

Investigation of Innovation Concept in Architecture Using Bibliometric Analysis Method

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Abstract:

Background: Today's architecture is a process in which technology is included in architectural design, preliminary design and analysis processes with various "computer-aided" methods. It is directly affected by contemporary technologies during the formation process of the design product as well as within the scope of examining and analyzing the design product. These methods enable the concepts of "architectural design and analysis" to be reconsidered in the context of "new technologies", which constitute the first step of the concept of innovation and offer designers and theorists different perspectives.

Materials and Methods: In this study, "Scopus", which provides access to comprehensive and multiple databases for many different academic disciplines, was determined as the sampling field. The bibliometric mapping method, which is an important research subject in the field of bibliometry, in which statistical methods are used to quantitatively analyze the books, articles, and other publications published in a particular field in the process of researching the spread and uses of the concept of innovation in the specified sample area. In the visualization of bibliometric networks belonging to the data obtained; the "VOSviewer" software tool was used.

Results: As a result of the bibliometric analysis of the 2691 publications obtained, it is seen that there has been a significant increase in the number of innovation-specific researches in architecture and related fields, especially in the last 20 years. With this research, the most active countries in this field are respectively United States, China, and the United Kingdom. The most prolific authors are Li Y., Liu X., Liu Y., and Zhang J. Looking at the average number of citations per publication (Table 5), it is seen that Henfridsson O., Pande P. P., and Wang B.

Conclusion: In today's world where computers and information technologies continue to develop rapidly, with this study, the research and development dimension (developments in materials, building technologies, and construction techniques), the design dimension (design process - production, design education, and trends in evolution) and investment dimension (changes in organizational structure) It is seen that the contribution of innovation to contemporary design plays a key role.

Key Word: Innovation; Architecture; Bibliometric analysis; VOS viewer.

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I. INTRODUCTION

From the first periods of humanity to the present; the behaviour of curiosity is the basis of many innovations that are found, discovered, or invented by providing intelligence. Thus, the curiosity that leads people to research, to obtain new information and to discover new fields; forming the basis of today's technologies; It has been the trigger of numerous innovations that can be given as an example for innovation, from writing to printing, from steam engine to computer and internet. According to Fagerberg, this is an indication that innovation is not a new phenomenon, but as old as the human species itself¹.

Innovation, which is shown as the equivalent of taking new actions, is a concept that shapes today's world and carries many meanings together. In general, innovation, which is defined as creating more effective processes, products and ideas, aims to contribute to our knowledge by adding value to established norms or sustaining value^{2,3}.

Especially nowadays;

- a rapidly growing population,
- increased consumption,
- a world with limited resources,
- greenhouse gas emissions and carbon emissions associated with climate change,
- emerging competitiveness for globalization and industry efficiency
- increasing urbanization in both developed and underdeveloped countries,

Reasons such as the above, necessitate a much higher level of innovation (in products and processes) than the characteristics of the previous century, to make the built environment more sustainable. In this context, the necessity of innovation forces architectural practice to change in order to overcome the difficulties encountered in the built environment, as in many disciplines.

Accordingly, within the research, which concepts and fields of study are related to the concept of innovation in architectural practice was questioned. In answering this question, which includes large-scale research, "Scopus", which provides access to multiple databases for many different academic disciplines, was determined as the sampling area. The bibliometric analysis method, which allows the evaluation of scientific studies, was used to investigate the spread and uses of the concept of innovation. Relatedly, "VOSviewer" software tool was used to create and visualize network diagrams based on bibliometric data. The results show us that the publications on the concept of innovation in architecture and related fields have increased significantly after the 2000s. Among these publications, it is seen that studies on sustainability, design, technological innovation, energy efficiency, artificial intelligence, building information modelling and education are at the forefront.

In this context, the continuation of the study was organized in 6 sections. Theoretical framework in chapter 2, material and method in chapter 3, findings in the section 4, discussion in chapter 5, and results are given in chapter 6.

II. BACKGROUND

Innovation is a process that leads to change in a product, service, organization, industry sector or region as a result of transforming new ideas into something valuable and can be defined in three aspects (Figure 1):

1. Knowledge production; It is the generation or adaptation of new knowledge, ideas and concepts.
2. Knowledge application; it is the deployment of ideas in a real-world context.
3. Dissemination and absorption of information; It is the adoption and adaptation of knowledge by an individual or organization to provide new alternatives for problem-solving and creating new or large markets⁴.

