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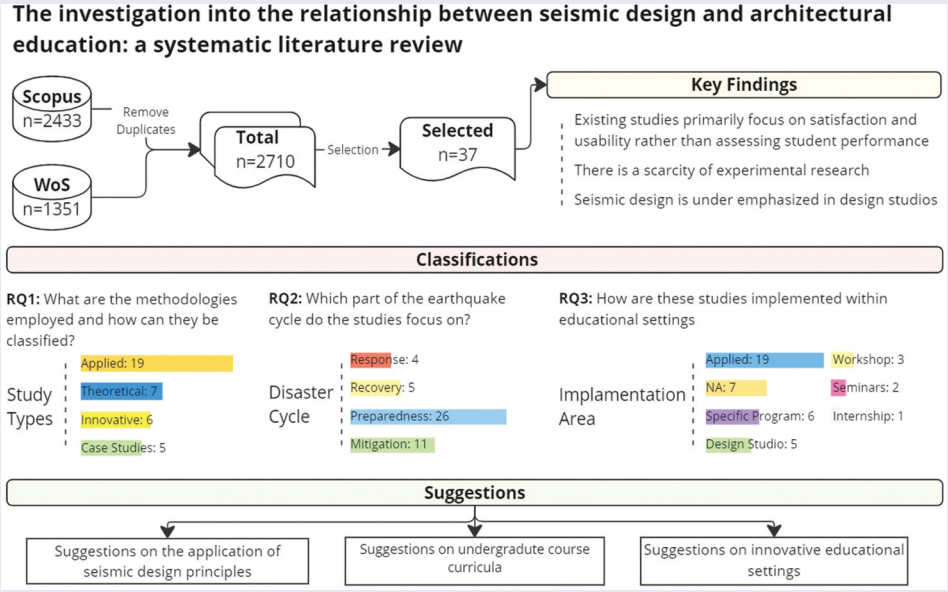
The investigation into the relationship between seismic design and architectural education: a systematic literature review

Arabacıoğlu Feride Pınar, Er İhsan Erdem and Tastan Hasan

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ABSTRACT

Recent advancements in earthquake research have not been sufficiently integrated into architectural design education. This study aims to fill this gap through identifying the focal points of research in earthquake studies and architectural design education. The study conducts a systematic literature review to explore how earthquake research findings are incorporated into curricula, lectures, studio projects, and design criteria. The qualitative and interdisciplinary features of the evaluated studies are analysed to determine the extent and depth of their contribution. A review of numerous studies reveals key insights: seismic design is underemphasized in design studios, there is a scarcity of experimental research, and existing studies primarily focus on satisfaction and usability rather than assessing student performance. These findings have significant implications, shedding light on how architectural research methodologies can be effectively integrated into educational contexts and design practices for disaster resilience. Educators and practitioners can leverage these insights to better prepare for and respond to disasters by integrating earthquake research findings into courses, lectures, and design projects.



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KEYWORDS
Earthquake; resilience; seismic design; architectural education; architectural design

1. Introduction

During the course of history there have been several catastrophic earthquakes that have had disastrous effects on humans and on the environment. In the last half century, severe earthquakes in the world like 1985 Mexico City (Alcántara-Ayala, Rodríguez-Velázquez, and Lucatello 2022), 1995 Kobe-Japan (Kusunoki, Tasai, and Teshigawara 2014), 1999 Kocaeli-Türkiye (Atmaca et al. 2020), 2009 L'Aqualia-Italy (Stratta et al. 2016), 2010 haiti (De León 2013), and 2023 Kahramanmaraş-Türkiye (Akın, Tuncer, and Yastı 2024; Avcil 2023; E. Işık 2023) have caused large-scale casualties and damage of manmade structures (Table 1). However, these earthquakes have made experienced professionals and academics in the construction sector to work together to enhance earthquake awareness. In recent years, earthquake research has increasingly focused on a multifaceted approach to understanding and mitigating the impacts of seismic events. Recent studies have primarily concentrated on seismic vulnerability assessments (Bayraktar et al. 2018;

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Table 1. Devastating earthquakes and their casualties in the last half century.

Date	Region	Magnitude (Mw)	Casualties	Damaged or Collapsed Structure
19.09.1985	Mexico City	7.1	369 (deaths) 6.000 (injured)	44 (collapsed) 73.000 (damaged)
17.01.1995	Kobe-Japan	7.3	6.434 (deaths)	104.906 (collapsed)
17.08.1999	Kocaeli-Türkiye	7.6	18,373 (deaths) 24286 (injured)	More than 150.000 (damaged)
06.04.2009	L'Aqualia-Italy	6.3	309 (deaths) 1.600 (injured)	100.000 (damaged)
12.01.2010	Haiti	7.0	316.000 (deaths) 350.000 (injured)	300.000 (collapsed)
06.02.2023	Kahramanmaraş-Türkiye	7.7	More than 50.000 (deaths)	100.000 (damaged)

E. Işık et al. 2022; Ortega et al. 2019; Valente 2021) and evaluations of seismic behaviour (Naik et al. 2024; N. Işık, Halifeoğlu, and İpek 2020; E. Işık et al. 2023; Valente and Milani 2018), as well as on developing more efficient systems for disaster preparedness (Papatheodorou et al. 2023) and response (Hategekimana et al. 2024; Kalantar et al. 2020). Collaboration among experts from numerous fields such as geology, engineering, and emergency management is essential for developing thorough earthquake risk reduction measures. The long-term goal is to build a more robust and well-prepared society that can endure the unexpected nature of seismic events.

The motivation behind this research stems from recognizing that seismic resilience is not merely a structural concern but also holds educational significance within the field of architecture. Decisions made during the initial stages of architectural design profoundly impact a structure's earthquake resistance. Soft-story and one-way shear column placement-based damages observed in the 2023 Kahramanmaraş earthquake (Akar et al. 2024; Avcil et al. 2024) can be given as examples of this situation (Figure 1). Hence, it's crucial for architecture students to gain a solid understanding of seismic design principles (SDP) as part of their education. However, studies such as those by Özdoğan and Güney (2016) Özdoğan and Güney (2016) and Akçaer, Banu, and Soyluk (2015) indicate that architecture students often lack the necessary seismic design knowledge essential for real-world projects. Furthermore, integrating SDP into architectural education is sometimes perceived as constraining design creativity (Morales-Beltran, Charleson, and Aydin 2020). As academics in this field, it is our responsibility to provide future practitioners with the knowledge and skills they need to design buildings that are capable of enduring seismic forces in our ever-changing geophysical environment.

Teaching earthquake or seismic design is a topic that requires significant attention in architectural education programs at universities located in earthquake-prone countries. However, the integration of seismic design education into undergraduate programs has been a challenging topic in the literature. Theodoropoulos (2006) addressed this issue by highlighting that design studio courses, where students learn through the process of designing, are the most appropriate context for seismic design education. However, it may be more challenging for architecture schools with different specializations to cooperate and agree on integrating seismic design into design studios. To address the challenge of integrating seismic design into architectural education, A. Charleson (2018) outlined a set of essential and comprehensive topics that should be taught, as presented in Table 2. However, it's worth noting that these two studies are not systematic literature reviews. Despite employing the method described in Section 3, our literature search did not yield a systematic review focusing on the relationship between earthquakes and architectural education.

This review, through a meticulous examination of the existing literature, aims to fill the gap in earthquake-related content within architectural curricula and lay the groundwork for advancements in integrating this crucial subject into educational programs. The systematic literature review conducted within this scope aimed to thoroughly analyse existing research concerning the impact of earthquakes on architectural



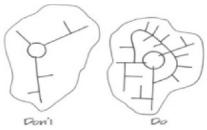
Figure 1. Soft-story (left) and one-way shear column placement-based (right) damages that were observed in 2023 kahramanmaraş earthquake. (photographed by author[2]).

Table 2. Seismic design principles and explanations compiled from the literature.

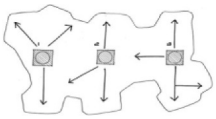
Urban Design Principles (Bahrainy and Bakhtiar 2022)



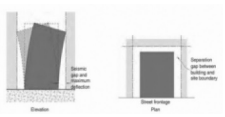
Location Decisions
Choosing building sites involves seismic zonation, placing sensitive public buildings in low-risk areas, and considering liquefaction-risk to minimize reannounce damage and enhance safety.



Roads and Open Spaces
Designing roads and open spaces involves creating accessible open areas, strengthening road walls, improving roads, removing non-structural hazards, reducing traffic, and optimizing passage dimensions for better earthquake resilience.

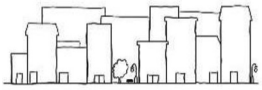


Decentralization
Distributing activities optimally, preventing high-density development, creating self-sufficient districts, evenly spreading open spaces, and ensuring alternative access to public services to enhance earthquake resilience.

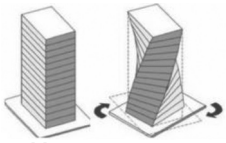


Gap Between Buildings
Thoughtful utilization of open spaces between structures and ensuring sufficient distance for safety, privacy, and pounding risk.

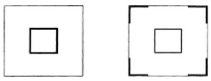
Building Design Principles(Arnold and FAIA, & RIBA 2001)



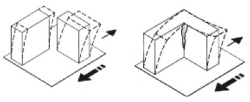
Building Size
As buildings increase in size, the structural design requirements become more stringent to mitigate the risk of resonance and earthquake effects. Meticulous engineering discipline is crucial to ensure safety and structural integrity.



Building Proportion
Managing slenderness ratio (height/least depth), alignment of the center of mass and the center of rigidity for torsion risk and subdivision of the building into simpler elements.

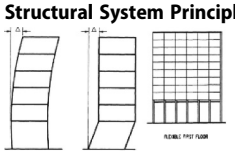


Plan Density Resistance
Optimal placement of resisting members along the perimeter, like walls or frames, effectively counteracts lateral forces and torsion, enhancing seismic performance.

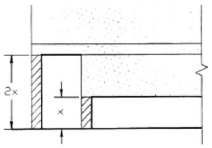


Reentrant/Inside Corners
Building shapes with reentrant corners cause rigidity variations and torsion, leading to stress concentrations. Solutions include structural separation or reinforcing stress points and strategic resistance element placement.

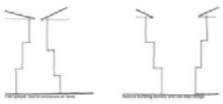
Structural System Principles (Arnold and FAIA, & RIBA 2001; A. Charleson 2012)



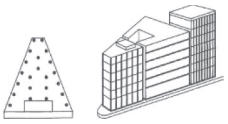
Soft and Weak Stories
Soft stories have less stiffness, and weak stories have less strength than the floors above, causing stress and deflection issues. Solutions include bracing, adding columns, or using lightweight materials.



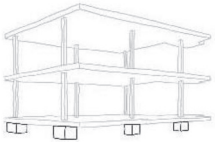
Columns
Seismic forces are drawn to stiffer, shorter columns, increasing stress and failure risk. Uniform short columns amplify forces, and mixed column stiffness can induce torsional effects.



Vertical Setbacks
Vertical setbacks create discontinuities in strength and stiffness, leading to stress concentrations and potential torsional forces. Minimizing setbacks and using seismic separation can mitigate these issues.



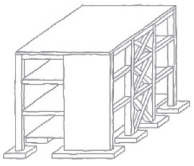
Nonparallel Systems
These systems increase torsional risks due to misaligned centers of mass and resistance. This challenge involves implementing specialized design solutions to enhance torsional resistance.



