and 2021. The data were obtained from the core database of Web of Science (WoS) as of December 1, 2021. The search field was the subject, specifically, ''user experience'' or ''user's experience,'' and the document type was ''article'' or ''review.'' Finally, 6,748 articles were collected from Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). The annual output analysis showed that the number of articles before 2011 was small and unstable. Therefore, we limited this study's scope to 5,842 articles published between 2011 and 2021. We used Derwent Data Analyzer (DDA10.0 build 27330, Norcross search technology company, Georgia, USA)—a statistical analysis tool for data cleaning, data mining, and data visualization—to process and analyze data extracted from 5,842 articles and tables. All articles related to UX from 2011 to 2021 were evaluated in the following aspects: countries, international cooperation, institutions, research fields, journals, authors, author keywords, and most frequently cited paper for each year.

III. RESULTS

From 2011 to 2021, 107 countries or regions published 5,842 articles regarding ''user experience.'' Of the 5,842 papers, 73 were highly cited papers on essential science indicators(ESI), and three were prominent papers on ESI. The annual growth trend of the research on UX is shown in Fig. 1. The number of publications per year increased from 144 (2011) to 998 (2021), nearly sevenfold. More than three quarters of the literature was published in the past six years (2016–2021). This finding shows that UX is a considerable topic in the field of HCI, attracting the attention of scholars worldwide.

A. CONTRIBUTION OF LEADING COUNTRIES OR REGIONS

The top 20 countries with the most contributions from UX papers are shown in Fig. 1, and their proportions are shown in Fig. 2. Among the 20 countries or regions with the highest productivity, 11 are from Europe; 3 from the

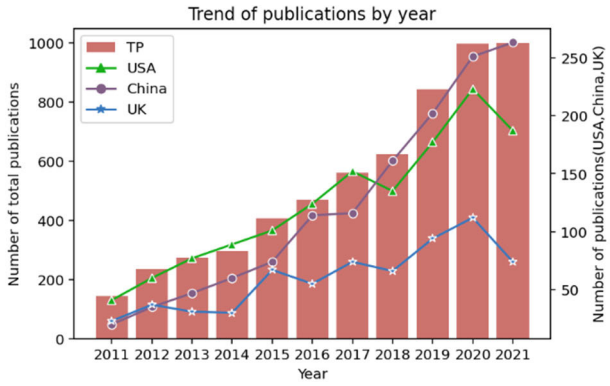

FIGURE 1. Trends in the number of published articles related to user experience by year.

Americas; 5 from Asia and 1 from Oceania. The United States is the most productive (1,366 articles), followed by China (1,343) and Britain (663). China includes Taiwan. Britain includes England, Wales, Scotland, and Northern Ireland. Japan has the highest average citations per publication (ACPP; 102.39), indicating that its influence in this field cannot be ignored. Among the literature of the top 20 countries, there are a lot of references to international cooperation, especially for Switzerland (87.76%), Singapore (81.37%), and Norway (65.31%). Therefore, scholars have intensively participated and cooperated in the knowledge exchange regarding UX. Although China has numerous publications, its ACPP is low at 12.43, probably because of language barriers and the quality of incremental articles. The cooperation among the top 20 countries is shown in Fig. 3. The more articles in each country, the larger the nodes. The connection between the nodes is representative of cooperation among these countries, and its width represents the intensity of such cooperation. The number of cooperative countries (NCC) values in Table 1 prove that the United States is the most active country in terms of cooperation. It has cooperated with 70 countries or regions, especially China, South Korea, the United Kingdom, and Canada; followed by Britain (69) and France (50). In addition to close cooperation with the United States, China also has strong cooperation with Australia.

B. CONTRIBUTION OF LEADING INSTITUTIONS

The top 20 institutions that contributed to user experience research from 2011 to 2021, as well as the number of citations and h-indexes, according to the number of publications are shown in table 2. Among all institutions, the top three with the largest contribution are from China, namely Tsinghua University, Chinese Academy of Sciences, and Beijing University of Posts and Telecommunications. In terms of the average citations per publication (ACPP), Sungkyunkwan University of South Korea ranks first with an ACPP of 40.26. The University of Toronto, Canada ranks second (32.89), while the University of Manchester, United Kingdom ranks

TABLE 1. Top 20 most productive countries or regions on the topic of user experience (2011–2021).

Rank	Country	TA	TC	ACPP	SP(%)	nCC	H-index
1	USA	1366	47,562	34.82	44.95	70	73
2	China	1343	16,698	12.43	47.65	47	58
3	UK	663	14,317	21.59	53.85	69	48
4	Spain	430	9,153	21.29	43.72	48	31
5	South Korea	376	10,308	27.41	29.79	30	34
6	Germany	353	4,243	12.02	54.67	46	30
7	Canada	307	5,864	19.10	57.33	44	36
8	Australia	298	8,449	28.35	59.73	44	28
9	Italy	260	9,225	35.48	47.31	46	33
10	Netherlands	194	2,480	12.78	62.89	40	25
11	France	192	3,270	17.03	57.29	50	25
12	Finland	143	2,955	20.66	54.55	39	30
13	Sweden	126	2,031	16.12	57.14	40	21
14	India	122	761	6.24	36.89	25	16
15	Japan	120	12,287	102.39	50.83	31	19
16	Brazil	115	717	6.23	43.48	28	13
17	Switzerland	105	5,297	50.45	87.76	39	22
18	Singapore	102	1,806	17.71	81.37	18	21
19	Norway	98	1,376	14.04	65.31	36	20
20	Ireland	93	919	9.88	55.91	36	16

TA means total articles; TC, total citations; ACPP, average citations per publication; SP, share of publications; and nCC, number of cooperative countries.