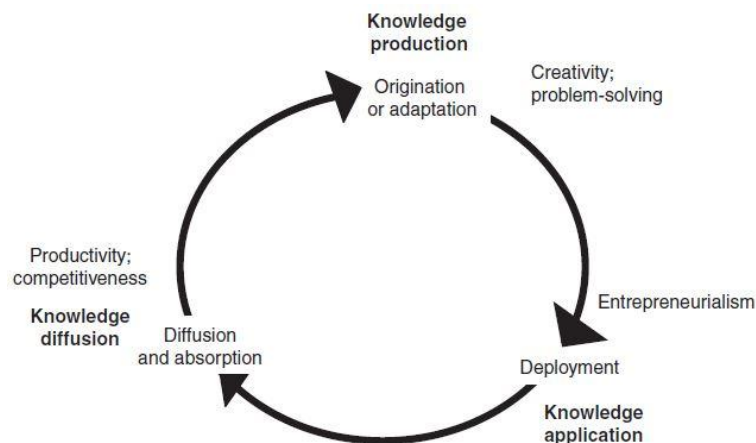


Figure 1: The innovation cycle⁴.

According to Schumpeter, who is known as the founder of the theory, the concept of innovation, which was first used in the field of economics in 1911; it is the use of new combinations of existing productive forces to solve the problems of the business world as the economic effect of technological change⁵.

In this study, it is questioned how the concept of innovation, which was developed in different sciences such as economy, social psychology, technology and management, is handled in architecture with the effect of developing technology. It is structured on the understanding that architecture is shaped by "new concepts" that we encounter today, rather than the facts that existed in the past.

Although "innovation" has become much more popular in the last two decades, it is not a new concept in architecture. In the name of innovation, there are numerous examples throughout the history of architecture where new ideas, design methods, materials and construction processes have been introduced that result in new building typologies, design and construction methods:

- The Romans found concrete and dominated the use of arches significantly influenced the monumental buildings and future architectural styles and forms.

- Innovative methods such as arches, ribbed vaults and buttresses were used to cross wide openings with stone and build high-rise buildings. This situation caused the innovations in structural form to develop the Gothic Architecture style.
- The invention of reinforced concrete in the late 19th century revolutionized architectural design and engineering. Also, developments in vertical transportation with the invention of steel frames and elevators in this period led to the development of high-rise buildings.
- Especially the second half of the 20th century has led to unprecedented developments in calculation methods, materials, building technologies and systems, manufacturing methods and mass production and construction processes for design².

However, it can be argued that today, the building industry is slower to adopt or develop new ideas compared to other manufacturing industries (such as air, land and sea transportation industries)⁶. Brookes and Poole associated this with the unwillingness of architects to use a new technique, method or material, often until evidence to support their success are found. Because architects are often asked to work according to rigorous schedules, and this situation forces them to manage the process with a traditional material or construction method, based on solutions that have been tried and tested according to experience and knowledge, without allowing an innovative method to be researched⁶. At this point, Brookes and Poole draw attention to a critical issue behind innovation talent. This is the current capacity at the point of design, prototype and testing, and the product or construction method obtained at the end of a process designed according to such an understanding can be trusted.

Today's architecture is a process in which technology is included in architectural design, preliminary design and analysis processes with various "computer-aided" methods. It is directly affected by contemporary technologies during the formation process of the design product as well as within the scope of examining and analyzing the design product. These methods enable the concepts of "architectural design and analysis" to be reconsidered in the context of "new technologies", which constitute the first step of the concept of innovation and offer designers and theorists different perspectives.

III. MATERIAL AND METHODS

There are different classifications related to the types of innovation in architecture, engineering and construction research. While Male and Stocks talked about four different types of innovation as technological, organizational, product and process, Wells defined the model of 6P's in which six types of innovation are distinguished in architecture^{7,8}. These; "Procedural Innovation, Process Innovation, People Innovation, Program Innovation, Price Innovation, and Product Innovation"⁸. Aksamija, on the other hand, defines 3 types of innovation: product innovation that includes the building, physical space or object, service innovation, which includes the way of interaction with customers, founding elements and building residents, and process innovation that expresses the design process². In this study where notions and fields of study are related to the concept of innovation in terms of architectural practice is researched, innovation in the field of architecture is classified under 3 titles as research and development dimension, education and design dimension and construction management dimension.