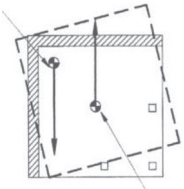
Foundation
Interconnecting individual footings with tie beams or slabs to prevent horizontal movement. Using piles for deep bearing in soft layers, with tie-beams between piles for shallow footings. Rafts are suitable for medium to high-rise buildings, while ground anchors resist tension and stabilize foundations on slopes.



Horizontal Structural Assemblies
Designing diaphragms for efficient force transfer, ensure stiffness and strength. Integrating bond beams for force transmission, and coordinate with architectural elements to enhance seismic performance.



Vertical Structural Assemblies
Ensuring optimal seismic performance involves using regular frame configurations with equal bay widths and properly oriented columns. Alternatively, symmetrically positioned shear walls or braced frame systems can be employed for enhanced seismic resistance.

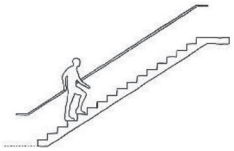
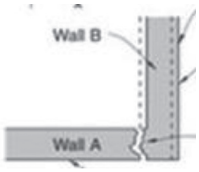
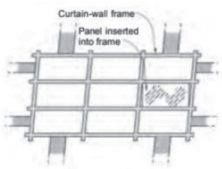


Perimeter Strength and Stiffness Variations
Strategically arranging resistance perimeter elements involves careful placement to minimize torsion risk and achieve balanced resistance throughout the structure. This approach is crucial, especially in geometrically symmetrical yet structurally irregular buildings.

(*Continued*)

Table 2. (Continued).

Non-Structural Elements Principles(A. Charleson 2012)

			
Staircase Integrating staircases into the building structure enhances seismic resistance, managing potential high seismic forces and torsional stress from asymmetrical placement. Installing sliding joints between floors mitigates damage, ensuring safe evacuation post-earthquake.	**Cladding** For masonry claddings, anchoring them back to the internal structure through reinforced masonry walls or vertical wood or steel studs. Keeping non-structural masonry walls separate from structure. For panel claddings, separating panels both from the structure and from each other.	**Windows & Curtain Walls** Earthquake-induced drifts pose a risk to building glass. That's why, protecting glass is critical for safety and cost. Adding clearance around glass panes and using seismic mullions for larger drifts are effective measures.	**Suspended Ceiling** Bracing suspended ceilings significantly reduces operational disruptions in buildings during earthquakes. Unbraced ceilings sway like pendulums in an earthquake, causing damage to structures and other elements.

education, identifying key themes andgaps in current knowledge. Three research questions (RQ) guided this endeavour:

- **RQ1** What are the methodologies employed in the field, and how can they be classified?
- **RQ2** Which part of the earthquake resilience cycle do the studies focus on?
- **RQ3** How are these studies implemented within the educational process?

For these research questions, the initial step involved coding and grouping the examined studies according to their study types. Subsequently, the relationship between the studies and the stages of the earthquake resilience cycle was investigated. In the final step, the implementation areas of the studies within the educational process were examined. For the first research question, a new classification was proposed for the existing literature based on the research methods of Groat and Wang (2013). For the second question, Minnery's (2013) resilience cycle model was utilized. For the third research question, the findings of the identified studies were categorized based on their adaptation to various courses, lecture topics, design studios' project themes, and design parameters.

Through these three research questions, four fundamental issues in the field of seismic design and architectural education were identified. These issues are addressed under four headings: implications of SDP, collaborative relations, undergraduate course curricula, and innovative educational settings. Recommendations to address these issues are presented. In doing so, this study not only offers theoretical insights but also explores practical implications in this field. It aims to contribute to the ongoing discourse on enhancing architectural education to effectively address real-world challenges and foster resilient communities. It is widely acknowledged that the educational framework established in lecture halls and design studios today will profoundly shapes the architectural landscape of the future.

2. Theoretical background

This review explores the foundational aspects of seismic design within architectural education, focusing on three critical dimensions: architectural study types, the resilience cycle factor, and implementation areas of SDP. This section describes the classification systems used for each research question.

2.1. Architectural study types

In addressing the nuances of seismic design education, it is imperative to employ a structured approach that can effectively categorize and analyse the diverse array of research studies in the field. Drawing from established methodologies in architectural research, this study undertakes a meticulous examination of the existing literature on seismic design education. By applying an adapted classification system developed by Groat and Wang (2013), this study aims to provide deeper insights into the various research types and methodologies employed in this domain. The existing literature on seismic design education was analysed through this adapted categorization. The headings "logical", "historical", "qualitative" and "correlational" in Groat and Wang's classification were not used directly due to the scarcity of statistical studies in the field and were merged in one class as theoretical evaluation. Additionally, "correlational" and "experimental" were merged into a single heading for clarity and coherence. "simulation" heading was re-named as innovative and "case study" heading directly used without any change.

- **Case studies** analysed current structures, locations, or communities in depth. Various strategies

can be used alone or in conjunction with this classification. Seismic design case studies in education focus on teaching students about seismic design by examining how existing structures respond during seismic event occurrences.

- **Innovative methods** align with Groat and Wang (2013) simulation classification; however, in this study, the scope under this heading has been broadened. Consequently, all simulation studies leveraging digital and technological tools are comprehensively examined within this classification. These studies focus on digitally or physically simulating the behaviour of structures under earthquake loads.
- **Applied courses** encompass studies where students are exposed to experimental investigations of earthquakes and the structural characteristics of buildings. In these studies, students create physical models of their designs and subject them to testing against earthquake loads. This approach ensures that students develop a deeper understanding of the relationship between earthquakes and the structural features of buildings.
- **Theoretical evaluation** includes Groat and Wang (2013) logical and historical methods within the theoretical framework. Additionally, studies that utilize qualitative methods are also included in this category, even though they do not specifically fit in this classification. This classification features diverse research works concentrating on survey-based measurements of seismic design knowledge and providing course recommendations for seismic design education.

2.2. Resilience cycle factor

Earthquakes and similar natural disasters highlight the crucial responsibilities of the design and construction sectors in protecting both the built environment and the safety of the local communities. Minnery (2013) described these responsibilities in four stages of the resilience cycle: response, recovery, resilience, and mitigation.

- **The response phase** involves activities that are needed immediately following the disaster. Such as rapid damage assessment, directing volunteers to the affected region, and urgent shelter production.
- **The recovery phase** includes comprehensive activities conducted sometime after the disaster, including detailed damage identification, repair, construction of temporary housing structures, and resettlement efforts.
- **The preparedness phase** involves pre-disaster and educational activities to enhance readiness for potential disasters.
- **The mitigation phase** involves measures taken to reduce the harmful effects of risky hazards or manage the impacts of already-occurring events. Examples of mitigation efforts include earthquake risk assessments for structures, the formulation of earthquake regulations, and retrofitting of buildings to enhance structural resilience.

According to Minnery (2013), this resilience cycle offers a comprehensive framework for addressing the various difficulties caused by seismic events and ensuring a resilient and secure future for communities at risk. In this systematic literature review, studies have been examined and grouped and discussed based on the phases they focus on.

2.3. Seismic design principles and implementation areas

Seismic design is a critical aspect of architecture, particularly in regions prone to earthquakes. Architectural parameters significantly affect the earthquake behaviour of buildings. Parameters such as building shape, structural symmetry, and distribution of mass and stiffness can influence how a building responds to seismic forces. Collectively categorizing the effects of these parameters as design principles is a subject studied in the literature, aiming to improve the earthquake resilience of buildings through better architectural design.

Design principles for seismic resistance focus on creating safe environments and structures that can withstand the forces exerted by earthquakes. The primary objectives of SDP are to ensure the safety of occupants, maintain the integrity of the building, and minimize damage. Akçaer, Banu, and Soyluk (2015) emphasized that architects must be equipped to implement optimal designs to withstand the powerful impacts and destructive results of earthquakes. The same study outlined the fundamental design principles that buildings should possess regarding earthquake resistance and behaviour during seismic events.

Arnold and FAIA, and RIBA (2001) proposed a three-part classification for SDP, including building configuration, structurally restrictive detailed architectural design, and hazardous non-structural components. These classifications provide a comprehensive framework for understanding the essential aspects of seismic design. In a similar study, Akdag and Beyhan (2024) classified the causes of earthquake damage into project errors, reinforcement errors, and implementation errors based on observations and research following past earthquakes. They also identified design principles for earthquake-resistant design, which are crucial for improving the resilience of structures.

Shareef (2023) reviewed earthquake risk reduction techniques by examining case studies from seismic and non-seismic locations and then explained the guidelines for reducing seismic risks in building design. This study provides practical examples of how SDP can be implemented in various contexts. Özmen and Ünay (2007) indicated commonly encountered seismic design faults due to the architectural design of residential buildings, illustrating essential SDP that need to be considered to prevent such faults.

In addition to these studies focusing on building design principles, Bahrainy and Bakhtiar (2022) examined the application of seismic design from an urban planning perspective. Considering the broader impacts of earthquakes at the urban scale, urban planning is also a significant factor in reducing earthquake vulnerability. Therefore, SDP should be considered not only for individual buildings but also for urban planning. Urban planning can significantly influence the overall resilience of a city to seismic events.

One of the most comprehensive studies on SDP is by A. Charleson (2012), titled "Seismic Design for Architects." Based on these works, the implementation areas of SDP can be broadly categorized into urban design, building design, structural systems, and architectural details. Each area contributes significantly to the overall resilience and safety of buildings. By addressing these key principles, architects and engineers can develop comprehensive strategies for each step of the earthquake resilience cycle. Understanding and applying these principles are essential for creating sustainable and disaster-resilient urban environments.

This study focuses on how these principles are taught in architectural education. Therefore, the SDP that are collectively gathered from literature are listed in Table 2 rather than explaining each principle individually. When examining architectural education worldwide, undergraduate programs encompass a variety of theoretical, practical, and studio courses aimed at transferring these SDP and skills (Ghonim and Eweda 2018). Design studio courses form the backbone of the architecture curriculum and enable students to engage in design tasks aimed at solving specific challenges. The solution of design studio problems is supported by different theoretical and practical courses. Theoretical courses play a broad role in introducing students with various architectural topics and increasing their awareness, while practical courses focus on cultivating the abilities necessary for general architectural tasks (Ghonim and Eweda 2018).

For implicating SDP in education apart from curriculum-courses, internships can be a common form of support, frequently required in numerous architectural education programs. Internship programs facilitate students applying their education to professional work settings and gaining practical experience. Moreover, current architectural education plans face restrictions regarding credit hours and course schedules (Theodoropoulos 2006). As a result, implicating SDP into the existing curriculum presents a significant challenge. In the literature, various solutions have been proposed to address this issue, including specific certification programs (Daza, Cavallin, and Lopez Del Puerto 2021; Potangaroa, Chhetri, and Timarzi 2010), workshops (Jain 2016; Morales-Beltran, Eigenraam, and Latka 2019; Mwangi 2013a), and seminars (Krishnan and Liao 2019; Neumann et al. 2014).

3. Materials and method

This systematic literature review (SLR), which reviews in line with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Moher 2009), examines education on earthquakes and seismic design in architecture.

3.1. Information sources

The eligible studies for this SLR are gathered from journal articles and conference proceedings in the SCOPUS and Web of Science (WoS) digital databases. This SLR is also aware of other existing databases, such as the IEEE Xplore digital library, the ACM digital library, ScienceDirect, JSTOR, EBSCO, and Taylor & Francis. However, Scopus and WoS databases, unlike other literature databases, are utilized to provide comprehensive scientific research because they include both journal articles and conference proceedings. Sample cross-checks support this claim.

3.2. Eligibility criteria

The suitable papers must meet the following criteria to be included in this SLR:

- A model, technique, or method is presented to evaluate a technical and/or pedagogical factor in earthquake or seismic design.
- At least one user group or training participant must be an architecture student.