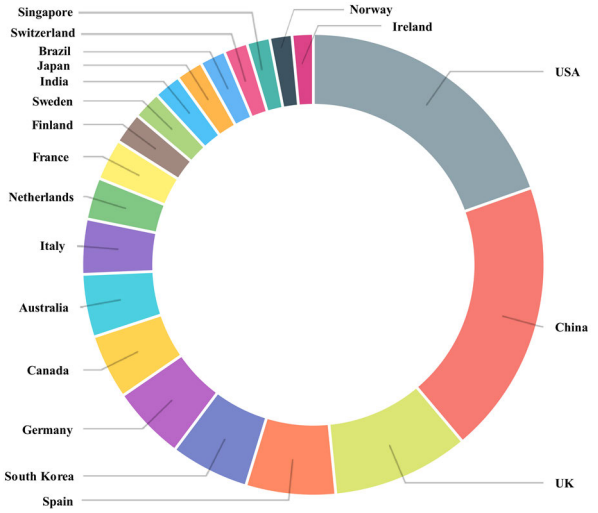

FIGURE 2. Proportion map of the top 20 countries with the largest number of documents issued.

third (30.30). The Chinese Academy of Sciences has the highest h-index (17); Sungkyunkwan Univ and Aalto University of Finland both rank second (16). Clearly, these institutions have played a vital role in the development and promotion of UX. Among the top 20 institutions, 8 institutions are from China, but their ACPP values are all low. As shown in Fig. 4, the top ten institutions produce articles continuously and have a stable output every year. The cooperation between

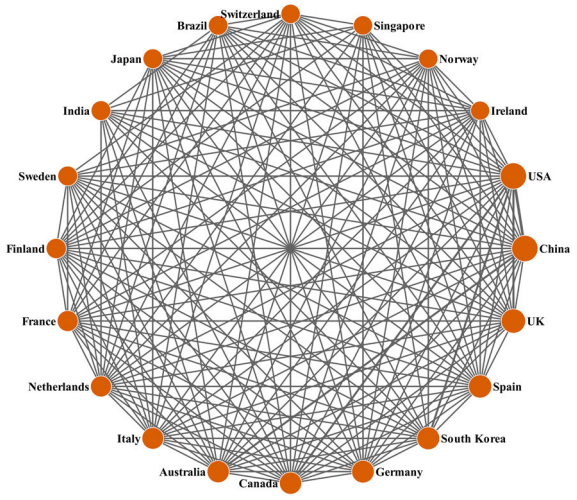

FIGURE 3. Collaboration matrix map among the top 20 productive countries or regions.

TABLE 2. Top 20 most productive institutions in terms of publications (2011–2021).

Rank	Institution	TA	TC	ACPP	h-index	Country
1	Tsinghua University	80	1,211	15.14	13	China
2	Chinese Academy of Sciences	71	1,213	17.08	17	China
3	Beijing University of Posts and Telecommunications	65	888	13.66	12	China
4	Sungkyunkwan University	50	2,013	40.26	16	Korea
5	University College London	50	666	13.32	15	UK
6	Aalto University	45	934	20.76	16	Finland
7	Nanyang Technology University	44	735	16.70	14	Singapore
8	Universitat Politècnica de Valencia	44	271	6.16	9	Spain
9	Huazhong University of Science and Technology	42	1,000	23.81	14	China
10	Shanghai Jiao Tong University	39	1,002	25.69	13	China
11	University of British Columbia	37	767	20.73	13	Canada
12	Hong Kong Polytechnic University	35	364	10.40	10	China, Hong Kong
13	Stanford University	35	458	13.09	12	USA
14	University of Sydney	35	294	8.40	9	Australia
15	University of Toronto	35	1,151	32.89	11	Canada
16	University of Washington	35	463	13.23	12	USA
17	Beihang University	34	250	7.35	9	China
18	Northeastern University	33	407	12.33	10	China
19	University of Manchester	33	1,000	30.30	15	UK
20	University of Melbourne	33	392	11.88	11	Australia

TA means total articles; TC, total citations; and ACPP, average citations per publication.

the top 20 institutions is shown in Fig. 5. The Chinese Academy of Sciences has the most extensive cooperation

