

PAPER

Spanish Doctoral Dissertations on the Properties of Materials in Engineering

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ABSTRACT

We present a bibliometric study of engineering doctoral dissertations focusing on the properties of materials. The study exhaustively examines the production of doctoral theses on material properties in the field of engineering at Spanish universities from 1977 to 2022. The main objective is to analyse the volume and temporal distribution of these theses, explore their production by authors and directors considering gender, and identify the most common descriptors in the research. Technological innovation and progress in engineering materials are essential for social welfare, economic competitiveness, and international cooperation, highlighting the significance of these studies. The results reveal a total of 508 valid theses after a meticulous filtering process, with a notable increase in production post-1998, particularly during 2011–2020. The study highlights the limited presence of women in both authorship and direction of these, indicating male dominance in the field. However, there is an increasing trend of female participation in these academic areas. This study offers detailed insights into the trends and composition of doctoral research in materials engineering in Spain, pointing to important gender dynamics and research themes.

KEYWORDS

doctoral dissertations, engineering, properties of materials, bibliometry, gender

1 INTRODUCTION

The development of different engineering disciplines is crucial in contemporary society. This advancement facilitates technological innovation, enhances the production of consumer goods, improves energy efficiency and production, provides access to new materials and technologies, creates new educational and entertainment opportunities, and generates numerous job opportunities [1]. Consequently, technological innovation, driven by technical research, enhances the social welfare of individuals and fosters economic, scientific, technical, and cultural collaboration on a global scale. In essence, technological innovation serves as a bridge connecting nations. Proficiency in new technologies not only grants access to cultural expressions but also

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enhances the competitiveness of various social and cultural contexts. The development of engineering disciplines is vital not only for addressing current challenges but also for anticipating and preparing for future requirements. This field serves as a primary catalyst for innovation and technological advancement, playing a pivotal role in enhancing quality of life, promoting sustainable development, and ensuring the safety and well-being of global populations. Therefore, investing in and promoting engineering education and research is an investment in the future of society.

Moreover, the processes of scientific innovation require the use of various methodological techniques, which are often acquired through doctoral studies. The significance of doctoral dissertations is multifaceted, with a consensus that one of the most crucial aspects is to showcase that new PhDs have attained research competence and can contribute to generating new scientific knowledge [2–3].

On the other hand, doctoral dissertations constitute a source of data that allows us to know different patterns of scientific production in a region, a country, an institution, or a specific scientific field. This is why dissertations are frequently used in bibliometric studies. From the perspective of scientific policy administration, these studies can be relied upon to establish strategies that guide and direct research towards less-investigated subjects or to provide incentives to the groups with the greatest scientific impact [4–6].

At the international level, studies that take doctoral dissertations as the object of study have also been carried out on doctoral dissertations in different branches of engineering. For instance, Sachini [13] analysed 443 chemical engineering dissertations from universities in Greece to determine the professional mobility of their authors after their doctorate. Haque [14] conducted a bibliometric analysis of PhD dissertations in agricultural engineering from 1974 to 2014 at Bangladesh Agricultural University (BAU). Mulla [15] examined the obsolescence of references found in 275 engineering and technology dissertations in the universities of the Karnataka region of India.

All-important properties of solid materials are grouped into six categories: mechanical, electrical, thermal, magnetic, optical, and chemical. It is important to note that the properties of a material are expressed in terms of the type and magnitude of the response to a specific imposed stimulus [19]. The aim of this study is to conduct a bibliometric analysis of doctoral dissertations on material properties in engineering conducted at Spanish universities.

2 METHODOLOGY

Bibliometric studies are a powerful tool for analysing the production and impact of scientific literature, providing valuable information for researchers, academic institutions, publishers, and science policymakers. This is a bibliometric, descriptive, census, and retrospective study. This choice has been made because it does not intend to make inferences beyond the population of theses analysed. The aim is to obtain a perception of production at the level of doctoral dissertations on the properties of materials in engineering without going into the elements or situations that give rise to these results.