Studies are excluded if

- The language of the study is not English.
- The study is not related to education or training in architecture.
- The users or trainees do not include architecture students.
- The profile of participants or trainees (architecture students) is not clear.
- Studies are repetitive (same study from different databases).
- The paper or article has the same content.

- The full text is not accessible.

3.3. Search strings

The aim of the search strategy is to identify primary studies relevant to this literature review. First, keywords were selected for the search. Eligible studies had to include three main concepts: seismic/earthquake, architecture, and education/training. The search terms were derived from different searches to ensure that as many relevant studies as possible were included in this study. In line with previous searches, the search string in Table 3 was used to achieve maximum coverage of studies.

3.4. Selection process

The database search was conducted between March 3 and 5, 2023, resulting in a total of 3784 records obtained (2433 from SCOPUS and 1351 from WoS). After removing duplicate publications, the selection process started with 2710 records. This process consisted of two steps. In the first step, the title and abstract of each study that met the inclusion and exclusion criteria were analysed. In the second step, the list was reduced to 197 studies. Then, the second review of the selection process, in which the full text was analysed, was conducted. As a result of this second review, a total of 37 studies were eligible and retained for review (Figure 2).

3.5. Classifying the papers

The eligible studies were coded and analysed using the analysis tools of the WoS and Scopus databases and MaxQda. The authors noted and defined any themes or categories that emerged during coding. To ensure evaluation reliability, the authors read all studies. The first and second raters read the studies independently and classified them into distinct categories. In case of any discrepancy between the two raters, the third author of the study agreed with the decision. In this

Table 3. Keywords of this SLR.

Databases	Results	Keyword search and other applied filters
SCOPUS	2433	(TITLE-ABS-KEY (seismic* OR earthquake*) AND TITLE-ABS-KEY (construction OR architectur* OR "architectural engineering" OR "architectural design" OR "building design" OR "built environment" OR "urban design") AND TITLE-ABS-KEY (educat* OR train* OR learn* OR teach* OR skill* OR student*)) AND (LIMIT-TO (LANGUAGE, "English"))
WoS	1351	Results for seismic* OR earthquake* (Topic) AND construction OR architectur* OR "architectural engineering" OR "architectural design" OR "building design" OR "built environment" OR "urban design" (Topic) AND educat* OR train* OR learn* OR teach* OR skill* OR student* (Topic) and English (Languages) and Article or Proceeding Paper (Document Types) and English (Languages)

* was used as a truncation operator to search for documents that include the root of the term followed by any number of characters.

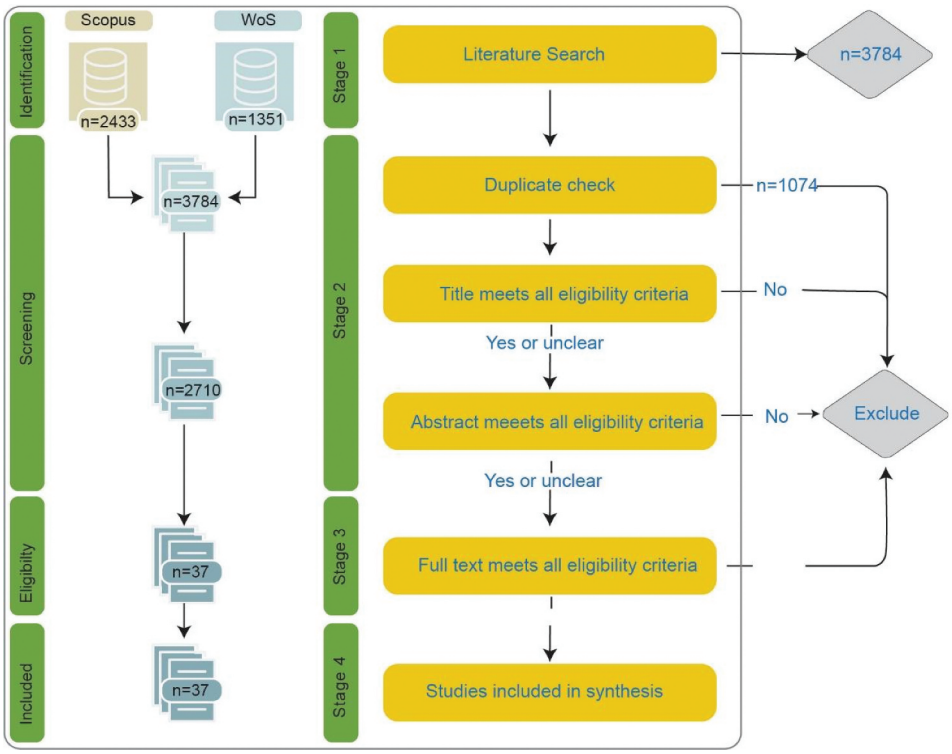


Figure 2. Selection process.

process, the studies were discussed until consensus was reached.

In this study, 37 papers were selected through the conducting method shown in Figure 2. While twenty-five of them are conference papers, 12 papers are journal articles. The number of documents published each year is displayed in Figure 3. There was no restriction on the year of the study; however as it was conducted in 2023, no data from that year were found. The initial studies in this field date back to 1995. A bibliometric analysis indicates that despite the serious issue of earthquakes, there has not been a notable rise in articles published in journals. However, there is a slight increase in the number of conference papers from 2000 to 2022. The *Journal of Architectural Engineering* published the most papers based on our selection criteria, while the American Society for Engineering Education (ASEE) conference published the most outcomes related to seismic design education.

Figure 3 displays the number of document types and the scientific journal rankings (SJR) of the selected journal articles. The selections were acquired using the method outlined in Figure 2. Based on SJR analysis, out of twelve selected articles, five are from Q1, four are from Q2, one is from Q3, and two are from Q4 quartiles. The majority of studies in this sector are concentrated in the first and second quartiles, suggesting higher-quality output despite the limited quantity.

4. Findings

In this section, the publications identified through systematic screening are examined in accordance with the research questions. The analysed publications are categorized based on their study types, resilience cycle factors, and implementation areas (Figure 4). The classifications obtained for each research question are presented in section 1. In addressing the first research question, the research methods utilized in the selected studies are scrutinized using a modified version of Groat and Wang (2013) architectural research classification. As for the second question, Minnery's (2013) disaster resilience cycle model is employed to classify their focus on resilience cycle. This model enables an assessment of where the subjects of the analysed publications fall within the disaster resilience cycle. Lastly, the studies are categorized based on their adaptation to various courses, lecture topics, design studios'

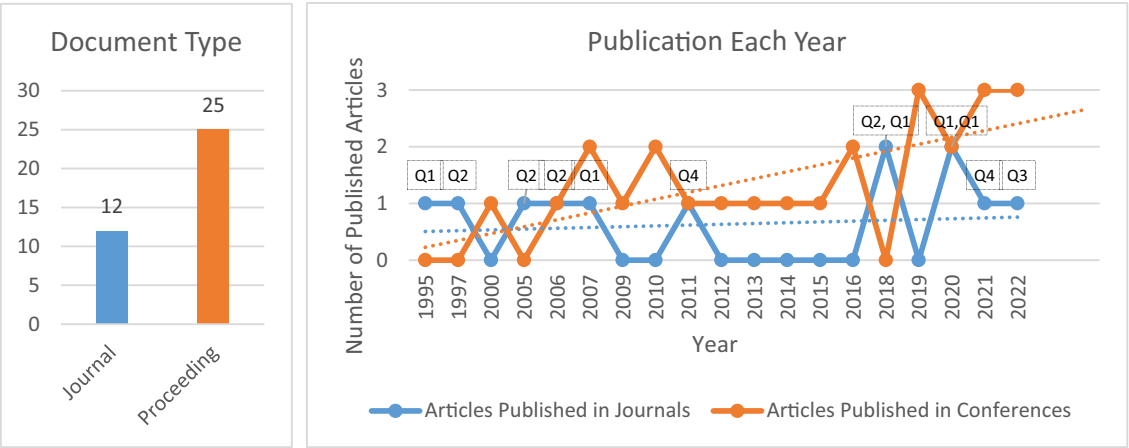


Figure 3. Quantity of published content each year, document types.

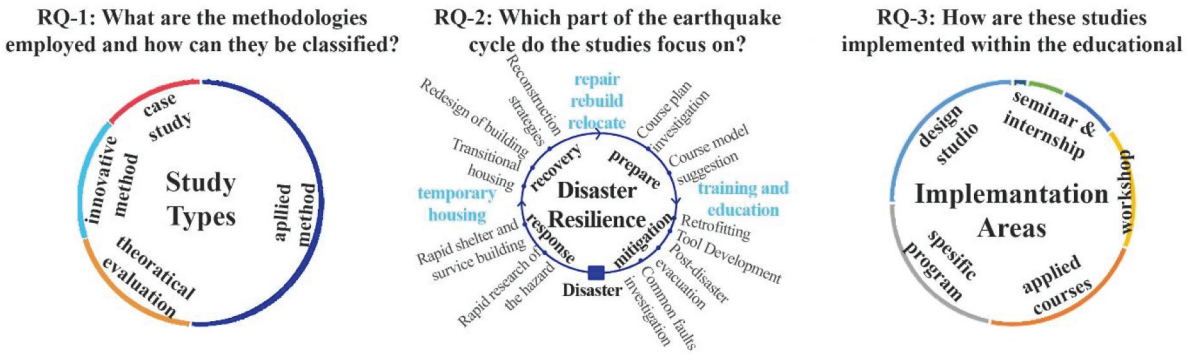


Figure 4. Classifications obtained for each research question.

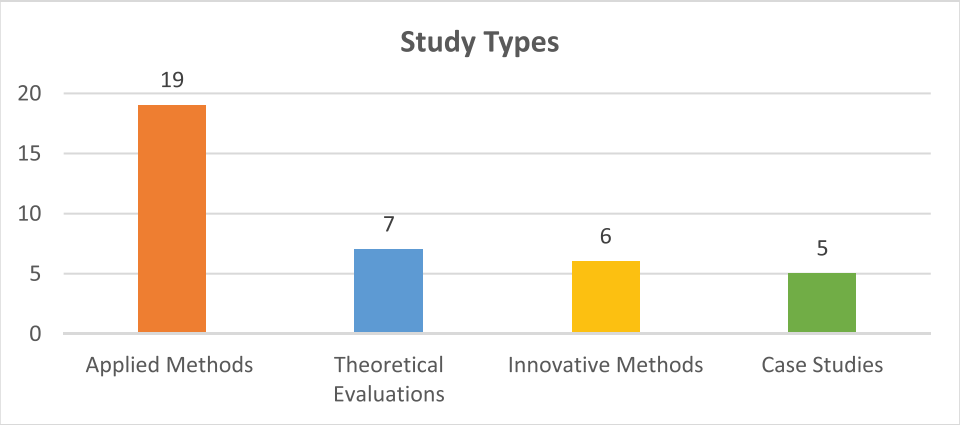


Figure 5. Study type distribution of the selected studies.

project themes, and design parameters, addressing the third research question.

4.1. Study types

In this section, reviewed documents are categorized into four main groups according to their methods (Figure 5). In the field of seismic design education, the majority of the studies are applied studies. It is followed by theoretical evaluation, innovative methods and case studies respectively.