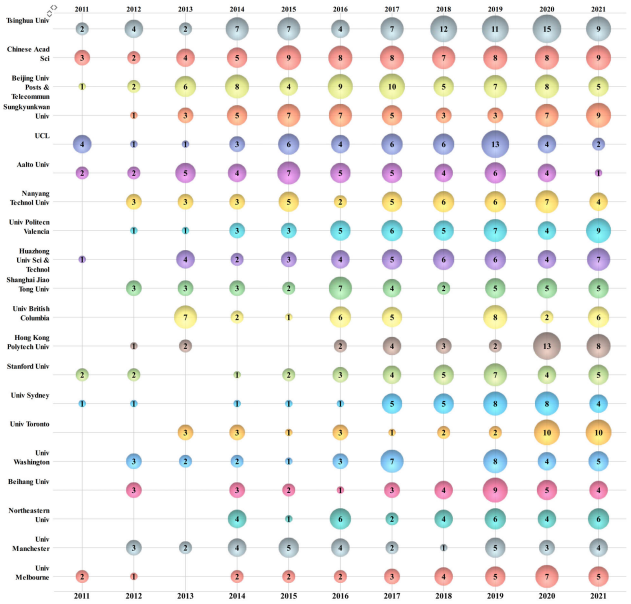

FIGURE 4. Bubble chart of the top 20 most productive institutions by published articles per year.

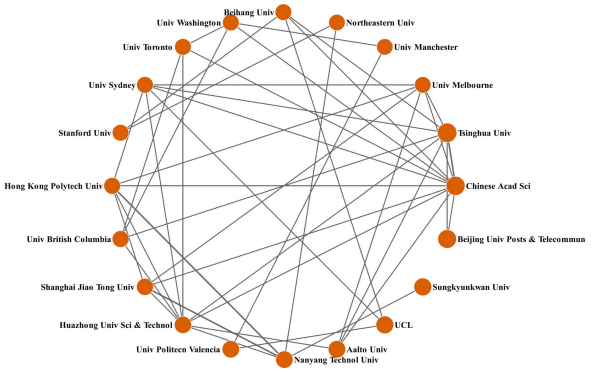

FIGURE 5. Collaboration matrix map among the top 20 productive institutions.

network, having cooperated with 11 institutions. Huazhong University of Science and Technology has cooperated with nine institutions, and Tsinghua University has cooperated with eight institutions. These results suggest that institutions from China often have a good foundation for cooperation. Sungkyunkwan University shows the least cooperation, having cooperated only with Nanyang Technology University in Singapore. Most of the cooperation between institutions is not limited to domestic contacts; all have the experience of cooperating with foreign institutions, indicating the global nature of UX research.

C. CONTRIBUTION OF LEADING RESEARCH AREAS

It is generally accepted that UX is a topic relevant to multiple disciplines. Based on the number of articles, table 3 shows the top 20 most popular research areas for UX. Computer science information systems ranks first with 1,348 articles,

TABLE 3. Contribution of leading research areas.

Rank	WoS research area	TA	TPR%	TC	ACPP
1	Computer Science Information Systems	1348	23.07	17,627	13.08
2	Engineering Electrical Electronic	1179	20.18	20,968	17.78
3	Telecommunications	1001	17.13	21,009	20.99
4	Computer Science Software Engineering	619	10.60	6,481	10.47
5	Computer Science Cybernetics	446	7.63	6,948	15.58
6	Ergonomics	420	7.19	5,861	13.95
7	Computer Science Theory Methods	415	7.10	4,330	10.43
8	Computer Science Artificial Intelligence	329	5.63	4,288	13.03
9	Health Care Sciences Services	312	5.34	4,338	13.90
10	Medical Informatics	299	5.12	4,174	13.96
11	Computer Science Interdisciplinary Applications	279	4.78	3,351	12.01
12	Information Science Library Science	274	4.69	2,738	9.99
13	Computer Science Hardware Architecture	256	4.38	4,704	18.38
14	Psychology, Multidisciplinary	226	3.87	5,010	22.17
15	Engineering, Multidisciplinary	206	3.53	953	4.63
16	Public Environmental Occupational Health	175	3.00	1,412	8.07
17	Instruments Instrumentation	149	2.55	1,361	9.13
18	Physics, Applied	148	2.53	652	4.41
19	Engineering, Industrial	140	2.40	2,023	14.45
20	Communication	121	2.07	982	8.12

TA means total articles; TPR%, the share of cited articles in the total publications of each journal; TC, total citations; ACPP, average citations per publication.

followed by electrical engineering and electronics (1,179) and telecommunications (1001). These are the main areas of UX research, accounting for 60.38% of the total published articles. As shown in Fig. 6, the number of articles published in the top 20 fields generally rises yearly, indicating that the topic of UX is increasingly attracting scholars' attention. The aforementioned three areas are also the most closely linked, as shown in Fig. 7. Next is computer science information systems, which is closely related to computer science software engineering and computer science theory methods. Meanwhile, the area of psychology has the highest ACPP value, which indicates that many theories and models of UX are from this field, and many psychology-related methods are used in the UX evaluation process.