In the research, bibliometric mapping method, which is an important research subject in the field of bibliometry, which uses statistical methods to quantitatively analyze books, articles and other publications published in a particular field. With this method, how disciplines, fields, areas of expertise and individual documents or authors relate to each other can be represented^{9,10,11}. Generally, a bibliometric mapping analysis includes different stages of the overall workflow such as data acquisition, preprocessing, network extraction, normalization, mapping, analysis and visualization. At the point of obtaining the data, different bibliometric sources such as ISI Web of Science (WoS), Google Scholar or Scopus are used¹². Within the scope of the study, the fact that it provides the researcher with considerable convenience in obtaining the data and providing rich content has been effective in the selection of "Scopus" in the study.

Visualization of the bibliometric networks of the obtained data is generally created through the networks of quoting, co-citation, bibliographic matching, keyword, coauthoring. At this point, specially developed software tools are used to analyze scientific fields through bibliometric mapping. Visualizations made with these tools are structured on three generally accepted basic visualization approaches: distance-based, graph-based and timeline-based approaches¹⁰. Current software tools used for this purpose are given in Table 1. The VOSViewer software tool was used for the visualization of the data in the study, due to its widespread use, ease of learning and efficiency of use.

Table no 1: Software tools used in scientific field analysis (Adapted from Cobo et al.)¹².

Software tool	Last version	Year	Developed by	Accessibility
Bibexcel	2011-10-12	2017	University of Umeå (Sweden)	freely accessible
CiteSpace II	5.3.R10	2019	Drexel University (USA)	freely accessible
CoPalRed	1.0 beta	2005	University of Granada (Spain)	
IN-SPIRE	5.9	2011	Pacific Northwest National Laboratory	
Leydesdorff's Software	N/A	N/A	University of Amsterdam (The Netherlands)	freely accessible
Network Workbench Tool	1.1.0 beta 5	2009	Indiana University (USA)	freely accessible
Sci2 Tool	v1.1 beta	2013	Indiana University (USA)	freely accessible
VantagePoint	13.1	2020	Search Technology, Inc.	
VOSViewer	1.6.16	2020	Leiden University (The Netherlands)	freely accessible

In this direction, the study was carried out in 3 stages as;

- Obtaining files in "CSV excel" format to be used in the software tool by scanning the concept of "innovation in architecture" in the "Scopus" database,
- Creating network maps containing the distribution-densities of the keywords, authors and countries related to innovation by using the "CSV excel" file obtained through "Scopus" and the "VOSviewer" program,
- Determining the current situation by analyzing the obtained maps.

IV. RESULT

The concept of "innovation in architecture" was written in the subject section of the "Scopus" database. While making the category limitation, "engineering" and "materials science" categories were selected, which can be associated with architecture due to the absence of the architecture category. Publication type is limited to Conference Paper (1730), Article (788), Review (88), Book Chapter (58), and Book (27). As a result of the screening, 2691 publications were reached. The bibliometric analysis data made over the obtained publications are given in figures 2, 3, 4, 5,6, and tables 2, 3, 4, and 5.

Featured concepts

The information obtained at this stage of the study shows which concepts and fields of study are related to the concept of innovation in architectural practice. Accordingly, in Figure 2, the visualization of the data obtained as a result of the bibliometric analysis through the Vosviewer software, and in Table 2, the first 50 keywords that stand out among 192 keywords obtained from the selected sample area are expressed.