To obtain the information, all the websites of Spanish public and private universities were consulted, with the aim of delimiting the various departments related to material properties in the field of engineering. In some cases, these were found to be attached to different departments than Materials Science; among them we can find Optics, Applied Physics, Mathematics, Inorganic Chemistry, and Chemistry-Physics, among others.

To download those carried out in the identified university departments, the TESEO database was consulted; this database is where all the doctoral theses carried out in

Spanish universities are registered. Records have been kept there since 1976. For this study, all records up to the year 2022 have been consulted. The search produced 685 dissertations. All the information was downloaded into an ad hoc database. To verify that all the dissertations are suitable for material properties in engineering, they were manually cleaned by reading titles, descriptors, and abstracts. The researchers of the study, who were experts in engineering research at Cordoba and Salamanca universities, carried out initial readings to ascertain whether these dissertations matched the subject matter. They followed that up with a validation process using triangulation techniques. Their academic reputation and their previous collaboration with the research group on which this study was based have made them that choice.

Once this manual was completed, 508 dissertations were obtained, which comprised the population to be analysed.

Afterwards, variables related to authorship, address, gender of authors, directors, gender of the evaluation committee, university, year of completion of thesis defence, and descriptors were subjected to analysis. The selected variables will enable the identification of trends and areas of doctoral research on material properties at the universities where most research is conducted at the doctoral level on this subject. It will also provide insight into the researchers leading these scientific training processes and the involvement of women in directing and evaluating doctoral theses.

One aspect that required a systematic and manual review was the process of verifying that the names of both the directors and the members of the assessment committees were written consistently. In a few cases, the middle name was omitted or the surname was merged with the first name in compound names. In some cases, some of the members of the assessment committees have belonged to different universities throughout the period; in these cases, the institutional affiliation of the date of reading of the thesis has been considered (see Figure 1).

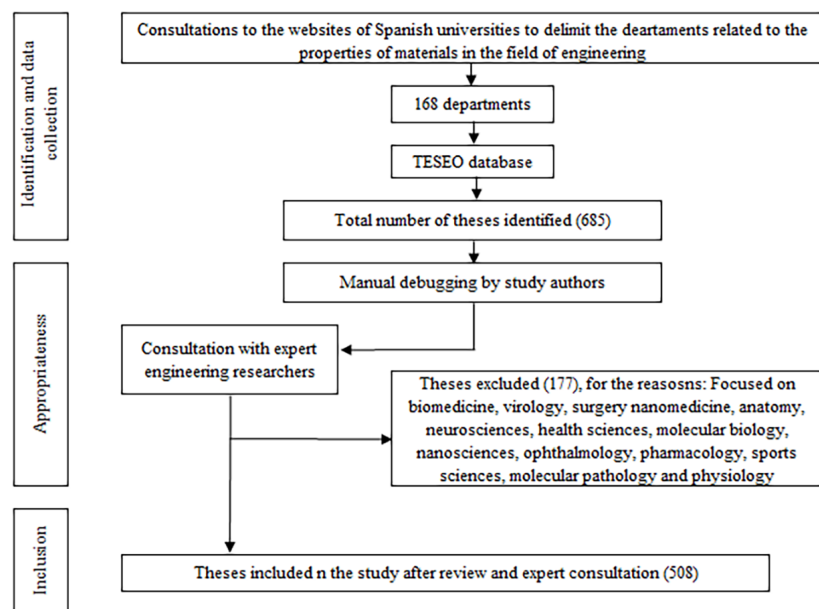


Fig. 1. Search flowchart

Source: Own elaboration.

In many bibliometric or scientific output analysis studies, such as the one we conducted, the only information available on authors may be their names. Using name-based gender identification may be the only practical way to analyse gender

representation in research and has been utilised in other studies [20–21]. The VOS viewer software version 1.6.20 was used to visualise the keyword co-occurrence network and to extract the clusters in which these keywords are grouped.