The category of applied methods holds a prominent position in seismic design education contributing significantly to the field. These studies actively engage students in various activities, including design projects, large-scale prototyping, shaking table tests, and production, aiming to instil a deep understanding of the fundamental principles of seismic design. For instance, Cardinale et al. (2021) demonstrated life-size timber load-bearing walls subjected to various loads for behaviour testing. Similarly, Williams et al. (2019) conducted large-scale prototype fabrication and shaking table testing for steel structures. Estes, McDaniel, and Zavala (2016) adopted a unique approach, using K'nex toys for prototype production followed by shaking table tests.

Lucko et al. (2007) advocated a student-centred seismic design course, emphasizing active participation in literature presentations, creative design studies, and laboratory testing. Building on this strategy, Morales-Beltran and Yildiz (2020) challenged students to model the structural systems of their design studio projects before conducting shaking table tests. Post-course surveys of this study revealed that practical applications reinforced theoretical knowledge, significantly enhancing overall course enjoyment for the majority of students. Despite these benefits, challenges persist due to limited accessibility to necessary equipment and laboratory space in many universities. To address this issue, Tsujihara et al. (2021) developed an economical shaking table test model, potentially expanding the reach of seismic design education. The applied methods provide students with the opportunity to understand the practical implications of SDP in real-world contexts through tests such as diverse load behaviours or shaking tables (Lucko et al. 2007; Morales-Beltran and Yildiz 2020) employed in professional work life, as well as the implementation of prototypes of different scales (Cardinale et al. 2021; Morales-Beltran, Eigenraam, and Latka 2019; Williams et al. 2019) in educational settings. The diverse applied methods presented highlight not only the diverse nature of seismic design education but also the critical role of practical applications in helping students gain a deeper understanding of SDP.

In addition to prototyping, applied methods also include design project studies, often focused on post-disaster design and reconstruction. For instance, Shah and Chauhan (2010) tasked students to investigate the settlement area in the Kalyanpur region after an earthquake and create post-earthquake housing using local materials. Krishnan and Liao (2019) employed digital prototyping for post-disaster residential design; this methodology was also similarly applied by Lončar-Vicković, Krajnović, and Kamenarić (2022) in the context of shelters. Wesener (2018) engaged 35 landscape engineering students in the design of public spaces for an earthquake-devastated city centre.

The study by Cowan, Ogle, and Svarczkopf (2007) delves into project courses where architecture students engage in designing post-earthquake shelters. This study utilizes ethnographers' interviewing, journaling, and phenomenological methods in project courses to underscore a human-centric approach, emphasizing collaboration with affected individuals rather than treating them as mere objects. This inclusive methodology opens avenues for diverse perspectives, thereby creating a robust database that holds immense potential for future research and educational endeavours.

Morales-Beltran et al. (2019) focused on the need for clean water in post-earthquake zones, conducting

a water tower design studio integrating both physical and digital prototyping. A similar investigation by Ünay and Özmen (2006) assigned students with bridge design, implementing small-scale physical models and digital simulations. This study also demonstrated that post-testing discussions provided a platform for students to develop ideas for enhancing these behaviours, contributing not only to practical design experience but also to a profound comprehension of SDP.

Morales-Beltran, Charleson, and Aydin (2020) introduced "sawtooth mouth" technique to the design project, which belongs to the discipline of climbing. The approach was initially created to help individuals adjust to low-pressure surroundings using brief breathing exercises. By analogizing the design and climbing processes, students were tasked with concentrating on different facets of the design journey, allowing them the flexibility to step back, reconsider, generate alternative solutions, and focus again. However, it is worth noting that the effectiveness of this method appears to be contingent on the project's size, as the sawtooth method may be less impactful when applied to small-scale projects where integration is more seamless.

Some studies under this category focused on collaborative projects. Kalay and Black (2000) undertook a multidisciplinary redevelopment project for Oakland's First Baptist Church, heavily damaged by earthquakes. A similar multidisciplinary project by González and Irizarry (2022) in Puerto Rico involved interdisciplinary workgroups in a comprehensive examination. Vidot Vega (2022) focused on the conceptual design and evaluation of a potential structure for vertical evacuation in Guanajibo, Mayaguez, and Puerto Rico, aiming to provide students with interdisciplinary teamwork experience to address real-life challenges related to earthquake hazards.

In addition to these multidisciplinary studies, collaborative efforts with the local community were noteworthy. In Mwangi's study (2013b), students actively participated in practical tasks collaboratively with construction workers, such as concrete mixing, reading plans, cutting reinforcement, and tying rebars. Similarly, Neumann et al. (2014) organized educational workshops involving local community members and university participants, focusing on preserving and reinforcing locally made adobe architectural examples against earthquakes.

In the theoretical evaluation of seismic design, there were various studies that focus on measuring seismic design knowledge through surveys and providing course recommendations for seismic design education. In a study by Adhikari, Mosier, and Langar (2020), a survey method was employed to determine students' experiences with natural disasters, explore sources of knowledge for resilience against them, measure knowledge about post-disaster evacuation, and evaluate disaster preparation obtained through university education. Similarly, Theodoropoulos (2006) conducted a survey to explore the approaches of NAAB-accredited architecture schools in the United States toward seismic design education. The study found that design studio courses, where students experientially learn the design process, are considered the most suitable context for seismic design education. Despite this recognition, existing architecture education plans face limitations in terms of credit hours and course numbers. Theodoropoulos highlighted the challenges of integrating seismic design courses into the current curriculum due to these constraints. Acknowledging the difficulty of integrating seismic design into architectural education, A. Charleson (2018) outlined a series of fundamental and comprehensive topics for seismic design education, as presented in Table 4.

Another survey study conducted by Soyluk and Harmankaya (2012) aimed to identify the knowledge of last-year undergraduate students about irregularities in structures and assess the impact of a provided PowerPoint presentation. Pre-test results revealed a common belief among participants that earthquake

Table 4. Minimum and maximum topics to be covered for seismic design education (A. Charleson, 2018).

Lecture Topics	Min	Ideal	Max
Nature of earthquake and their shaking	X	X	X
How buildings resist earthquakes	X	X	X
Horizontal structure (diagrams, bond beams, collectors)	X	X	X
Vertical structure (frames, walls, braced frames)	X	X	X
Horizontal configuration (torsion and other issues)		X	X
Vertical configuration (soft stories and other issues)		X	X
İntegrating seismic design and architecture		X	X
Nonstructural elements (that affect structure and others)		X	X
New technologies (including seismic isolation)		X	X
Seismic design approaches now and previously		X	X
Retrofitting			X
Foundations and geotechnical issues			X
Urban planning (including tsunami and fire)			X
Earthquake architecture			X
Total	4	10	14

regulations were more the responsibility of civil engineers than architects. However, after the PowerPoint presentation, respondents demonstrated increased awareness of architectural design's importance in the seismic performance of buildings and the roles and responsibilities of architects in seismic design. The study also underscored the importance of laws and regulations for seismic resilience and highlighted the need for adequate education to implement them. Similarly, to demonstrate the importance of seismic design training, Özdoğan and Güney (2016) conducted a comparative study according to the content of seismic design courses in architecture schools in Türkiye, Japan, Italy, and the USA. Subsequently, a survey study was prepared to understand and evaluate the disaster preparedness of architecture students. Despite participants' awareness of the importance of disasters, architecture students expressed concerns about lacking sufficient background and knowledge for professional life. The study revealed students' feelings of unreadiness in the subject and their desire to learn seismic design criteria for disaster-resistant buildings.

Addressing the challenge of seismic design education, the RISE-UP (Resilient Infrastructure and Sustainability Education – Undergraduate Program) project in Puerto Rico, initiated by the National Science Foundation (NSF), stands out (Daza, Cavallin, and Lopez Del Puerto 2021; González and Irizarry 2022; Lopez Del Puerto et al. 2020; Vidot Vega 2022). This project aims to develop an integrated curriculum for resilient and sustainable infrastructure, with the overarching goal of educating future architects, environmental designers, and engineers to contribute to the creation of a more resilient and sustainable infrastructure in Puerto Rico.

Overall, these studies underscore the multidisciplinary nature of seismic design. In response to this recognition, Özmen and Ünay (2011) conducted an investigation that specifically focused on fostering collaboration between architects and structural engineers in the context of seismic design education. Their research delved into methods for a redevelopment project aimed at creating a common learning platform for architects and structural engineers, seeking to establish a more harmonious future professional collaboration with a focus on renewing existing structures.

Case studies play a crucial role in seismic design research by providing valuable insights into earthquake-prone regions. These studies vary from local analyses, which focus on the behaviour of structures during seismic events, to more comprehensive examinations of regions from a social and political standpoint. The local analyses aim to impart seismic design knowledge to students by investigating how structures in a region respond to seismic events. In contrast, general analyses examine local authorities' enforcement of seismic design regulations as well as seismic awareness education for the community. These studies collectively aim to equip students with the capacity to critically analyse seismic resilience strategies.

Brighenti's study (Brighenti 2021) provides an in-depth exploration of post-earthquake reconstruction and rebirth strategies, utilizing the renewed municipal structures of Amatrice, Norcia, and Camerino in Italy. Daza, Cavallin, and Lopez Del Puerto (2021) contribute insights from the Elvira Vicente school in Puerto Rico, investigated as part of the Rise-Up project. This case study diligently examines how structures behave during disasters, identifies stakeholders in the production process, and investigates potential errors in production. The subject structure was also digitally modelled and examined for earthquake loads. Based on these tests, retrofitting recommendations were then developed. Subsequently, a cloud-based case study repository was established for further investigations. A similar local case study was also conducted by Santa Ana and Santa Ana (2021) to educate architecture and civil engineering students by examining six iconic high-rise buildings in Mexico City, emphasizing material, structure, earthquake, and soil property relationships.

Hedges (2011) conducted a more comprehensive examination based on the 2010 haiti earthquake, involving 44 third-year architecture students. This comprehensive study extends beyond structural considerations, encompassing the region's social dynamics in three stages: before, during, and after the earthquake. Özmen and Ünay (2007) focus on common seismic design errors in residential structures in Türkiye. The case studies not only allow students to develop critical thinking abilities, but they also address the issue of inadequate educational materials. The studies contribute practical solutions by accumulating a valuable repository of real-world cases and analyses, creating a continuously expandable knowledge archive through successive iterations. In essence, case studies play a pivotal role in advancing seismic design education, bridging theoretical knowledge with practical insights.

Innovative methods include studies that utilize digital and technological tools. For instance, Okamoto et al. (2015) have pioneered the development and utilization of digital shake table test software and implemented it in seismic design education. Through subsequent surveys with students provided evidence that this program significantly contributed to enhancing students' comprehension of structural behaviour during seismic events. In a parallel vein, initiatives like the one by Wijanto, Andriono, and Tjondro (2010) have established e-networks, fostering an environment for students to exchange ideas and support one another. This initiative study foresees the designated website as a comprehensive e-learning resource platform for seismic design standards, and research outcomes.

A distinctive approach taken by Setareh et al. (2005) involved conducting shake table tests within a virtual reality (VR) environment. The outcomes of this study revealed heightened interest and increased class participation following the integration of VR into seismic design education. Moving beyond traditional shake table tests, some studies explore the integration of various digital analysis tools into seismic design education. In the study by Estrada and Lee (2009), the use of five different software programs facilitated the execution of complex mathematical operations integral to seismic engineering analyses. These digital tools, encompassing Excel, Matcad, and RISA 3D, empower students to develop the essential skills required for modern seismic analysis and design.

Another intriguing exploration, as undertaken by Ünay and Özmen (2006), involved architecture students participating in a studio course where they were assigned the task of designing bridges. Employing SAP2000 software, students conducted static analyses on digital models of their designed bridges. Despite having acquired substantial theoretical knowledge in seismic design through their architecture courses, students encountered challenges when translating this knowledge into practical applications for their projects. This study proposed the integration of digital simulation tools into design studio courses as a potential solution to bridge that gap.