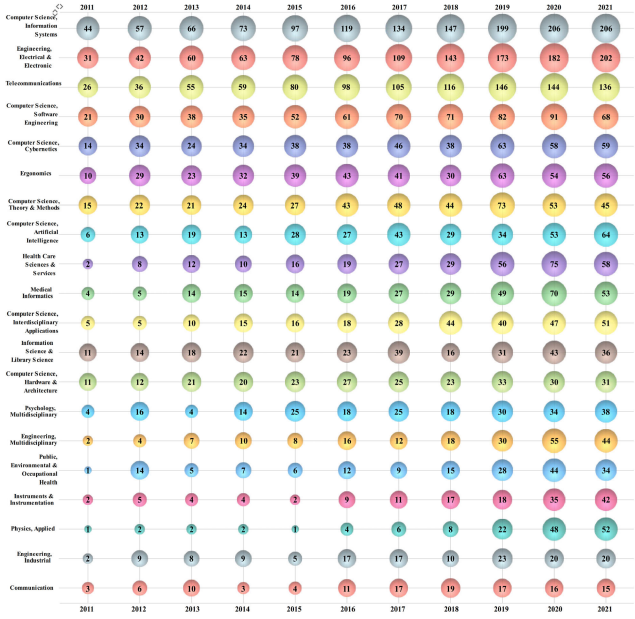

FIGURE 6. Bubble chart of the top 20 user experience research areas by published articles per year.

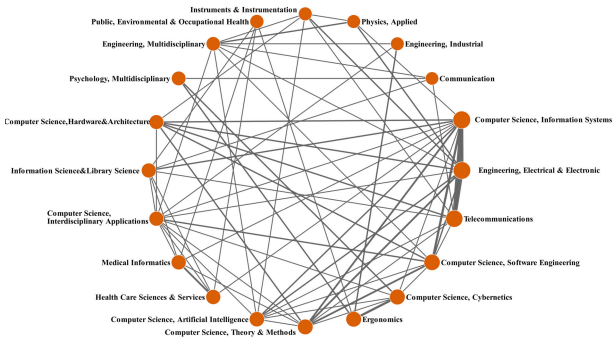

FIGURE 7. Intersection matrix map among leading research areas.

D. CONTRIBUTION OF LEADING JOURNALS

Between 2011 and 2021, 5,842 articles in the field of UX were accepted by 1,462 journals. As shown in Table 4, 1EEE Access leads with 200 articles on UX, followed by Multimedia Tools and Applications (107), Sensors (106), International Journal of Human–Compute Studies (87 articles), and International Journal of Human–Computer Interaction (85 articles). The 20 journals listed in Table 4 published 1,255 articles, accounting for 21.48% of the total. In terms of impact factor (IF), IEEE Communications Magazine ranks first with an IF of 9.619. It also has the highest ACPP (49.22), followed by Future Generation Computer Systems and Computers in Human Behavior. In order to show the annual publication of the top 20 journals, we present a bubble chart of the top 20 productivity journals (Fig. 8). Articles on the topic of UX have been published since 2011. However, from 2016, numerous articles on this topic have been published in journals represented by IEEE Access, suggesting that this topic has received great attention from academia and that product development, website design, and other works have prioritized the users' perspective.

E. CONTRIBUTION OF LEADING AUTHORS

The 5,842 articles from 2011 to 2021 involved 21,432 authors. Among the top 20 authors in terms of publication production, Shin, Dong-Hee ranks first for contributing 35 articles, followed by Park, Jaehyun (15), and Thomaschewski, Joerg (15) according to table 5. Chen, Min ranks first in the ACPP score with 48.89 points, followed by Dey, Sujit (42.90), and Shin, Dong-Hee (37.77). Shin, Dong-Hee has 20 points in the H-index, far surpassing Park,

TABLE 4. Top 20 journals publishing articles on user experience.

Rank	Journal title	TA	TPR %	TC	ACPP	IF
1	IEEE Access	200	3.42	1,245	6.23	3.367
2	Multimedia Tools and Applications	107	1.83	599	5.60	2.757
3	Sensors	106	1.81	681	6.42	3.031
4	International Journal of Human–Computer Studies	87	1.49	2,114	24.30	3.632
5	International Journal of Human–Computer Interaction	85	1.45	898	10.56	3.353
6	Computers in Human Behavior	81	1.39	2,362	29.16	6.829
7	Applied Sciences-Basel	80	1.37	160	2.00	2.679
8	Journal of Medical Internet Research	68	1.16	1,633	24.01	5.428
9	JMIR mHealth and uHealth	61	1.04	918	15.05	4.773
10	Behaviour and Information Technology	60	1.03	679	11.32	3.086
11	Sustainability	51	0.87	153	3.00	3.251
12	Future Generation Computer Systems	46	0.79	530	11.52	7.187
13	Personal and Ubiquitous Computing	46	0.79	546	11.87	3.006
14	PLoS One	46	0.79	1,617	35.15	3.24
15	IEEE Communications Magazine	45	0.77	2,215	49.22	9.619
16	Interacting with Computers	44	0.75	651	14.80	1.174
17	Frontiers in Psychology	42	0.72	312	7.43	2.988
18	IEEE Transactions in Mobile Computing	40	0.68	540	13.50	5.538
19	IEEE Transactions on Visualization and Computer Graphics	39	0.67	827	21.21	4.579
20	Universal Access in Information Society	36	0.62	201	5.58	3.078

TA means total articles; TPR%, the share of cited articles in the total publications of each journal; TC, total citations; IF, impact factor; and ACPP, average citations per publication.

