buildings

Article

Emerging Trends in Structural Mechanics Education: A Bibliometric Approach from the Perspective of Colombian Professors

Jesús D. Villalba-Morales [1,*], Sandra Jerez [2], Ricardo Parra [3], Juan C. Obando [4], Andrés Guzmán [5], José M. Benjumea [6], Orlando Arroyo [6] and Orlando Cundumi [7]

1 Department of Civil Engineering, Pontificia Universidad Javeriana, Bogotá 110231, Colombia
2 Programa de Ingeniería Civil, Escuela Colombiana de Ingeniería Julio Garavito, Bogotá 111321, Colombia; sandra.jerez@escuelaing.edu.co
3 Departamento de Ingeniería Civil y Agrícola, Universidad Nacional de Colombia, Bogotá 111321, Colombia; rparraar@unal.edu.co
4 Escuela Ambiental, Universidad de Antioquia, Medellín 050010, Colombia; jcarlos.obando@udea.edu.co
5 Departamento de Ingeniería Civil y Ambiental, Universidad del Norte, Barranquilla 080001, Colombia; faguzman@uninorte.edu.co
6 Escuela de Ingeniería Civil, Universidad Industrial de Santander, Bucaramanga 680002, Colombia; josbenro@uis.edu.co (J.M.B.); odarrame@uis.edu.co (O.A.)
7 Departamento de Ingeniería Civil e Industrial, Pontificia Universidad Javeriana-Cali, Cali 760031, Colombia; orlando.cundumi@javerianacali.edu.co
* Correspondence: jesus.villalba@javeriana.edu.co

Abstract

Recent developments in higher education have transformed teaching–learning processes across disciplines, including structural mechanics in civil engineering programs. However, reports on innovative teaching practices in structural engineering are scattered, hindering their application in other contexts. This study consolidates and analyzes global research trends in structural mechanics education (from 2014 to 2023), complemented by insights obtained from surveys applied to students, instructors, and senior structural engineers in Colombia. The sample literature comprises 150 Scopus-indexed English articles analyzed with Bibliometrix. Eight guiding questions serve to characterize the literature, identify predominant pedagogical strategies, and outline future research directions. Results reveal limited collaboration networks, inconsistent keyword usage, and a strong concentration of U.S.-based authors and institutions. Most papers appear in engineering education journals, and the recurrent topics (active learning strategies, digital and virtual resources, and assessment methods) confirm the prevalence of experiential, student-centered approaches. Based on the findings, eight emerging areas should guide future research: sustainability, educational research, non-disciplinary competencies, digital resources, artificial intelligence, innovation, disciplinary competencies, and digital competencies. Also, it is recommended that engineering faculties focus efforts on clarifying competency frameworks, strengthening pedagogical and faculty development, investing in educational technologies and laboratory infrastructure, fostering collaborative networks, and enhancing the visibility of structural mechanics education research.

Keywords: engineering education; structural mechanics; innovation in education; bibliometric analysis

Academic Editor: Gabriele Milani

Received: 31 October 2025
Revised: 1 December 2025
Accepted: 13 December 2025
Published: 4 January 2026

1. Introduction

Teaching and learning processes in engineering have evolved rapidly in recent decades, driven by accelerated global transformations that demand innovative curricula. The CDIO (Conceive, Design, Implement, Operate) approach offers a framework that considers all stages of engineering systems, such as civil infrastructure [1]. Simultaneously, ABET certification provides essential standards for assessing educational quality. In civil engineering specifically, the Civil Engineering Body of Knowledge (CEBOK3), prepared by the ASCE Task Committee [2], defines 21 fundamental learning outcomes aligned with ABET criteria and extensive educational experiences [3]. These outcomes span undergraduate education, technical skills, and professional responsibilities. However, technological advances offer possibilities for classroom innovation. The widespread diffusion of artificial intelligence (AI) tools offers both possibilities and challenges for educational practices. Consequently, both external transformations (AI) and internal modifications (curricula) make civil engineering education a promising area of study.

The education of structural engineers is of the utmost importance, given their crucial role in ensuring public safety and well-being. Structural engineers require solid foundations in technical concepts, along with the ability to meet societal demands for sustainability. As globalization demands cross-disciplinary integration, structural engineers should collaborate seamlessly with architects and other specialists. This requires skills such as effective communication and teamwork, in addition to traditional technical knowledge. To meet these demands, new educational approaches are urgently needed. Modern strategies applicable to the classroom include physical models, digital resources, collaborative strategies, and case studies. The industry's future depends on educators adapting to these changes, a sentiment echoed by the Structural Engineering Institute's vision for the profession through 2033 [4].

Modern pedagogical strategies, such as the Flipped Learning Model [5], Problem-Based Learning (PrbBL) [6], and Project-Based Learning [7], can significantly impact structural engineering training. However, a key challenge remains: these strategies are often misunderstood or improperly implemented. For instance, PrbBL is sometimes reduced to merely assigning problems, whereas effective implementation requires comprehensive curriculum planning, collaboration among faculty, and adequate facilities. Furthermore, frameworks like Universal Design for Learning [8] emphasize that teachers and students should understand metacognitive processes to maximize the benefits of training. While universities are increasingly establishing pedagogical training centers, some institutions and professors may not be prepared to implement these trends. As noted in previous works [9–14], a PhD in structural engineering does not guarantee pedagogical expertise; yet, the new vision for the profession demands professors with appropriate knowledge of engineering education.