According to Morales-Beltran and Yildiz (2020), seismic design education, often imparted by engineering professors within structural system courses, poses a unique challenge for architecture students. The traditional trajectory of engineering courses, progressing from simpler to more complex topics, conflicts with the typical progression in architectural education, which moves from holistic understanding to detailed aspects. To reconcile this disparity, seismic design education, when tailored to architectural contexts, must encompass both quantitative and qualitative contents. In alignment with this perspective, A. W. Charleson (1995) introduced the "Resist" software, designed to empower students to upload their designs and analyse them using SDP. A. Charleson (2018) delved into the practical application of this software in seismic design education, presenting insights gained from student feedback. Survey results indicated a notable increase in understanding and confidence among students in integrating seismic resistance principles into their designs. However, some students expressed challenges in accurately modelling their buildings, signalling the need for ongoing improvements in the software's versatility and functionality to align with contemporary standards. Furthermore, this review also supports Theodoropoulos's (2006) finding that there aren't enough digital tools and educational materials for seismic design in architectural education. In this field, there are no studies on the use of XR tools, which are very popular in many educational subjects. Only Setareh et al. (2005) used the desktop VR tool.

4.2. Resilience cycle factor

This section of the study examines the selected studies to classify their placement within the disaster resilience cycle and the specific factors they emphasize. This classification was conducted to allow the possibility that a single study might contribute to multiple steps in the cycle, as illustrated in Figure 6. Given the educational focus of this literature review, it becomes evident that the majority of the selected studies are placed in the preparedness phase of the disaster resilience cycle. The remaining studies are distributed in increasing order in the recovery, response, and mitigation phases. This analysis also shows the common themes within the selected studies and emphasizes their contributions to distinct stages of the disaster resilience cycle.

Among the selected studies, there are four that focus on the response phase. These studies centre around topics such as rapid damage assessment and the swift production of shelters. In the study by Cowan, Ogle, and Svarczkopf (2007), one month after the 2006 earthquake in the Jogjakarta region of Indonesia, researchers visited the area with students to conduct on-site investigations. During this research, they employed interview and participatory observation techniques that are commonly used by anthropologists. Other studies concentrating on the response phase provided students with the design challenge of post-disaster structure production. In these studio-based studies, Krishnan & Liao, (2019) and Lončar-Vicković, Krajnović, and Kamenarić (2022) selected shelter design, while Morales-Beltran et al. (2019) took a unique approach by choosing water tower design as a design problem. This not only drew attention to the need for clean water in post-disaster areas but also directed students to focus on structural system design rather than spatial relationships.

Studies in the recovery phase are categorized into three main themes. The first focuses on redesigning structures that are damaged after an earthquake. Kalay and Black (2000) addressed this by examining the structure of Oakland's First Baptist Church in a design project. The second theme in this phase is reconstruction strategies. The distinction between reconstruction and redesign lies in the fact that while redesign projects involve reprogramming, reconstruction projects do not involve a change in function. In Brighenti's study (Brighenti 2021), the reconstruction processes of municipal buildings demolished due to an earthquake in Italy were investigated. Shah and Chauhan (2010), and Mwangi (2013) conducted reconstruction project studies involving students and the local community. In the last theme, which is transitional housing,

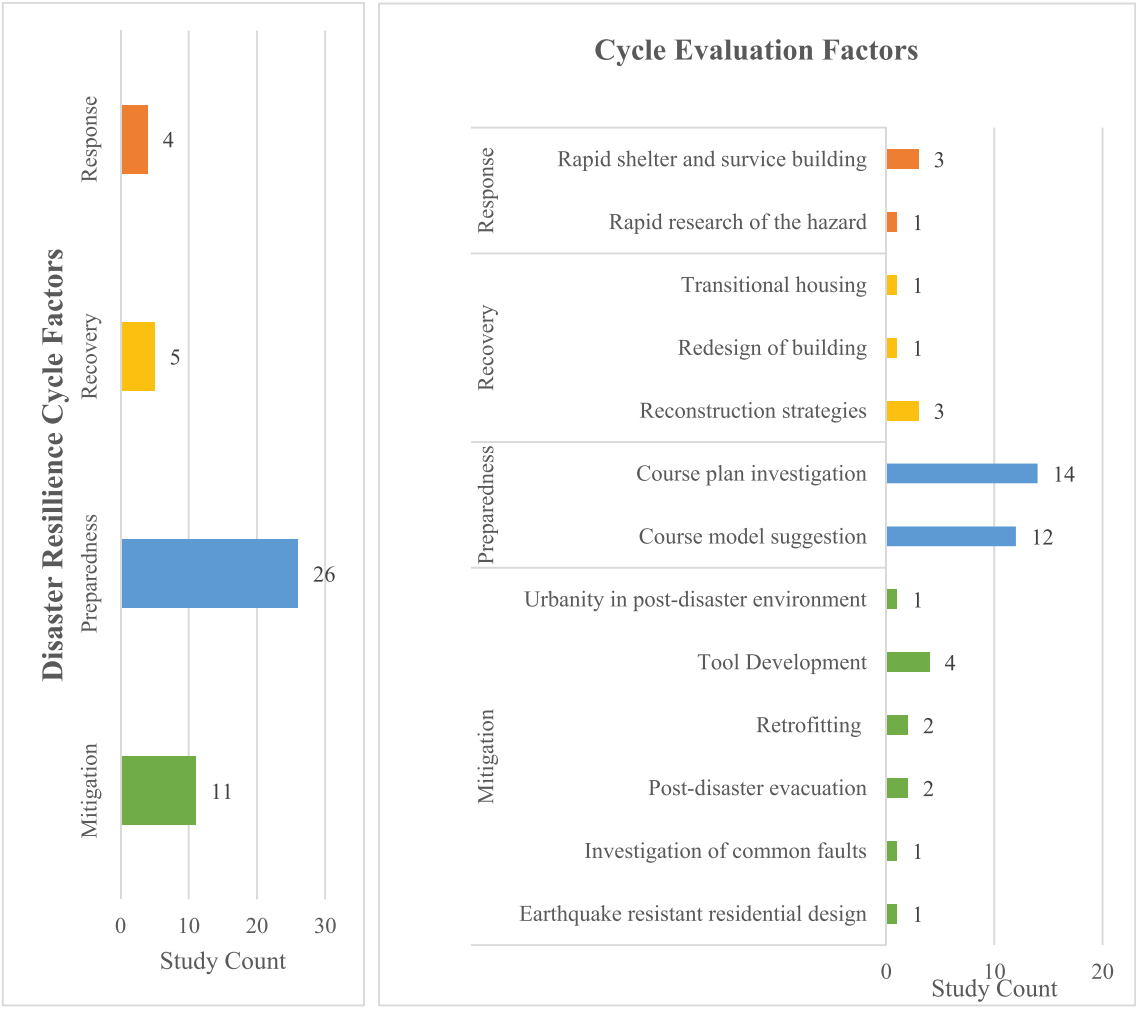


Figure 6. The distribution of studies according to disaster resilience cycle factors is on the left. The distribution of topics studied for each factor is shown on the right.

González and Irizarry (2022) conducted a studio project on the design of temporary housing for earthquake victims within the RISE-UP project.

In the examined studies, the most emphasized phase is the preparedness phase. This phase encompasses studies conducted within the context of courses. To classify these studies, two sub-factors, namely course plan investigation and suggestion, have been utilized. Investigation studies define activities conducted within an ongoing course, whereas suggestion studies propose either a new course or a novel instructional model for an existing course.

In studies under the course plan investigation factor, there are comprehensive investigations that analyse existing course plans both locally and through the broader educational framework. In the study by Özdoğan and Güney (2016), the undergraduate architectural programs in Türkiye, the United States, Japan, and Italy were compared in terms of disaster preparedness. The comparison revealed that, except for Japan, the curriculum plans in other countries were found to be weak in terms of direct content related to disaster preparedness. In another study by Theodoropoulos (2006) the seismic design programs of NAAB-accredited schools were scrutinized. Additionally, a survey was conducted with instructors to evaluate seismic design education in architecture schools in the United States, identifying problematic points. This study highlights the challenge of not allocating sufficient importance and time to structural system design in design studios and the shortage of expert instructors in structural system design, which contributes to the difficulty of integrating technical aspects of building design into the architectural design process. In a similar study by A. Charleson (2018) identified three fundamental problems in seismic design education in architecture: a weak connection between studio and static courses, a lack of sufficient resource materials for earthquake education and a deficiency in digital software.

In studies conducted within existing courses, various methods aim to impart earthquake preparedness to students. However, a fundamental distinction from studies under the course plan suggestion factor is that these studies do not propose a new educational method. This section's studies encompass diverse

topics within existing course content. For instance, in the study by Hedges (2011), the 2010 haiti earthquake was used as a case within the computational-based structures course at Drury University. Architecture students were engaged in research and discussions based on real-life earthquake examples. In the work by Lončar-Vicković, Krajnović, and Kamenarić (2022), the design project focused on post-disaster shelter design in Croatia. Vidot Vega (2022) selected vertical evacuation structure design in Puerto Rico as the project topic within the RISE-UP project. Similarly, Morales-Beltran et al. (2019) focused on water tower design, while Lucko et al. (2007) chose shelter design as the project theme but uniquely implemented it in a two-semester project that included production experiments.

Within the category of course plan suggestions, 12 studies have been identified. In Charleson's study (A. W. Charleson, 1997), an examination of the optimal approach to seismic design education is provided. The paper discusses essential topics, potential educational materials, and outlines ideal instructor characteristics. However, it's notable that the suggested recommendations were not implemented. Another study by Estrada and Lee (2009) proposed a six-topic curriculum for seismic design education.

In Cardinale et al.'s study (2021), a practical course is designed to instruct on the behaviour of wooden systems under earthquake loads. Similarly, Williams et al. (2019) developed an applied course model evaluated across three terms with structural engineering students. This model involved design, build, and testing steps, ensuring an enduring understanding of the subject matter. Morales-Beltran and Yildiz (2020) devised an applied course model to teach SDP to architecture students, a departure from traditional seismic design teaching.

Krishnan and Liao (2019) crafted a comprehensive course model for a studio project on shelter design, integrating seminars, research topics, and practical implementation steps. González and Irizarry (2022) proposed a multi-disciplinary studio project model for post-disaster housing design within the RISE-UP project. Additionally, Lopez Del Puerto et al. (2020) suggested a multi-disciplinary program comprising four courses to equip environmental design and engineering students with earthquake-resistant design skills. Collectively, these studies demonstrate a diverse array of approaches to integrating earthquake-related topics into existing curricula.

When examining studies focused on the preparedness phase, it has been observed that the parameters used in these studies can be grouped. Based on this hypothesis, the distribution of parameters used in studies at this phase is presented in Figure 7. Among the grouped studies, only Santa Ana and Santa Ana's study (Santa Ana and Santa Ana 2021) was based on construction history. Two studies investigated the benefits of computer-aided presentations in seismic design education (Soyluk and Harmankaya 2012; Ünay and Özmen 2006). In two studies, survey studies were conducted to understand and measure thedisaster preparedness evaluation of architecture students (Adhikari, Mosier, and Langar 2020; Özdoğan and Güney 2016). In six studies, the focus was on transferring SDP for earthquake resilience to architecture students, rather than providing intensive static education similar to that in civil engineering.