Jaehyun; Thomaschewski, Joerg; Han, Sung H; and Chen, Min. The results suggest that Shin Dong-Hee is an authority on UX. Among the top 20 authors, signs of collaboration are evident but not widespread; for instance, in the cases of

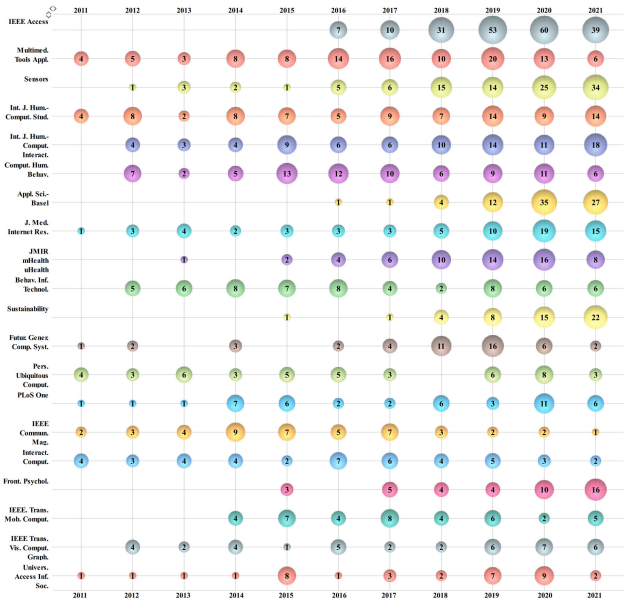

FIGURE 8. Bubble chart of the top 20 most productive journals by published articles per year.

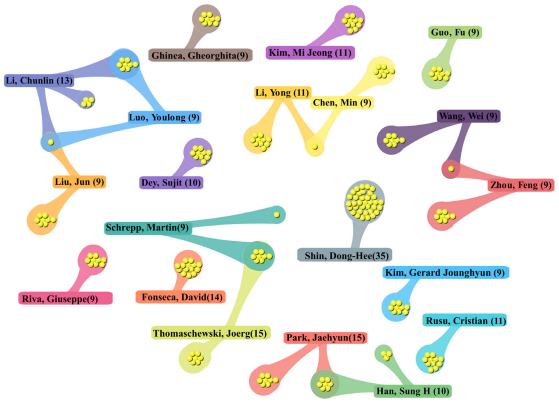

FIGURE 9. DDA cluster map of the top 20 productive authors.

Li, Chunlin; Liu, Jun; Luo, Youlong; Li, Yong; Chen, Min; Thomaschewski, Joerg; and between Schrepp and Martin (Fig. 9). Nine of the top 20 authors have not collaborated with other authors. The publications of the top 20 authors accounted for only 4.02% of the total, which means that many researchers are involved in the field of UX, contributing to 5,842 articles. Such a large research population also promotes the field of UX to achieve breakthroughs in the future.

F. RESEARCH HOTSPOTS AND TRENDS

The author's keywords contain key information about the current research status and hotspots. These keywords have been proven to play an important role in the analysis of future development trends [81], [82], [83]. We analyzed 14,660 keywords in 5,842 articles, of which 1,606 were used more than 3 times. Note that some articles without keywords may be excluded from the statistics. The top 20 keywords

TABLE 5. Contributions of the top 20 authors in user experience research.

Rank	Author	TA	TC	ACPP	H-Index
1	Shin, Dong-Hee	35	1,322	37.77	20
2	Park, Jaehyun	15	234	15.60	7
3	Thomaschewski, Joerg	15	348	23.20	7
4	Fonseca, David	14	250	17.86	6
5	Li, Chunlin	13	97	7.46	5
6	Kim, Mi Jeong	11	124	11.27	6
7	Li, Yong	11	254	23.09	6
8	Rusu, Cristian	11	100	9.09	3
9	Dey, Sujit	10	429	42.90	6
10	Han, Sung H	10	216	21.60	7
11	Chen, Min	9	440	48.89	7
12	Ghinea, Gheorghita	9	90	10	5
13	Guo, Fu	9	124	13.78	5
14	Kim, Gerard Jounghyun	9	45	5	4
15	Liu, Jun	9	132	14.67	4
16	Luo, Youlong	9	34	3.78	2
17	Riva, Giuseppe	9	190	21.11	6
18	Schrepp, Martin	9	226	25.11	4
19	Wang, Wei	9	80	8.89	4
20	Zhou, Feng	9	152	16.89	6

TA means total articles; TC, total citations; and ACPP, average citations per publication.

sorted by year are shown in Fig. 10. Keywords with similar meanings are classified into the same item after DDA processing. The three-dimensional development trend of the field is shown in a bubble chart. The chart tracks the research frontier by using bubble size as a third dimension [84]. The number in the bubble indicates the frequency of the keyword for a specific year. Ranking second after the search term ''user experience'' is ''usability,'' which is considered part of UX (260), followed by ''virtual reality'' (209), ''human–computer interaction'' (178), ''augmented reality'' (128), ''mhealth'' (111), ''mobile app'' (98), ''Internet of Things (97), ''machine learning'' (91), and ''quality of experience'' (86), which correspondingly rank third to tenth.