Despite these needs, documentation regarding teaching practices in structural engineering is scattered, preventing the transfer of accumulated experience. While bibliometric reviews exist for transportation [15], construction games [16], lean construction [17], and geotechnical technology-enhanced learning [18], there is a distinct lack of recent research reviews specifically focused on structural engineering education. The most relevant existing reviews are historical overviews from 2007 [19] or focus on structural art [20]. This represents a significant research gap: information on methods, tools, and assessment in structural mechanics is currently dispersed, hindering its adoption by educators.

This paper addresses this gap by presenting a systematic analysis of worldwide research on the teaching of structural engineering. It aims to gather dispersed information to facilitate its use by researchers and professors seeking to improve their teaching methods. The study analyzes 150 papers published between 2014 and 2023 in the Scopus database.

While the Bibliometrix tool [21] supports analysis following the PRISMA approach, a further manual extraction of information was necessary to complete it. This dual approach allows for a deeper understanding of collaboration networks and proposes a novel classification of pedagogical strategies by specific domains (statics, mechanics of materials, and structural analysis). Additionally, Section 2 describes structural mechanics education in Colombia from the perspective of the authors, who work at universities in the main cities of Colombia (Figure 1). To address the research objective, the following questions are proposed:

- Q1: Who are the main authors, collaboration networks, institutions, and countries researching the subject?
- Q2: What are the leading journals for publications on this subject?
- Q3: Is research on this subject showing an increasing trend?
- Q4: Are the keywords adequately defined?
- Q5: What are the main topics of research?
- Q6: What are the most cited articles on the subject?
- Q7: What does the evidence from the analyzed research tell us about the education of structural mechanics?
- Q8: What research lines should be followed in structural mechanics education?

Figure 1. Map of Colombia showing the location of the universities participating in this study.

2. Structural Mechanics: The Author's Perspective

This section provides an overview of the general approach to teaching the principles of structural mechanics, underscoring the importance of this area for several professions. The typical curricular layout for structural mechanics in undergraduate civil engineering programs is presented, along with the perceptions of undergraduate students, professors, and practitioners associated with structural mechanics. Some survey results are presented in word clouds. For these, it was necessary to carefully revise and eliminate some of the respondents' contributions, as certain inputs introduced ambiguity in their interpretation. For example, when asked about their perceptions of structural mechanics courses, five students responded with "dynamic." In this case, it was unclear whether they referred to the course content (e.g., dynamic response of an element) or the pedagogical approach used by their professors. This highlights the importance of developing skills in formulating and assessing qualitative research in engineering education.

Structural mechanics forms the basis of the structural thinking of civil engineers. The concept of structural thinking is introduced here to illustrate an engineer's ability to understand how a structure responds under various loading conditions. It is important to note that a structure can be understood differently across various engineering disciplines. Figure 2 illustrates interpretations of structures in some related fields of civil engineering; interestingly, all of these systems can be analyzed using the foundational concepts and procedures of structural mechanics. At the undergraduate level, structures are assumed to exhibit linear and elastic behavior, and energy, flexibility, or stiffness-based methods are used to calculate the responses (displacements, internal forces, strains, and stresses) under static loads.

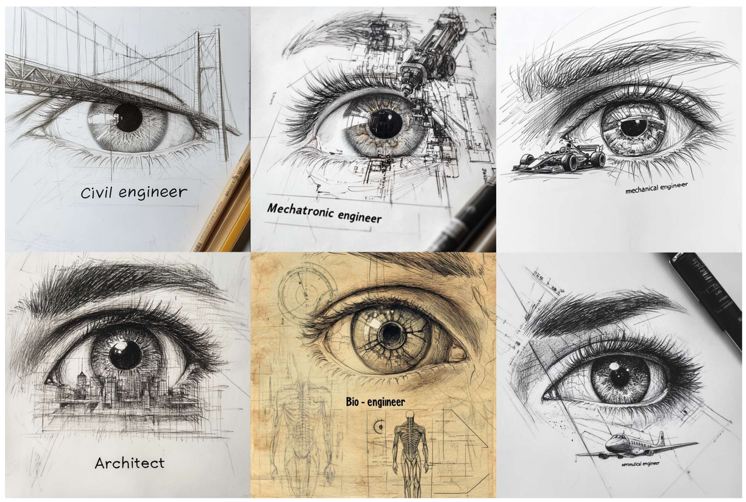

Figure 2. Visual representations of professional fields connected to structural mechanics learning. Images generated with Midjourney AI (version 6), Midjourney, Inc., San Francisco, CA, USA, 2024. Available online: https://www.midjourney.com (accessed on 30 October 2025).