In ten of the studies examined in the preparedness phase, collaborative teaching methods were either used or investigated. The majority of these collaborations consist of interdisciplinary design studio studies, as seen in González and Irizarry (2022). Additionally, Neumann et al. (2014) include collaboration with local communities and professionals. The distribution of participants in collaborative studies is shown in Figure 8. Only studies with clearly identified participants are shown in this table. It is observed that in architectural education, the most common

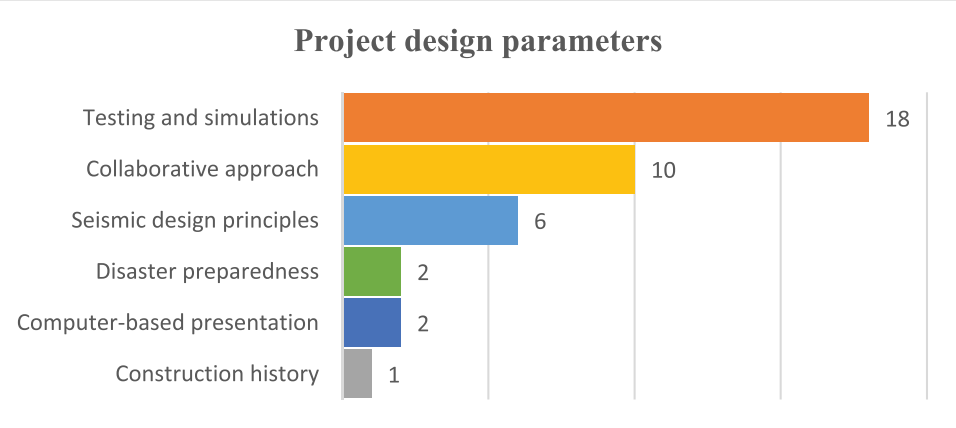


Figure 7. Distribution of studies focused on the preparedness phase according to their focus.

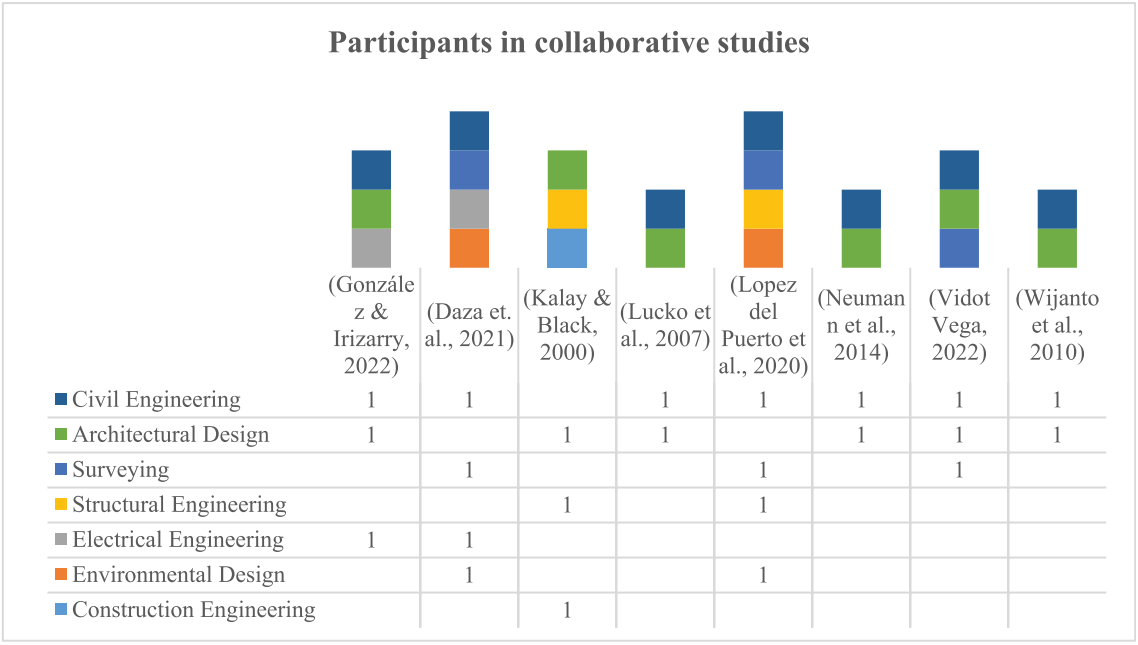


Figure 8. The distribution of participants in collaborative studies.

collaborative studies are conducted with civil engineering students, followed by surveying, environmental design and other engineering students. The number of studies conducted with other engineering disciplines is significantly limited compared to civil engineering.

The largest group consists of 18 studies focused on testing and simulation. The distribution of tools and methods used in these studies is presented in Figure 9. Upon examination, it is evident that shaking table experiments are frequently utilized in seismic design education. Shaking tables enable the simulation of earthquake scenarios, allowing students to practically observe the impact of earthquakes on structures. Therefore, this method is commonly employed in the literature. With advancing technology, these physical tests can also be simulated digitally. Setareh et al. (2005) and Ünay & Özmen (2006) included the use of digital simulation tools in their works. However, no comparative study has been found to determine which method is more effective for education.

In the examined studies, the second area with the highest number of works was the mitigation phase. The studies in this area cover general efforts towards earthquake risk mitigation. When the distribution of factors in these studies is examined, the most emphasized topic is the development of new tools for seismic design education. In this regard, Tsujihara et al. (2021) developed a portable shaking table. Okamoto et al. (2015) have developed a similar model for the digital environment. Setareh et al. (2005) have transferred digital simulation to a VR environment. Another study in this area is the software named RESIST by A. W. Charleson (1995). With this software, Charleson aimed to test students' designs in terms of SDP. However, since the software is in prototype mode, it does not allow for the modelling of complex structures, and therefore, it needs further development.

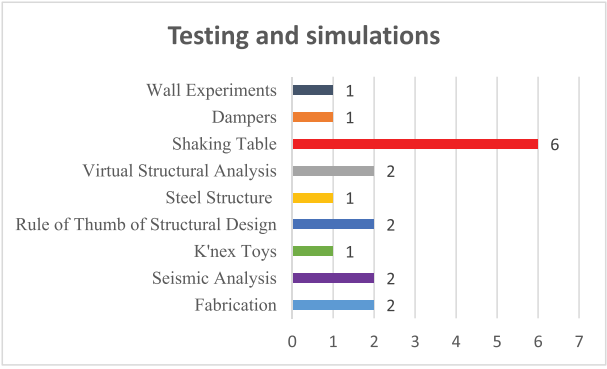


Figure 9. The distribution of tools and methods used testing and simulation studies.

The second important topic in the mitigation field is retrofitting and post-disaster evacuation. There are studies on retrofitting by Daza, Cavallin, and Lopez Del Puerto (2021) and Neumann et al. (2014). Especially in areas with earthquake risk, the improvement of aging building stocks is essential. There is a need for more studies on this issue in the education plans of architects who will work on this problem. In the studies by Adhikari, Mosier, and Langar (2020) and Vidot Vega (2022), students' awareness of post-disaster evacuation is questioned.

Özmen and Ünay (2007) examined common seismic design errors in Türkiye. This study is particularly important as a resource for studies focusing on teaching SDP in architectural education. Lucko et al. (2007) focused on earthquake-resistant housing design for canoe structures. Wesener (2018) addressed post-earthquake urban planning.

4.3. Implementation area

This part focuses on the examination and classification of the areas in which the selected studies were implemented and which SDP are implemented. Figure 10 displays the distribution of studies based on this classification. After examining the data, it is clear that applied studies are the most prevalent subject in earthquake design education. The second category, indicated as NA (Not Applied), encompasses studies in which the proposed model has not been deployed in any context or where the specific application domain is not well comprehended. These studies provide insights and recommendations for seismic design education, but they have not tested these suggestions. In the third category, studies implemented in specific programs are found. Here, specific programs refer to studies conducted within a certain undergraduate or graduate education group without any class or course restrictions. For example, in Özdoğan and Güney's study (Özdoğan and Güney, 2016), a survey was conducted on architecture undergraduate students.

In three studies (A. Charleson 2018; Morales-Beltran and Yildiz 2020; Theodoropoulos, 2006), it is stated that design studio courses are the most suitable place for teaching seismic design in architectural education. However, according to the analysis conducted in this study, design studios were ranked fourth. In these studies, the focus was on addressing post-earthquake regions or giving priority to seismic resilience in design criteria, aiming to encourage students to prioritize seismic design and thereby enhancing their skills. In addition to this, parallel seminars on seismic design were organized in studio studies (Krishnan and Liao, 2019; Ünay and Özmen, 2006).

The distribution of topics identified as design problems in design studio studies is presented in Figure 11. It is observed that the topics exhibit a non-skewed normal distribution. However, topics related to post-earthquake housing needs, such as residential and shelter design, are more frequently used compared to others.

(A. Charleson 2018; Morales-Beltran and Yildiz 2020; Theodoropoulos, 2006), (Krishnan & Liao, 2019; Ünay & Özmen, 2006) According to the analysis, fewer studies focus on supporting areas such as workshops, seminars, and internships. During internships, students have the opportunity to apply what they have learned in a professional working environment. Despite the prevalence of applied studies in seismic design education in the literature, only one study (Mwangi 2013b) specifically addresses internships.

The studies were examined in terms of which of the four main SDP listed in Table 2 they focus on teaching (Figure 12). Out of 37 studies, only 19 have addressed the SDP. In terms of study intensity, the SDP are lined up as structural, building, urban, and non-structural design principles. It has been observed that there are very few studies on urban design (Morales-Beltran, Charleson, and Aydin 2020; Özmen and Ünay 2007; Wesener 2018) and non-structural elements (Morales-Beltran, Charleson, and Aydin 2020; Mwangi 2013a). Although the majority focus

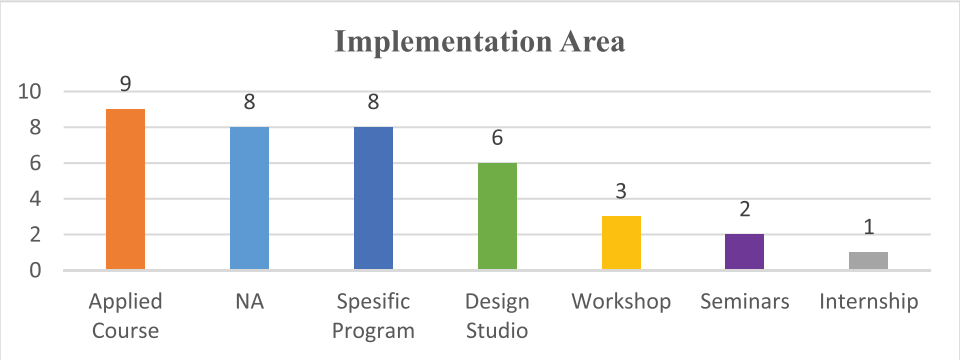


Figure 10. Implementation areas of the selected studies.

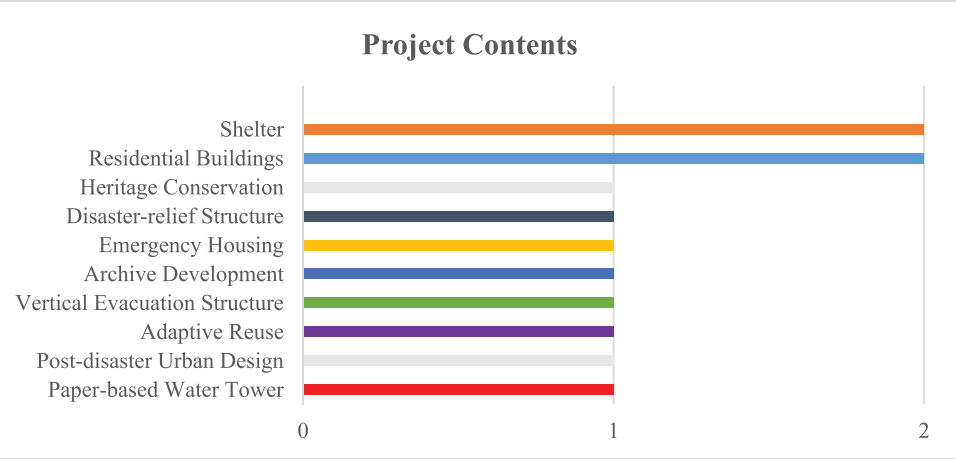


Figure 11. Project contents of the studies that were implemented in the design studios.

