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BIBLIOMETRIC STUDY OF THE COOPERATION IN THE ENGINEERING AND SCIENTIFIC PUBLICATIONS RELATED TO FURNITURE DESIGN

This paper provides an overview of scientific and patent publications in furniture design and their connections from 1972-2020. The scientific publications were searched in the Scopus database, while the number of patent documents available in The Lens database was an indicator of the innovations in furniture. 1,465 scientific publications and 2,880,188 patent documents were identified. The results show that: authors from China and the USA published the largest number of scientific works, authors from the USA are the most often cited, there are 15 outstanding institutions from which the authors of the largest number of analyzed articles come, i.a.: University of Zagreb (Croatia), Poznań University of Life Sciences (Poland), Central South University of Forestry & Technology (China), Wood Technology Institute (Poland), Delft University of Technology (Netherlands) and others. The analysis of co-authorship shows cooperation in four groups of countries: (1) Brazil-Netherlands-Portugal, (2) the United States and a wide group of cooperating countries, (3) China-UK-Japan, and (4) Croatia-Poland-Turkey. The annual number of scientific publications and patent documents are strongly correlated. The increase in the number of scientific publications is much more than the increase in the number of patent documents. The statistical Granger causality test does not predict the patent documents' annual number trend by the scientific

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publications time series. The results presented in this article may facilitate scientific cooperation in "furniture design" showing leading authors and institutions.

Keywords: furniture, furniture design, patents, bibliometric analysis, Scopus, VOSviewer, The Lens

Introduction

The purpose of every engineering design is to develop "executive" information about an object or process that will meet the user's requirements, manufacturer, and legal regulations [Pahl and Beitz 1977]. Pieces of furniture are movable objects to satisfy various human needs such as seating and sleeping, eating, work, storage, recovery and many others. Besides strictly functional requirements, they also meet aesthetic needs [Eckelman 1978]. Due to the diversity of human needs met by furniture, state of art in engineering furniture design extends to all scientific fields. For example, articles on furniture design in the Scopus classification system can be found in all four subject areas (Physical Sciences, Health Sciences, Social Sciences and Life Sciences). The subject of research was the quantitative state of the art on selected aspects in furniture design, Abu et al. [2021], based on the bibliometric analysis of 2879 articles, stated that the lean manufacturing methodology has not yet been widely accepted in the furniture industry. Ansari et al. [2021], based on 483 articles, described the intensity of the increasing knowledge about anthropometric measurements in the application for furniture design. Both articles provide information on the dynamics of knowledge growth in selected subject areas. However, they do not comprehensively cover all the furniture design literature.

This paper provides a broad overview of furniture design in scientific and patent literature. Diffusion of knowledge in all the science subject areas in the scientific literature justifies four very general research questions: what does the broad "quantitative" state of knowledge about engineering furniture design? What is the collaboration between research centers around the world? What is the growth rate of furniture design literature? Is there an interaction between two large areas of technical literature: scientific literature and patent literature?

Research methodology

Scientific publications indexed in the Scopus database were retrieved on January 5, 2021. A two-level search was performed: (1) documents with a combination of "furniture" and "design" in the "Keywords" section were found, (2) and then the results were narrowed down by eliminating the areas of medicine and nursing from the analysis. In addition, the types of documents searched for were limited

to Article, Conference Paper, Review, Book Chapter, Book, Report; so the following types of publications were excluded: Note, Short Survey, Letter, Editorial. After the first search was performed, 4,870 documents were identified, while after the described narrowing of the search area, 1,468 documents from the years 1972-2020 were identified and were subject to detailed analysis. The Scopus database query had the following structure and content:

(KEY (furniture) AND KEY (design)) AND (EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "ed")) AND (EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "NURS"))

The bibliometric information of the analyzed collection of publications (e.g., authors, title, year of publication, number of citations, affiliations, and correspondence address) was exported as a CSV format for further analysis. Informed consent to process the information from the authors of the articles was not necessary as the data was collected as secondary data (without personal data).