In Colombia, structural mechanics involves three sequential courses (Figure 3). The first, statics, introduces students to static equilibrium and its applications in solving basic and rigid structural systems. Then, in Mechanics of Materials (Strength of Materials or Mechanics of Solids), students are expected to consider the deformation capability of structures under a set of loads when solving problems involving hyperstatic systems. Laboratory sessions are typically included with this course to help students properly understand the mechanical phenomena. Finally, more complex and larger structures are analyzed in the structural analysis course, where analytical, numerical, and computational methods are explored primarily through the computer implementation of a matrix approach. In the universities involved in this study, and considering the country's seismic hazard, a project involving the seismic analysis of a building using the Equivalent Lateral Force method is integrated. This project is sometimes continued in subsequent courses, such as structural dynamics or reinforced concrete design.

As seen in Figure 4, which summarizes the number of structural mechanics courses taught in 37 civil engineering programs in Colombia, half of the programs follow the three-course sequence described above. In programs with four courses, structural analysis is sometimes divided into two courses: the first is dedicated to classical analysis techniques, while the second focuses on matrix or finite element analysis (FEA). Alternatively, the three-course sequence precedes a course in structural dynamics. It is worth mentioning that only one program integrates mechanical concepts into two courses, whereas another program comprises six basic courses, including FEA and topics related to earthquake engineering.

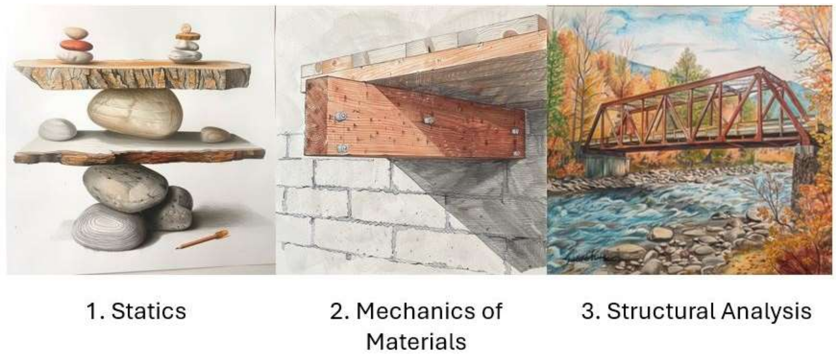

Figure 3. Core structural mechanics courses in the civil engineering curriculum: A visual representation. Images generated with Midjourney AI (version 6), Midjourney, Inc., San Francisco, CA, USA, 2024. Available online: https://www.midjourney.com (accessed on 30 October 2025).

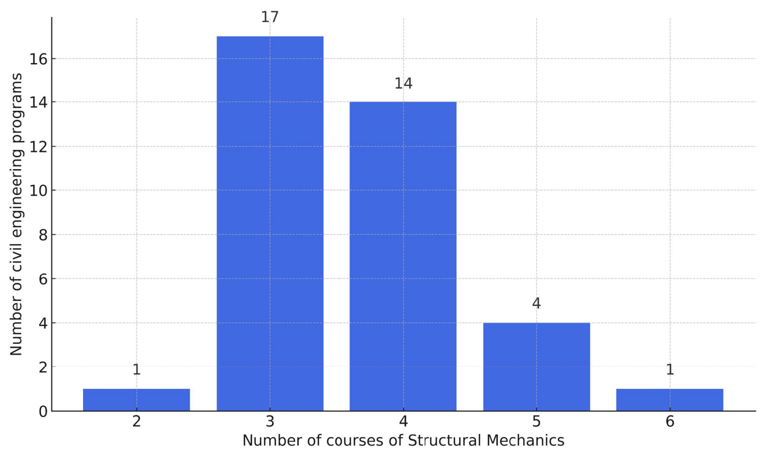

Figure 4. Overview of the number of structural mechanics courses offered by Colombian universities.

For students, structural mechanics is commonly regarded as a challenging yet essential area in their development as civil engineers. This can be confirmed in the word cloud shown in Figure 5, which presents the opinions of 182 students from nine Colombian universities about their experiences in the respective courses. The students were asked to respond to the statement: "Use three words (or groups of words) to describe the perception of your learning experience when taking the fundamental courses in structural engineering: statics, strength of materials, and structural analysis." The results, which are indicative, show that despite the perceived complexity, students recognize the importance of structural mechanics. For some, the courses present a positive challenge to their formation, requiring self-learning and involving non-disciplinary aspects such as motivation, ethical issues, and pedagogical considerations. Yet, the courses can be time-consuming for many and may sometimes evoke negative emotions. The above results underscore the need for more comprehensive and didactic approaches to teaching structural mechanics.

Given the perceived complexity of the subject, educators are encouraged to employ pedagogical strategies that enhance the teaching and learning process of structural mechanics. Figure 6 presents the responses of 33 Colombian professors to the prompt: "Identify up to four pedagogical strategies that you have implemented in undergraduate structural engineering courses (Statics, Mechanics of Materials, Structural Analysis) that facilitated the teaching-learning processes. Use only one sentence per suggestion". As seen in the plot, three strategies (programming methods, lab work for structural concepts, and exposure to real-world scenarios) are preferred. Notably, the fourth strategy corresponds to assessment strategies that complement the learning process. The adoption of strategies related to