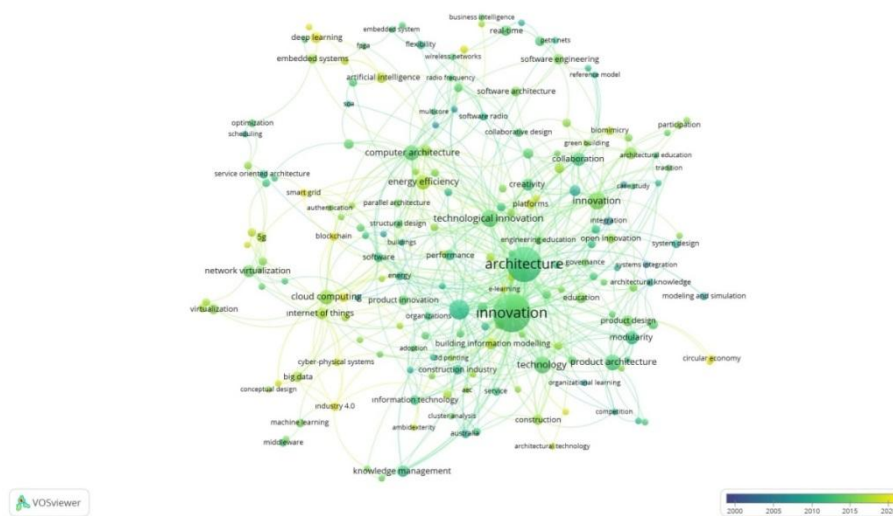


Figure 2: Keywords and dispersion by years.

Table no 2: Top 50 keywords in innovation research in Scopus database.

	keyword	occurrences	total link strength
1	sustainability	28	34
2	design	25	42
3	technological innovation	18	28
4	technology	18	29
5	product architecture	16	19
6	energy efficiency	14	16
7	sustainable development	10	8
8	artificial intelligence	8	6
9	building information modelling	8	12
10	education	8	9
11	product design	8	13
12	construction	7	15
13	performance	7	7
14	virtualization	7	4
15	architectural design	6	3
16	architectural innovation	6	8
17	environment	6	14
18	product innovation	6	7
19	information technology	6	8
20	cloud manufacturing	5	4
21	energy	5	8
22	project management	5	7
23	structural design	5	4
24	teaching innovation	5	7
25	innovative design	5	5
26	integration	5	4
27	architectural knowledge	4	5
28	biomimetics	4	4
29	decision making	4	9
30	evolution	4	5
31	knowledge	4	6
32	management	4	6
33	modeling and simulation	4	2
34	optimization	4	3
35	prefabrication	4	11
36	sensors	4	5
37	urban design	4	6
38	urban planning	4	6
39	virtual reality	4	5
40	innovation diffusion	4	7
41	3d printing	3	6
42	application	3	2
43	architectural education	3	4
44	architectural technology	3	2
45	automation	3	4
46	building information modeling	3	6
47	buildings	3	7
48	competition	3	7
49	computer aided design	3	7
50	conceptual design	3	1

When the keywords obtained within the scope of the study are examined, 68 keywords are classified under the titles determined as research and development dimension, education and design dimension, and construction management dimension and given in Table 3.

Table no 3: Classification of the obtained keywords under the headings determined within the scope of the study.

Keywords Grouped Under Specified Titles		
Dimension of Research and Development	Dimension of Education and Design	Dimension of Production Management
architectural knowledge	architectural design	construction
architectural technology	architectural education	cloud manufacturing
artificial intelligence	architectural innovation	competition
automation	application	information management
conservation	biomimetics	information sharing
energy	building information modelling	innovation management
energy efficiency	computer aided design	innovation strategy
green building	conceptual design	management
integration	decision making	project management
knowledge	design	product lifecycle management
performance	education	risk
prefabrication	environmental design	risk management
product architecture	evolution	smart cities
product design	genetic algorithm	sustainable development
product development	high performance computing	systems integration
product innovation	information technology	
renewable energy	innovative design	
sensors	landscape architecture	
sustainability	modeling and simulation	
sustainable architecture	optimization	
technology	performance evaluation	
technological innovation	robots	
urban sustainability	simulation	
	structural design	
	teaching innovation	
	urban design	
	urban planning	
	virtualization	
	virtual reality	
	3d printing	

Most influential countries

To find the most effective countries in the studies related to innovation in the field of architecture, it has been analyzed based on the data including the number of publications in the relevant literature and the total citations received, and it is expressed in Figure 3 as a network diagram. As a result of the analysis, the top 30 countries that stand out are given in Table 3. Specifically, the top countries are the United States, China, and the United Kingdom respectively.