Patent documents indexed in the Patent Lens database were obtained on January 30, 2021. We searched for patents filed from January 1, 1972, to December 31, 2020, containing the word "furniture" in "TAC" (Title, Abstract, Claims) and at the same time classified in The International Patent Classification (IPC) in class A47 (furniture; domestic articles or appliances). The Patent Lens database query had the following structure and content:

(Title: furniture OR (Abstract: furniture OR Claims: furniture)) OR IPCR Classifications: A47* Filters: Publication Date = (1972-01-01 – 2020-12-31) Group by Simple Families.

Microsoft Excel was used for statistical calculations and data visualization, while VOSviewer 1.6.16 was used to visualize the relationships between the analyzed data.

Results and analysis

As a result of the bibliometric query in Scopus, 1,465 scientific publications were identified, the oldest of which was from 1972 entitled "Design and Uses of Plastics Joints and Metal-Plastics Composite Structural Members - 2" [Matern and Wieland 1972]. As a result of a query in Patent Lens, 2,880,188 patent documents were identified. These documents were searched from 128,787,496 records from over 95 different word patent jurisdictions. The time series of document numbers for each year are summarized in Fig. 1.

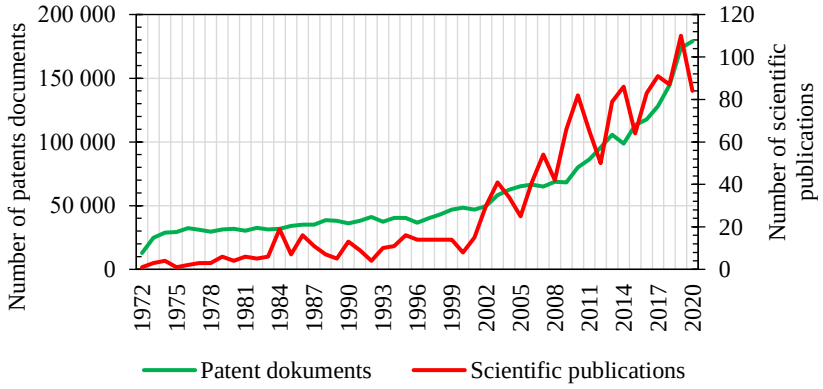

Fig. 1. Time-series: the annual number of furniture scientific publications and the annual number of furniture patent documents (1972-2020)

A strong correlation was found between the number of scientific publications and patent documents ($r = 0.93,\ t = 16.8,\ p = 0.000$). The two-time series presented in Fig. 1 differ in terms of values and dynamics, therefore the Annual Growth Rate (AGR) was calculated for each of these [Tsay 2008]:

$$AGR_i = \frac{N_i - N_{i-1}}{N_{i-1}} \cdot 100\%$$

The AGRs are shown in Fig. 2.

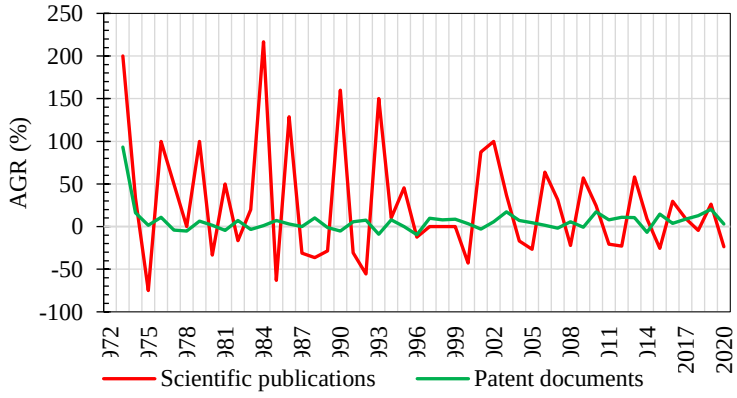

Fig. 2. Annual Growth Rate (AGR) for number of scientific publications and patent documents

The AGR for the number of scientific publications was initially uneven, and after 2000 it became more even. The largest annual increase in scientific publications was in 1984. AGR for the number of patent documents is relatively unchanged in the analyzed time range.

