



## Integrating Spatial Policy, Infrastructure Design, and Evaluative Technology in Disaster Risk Reduction for Vocational Education: A Bibliometric and Systematic Literature Review

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### ABSTRACT

**Purpose** - Vocational education is highly vulnerable to disasters; however, current mitigation strategies are fragmented across spatial planning regulations, infrastructure design, and assessment technologies. This study seeks to carefully examine the evolution of Disaster Risk Reduction (DRR) research within vocational education, finding trends, knowledge frameworks, and research deficiencies, while also developing a cohesive transdisciplinary framework.

**Methodology** - The study employs a synthesis of bibliometric analysis and Systematic Literature Review (SLR), adhering to the PRISMA 2020 guideline. The search was conducted in the Scopus database for the period 2004–2024, yielding 162 initial documents, which were further refined to 16 core papers using rigorous selection criteria. Bibliometric analysis encompasses publishing trends, keyword co-occurrence, and co-citation, utilizing bibliometrics and VOSviewer.

**Findings** - Publications increased by 18% per year, with the Asia-Pacific region dominating (62%). Three thematic clusters were identified: adaptive infrastructure design (43.75%), spatial planning policy (31.25%), and geospatial information systems (25%). Co-citation analysis confirms that no single influential document integrates all three dimensions simultaneously within the context of vocational education.

**Contribution** - The study formulates a transdisciplinary framework that integrates technical, spatial, and technology-based resilience within vocational education. The implications include strengthening national standards (SNI) for school buildings, integrating Geographic Information Systems (GIS) into the construction vocational school curriculum, and fostering institutional partnerships between the Ministry of Education, Culture, Research, and Technology and the National Disaster Management Authority to support region-based risk management.

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### INTRODUCTION

Vocational education is one of the area most significantly impacted by the escalating unpredictability of climate change and the rising incidence of large-scale disasters (Poza-Vilches et al., 2025). Contemporary institutional methodologies continue to treat disaster mitigation, spatial planning, and infrastructure design as distinct domains, overseen by various sectors—specifically disaster management, urban planning,

education, and construction (Lassa et al., 2023; Opabola et al., 2023; Segarra-Alméstica et al., 2022). This fragmentation results in three interrelated systemic failures: (1) vocational schools are situated in disaster-prone regions without sufficient risk assessment; (2) infrastructure is constructed according to generic standards, neglecting specific disaster resilience criteria; and (3) risk assessment technologies, including Geographic Information Systems (GIS) and monitoring systems, function independently from educational facility management and curriculum development.

Data from the National Disaster Mitigation Agency reveal that Indonesia has experienced an average of roughly 3,000 disasters each year over the past five years, significantly disrupting educational institutions. According to UNESCO, over 75% of educational institutions in disaster-prone regions experience learning interruptions of at least 1 month annually. Vocational schools are especially susceptible due to their dependence on expensive laboratory facilities and practical fieldwork that cannot be entirely replaced by online education (Takinana & Baars, 2023). Historically, research on disaster-resilient educational infrastructure has predominantly concentrated on general public facilities. Concurrently, evaluative technologies—such as GIS, building sensors, and risk modeling—have advanced rapidly in the construction and risk management fields, yet they remain inadequately incorporated into vocational education (Kholoshyn et al., 2021; Zhu et al., 2018).

Theoretically, resilience theory and socio-technical systems thinking can be used to understand catastrophe risk reduction in vocational education. Resilience theory highlights the ability of institutions and infrastructures to foresee, absorb, adapt to, and recover from disruptive events while preserving critical functions. Resilience in educational contexts encompasses more than just physical infrastructure; it also includes institutional readiness, spatial design, governance frameworks, and adaptable learning methods. In the meantime, socio-technical systems theory emphasizes how social factors like policy, governance, and educational practices interact with technological elements like buildings, infrastructure, and monitoring technology to determine catastrophe resilience. Therefore, disaster mitigation in vocational education should be viewed as an integrated system that connects spatial governance, infrastructure resilience, and technology-assisted decision making rather than as discrete technical interventions.