3 RESULTS

3.1 Completion of doctoral theses

For the period between 1977 (the year of the first thesis indexed in TESEO) and 2022, Spanish universities have recorded 509 doctoral dissertations on materials properties in the field of engineering or any of its related disciplines (such as applied physics, mechanics, agronomy, energy, chemical engineering, physics-chemistry, etc.). The average is 11.27 dissertations per year. Between the years 2011 and 2020, the highest number of dissertations were carried out, with an output of 41.14% of the total number of dissertations generated (see Figure 2).

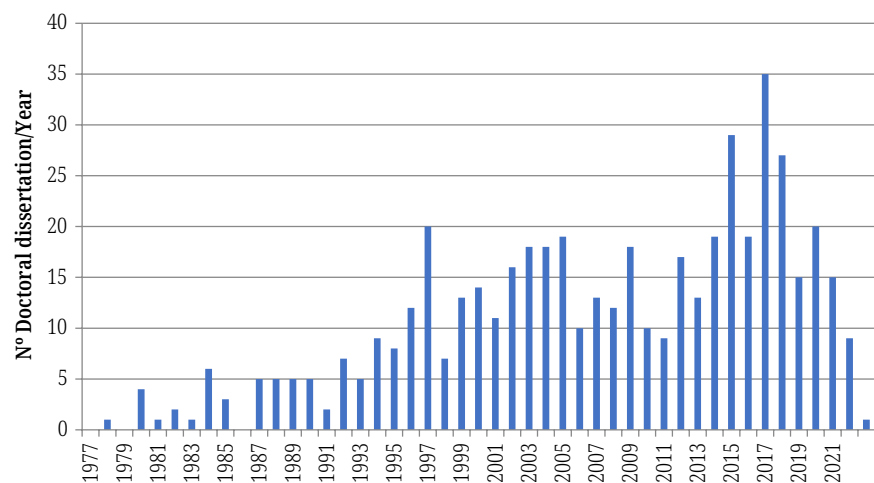


Fig. 2. Diachronic production of doctoral dissertations on materials properties in the field of engineering in Spain

Source: Own elaboration.

In the production of doctoral dissertations on the properties of materials in the field of engineering, no pattern of continuous or regular growth has been examined. Specific cycles in thesis production over the years have been identified. The cycles of growth and decline in the production of doctoral dissertations on the properties of materials in engineering cover the following periods:

Growth Cycle (1993–1997): During this period, a significant increase in the production of PhD theses on materials properties in engineering was observed.

Decline Cycle (1997–1998): A decrease in thesis production was recorded during these years, marking a cycle of decreasing research in the field of material properties.

Growth Cycle (1999–2005): Another growth cycle in thesis production was identified between 1999 and 2005, where an increase in the number of doctoral theses defended in this field was observed.

Decline cycle (2009–2011): In these years, a new cycle of decrease in the production of theses on properties of materials in engineering was detected.

Growth Cycle (2014–2017): Finally, another growth cycle was observed between 2014 and 2017, where an increase in the production of doctoral theses in this specific field was again observed.

These cycles of growth and decline in thesis production provide information on trends over time in materials engineering research, helping to better understand the evolution and focus of research in this specific field.

The Autonomous University of Madrid, together with the Complutense University of Madrid, are the leading Spanish institutions in terms of the production of doctoral dissertations in materials properties in the field of engineering (refer to Table 1). These universities generate 11.61% of the total.