Exponential trend models were created for the time series representing the number of scientific publications and the number of patents. Exponential trend model for the number of scientific publications ($\hat{y}_t = 0.6318 \cdot 1.0876^t$) has a coefficient of determination $R^2 = 88.75\%$, the significance of structural parameters ($t_{b_0} = 5.04$ and $p = 0.000$; $t_{b_0} = 19.25$ and $p = 0.000$) and low mean errors of these parameters (respectively: 0.1253 and 0.0044). On the other hand, an exponential trend model for the number of patent documents $\hat{y}_t = 9.8891 \cdot 1.0377^t$ has a coefficient of determination $R^2 = 89.22\%$, the significance of structural parameters ($t_{b_0} = 183.4$ and $p = 0.000$; $t_{b_0} = 19.72$ and $p = 0.000$) and low mean errors of these parameters (respectively: 0.0539 and 0.0019).

Based on these models, the average annual rate of change was calculated: $r_g = (b_1 - 1) \cdot 100\%$. It allows assessing the dynamics of the number of scientific publications and the number of patent documents in the analyzed period. In the years 1972-2020, the number of scientific publications increased by 8.76% per year on average, and the number of patent documents – by 3.77% on average per year. Thus, the number of scientific publications grew more than twice as fast as the number of patent documents.

Figure 3 presents a list of the 10 countries where the greatest number of authors of "furniture" scientific publications comes from. The number of citations of these articles in other Scopus-indexed publications is also provided.

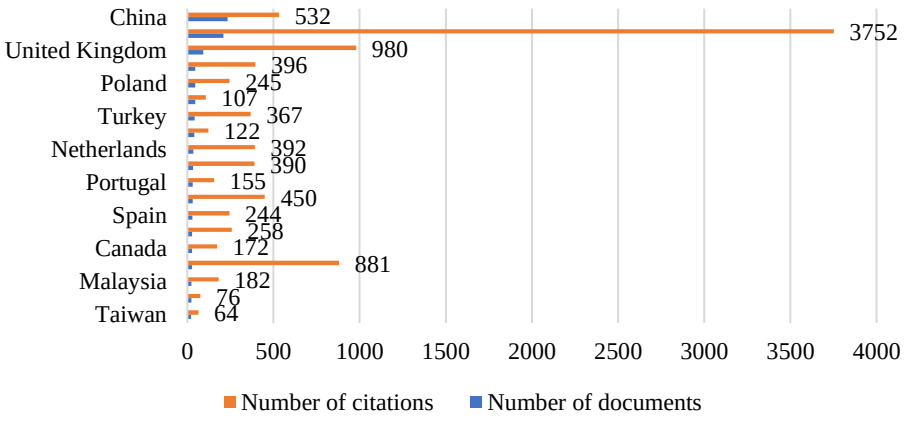

Fig. 3. List of countries with numbers of scientific publications about "furniture design"

As shown in Fig. 3, authors from China and the USA published the greatest number of papers (234 and 210 papers, respectively). Scientific publications of US authors are the most cited (3752 citations, 17.9 citations per document). Authors from Sweden have the greatest number of citations per document (32.6 citations per document).

The authors' teams of many publications were international. Figure 4 shows the cooperative relationship between countries.