The top 20 keywords are divided into the following categories:

1) Terms related to UX—This includes ''user experience,'' ''usability,'' ''human–computer interaction,'' ''quality of experience,'' ''user interface,'' and ''user-centered design.'' UX is an important module in the field of HCI [1], [85], [86], and usability is an important part of UX [87], [88]; thus, the frequency of these two keywords is very high. A large part of UX research focuses on usability. For example, Hoehle and Venkatesh [89] proposed a conceptualization and survey tool for mobile application availability. To understand the effectiveness and availability of e-learning systems, Harrati et al. [90] discussed how teachers can interact with the e-learning environment based on a predefined task model. Some researches focus on quality of experience (QoE) or quality of service (QoS) in UX. Hobfeld et al. [91] discussed the technical challenges in transferring services to cloud computing and how this transformation affects QoE and QoE management. Yin et al. [92] emphasized the importance of QoS in internet video applications and developed a principled control theory model to infer a wide range of policies. Research in the field of computer systems often evaluates UX from the perspective of user interface (UI). Hussain et al. [93] believe that many methods affect the UX by providing individualized services in the form of adaptive UI. Shahzad [94] discussed the strategy of introducing ontology into different user interface layers according to UX elements. Kim et al. [95] studied and investigated the degree of user interface reflection, that is, the degree of interaction between the user's body and the game, and how this influence the UX, game behavior, and purpose of behavior change. In addition, more studies have focused on emotional factors other than usability in the UX. Park et al. [96] believe that emotion is an important aspect of UX. To design a UI for positive emotional experience, we need to consider the emotional quality of the UI carefully. Gil et al. [97] pointed out that as a means of improving the UX, emotion-awareness applications are receiving widespread attention.

2) Relevant stages of UX—This includes design and evaluation. Previous UX studies often focused on the evaluation stage [98], [99], [100]. Now, studies increasingly begin to consider UX from the design stage [101], [102], which coincides with the concept of UCD. At present, research on product design and development increasingly use the keyword ''user-centered design,'' emphasizing the idea of UX throughout the whole process of product design. Kübler et al. [103] applied UCD in the development of brain computer interfaces (BCI) to bridge the gap when providing users with BCI for controlling applications. To help realize UCD, Yamazaki and Furuta [104] developed a tool for UX design and evaluated the tool by prototyping experiments. Maher et al. [105] designed and developed tools that can be used for the habitual practice of patients and caregivers in the inpatient environment according to the concept of UCD. Triberti et al. [106] discussed the necessity of integrating emotional analysis into UCD. The research on UX is gradually developing toward the full cycle.

3) Different scenarios and domains of UX—This includes virtual reality, augmented reality, mMealth, mobile app, Internet of Things, cloud computing, eHealth, telemedicine, smart phone, and recommender system. Keywords in different scenarios and fields account for a large proportion, suggesting that UX is a popular research topic applied in many fields, and UX evaluation in many new scenarios has emerged [107], [108], [109].

4) Related technologies of UX—This includes machine learning and eye tracking. At present, the technology of evaluating UX shows a multimethod and multi-index trend, combining subjectivity and objectivity, which is

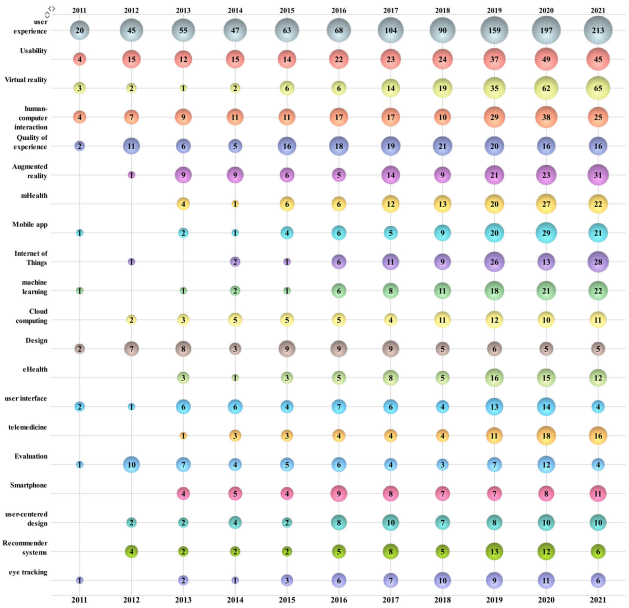

FIGURE 10. Bubble chart of the top 20 author keywords by published articles per year.

specifically reflected in the expansion of machine learning and the application of eye movement technology. In the past, questionnaire and interview methods were mostly used to conduct feedback surveys on a narrow range of users, with a small amount of data and strong subjectivity. These problems disappeared after machine learning was applied to UX evaluation [110], [111]. In addition, many studies evaluate the UX in machine learning models [112], [113], [114]. Eye-tracking technology also ensures the objectivity of data [115], [116], [117].