Table 1. Production of dissertations on properties of materials in the field of engineering in Spanish universities (1977–2022)

University	Total	%
Autonomous University of Madrid	59	11.59%
Complutense University of Madrid	59	11.59%
University of Navarra	36	7.07%
University Politécnica de Madrid	25	4.91%
University of País Vasco	24	4.72%
University of Granada	23	4.52%
University of Barcelona	22	4.32%
University Politécnica de València	21	4.13%
University Politécnica de Catalunya	16	3.14%
University of València (Estudi General)	16	3.14%
University of Valladolid	15	2.95%
Autonomous University of Barcelona	14	2.75%
University of Oviedo	14	2.75%
University of Castilla-La Mancha	13	2.55%
University of Sevilla	13	2.55%
University of Carlos III de Madrid	10	1.96%
University of Cantabria	10	1.96%
University of Santiago de Compostela	10	1.96%
University of Zaragoza	10	1.96%
University of A Coruña	8	1.57%
University of Córdoba	7	1.38%
University of Cádiz	6	1.18%
University of Málaga	6	1.18%
University of Vigo	6	1.18%
University Pública de Navarra	6	1.18%
University of Alicante	5	0.98%
University of La Laguna	5	0.98%
University of Jaume I de Castellón	5	0.98%

Source: Own elaboration.

3.2 Management of doctoral dissertations

A total of 590 researchers from different universities participated in supervising doctoral theses. Ángel Vicente Delgado Mora, the director of the Department of Applied Physics at the University of Granada, exhibited the highest productivity during the analysed period. He supervised eight theses, four of which were solely his. In second place is José Javier Urcola Galarza from the University of Navarra, who supervised a total of seven theses, all individually.

In third position are Miguel Ángel Rodríguez Pérez from the University of Valladolid and Óscar Antonio Ruano Mariño from the Complutense University of Madrid, both of whom supervised a total of six doctoral dissertations.

Bradford's Law, applied to the production of doctoral dissertations, can help identify the most visible directors in a discipline at the university level. According to Bradford's law (1948), it has been confirmed that, in Spanish universities, there are no significant producers in the work of supervising doctoral dissertations on properties of materials in the field of engineering because they do not add to anyone with a number greater than 10 ($\text{Log } n \geq 1$). There were 100 average producers ($0 < \text{Log } n < 1$) with 81 men (81.00%) and 19 women (19.00%), and 490 transient producers ($\text{Log } n = 0$), who have supervised a single thesis, in this case 387 men (78.98%) and 103 women (21.02%) (refer to Table 2).

Table 2. Most productive dissertation headmasters ($10 > n > 1$)

Directors	Frequency	%
Delgado Mora, Ángel Vicente	8	1.08%
Urcola Galarza José Javier	7	0.94%
Rodríguez Pérez, Miguel Ángel	6	0.81%
Ruano Mariño, Óscar Antonio	6	0.81%
Martín León, Nazario	5	0.67%
Flores Sintas, Fernando	4	0.54%
Gil Sevillano, Javier	4	0.54%
González Caballero, Fernando	4	0.54%
Gutiérrez Sanz, Isabel	4	0.54%
Jiménez Melendo, Manuel	4	0.54%
Muñoz González, Alfonso	4	0.54%
Piqueras De Noriega, Francisco Javier	4	0.54%
Rubio Bollinger, Gabino	4	0.54%

Source: own elaboration.

3.3 Thematic of investigation

A total of 304 different descriptors were found in the theses. Physics descriptors accounted for 17.29%, solid-state physics for 10.40%, technical sciences for 9.77%, material properties for 8.02%, material technology for 7.52%, and mechanical properties of materials for 5.01% of the theses. These descriptors were found in 53% of the theses analysed (refer to Table 3). A high proportion of topics related to the physical properties of materials are observed.