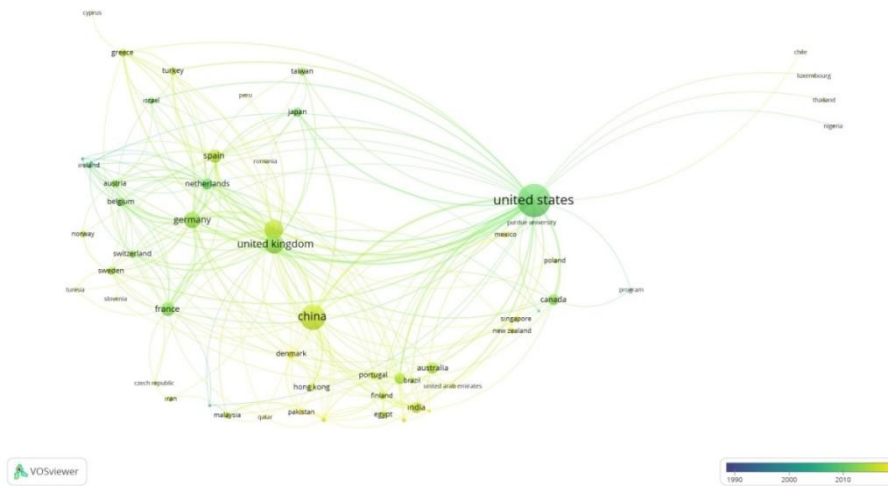


Figure 3: Publication density of countries and its dispersion by years.

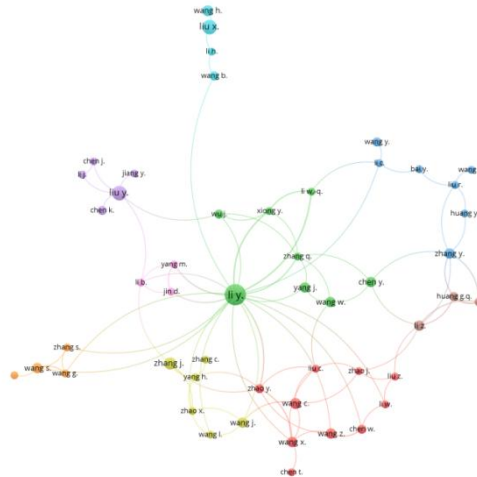
Table no 3: 30 most influential country in innovation research in Scopus.

	country	documents	citations	total link strength
1	United States	297	12100	152
2	China	175	1821	59
3	United Kingdom	101	2254	97
4	Italy	98	1027	60
5	Germany	75	2022	84
6	France	55	836	34
7	Spain	49	889	38
8	Australia	37	1409	15
9	Canada	34	358	29
10	Netherlands	34	697	32
11	South Korea	34	1552	23
12	India	33	342	26
13	Japan	23	302	18
14	Belgium	21	229	26
15	Austria	19	463	22
16	Sweden	19	1454	22
17	Greece	18	400	27
18	Taiwan	17	401	7
19	Denmark	16	286	16
20	Egypt	16	161	10
21	Turkey	16	136	13
22	Hong Kong	15	301	12
23	Portugal	14	183	16
24	Switzerland	14	453	22
25	Finland	12	195	11
26	Malaysia	12	179	9
27	Norway	12	1179	4
28	Israel	12	339	13
29	Singapore	11	247	11
30	Mexico	9	162	15

The most influential scientists

When conducting a bibliometric analysis in a particular field, the evaluation of research performance at the level of individual scientists is significant mainly for two different reasons. (1) A satisfactory number of publications is required to reach statistically reliable performance criteria, and (2) the evaluation of the relationship between research productivity and the number of citations to quantify performance¹³.

In this context, the authors who have at least three publications in the sample area determined are shown in Figure 4. In Table 4, the 30 most influential writers in the field are stated. The most prolific authors are Li Y., Liu X., Liu Y., and Zhang J. Looking at the average number of citations per publication (Table 5), it is seen that Henfridsson O., Pande P. P., and Wang B.



VOSviewer

Figure 4: Authors who have at least 3 publications in the sampling field.