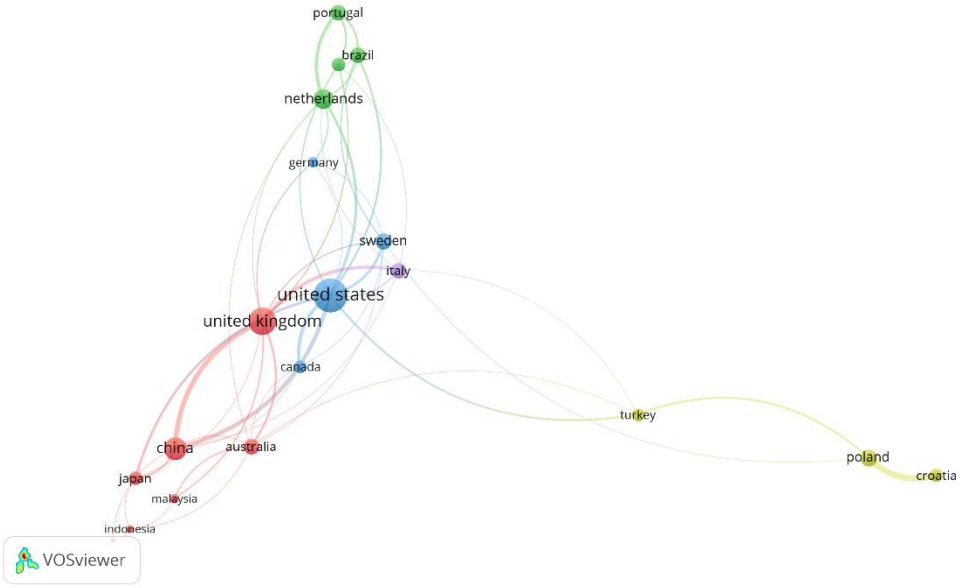

Fig. 4. Map of cooperation at scientific publications (the size of the circle indicates the total number of connections with other countries, the thickness of the connecting lines indicates the number of connections; the groups of cooperating countries are marked with colors)

Figure 4 shows cooperation in four groups. The following groups of countries can be identified: (1) Brazil-Netherlands-Portugal, (2) the United States and a broad group of cooperating countries, (3) China-UK-Japan, and (4) Croatia-Poland-Turkey. The United States has the largest number of connections with other countries.

Table 1 lists the 15 research centers from which the authors of the largest number of scientific publications come from, with the keywords "furniture" and "design".

Table 1. List of institutions

Institution	Number of Documents	Country
University of Zagreb	45	Croatia
Poznań University of Life Sciences	34	Poland
Central South University of Forestry & Technology	30	China
Wood Technology Institute, Poznań	22	Poland
Delft University of Technology	19	Netherlands
Nanjing Forestry University	19	China
Mendelova univerzita v Brne	14	Czech Republic
Politecnico di Milano	14	Italy
Gazi Üniversitesi	12	Turkey
University of Ljubljana	12	Slovenia
Northeast Forestry University	11	China
Jiangnan University	11	China
Hong Kong Polytechnic University	11	China
Purdue University	11	USA
Mississippi State University	10	USA

The largest number of affiliated institutions with scientific publications in "furniture design" is in China (5 institutions). Based on Table 1, five centers with a particularly large amount of work can be identified: University of Zagreb (Croatia), Poznań University of Life Sciences (Poland), Central South University of Forestry & Technology (China), Wood Technology Institute (Poland), Delft University of Technology (Netherlands).

Table 2 lists the authors who published the most works in "furniture design". Two authors have published over 20 works with the keywords "furniture" and "design" (Domljan D. and Grbac I.). However, the most cited authors are Stapleton H.M., Zhang Y., Molenbroek J.F.M., and Smardzewski J., cited, respectively: 1108, 197, 179 and 126 times. Authors that published the most papers were not the same as most-cited authors. Citation count is a scientific discipline-dependent factor. The total number of papers does not clearly indicate the quality of scientific research. A better indicator is the total number of citations, on the other hand, this indicator can be affected by participation in a single publication of significant influence (for instance, review papers, which can generate a large number of citations). Citation count is also a scientific discipline-dependent factor. In disciplines where many works are published, there are usually many citations. Despite these objections, the total number of citations seems to be a good indicator of author's contribution to a specific area of scientific knowledge.