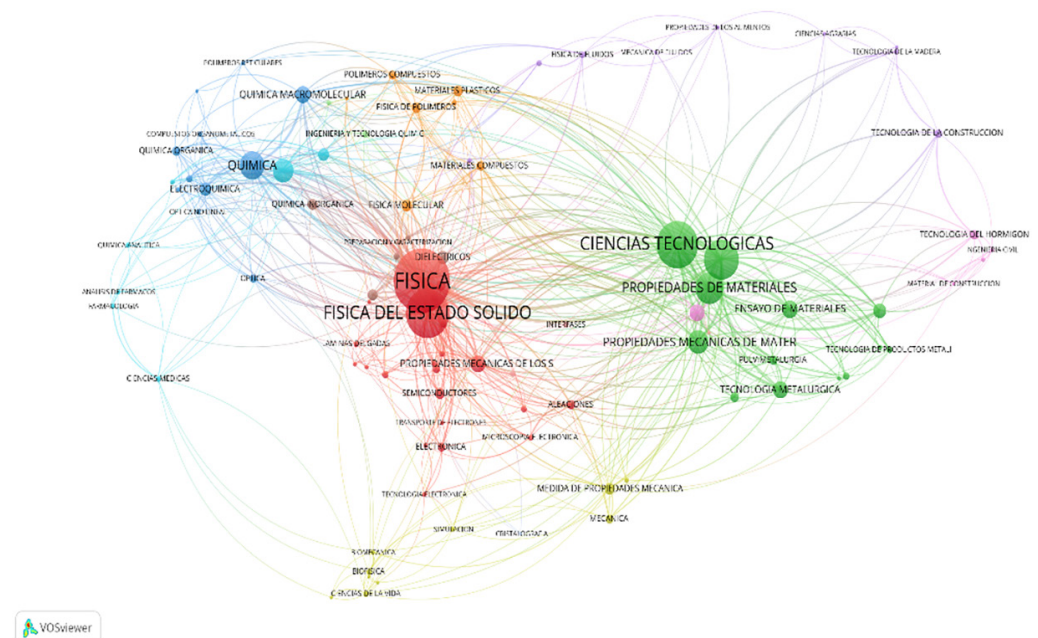
Table 3. Most frequently used descriptors ($n \geq 20$)

Descriptors	Frequency	%
Physics	138	17.29%
Solid-State Physics	83	10.40%
Technological Sciences	78	9.77%
Properties of Materials	64	8.02%
Technology of Materials	60	7.52%
Mechanical Properties of Materials	40	5.01%
Chemistry	37	4.64%
Physical chemistry	35	4.39%
Materials testing	27	3.38%
Material resistance	20	2.51%
Metallurgic Technology	20	2.51%

Source: own elaboration.

The co-occurrence maps generated for each set of descriptors differ in the word with the highest density accumulation. In the authors' descriptors (see Figure 3), the map shows denser areas around "physics."

Figure 2 illustrates a 2D representation of the initial 3D co-occurrence map of the authors' descriptors. Different nodes represent different descriptors, and their size is determined by the frequency of occurrence of each descriptor. The lines link each descriptor with the other keywords that co-occur with it.

**Fig. 3.** Network of co-occurrence of descriptors

Source: Own elaboration.

The descriptors with a frequency of 80 or more are "Physics," which appears in 17.29% of the documents, and "Physics of the State," which appears in 10.40%.

In addition, a co-occurrence map of these descriptors has been created, and they have been grouped into clusters of at least 10 elements to enhance clarity in the analysis documents (see Figure 3). Table 4 presents the descriptors of the six clusters and the underlying themes that made the formation of the clusters possible.

Table 4. Clusters of at least six elements for descriptors that include physics

Clusters	Descriptors
Cluster 1 (22 Items)	Alloys, semiconductor devices, electromagnetism, electronics, optical spectroscopy, electronic states, non-crystalline states, crystal structure, physics, solid state physics, imperfections, thin films, magnetism, electron microscopy, electron transport properties, magnetic properties, mechanical properties of materials, optical properties, semiconductors, electronic technology, quantum theory, electron transport.
Cluster 2 (13 Items)	Technological sciences, materials testing, metallurgical materials, metallurgy, metal products, metallurgical products, properties of materials, mechanical properties of solids, powder metallurgy, strength of materials, materials technology, technology of metal products, metallurgical technology.
Cluster 3 (11 Items)	Heterocyclic compounds, organic compounds, electrochemistry, luminescence in solids, optics, nonlinear optics, reticular polymers, chemistry, macromolecular chemistry, organic chemistry, synthesis of macromolecules.
Cluster 4 (10 Items)	Aluminium, bioelectricity, biophysics, cell biology, biomechanics, life sciences, human physiology, mechanics, measurement of mechanical properties, simulation.
Cluster 5 (10 Items)	Agricultural sciences, conductivity, wooden constructions, colloid physics, fluid physics, fluid mechanics, food properties, construction technology, wood technology, food technology.