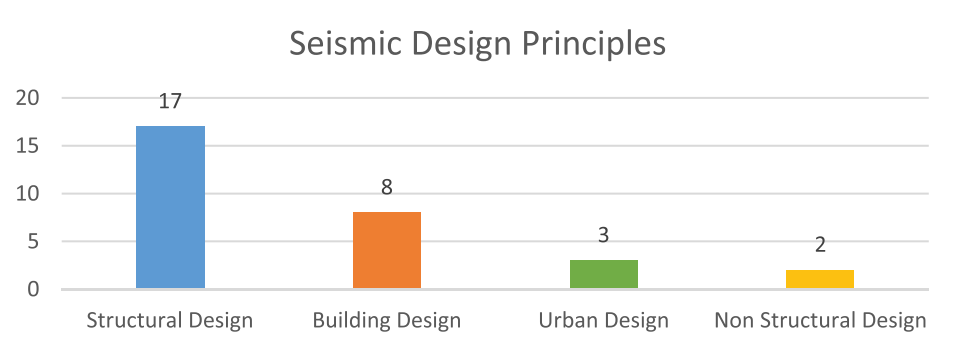


Figure 12. The number of studies that utilize SDP.

on structural and building design, all SDP were comprehensively covered only in Morales-Beltran, Charleson, and Aydin (2020)'s study.

5. Discussion

This section discusses existing literature findings and offers theoretical and practical recommendations. Studies using the applied method (Figure 9) highlight various approaches in seismic design education, enhancing academic understanding and providing insights for post-disaster scenarios (Krishnan and Liao 2019; Lončar-Vicković, Krajnović, and Kamenarić 2022; Morales-Beltran, Eigenraam, and Latka 2019) and urban redevelopment (Wesener 2018). The methods allow students to grasp real-world implications of seismic design through tests like load behaviours and shaking tables, as well as prototype implementations. Moreover, the case studies contribute practical solutions by accumulating a valuable repository of real-world cases and analyses, creating a continuously expandable knowledge archive through successive iterations. Despite their benefits, these studies lack well-structured instructional models and assessments to measure the success of these approaches.

Figure 13 shows the number of studies that utilize learning theories and models in existing studies. It can be seen that the number of studies applying them is quite low among all studies. However, learning theories and models play a critical role in educational practice because they have been developed to systematically explain student behaviour, learning processes and interactions. These theoretical frameworks guide educators to design, implement and evaluate effective instructional strategies (Khalil and Elkhider 2016). Learning theories can also assist in improving learning by understanding student requirements and motivations. Learning theories and models help educators create more effective, student-centred, and successful learning experiences.

The distribution of methods for measuring learning outcomes is shown in Figure 14. It reveals that the most common method is evaluating student feedback through questionnaires. However, this approach relies on participants' self-evaluation, which is more about attitudes and interest than actual learning performance, raising reliability issues. Therefore, more experimental studies are needed in this area. Table 5 lists the topics that can be focused on for future studies. These topics were determined in line with the analysis of Figure 14. Focusing on learning theories

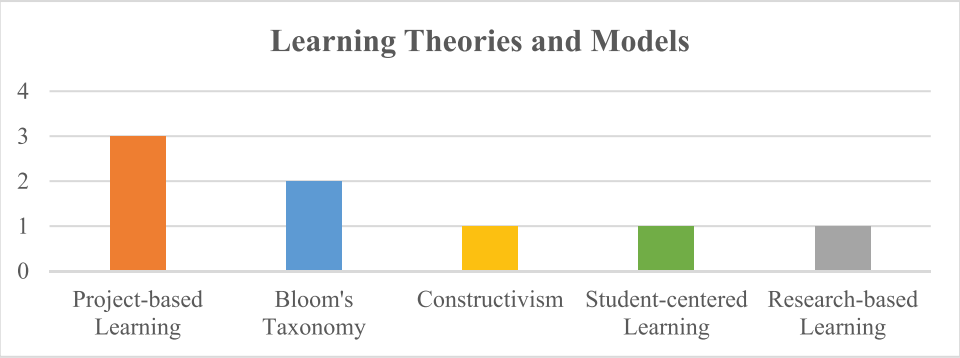


Figure 13. The number of studies that utilize learning theories and models.

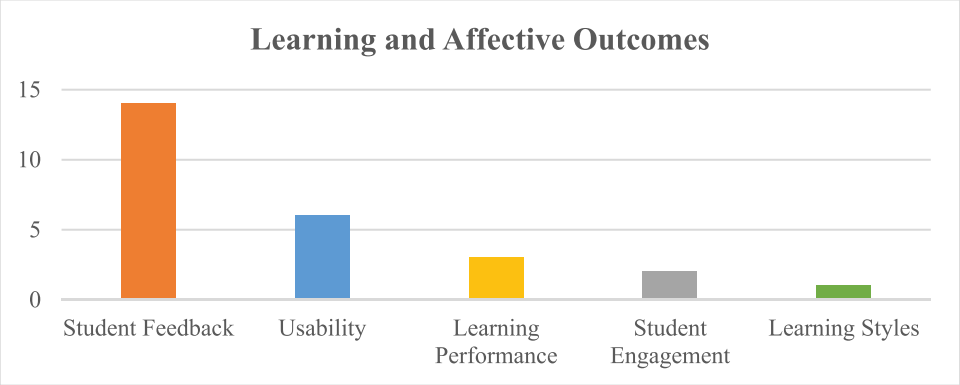


Figure 14. The distribution of the methods used to measure learning outcomes.

Table 5. Topics that can be focused on for future studies.

Application of learning theories and models in experimental studies
Development of instructional methods based on experimental studies
Allocating sufficient importance and time to SDP in design studios
Selection of topics in design studios according to the disaster resilience cycle
Contribution of experts on seismic design to architectural education
Development of adequate and up-to-date course materials for earthquake education: (i) Computer-based simulation of the principles of seismic design through students' own projects
(ii) Simulating structural movements during an earthquake with XR-based applications and making students experience them

and models in experimental studies to be conducted on seismic design in architectural education is very important to reveal the effectiveness of future studies. This may be an effective method to increase knowledge and skill acquisition in the field of seismic design. In addition, designing scientific studies in this field in accordance with the principles of experimental studies in the educational sciences can contribute to increasing the rigor of future studies and scientific robustness (Sung et al. 2019). This may contribute to the development of instructional methods based on experimental studies and empirical findings, and thus to more effective learning of seismic design in architectural education.

Although the field of seismic design is a very important topic for architectural education, only seven studies applied innovative methods and two methods adapted methods from other disciplines. Furthermore, this review also supports Theodoropoulos's (2006) finding that there aren't enough digital tools and educational materials for seismic design in architectural education. In this field, there are no studies on the use of XR tools, which are very popular in many educational subjects. Only Setareh et al. (2005) used the desktop VR tool.

This review critically assesses current educational approaches to disaster resilience, revealing a predominant focus on the preparedness phase to the detriment of recovery, response, and mitigation phases. This situation potentially leaves students ill-equipped for holistic disaster management. When the existing literature on course plan suggestions and investigations is examined, there are important findings, such as the lack of sufficient importance and time allocated to structural system design in design studios (Theodoropoulos 2006) and the lack of expertise in seismic design (A. W. Charleson 1997), a deficiency of

sufficient resource materials for earthquake education (A. Charleson 2018; Theodoropoulos 2006) and a deficiency in digital software (A. Charleson 2018). Despite these insights, there are a limited number of studies addressing these issues comprehensively. Furthermore, while some studies focus on specific design challenges during the response phase, integrating practical, real-world scenarios into educational settings remains a challenge. Studies examining the recovery phase highlight several key challenges. Despite efforts to redesign damaged structures and implement reconstruction strategies, there's notably less educational emphasis compared to the preparedness phase. This imbalance may restrict students' exposure to critical skills and knowledge necessary for effective post-disaster reconstruction and transitional housing initiatives.

Studies on disaster resilience education across preparedness, mitigation, and recovery phases underscore both progress and persistent challenges. In the preparedness phase, there's a noticeable emphasis on collaborative teaching methods. However, the predominance of civil engineering students in interdisciplinary collaborations suggests a need for broader integration of diverse engineering disciplines. Existing studies indicate limited interdisciplinary projects (González and Irizarry 2022; Kalay and Black 2000; Özmen and Ünay 2011). Moreover, efforts mainly focus on incorporating architecture students into civil engineering courses to develop computational skills in statistics. Conversely, involvement of civil engineering students in architectural design processes and methods remains sparse. Achieving consensus on structural design in architectural processes is crucial, necessitating architectural students' familiarity with SDP and civil engineering students' adaptation to design culture. In the mitigation phase, considerable efforts concentrate on developing new tools for seismic design education and retrofitting aging building stocks, particularly in earthquake-prone regions. Challenges persist in advancing digital tools like VR simulations and software prototypes, such as RESIST, requiring further development to enhance their effectiveness in teaching SDP and post-disaster urban planning.

When it comes to implementation area, although the existing studies in the field mostly emphasize the importance of seismic design education in design studios (A. W. Charleson 1997; Theodoropoulos, 2006), according to Figure 9, studies carried out in applied courses come to the forefront. In addition, existing studies show that internships are practiced in one study. When the topics in the design studios are analysed, it is seen that the topics related to shelter design and new building design are mostly studied. However, it is essential to keep in mind that another important issue related to seismic design is the retrofitting of existing structures. In addition, it is important to make use of the disaster resilience cycle in the process of determining topics in project studios. Because according to this classification, the needs of a shelter design and the process of retrofitting a building are different from each other. If students gain this perspective, they can approach seismic design issues more systematically.

The following part of this section addresses these issues with practical suggestions. We categorize these as: implications of SDP, collaborative relations, undergraduate course curricula, and innovative educational settings. Table 6 includes existing literature deficiencies and suggestions for seismic design education.

5.1. Suggestions on the application of seismic design principles

In architectural education, it should be emphasized that the criteria specified in Table 2 for SDP are not an obstacle to the creation of original design projects. It is important to discuss original architectural practices through high-quality examples where these principles are taken into consideration.

In architectural education, it is crucial to equip architect candidates with essential knowledge on urban design principles, including land use types, construction, transportation, infrastructure, and more. These

Table 6. Literature deficiencies and suggestions for seismic design education.