Table no 4: In the Scopus database, the first 30 authors that stand out in innovation research in terms of number of publications.

	author	documents	citations	total link strength	average number of citations
1	Li Y.	22	320	46	14,55
2	Liu X.	10	262	14	26,20
3	Liu Y.	10	115	19	11,50
4	Zhang J.	7	10	8	1,43
5	Wang C.	6	148	10	24,67
6	Wang H.	6	55	7	9,17
7	Chen Y.	5	142	7	28,40
8	Li Z.	5	94	15	18,80
9	Panuwatwanich K.	5	121	9	24,20
10	Stewart R.A.	5	121	9	24,20
11	Wang J.	5	2	7	0,40
12	Wang S.	5	107	10	21,40
13	Wang W.	5	44	5	8,80
14	Wang X.	5	49	8	9,80
15	Wang Z.	5	22	7	4,40
16	Yang J.	5	11	6	2,20
17	Zhang Y.	5	136	10	27,20
18	Chen K.	4	10	2	2,50
19	Chen W.	4	8	7	2
20	Guy S.	4	116	2	29
21	Huang G.Q.	4	196	14	49
22	Mohamed S.	4	101	8	25,25
23	Gu T.	4	196	14	49
24	Wang B.	4	1091	3	272,75
25	Wang Y.	4	37	5	9,25
26	Wu J.	4	12	7	3
27	Zhao Y.	4	22	9	5,50

28	Bai Y.	3	14	5	4,67
29	Bernard A.	3	13	2	4,34
30	Booch G.	3	4	0	1,34

Table no 5: In the Scopus database, the first 30 authors who stand out in innovation research in terms of average number of citations.

	author	documents	citations	total link strength	average number of citations
1	Henfridsson O.	2	869	0	434,5
2	Pande P.P.	2	566	1	283
3	Wang B.	4	1091	3	272,75
4	Smith J.E.	2	492	0	246
5	Gu N.	2	406	1	203
6	Wu D.	2	348	2	174
7	Wang L.	3	348	4	116
8	Zeng L.	2	232	8	116
9	Gassmann O.	2	216	0	108
10	Akyildiz I.F.	2	211	4	105,5
11	Lin S.-C.	2	211	4	105,5
12	Wu X.	2	204	5	102
13	Sun J.	2	191	1	95,5
14	Teuscher C.	2	190	1	95
15	Yang Y.	2	181	3	90,5
16	Wu Z.	2	174	2	87
17	Havinga P.J.M.	2	161	4	80,5
18	Mizuno M.	2	161	4	80,5
19	Wu G.	2	161	4	80,5
20	Wang P.	3	237	7	79
21	Kaloxylas A.	2	156	0	78
22	Yang M.	3	212	13	70,66667
23	Jin D.	3	209	8	69,66667
24	Yoon J.	2	125	2	62,5
25	Kim K.	3	170	3	56,66667
26	Boersma M.	2	108	8	54
27	Brown M.D.	2	108	8	54
28	Huang G.Q.	4	196	14	49
29	Qu T.	4	196	14	49
30	Hrusecky D.	2	98	12	49

V. DISCUSSION

The general purpose of this study is to show which concepts and fields of study are related to the concept of innovation in architectural practice with a bibliometric analysis method. With the bibliometric analysis method, the publications containing the concept of innovation in the "Scopus" database, providing comprehensive and access to multiple databases for many different academic disciplines, have been examined. Thus, the most productive and most cited authors were identified in this study, in which the density of studies conducted by years and countries was investigated.

The graphic of the years of 2691 publications included in the analysis is given in Figure 5. The first publication was made in 1974, but there was no significant increase in the number of publications until the 1990s. It is seen that the graph of the number of publications has increased gradually until 2012. Although it has displayed a relatively with ups and downs graphic since 2012, it was determined that the highest number of publications was reached with 227 publications in 2019.

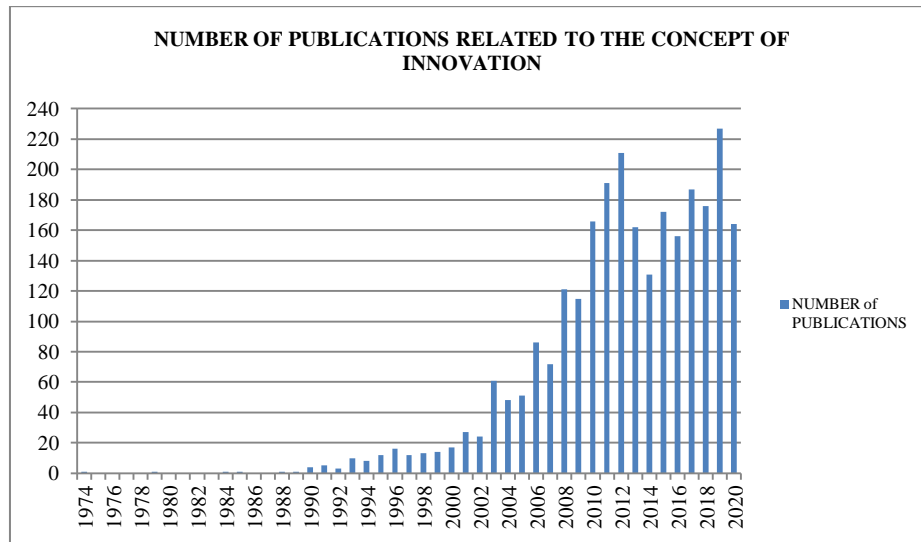


Figure 5: Dispersion of publications by years.