Source: Own elaboration.

3.4 Gender of authors and directors

In terms of authorship, 174 (34.25%) dissertations were written by women and 334 (65.75%) by men. As far as women are concerned, only 28 engineering theses were completed during the period 1977–1987. The maximum production was in 2016, with 35 dissertations read. In the case of men, the lowest number of dissertations was recorded between 1977 and 1985 with 15 dissertations read, and the maximum in 2016 and 2017 with 19 dissertations. The annual average number of dissertations defended was 7.26 for men and 3.78 for women.

This predominance of the male gender is also evident in the direction of the dissertations, where women represent 17.13% and men 82.87%. When considering the composition of the thesis supervisors, 9.06% were entirely supervised by women, 74.21% by men, and 16.73% of all dissertations were supervised and co-supervised by a mixed team.

As for the composition of the evaluation commissions, only 0.39% are women compared to 40.16% men, and 59.45% have a mixed composition of men and women.

A total of 590 researchers were involved in supervising and co-supervising doctoral theses. Women accounted for 20.68% of the total, men 79.32% and 9.06% as all-female supervisors, 70.41% as all-male supervisors, and 16.34% in theses supervised by combined male and female supervisors.

It can be observed that there is scarce parity in the management of universities in Spain. The universities with parity in this aspect are the University of the Rioja, Mondragón Unibersitatea, and the Universidad Cardenal Herrera CEU. The autonomous University of Madrid is the most uneven. A total of 59 dissertations were defended there; women supervised seven of the dissertations read there (11.86%) compared to the 44 supervised by men (74.58%), while mixed supervision was used in 8 of them (13.56%); at the Complutense University of Madrid, a total of 59 dissertations were defended; women supervised four of the dissertations read there (6.78%) compared to 38 supervised by men (64.41%), and mixed supervision reached 17 of them (28.81%).

Once it has been discriminated against the composition of the thesis management according to whether the members are only men, only women, or men and women (refer to Table 5), we see that the dissertations were not supervised in equal percentages by only women (9.23%) and by only men (74.07%). The shared supervision by men and women amounted to 16.70%. The average number of supervisors was 1.17 per thesis. 286 dissertations had only one supervisor; 204 had two supervisors; and 19 had three supervisors.

When analysing gender both in terms of authors and directors, it is observed that women were supervised by other women in 9.71%, were supervised by men in 65.57%, and were supervised by mixed groups in 21.71%. Whereas men were directed by other men at 76.95%, women at 8.98%, and mixed groups at 14.07% (refer to Table 5).

Table 5. Correlation between the gender of authors and directors

		Gender of the Directors		
		Only Women	Only Men	Mixed: Women and Men
Gender of the authors	Women	17	120	38
	Men	30	257	47
	Total	47	377	85

Source: Own elaboration.

When analysing gender in terms of both the authors and the members of the thesis evaluation commissions, it is observed that women were evaluated by other women in 1.14%, were supervised by men in 26.86%, and were supervised by mixed groups in 72.00%. While 47.01% of the men were assessed by other men, no assessment was made entirely by women, and 52.99% of the assessments were carried out in the mixed groups (refer to Table 6).

Table 6. Correlation between the gender of the authors and the evaluation committees

		Gender of Evaluation Committes		
		Only Women	Only Men	Mixed: Women and Men
Gender of the authors	Women	2	47	126
	Men	0	157	177
	Total	2	204	303

Source: Own elaboration.

4 DISCUSSION

The bibliometric study carried out on Spanish doctoral theses in engineering that address the properties of materials has provided valuable information on academic production in this field.