Table 2. List of authors with a number of documents

Author	Number of documents	Number of citations	Author	Number of documents	Number of citations
Domljan D.	24	46	Guastamacchia F.	7	0
Grbac I.	22	72	Guo Y.	7	9
Smardzewski J.	18	126	Hrovatin J.	7	24
Fabisiak B.	12	15	Lausch G.	7	0
Zhang H.	12	38	Molenbroek J.F.M.	7	179
Zhang Z.	11	7	Stapleton H.M.	7	1108
Xu J.	10	4	Vlaović Z.	7	18
Zhang J.	10	41	Dell'era C.	6	119
Zhang Y.	10	197	Haviarova E.	6	8
Liu W.	9	54	Kłos R.	6	8
Wang Y.	9	25	Li X.	6	8
Prekrat S.	8	32	Liu S.	6	8
Siu K.W.M.	8	27	Ratnasingam J.	6	44
Chen M.	7	6	Verganti R.	6	119
Frova F.	7	0	Vink P.	6	77

Figure 5 shows cooperative links between the 30 authors with the largest number of published documents. The analysis of co-authorship shows the cooperation of two large groups of authors, several smaller (two people). Five of the most cited authors do not regularly collaborate with any of the most cited authors. The thicker the line connecting the circles representing the authors, the more frequent the cooperation between them. The size of the circle after the author's name means the number of co-authoring scientific publications (the more such publications there are, the larger the circle).

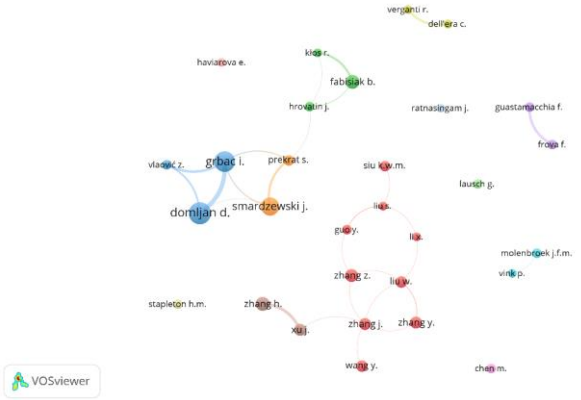

Fig. 5. Links between the authors with the most published documents

Figure 5 shows only two groups of related authors; the Polish-Croatian group has three outstanding leaders (Grbac, Domljan, Smardzewski), while in the Chinese group, the distribution of publication numbers is even.

Table 3 presents a list of scientific journals publishing articles related to furniture design. The largest number of articles of this type was published in Applied Ergonomics, Architectural Record, and Ergonomics. Articles published in the journals Environmental Science and Technology, Applied Ergonomics, and Ergonomics were the most cited.

Table 3. List of journals

Journal	Number of Documents	Number of Citations
Applied Ergonomics	60	1056
Architectural Record	49	4
Ergonomics	44	1025
Advanced Materials Research	38	18
Applied Mechanics and Materials	33	15
Advances In Intelligent Systems And Computing	29	15
Dentistry Today	24	4
Lecture Notes In Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	23	134
Drvna Industrija	22	85
Upholstery Design and Management	22	0
Behavioral Healthcare	18	0
Iop Conference Series: Materials Science and Engineering	14	9
Journal of Design History	14	71
Bioresources	12	98
Environmental Science and Technology	11	1585
Perceptual and Motor Skills	11	133
ACM International Conference Proceeding Series	9	33
Communications in Computer and Information Science	9	1
Dental Cadmos	9	1
Forest Products Journal	9	87
Human Factors	9	86
Journal of the Acoustical Society of America	9	99
ACM Transactions on Graphics	8	393
Conference on Human Factors in Computing Systems Proceedings	8	221

Figure 6 shows the relationships between the keywords, taking into account the years of their occurrence. The thickness of the links shows the strength of the interaction between the individual keywords. The keyword "Furniture" is most strongly associated with "interior design and furnishings", and these two (partially synonymous) terms are most closely associated with "human", "male" and "female".