In the analysis of the most influential countries, when the number of publications in the sample field is considered; It is understood that American-based studies have made significant contributions to the field. It is seen that United States (297), China (175), and United Kingdom (101) take place in the first three places (Figure 6), respectively.

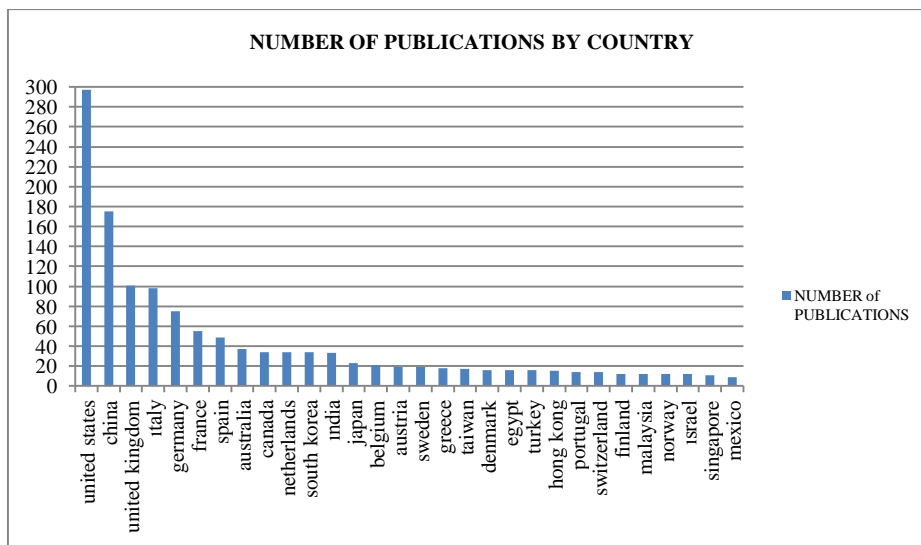


Figure 6: Total publication numbers of countries.

In the analysis of the most effective authors, total citations, and total number of publications based on the data obtained from Scopus in the context of architecture and innovation; Li Y., Liu X., Liu Y., and Zhang J. are the top three in the ranking of publications. However, considering the average number of citations per publication; Henfridsson O., Pande P. P., and Wang B. stand out as other outstanding writers in this field.

VI. CONCLUSION

In today's world where computers and information technologies continue to develop rapidly, with this study, the research and development dimension (developments in materials, building technologies, and construction techniques), the design dimension (design process - production, design education, and trends in evolution) and investment dimension (changes in organizational structure) It is seen that the contribution of innovation to contemporary design plays a key role.

So much so that the demand for continuous progress, development, and innovation is a quest that affects our design style. At this point, innovation in architectural design requires the application of new design strategies and new project delivery methods. In this process, it is observed that digital technologies are included in the design process in various aspects. These;

(1) improvement through form-finding, facade optimization, digital fabrication, material assembly, and cost optimization;

(2) sustainability using building performance simulation tools to assess energy efficiency, daylight, wind analysis, and climate impact on architectural forms;

(3) structural conceptualization with finite element analysis to investigate structural behavior and stability;

(4) productivity is improved to save time and cost.

On the other hand, changing market and economic conditions determine the development and opportunities in the building industry, but only entrepreneur companies can respond to these changes and realize their applications. At this point, the search for innovation in architectural design; While helping architectural firms to adapt to changing market conditions and internal dynamics, it improves design processes by encouraging creative thinking thanks to its structure that affects productivity and business performance.

Beyond economic and competitive advantages, the pursuit of innovation in architectural design plays a significant role in increasing social welfare by contributing to the built environment becoming more sensitive to the planet and its inhabitants.

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