Problems	Suggestions
Inadequate attention to SDP in undergraduate course curricula and practical training.	Emphasize all SDP in undergraduate curricula and provide practical training through internships and real-world projects.
Lack of well-structured learning theory and instructional models	Incorporate well-structured learning theories and instructional models to measure the effectiveness of seismic design education approaches.
Predominant focus on disaster preparedness phase, with insufficient emphasis on recovery, response, and mitigation.	Balance focus across all phases of disaster resilience, including recovery, response, and mitigation.
Lack of sufficient digital software and resource materials for seismic design education.	Develop and integrate more digital software and resource materials for comprehensive seismic design education.
Insufficient interdisciplinary collaborations and integration in disaster resilience education.	Foster interdisciplinary collaborations, involving diverse engineering fields, in disaster resilience education.
Limited experimental studies on collaborative learning models and their application in seismic design.	Apply collaborative cognitive load theory and social learning theory to enhance collaborative learning in seismic design.
Deficiency in developing and using up-to-date course materials and innovative educational settings for seismic design education.	Develop and utilize up-to-date course materials and innovative educational settings, such as computer-based simulations and XR-based applications, for effective seismic design education.

principles directly impact the earthquake safety of densely populated areas. Emphasizing these topics in curricula, particularly at the urban design level, ensures adequate urban spaces for evacuations and well-organized road systems that align with evacuation and emergency response requirements. In education, the necessary equipment should be provided on earthquake safety issues related to the "planning" process, such as land use types, construction, transportation, circulation and infrastructure. Students should be equipped to evaluate scientific data for site selection in both temporary and permanent settlement areas.

Emphasizing the need to devote sufficient time and attention to SDP in design studios supports the creation of an environment that supports students in developing their skills in this area. This can help students integrate SDP when working on real-world projects and can help them be better prepared for practice after graduation. In addition, in the process of determining the topics to be presented to the students in the project studios, according to the resilience cycle can allow for a systematic approach to seismic design.

5.2. Suggestions on collaborative design

The literature highlights a limited number of studies carried out by architecture students from various engineering fields, particularly civil engineering. Additionally, it is important for architecture students to acquire expertise for large-scale decisions and an integrated approach with "urban planning" students. These decisions can be guided by the urban design principles outlined in Table 2.

It is seen that experimental studies on collaborative working models are lacking in the literature. At this point, collaborative cognitive load theory (Janssen and Kirschner 2020; Kirschner et al. 2018) and social learning theory (Li, Hong, and Craig 2023) from the field of educational sciences can be examined. These theories examine the learning performances of individuals in collaborative learning with cognitive and affective factors. Both collaborative cognitive load theory (CCLT) and social learning theory emphasize the importance of social interaction and cooperation in learning. CCLT suggests that cognitive load can be managed more effectively when distributed among group members, making complex tasks more manageable. Social Learning Theory, posits that individuals learn from observing, imitating, and modelling the behaviours of others, with motivation and social reinforcement playing key roles.

In seismic design studies, CCLT can be applied by distributing tasks among interdisciplinary teams, such as those in the projects by Kalay and Black (2000) and González and Irizarry (2022), allowing students to share the cognitive load and enhance their understanding through collaborative problem-solving. Social Learning Theory can be implemented by involving students in hands-on activities with local communities, as seen in Mwangi's study (2013) and Neumann et al. (2014)'s studies, where students learn through observation and active participation. This approach not only improves technical skills but also fosters motivation and emotional engagement, leading to a more comprehensive grasp of disaster resilience and preparedness.

In architectural education, future architects should be taught that they will have a significant role in fostering cooperation and coordination with other professionals. Therefore, as suggested in Özmen and Ünay (2011, 2006) studies, the ability to establish interdisciplinary relationships should be taught during the architectural education process by creating collaborative environments with engineering and planning students. The structure of both theoretical and practical courses within undergraduate education should be developed not only through the knowledge of civil engineers or architects alone but through interdisciplinary discussions and experimental trials. Additionally, undergraduate programs should be supported with extracurricular workshops (Brighenti 2021; Morales-Beltran, Eigenraam, and Latka 2019; Wesener 2018) and seminars (Krishnan and Liao 2019; Neumann et al. 2014).

5.3. Suggestions on undergradute course curricula

Methodologically, there is a reliance on qualitative methods that may overlook quantitative aspects essential for holistic disaster resilience understanding. Addressing these gaps could enhance learning outcomes and ensure that students develop robust skills across all phases of disaster resilience and contribute effectively to disaster preparedness and response efforts.

In architectural education, with regard to the response phase, it is essential to emphasize the importance of goals that protect and enhance human dignity and rights in the planning of temporary sheltering or permanent housing areas (Ayyıldız Potur and Metin 2021). Additionally, it is crucial to include the displacement process caused by these response phase studies into architectural education. This will ensure that, future architects develop sensitivity to this issue and avoid settlement and planning decisions that could victimize the local population.

Additionally, the identified challenges in curriculum content and integration suggest a need for comprehensive reforms to better prepare students to engage in rebuilding efforts and to address the diverse needs of disaster-affected communities. It is essential to consider the needs and socio-cultural conditions of these community members. Creating designs that respect

the culture and lifestyle of the affected community is crucial. Moreover, creating affordable designs that meet the economic criteria of affected communities will ensure their social sustainability (Colantonio et al. 2009). Therefore, understanding social sustainability should also become an essential part of architectural education.

Internships are important because they give students the opportunity to practice designing earthquake-resistant buildings, interact with experts in the industry, gain experience through mentoring, acquire real-world experience, and collaborate in teams. In addition to strengthening the theoretical knowledge of seismic design, these internships can provide students with the opportunity to follow developments in the sector and gain practical skills.

The centralization of the architectural curriculum around design studios (Ghonim and Eweda 2018) and the significant problems with the availability of mathematics courses in the architectural curriculum (Erman 2005) affect the integration of SDP into the architectural education. One way to solve this integration problem could be through extracurricular activities, but it is unclear to what extent student participation can be ensured. An alternative solution could be for students to complete internships focusing on SDP.

The engineering-based knowledge of SDP should be taught to architecture students at a level and scope that they can apply in their professional careers.. Otherwise, Morales-Beltran and Yildiz (2020) show that students tend to distance themselves from or fail to adopt these principles. In addition to SDP, architectural education should also include courses on professional ethics, where laws, regulations, and practices related to life safety are evaluated from an ethical perspective. So that, future architects can be educated on how to take a stance against illegal constructions that do not comply with building standards.

SDP should be integrated into both theoretical and practical courses. Especially in design studio courses, which are fundamental in architectural education, students should apply SDP that they have learned in their theoretical courses. The integration of disaster-related themes in design studio courses should vary not only in terms of disaster processes (response/during disaster/post-disaster, etc.) but also in terms of the type of disaster. Moreover, this integration should also be evaluated as a criterion for student success. Therefore, design studio courses should include expert academics in seismic design. However, not every university has a sufficient number of academics who are specialized in structural systems. In such cases, professionals with adequate experience in seismic design can be invited to design studios in roles such as studio instructors, guest speakers, or jury members. This ensures that both students and the academic environment stay current in this context. To overcome the shortage of expert academics, it is crucial to increase the number of graduate programs related to disasters/earthquakes. These programs should involvie architects, expandtheir subject areas and enhance theirimpact to support architects in developing expertise in seismic design(Ayyıldız Potur and Metin 2021).

5.4. Suggestions on innovative educational settings

The development of adequate and up-to-date course materials for earthquake education is important for effectively providing information to students. This may include teaching SDP to students through computer-based simulations. By practicing with computer-aided simulations on their own projects, students can better understand and apply theoretical knowledge. Furthermore, simulating the structural behaviour during an earthquake with XR-based applications can give students real-time experience and help them better understand the complexity of seismic design. For example, Kuncoro, Ichwanto, and Muhammad (2023) developed a VR-based earthquake-resistant construction application for civil engineering students and analysed it with students. Similar studies can be conducted to teach SDP to architecture students. These studies can support the practical application of theoretical knowledge and help students to make safer and more informed decisions in the field of seismic design.

As Lucko et al. (2007) and Morales-Beltran and Yildiz (2020) suggest, architecture students can simulate the impact of seismic design principles on structures using shaking tables. Integrating the shaking tables not only in practical courses but also in design studio courses is crucial for the sustainability of learning and its impact on professional processes. This allows students to see the earthquake resistance of their own designs and integrate SDP into their designs. As Theodoropoulos (2006) emphasized, not every school has access to such tools. However, alternative economical (Tsujihara et al. 2021) or virtual simulation based (Okamoto et al. 2015) devices can be used for this purpose.

In architectural education concerning SDP, it is beneficial to emphasize not only mandatory curricula and informal workshops but also competitions that are accessible to both students and graduates. These competitions can play a crucial role in fostering deeper engagement with SDP. They should be designed to vary in scale, focusing on different types of disasters, involving diverse disciplines, and ranging from conceptual exploration to practical application. This approach not only enhances learning by encouraging practical application of SDP but also promotes interdisciplinary collaboration and innovation in addressing seismic challenges (Ayyıldız Potur and Metin 2021). Such initiatives can further enrich the

educational experience by providing platforms where participants can explore creative solutions and contribute meaningfully to resilient architectural practices.

5.5. Research limitations

This systematic review, aimed at seismic design education in architecture, is not without its inherent limitations. It is important to acknowledge certain limitations that may influence the interpretation of the findings and the generalizability of the results. These limitations can be listed as:

- The studies included in this review were obtained through systematic search procedures (Figure 2); however, it is possible that relevant studies published in non-indexed journals or non-English proceedings were overlooked. This may introduce publication bias to the findings.
- The review is based on literature available up to the knowledge cutoff date in March 2023. Consequently, more recent studies may not be included, potentially affecting the comprehensiveness of the analysis.
- Assessing the quality and the classification of the included studies, especially those using qualitative methodologies, may be subject to interpretation. The subjective nature of quality assessment could introduce biases.
- The classification process of the studies in this review was conducted through grouping based on similarities identified by the authors. The number of groups formed during this process may impact the depth of analysis in specific areas.

Despite these limitations, this systematic review serves as a valuable contribution to the understanding of seismic design education in architecture. It sheds light on existing practices while acknowledging the need for future research to address these limitations and provide a more comprehensive perspective.

6. Conclusion

This review fills the gap in earthquake-related content within architectural curricula and supports the integration of this subject into educational programs. The systematic literature review addressed three key research questions: the methodologies employed in the field, the phases of the earthquake cycle studied, and the implementation of these studies within the educational process. Additionally, it examined the application of seismic design education in theoretical, practical, and studio courses and discussed the challenges of incorporating these courses into the existing curriculum.

The review contributes to the ongoing discussion on improving architectural education to address real-world challenges and create more resilient communities. By examining various approaches to seismic design education, it enhances academic understanding and provides insights for disaster scenarios and urban development. However, it also highlights the low number of studies applying learning theories and models, and the lack of digital tools and educational materials for seismic design in architectural education. Furthermore, the review underscores the need for broader integration of diverse engineering disciplines, incorporating civil engineering students into architectural design processes, and developing new tools for seismic design education. Practical implications are categorized into design principles, collaborative relations, undergraduate course curricula, and innovative educational settings.

The review emphasizes the application of design principles in architectural education, stressing the importance of urban design principles, collaborative design, and a focused undergraduate course curriculum. It suggests that architectural students should be equipped with knowledge of urban design principles such as land use types, construction, transportation, and infrastructure to ensure earthquake safety in densely populated areas. Collaborative design can be enhanced by distributing tasks among interdisciplinary teams and involving students in hands-on activities with local communities. Undergraduate programs should focus on quantitative aspects and integrate seismic design issues into the architectural curriculum. Internships can provide students with real-world experience and practical skills. Innovative educational settings, such as computer-based simulations and XR-based applications, can help students better understand the complexity of seismic design. The review acknowledges several limitations, including potential publication bias, a lack of recent studies, subjective quality assessments, and the grouping of studies based on similarities.

Seismic design education remains an essential component of the architectural curriculum that significantly influences the readiness and resilience of upcoming architects. Given the ongoing risks posed by seismic events to structures, it is crucial to adjust educational methods. This study highlights the importance of providing architects with comprehensive and practical seismic design education to help them create robust structures capable of withstanding seismic threats in the 21st century.

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