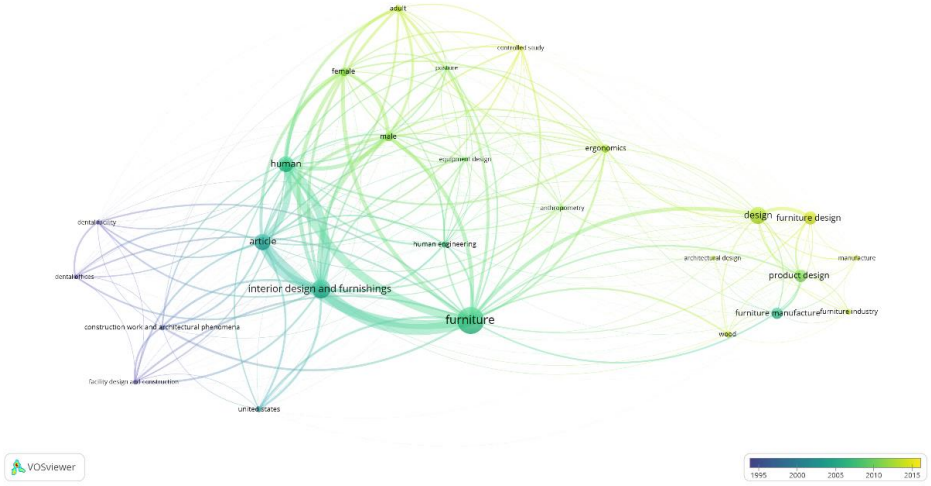

Fig. 6. Relationships between keywords, including years

When analyzing the annual numbers of scientific publications (Fig. 1), it can be noticed that their number has rapidly increased after 2000. However, the number of furniture patents increased around 2002 and was noticeable in 2009. It is visible in Fig. 7 which shows comparative annual percentage increments in the number of scientific publications and the number of patents.

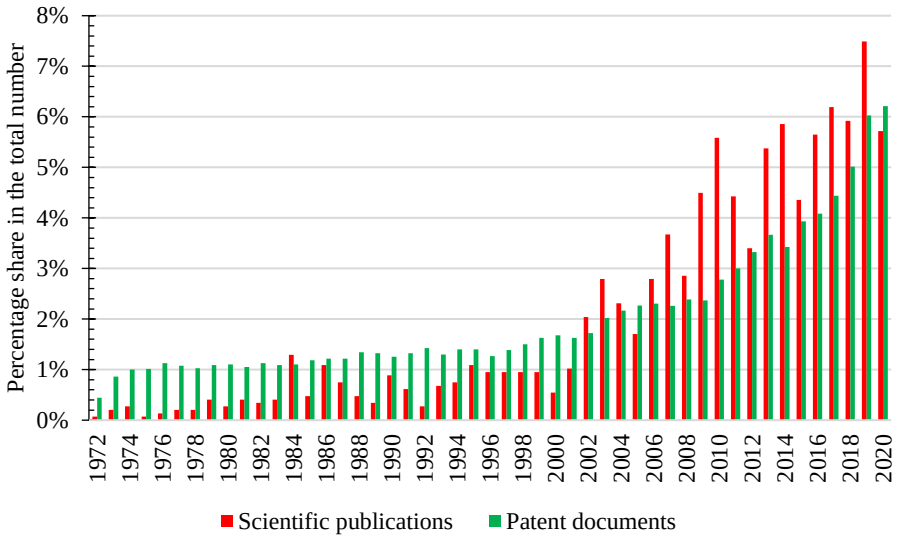

Fig. 7. Percentage shares of the total number: scientific publications and patent documents