G. ANALYSIS OF THE MOST CITED PAPERS

Although the citation of articles is influenced by many factors, it remains a widely used method to assess the quality of an article. The most cited articles from 2011 to 2021 are shown in Table 6. The most cited article was written by Sudhir et al. [118], which was published in Molecular Biology and Evolution, ranking first with 10,559 citations and simultaneously topping the total citation per year (TCY).

If a paper is co-authored by scholars from different countries, the paper is defined as a product of international cooperation [119]. Among the 11 most cited articles, 7 were co-authored by people from more than one country, indicating the importance of transnational cooperation to the literature in this field. The 10 articles include authors from the United States, indicating the dominant position of the United States in this field. Notably the most cited literature each year involves virtual reality, biology, communication engineering, the Internet of Things, and other fields, suggesting that UX has the characteristics of interdisciplinary integration.

TABLE 6. Yearly most cited publications for the period 2011–2021.

Year	Authors	Title	TC	TCY	Source	Country or Region
2011	Kohler *et al.*	Co-Creation in Virtual Worlds: The Design of the User Experience	189	17	Management Information System Quarterly	USA; Austria
2012	Chen *et al.*	Second Harmonic Generation Microscopy for Quantitative Analysis of Collagen Fibrillar Structure	498	49	Nature Protocols	USA
2013	Thorvaldsdottir *et al.*	Integrative Genomics Viewer (IGV): High-performance Genomics Data Visualization and Exploration	4,076	453	Briefing in Bioinformatics	USA
2014	Andrews	What Will 5G Be?	4,880	610	IEEE Journal on Selected Areas in Communication	USA; Italy; South Korea; Australia
2015	Bateman *et al.*	UniProt: A Hub for Protein Information	3,078	439	Nucleic Acids Research	UK; Switzerland; USA
2016	Agiwal *et al.*	Next Generation 5G Wireless Networks: A Comprehensive Survey	1,356	226	IEEE Communications Survey & Tutorials	South Korea
2017	Lin *et al.*	A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications	945	189	IEEE Internet of Things Journal	Peoples R China; USA
2018	Kumar *et al.*	MEGA X: Molecular Evolutionary Genetics Analysis across Computing Platforms	10,559	2,639	Molecular Biology and Evolution	USA; Saudi Arabia; Japan
2019	Zhou *et al.*	Metascape Provides a Biologist-oriented Resource for the Analysis of Systems-level Datasets	1,946	648	Nature Communications	USA
2020	Stecher *et al.*	Molecular Evolutionary Genetics Analysis	371	185	Molecular Biology and Evolution	USA; Japan; Saudi Arabia

TABLE 6. *(Continued.)* **Yearly most cited publications for the period 2011–2021.**

		(MEGA) for macOS			
2021	Pang *et al.*	MetaboAnalyst 5.0: Narrowing the Gap between Raw Spectra and Functional Insights	89	89	Nucleic Acids Research	Canada; USA

TC means total citations and TCY, total citations per year.

In 2014, Andrews et al. [6] introduced the similarities and differences between 5G and the previous four generations of cellular technology. 5G combines air interface and spectrum with long term evolution (LTE) and WiFi to provide universal high-speed coverage and a seamless UX [6]. The authors started the research and discussion on 5G in the following years. In 2016, Agiwal et al. [120] published an article, once again garnering the highest number of citations for that year. This article reviews 5G in detail after two years of development, and focuses on the new QoS, QoE, and SON functions related to 5G evolution, to understand the improvement of UX.

Among the 11 most cited articles each year, 7 are in the field of biochemistry and molecular biology, which shows that scholars in this field attach great importance to UX. Chen et al. [121] discussed the optical modification of laser scanning microscope for measurement and pointed out the calibration time required according to the UX level. Thorvaldsdottir et al. [12] introduced the integrated genomics viewer in detail, pointing out that it provides a smooth and better UX at all levels of genome resolution. In an article published in 2015, titled "UniProt: A hub for protein information," Bateman et al. [122] used the UX design process to design a new website about UniPort, to determine which proteins have the best characteristics and provide the most information for comparative analysis. The two most cited articles in 2018 and 2020 both introduced the molecular evolutionary genetic analysis (MEGA) software. Sudhir et al. [118] reported a transformation of MEGA to achieve cross-platform use on Microsoft Windows and Linux operating systems and provide a unified cross-platform UX. Stecher et al. [123] focused on the new version of the macOS of the MEGA software, which eliminates the virtualization and simulation programs required for using Mega on Apple computers as before, to provide a UX consistent with that on Windows and Linux.

The most cited article in 2017 introduced the integration and application of edge computing and the IoT, to provide a better UX and the resilience of services in case of failure [124].