Variability in thesis production was observed over the years, without a defined pattern of continuous growth. The universities of Madrid stood out as the main producers, representing 30.11% of the dissertations analysed. These data reflect the importance and diversity of the study of the properties of materials in Spain.

A focus on topics related to physics and the physical properties of materials has been observed, suggesting a strong emphasis on certain aspects of the properties of materials in the field of engineering. It may contribute to promoting the diversification of study areas within doctoral training in materials properties engineering by analysing research topics that are addressed in these dissertations. A concentration was observed on topics related to physics and the physical properties of materials, suggesting a predominant focus on certain aspects of material properties in engineering. The analysis carried out on the research topics addressed in the thesis can contribute to promoting the diversification of the areas of study in doctoral training in material properties engineering. Including a wide range of topics related to materials properties can enrich engineering education and better prepare students for diverse research opportunities and career paths.

On the other hand, descriptor co-occurrence analysis is a valuable tool to identify the most relevant and current topic areas in doctoral research in materials properties engineering. This analysis can guide us to know if doctoral training programmes are up-to-date and if the research promoted in them is in line with emerging trends in the field.

The results present significant gender biases regarding thesis authorship and direction by men compared to women. The lack of parity in the thesis direction and the majority presence of men both in the direction and in their evaluation is an aspect to consider for future analyses and policies of gender equality in research. The identification of gender biases both in the authorship of the dissertations and in their direction reveals the need to address gender equity in doctoral training in engineering.

It is important to consider these findings in the broader context of academic engineering research and work to promote diversity and gender equity to encourage more equal representation in the direction and evaluation of doctoral dissertations. This discussion opens opportunities for future research and actions that promote inclusion and equity in academia. These implications can contribute to strengthening the quality and relevance of doctoral training in the field of material properties in engineering.

5 CONCLUSIONS

We have analysed the production of doctoral dissertations on materials properties in the field of engineering or any of its related disciplines between 1977 and 2022, identifying some patterns. A clear increase in the production of doctoral dissertations on materials properties in the field of engineering in Spanish universities can be observed since the year 1998.

The authorship of doctoral dissertations shows an area dominated by men; the reason is that the number of male authors is higher than that of female authors. It has also been found that mixed authorship is frequent in this field of engineering, although the majority of the dissertations have been carried out under single authorship.

The gender biases identified in authorship and supervision suggest the need to promote diversity and inclusion in engineering academia. Engineering educators can use these findings to advocate for more equitable representation and equal opportunities for all genders in engineering education and research.

The Autonomous University of Madrid, the Complutense University of Madrid, the University of Navarra, and the Polytechnic University of Madrid are the leading institutions in the production of dissertations on materials properties in the field of engineering or any of its related disciplines, together generating 35.24% of all dissertations in Spain on this subject.

At the level of direction, there are no major producers of dissertations, and 83.90% of all of them are temporary residents, meaning they have only supervised one thesis. Also, it has been confirmed that mixed co-direction in the field of material properties in the sphere of engineering is not something usual and widespread, due to the fact that the highest percentage of dissertations have been carried out in a single direction. Recognising the significant impact of thesis supervisors and mentors can lead educational institutions to emphasise the importance of mentoring in doctoral programmes and promote effective supervision practices. This can improve the quality of guidance and support for engineering doctoral candidates.

This study, which focuses on Spanish doctoral theses in engineering on the properties of materials, is aimed at various audiences interested in academic research and engineering training. Researchers and academics working in the field of engineering, especially in areas related to materials properties, are presented with information on trends, research areas, and gender participation in this specific field.

On the other hand, the directors of doctoral programs in engineering are offered findings from the study to report on possible areas of improvement in terms of gender equity, curricular diversification, and promotion of research in their programs. By considering these implications, engineering educators and institutions can improve the quality and inclusivity of engineering pedagogy, promote research innovation, and foster a supportive and diverse academic environment for future engineers.

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