The sharp increase in the number of scientific publications (X) around 2000 resulted in an increase in the number of patents after 2002 (Y) (X causes Y). Therefore, this was checked with the Granger test, which allows checking whether the previous values of the X variables explain part of the variation observed in the Y variable. The configuration of the performed Granger test is shown in the equation:

$$Y_t = \propto_0 + \propto_1 Y_{t-1} + \propto_2 Y_{t-2} + \cdots + \propto_j Y_{t-j} + \beta_1 X_{t-1} + \beta_1 X_{t-2} + \cdots + \beta_j X_{t-j} + u_t$$

Null hypothesis (H_0): changes in the annual numbers of scientific publications (X) do not cause, in the Granger sense, changes in the annual numbers of patents (Y) $H_0: \beta_1 = \beta_2 = \cdots = \beta_j = 0$. While the alternative hypothesis: $H_1: \beta_j \neq 0$, for at least one value of j. To test the null hypothesis, two models were estimated:

(1) A limited model that ignores past values X: $Y_t = \propto_0 + \propto_1 Y_{t-1} + \propto_2 Y_{t-2} + \cdots + \propto_j Y_{t-j} + \varepsilon_t$,

(2) An unlimited model: $Y_t = \propto_0 + \propto_1 Y_{t-1} + \propto_2 Y_{t-2} + \cdots + \propto_j Y_{t-j} + \beta_1 X_{t-1} + \beta_1 X_{t-2} + \cdots + \beta_j X_{t-j} + u_t$

A *F* test was performed to check Granger causality, which compares the sum of the squared errors from the limited model (SSE_r) to the sum of squared errors of the unlimited model (SSE_u). If SSE_u is statistically different from SSE_r, then ignoring past X values is not statistically significant. The formula gives the *F* statistic:

$$F = \frac{(SSE_r - SSE_u)/m}{SSE_u/(n-k)}$$

where m – number of constraints, in this case, the number of past X values that were omitted from the unrestricted regression; n – number of observations in the historical sample; k – the total number of parameters estimated in the unlimited model (including the constant).

Having already got the F statistic, it was compared to the critical value to see if the null hypothesis could be rejected (H_0: X Granger does not cause Y). This procedure was performed for both time series to verify that X → Y (does X Granger Cause Y?) and Y → X (does Y Granger Cause X?). After these tests were performed, it was verified:

1) Granger's one-way causality X → Y (and not Y → X),
2) Granger's one-way causality Y → X (and not X → Y),
3) Granger's two-way causality X → Y and Y → X,
4) There is no Granger causality.

The first statistical test was to check whether the number of scientific publications (X) causes changes in the number of patients between 1972 and 2020 (Y). The test was carried out with two periodic delays. The regression was estimated, and the SS_u values were calculated (LINEST, MS Excel functions were used). The results are presented in Table 4 (the value in bold is the sum of squared errors in the unlimited model).

Table 4. Regression analysis in the unlimited model

	A	B	C	D	E
1	192.089885	8.024883	0.299447	0.221568	1626.289
2	85.1409196	83.10077	0.184756	0.142993	1024.73
3	0.22290515	5705.7	#N/D	#N/D	#N/D
4	3.15528625	44	#N/D	#N/D	#N/D
5	410881532	**1.43E+09**	#N/D	#N/D	#N/D

The regression was then estimated in a limited model (also using the LINEST function, but now only a range of columns containing patent data have been entered). The result is the value SS_r (Table 5).