IV. DISCUSSION

Although UX is a topic that has been researched for 30 years, with the rapid growth of computer network, artificial intelligence, and other technologies, as well as the deepening of the user-centered concept, this topic continues to receive research attention. From 2011 to 2021, 107 countries and regions paid attention to UX research and published a total of 5,842 articles. Except for China, India, and Brazil, the top 20 countries are all developed countries. A possible reason is that high-income countries pay more attention to the personal experience of users. In terms of the number of publications, China and the United States are far ahead, with little difference between them. The cooperation between the two countries is also the closest. However, a gap continues between the total cited number of Chinese literature and the h-index compared with the United States, which is also reflected in terms of institutions. Institutions from China account for eight of the top 20 most productive institutions, but the ACPP and H-index of the literature need to be improved, indicating that Chinese scholars need to conduct more in-depth research in the field of UX.

The development of UX puts forward higher requirements for computer science, electrical and electronics, communication engineering, and many other fields. These areas in turn promote the development of UX. This is reflected in the publication volume of journals. IEEE Access, which ranks first in publication volume, is a journal that collects articles in the whole field, and Multimedia Tools and Applications, which ranks second, covers computer systems and engineering electronics, while the third-ranked Sensors focuses on engineering technology. Different fields have different research paradigms for UX. For example, UX in computer science mainly focuses on human–computer interaction of websites and systems [125], [126]. In the aspect of industrial design, the user centered idea runs through the design, emphasizing users' positive experience of products [127], [128]. In addition to the theoretical background of UX measurement [129], [130], model framework [131], and measurement methods and tools [132], the emotional aspects (psychology) of UX are also explored, such as privacy acceptance and satisfaction [133], [134].

Virtual reality technology and augmented reality technology are popular technologies nowadays, which are widely used in many fields [135]. Although the development of VR/AR provides many new possibilities for content design, the design's immaturity poses severe challenges to practitioners. The design of VR/AR also needs feedback from the UX perspective to verify whether it is feasible. Simultaneously, with the improvement of users' requirements for content quality, whether there is a good experience determines whether users will continue to use the VR/AR product. The UX of VR/AR involves many aspects such as the VR/AR equipment itself [136], [137], education [65], [138], medical treatment [18], [139], industry [140], [141], and so on. Some scholars have discussed how UX in VR/AR can be evaluated. For example, Kuliga et al. [142] have investigated whether UX in real buildings and virtual buildings is consistent. Rebelo et al. [143] discussed how to conduct UX assessment in a VR environment to overcome the limitations of UX assessment in the laboratory.

With the innovation of mobile technology and the growing number of smartphone and tablet users, mobile applications are becoming increasingly popular. Good UX can improve customer satisfaction and loyalty. Therefore, UX of mobile applications has become critical in academia and various industries [144]. Compared with the traditional UX evaluation method, mobile applications can obtain data through the comments of the app store [86], [145], [146]. Compared with the amount of data obtained in previous UX studies, the amount of user feedback obtained in this manner has greatly increased, which is also the trend of future research.

V. CONCLUSION

In this study, we analyzed the UX research literature published from 2011 to 2021 using bibliometrics and DDA software. According to our analysis, scholars in North America, Europe, and Asia actively conduct research on UX. Among them, the United States is the leader, followed by China and Britain. China and the United States are the two countries that cooperate most closely. Japan has the highest ACPP. Tsinghua University, the Chinese Academy of Sciences, and Beijing University of Posts and Telecommunications in China are the three institutions with the highest output, while Sungkyunkwan University in South Korea has the highest ACPP.

Shin, Dong-Hee; Park, Jaehyun; and Thomaschewski, Joerg are the three most prolific authors. Shin, Dong-Hee also has the highest h-index, while Chen, Min has the highest ACPP value. Although the top 20 authors have great influence, many other researchers work in this field, accounting for 95.98%. In addition, ten of the most cited articles in the past 11 years involve American scholars, which, once again, reflects the leading position of the United States in this field. The keywords ''virtual reality,'' ''augmented reality,'' ''human–computer interaction'' and ''mhealth'' are the most common. In the past decade, the research on UX has been conducted in different fields and disciplines, and a series of discussions have been carried out on how to understand UX and how to improve it. In recent years, virtual reality, augmented reality, and molecular biology are the most popular areas of research concerning UX.

This study can help potential scholars better understand the research status in the field of UX worldwide and provide ideas and information for future research.

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WUHENG ZUO was born in 1973. He received the Ph.D. degree in psychology from Zhejiang University, in 2013. He is currently an Associate Professor and a Master's Supervisor. His research interests include user experience and usability evaluation, and human–computer interaction.

BAIJUN MU was born in 1998. He received the bachelor's degree in educational technology from the Zhejiang University of Technology, in 2021. His research interests include user experience and educational technology.

HUI FANG was born in China. She received the Master of Engineering degree. She currently works with the Library, Zhejiang University of Technology. She was given the title of medium-grade professional. She is active in the research of bibliometrics.

YUEHUA WAN is currently a Professor with the Zhejiang University of Technology, Hangzhou, China. Until 2019, he was the Director of the Institute of Information Resource, Library, and the Leader with the Science and Technology Innovation Workstations of Education Ministry, Zhejiang University of Technology. He has been a Counselor in multiple institutions, including Thomson Reuters, Elsevier, Scopus, and ProQuest. His current research interests include the areas of robots and bibliometric, especially the applications of bibliometric in various areas.