Table 5. Regression analysis in the limited model

	A	B	C
1	0.23914965	0.243223	2086.279
2	0.18443983	0.147548	1034.086
3	0.13087729	5901.466	
4	3.46346672	46	
5	241246375	**1.6E+09**	

The F statistic was then computed. The number of observations n = 49, number of parameters estimated in the unlimited model k = 5, number of constraints m = 2. Therefore $F = ((1{,}6E + 0{,}9 - 1.43E + 09)/2)/(1.43E + 09/(49 - 5) = 2.605$. Then the function FDIST (MS Excel) was used to calculate the value of p, using m and $n - k$ as degrees of freedom (in this case FDIST(2.605;2;49-5), that p = 8.25%. The p-value is greater than 1%, so there is no reason to reject the null hypothesis (changes in the annual numbers of scientific publications (X) do not cause, in the Granger sense, changes in the annual numbers of patents (Y), level 99% confidence).

Then the described calculation procedure was repeated the other way round to verify the lack of influence in terms of Granger causality of the annual numbers of patents (Y) on the annual numbers of scientific publications (X). The results are presented in Table 6.

Table 6. Granger causality verification: no impact of annual numbers of patents (Y) on annual numbers of scientific publications (X)

Parameter	Value
SS_u	3663.788
SS_r	3868.218
m	2
k	5
n	49
F-Stat	1.228
p-value	30%

The parameters in Table 6 do not indicate Granger causality Y → X. On this basis, no statistical causality in the Granger sense of the annual number of scientific publications (X) and the annual number of patents (Y) was found. Neither of these time series affects the other.

Summary and conclusions

The analysis of bibliometric query results: (1) gives an overview of all technical literature in "furniture design", including both scientific and patent documents; (2) identifies the network of connections between countries, research centers, and scientists involved in furniture design; (3) compares the dynamics of the increase in the scientific literature on furniture design with the dynamics of the development of state of the art in furniture technology. The publications number in the Scopus database was the indicator of the dynamics in the scientific publications annual number. The indicator of the furniture technology development was the number of furniture patents available in The Lens database.

The bibliometric methods used in the article enable an "umbrella" overview of interdisciplinary issues. It can be concluded that scientists from many research centers representing almost all fields of science dealt with "Furniture design". "Furniture design" in the scientific literature includes, among others: Anthropocentric and Universal Design [Panagiotopoulou et al., 2004], Human-Centered Design [Thomas 2011]; efficient selection of material [Sydor and Wieloch 2009]; research and development of new furniture materials [Madyaratri et al. 2022; Sydor et al. 2022]; design analysis and experiments (strenght furniture design) [Smardzewski, 2015]); application of computer science [Smardzewski 2007], Concurrent Engineering [Culbreth et al. 1996], simulation [Kyle and Ludka 2000], information acquisition directly from the future user of furniture to design and order furniture using Participatory Design, Web-based Configurators, Product-as-a-Service [Demirbilek and Demirkan 2004; Cheatle and Jackson 2015]; economic furniture production in "agile" cyber-physical Industry 4.0 manufacturing systems [Jazdi 2014], Mass Customisation [Yao and Carlson 2003]; the influence of furniture on human material culture and sustainable development (Circular Economy) [Parikka-Alhola 2008].

Interestingly, the results reveal:

1. The analysis of the countries in which the authors of scientific publications affiliate indicate cooperation in groups. The following four groups of countries can be identified: Brazil-Netherlands-Portugal, the United States and a broad group of cooperating countries, China-UK-Japan and Croatia-Poland-Turkey. The United States has the largest number of connections with other countries. On the other hand, the authors affiliated in China show the highest growth dynamics in the number of articles after 2010.
2. The analysis of co-authorship shows the collaboration of two large groups and several smaller; five of the most cited authors do not regularly collaborate with any of the most cited authors.
3. The annual number of scientific publications and the number of patent documents are strongly correlated. The increase in the number of scientific publications is more than twice the increase in the number of patent documents. A statistical Granger causality was not found between these two-time series.

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Conceived and designed the analysis: M.S. Collected the data M.S. and A.K. Contributed data or analysis tools: A.K. Performed the analysis: A.K., M.S., J.L. Wrote the paper: M.S. and A.K. Conclusions: M.S., A.K., N.L. Writing—review, and editing: M.S.

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