The principal deficiency noted is the lack of a holistic strategy that integrates disaster-resilient infrastructure design, risk-informed spatial planning, and the use of evaluative technologies into a cohesive framework for vocational education. Current research predominantly concentrates on either general elementary and secondary education (Hamid et al., 2021; Rusilowati et al., 2021) or analyzes individual components in isolation: infrastructure only (Bosher, 2014), policy solely (Egbelakin et al., 2025), or technology alone (Zain et al., 2024). None of these studies establishes the interrelationships among the three components as an integrated system within the vocational context, despite the practice-oriented nature of vocational education and its reliance on specialized physical infrastructure, which requires a more context-specific mitigation approach.

To address the fragmented nature of Disaster Risk Reduction (DRR) research in vocational education, this study combines bibliometric analysis with a PRISMA-based Systematic Literature Review (SLR). This combination is essential because DRR research is interdisciplinary, involving engineering, spatial planning, governance, and educational systems. Bibliometric analysis identifies the intellectual structure of the field by mapping publication growth, thematic evolution, co-occurrence patterns, and influential citation networks across disciplines. However, bibliometric mapping alone cannot explain the conceptual relationships, practical implications, and theoretical gaps underlying the identified clusters.

Therefore, a PRISMA-based SLR was incorporated to provide a more systematic and interpretative synthesis of the selected studies. This approach identifies dominant research trends and critically examines how infrastructure resilience, spatial governance, and evaluative technologies are conceptually interconnected within vocational education contexts. Bibliometric analysis provides macro-level knowledge mapping, while SLR enables micro-level theoretical interpretation and gap identification. Together, these methods support the development of a transdisciplinary resilience framework that bridges technical, spatial, and institutional dimensions in vocational education DRR research. Based on this framework, five research questions were formulated: RQ1 (publication trends and source distribution), RQ2 (thematic evolution through keyword co-occurrence), RQ3 (influential documents identified through co-citation analysis), RQ4 (design strategies for disaster-resilient vocational infrastructure), and RQ5 (the application of evaluative technologies and data-driven approaches for disaster mitigation assessment).

## **METHODOLOGY**

## Theoretical Framework

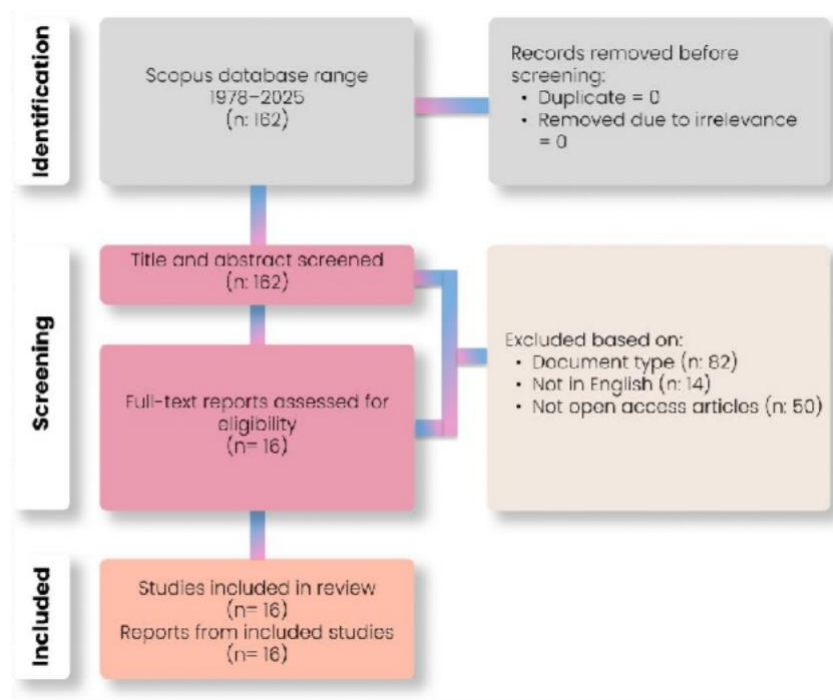
This study is grounded in three conceptual frameworks, examined as an integrated system rather than in isolation. First, technical resilience is derived from socio-technical systems theory (Trist, 1981), further developed by Boshier (2014), which posits that infrastructure resilience depends on the integration of the school community's social system and the technical building system. This framework serves as the basis for analyzing the adaptive infrastructure cluster (RQ2, RQ4). Second, spatial resilience is informed by the Sendai Framework for Disaster Risk Reduction 2015–2030, which emphasizes risk-based spatial planning as a mechanism for reducing regional vulnerability, directly relevant to site selection and zoning decisions for vocational schools (RQ2, RQ4). Third, institutional resilience, as conceptualized by Aldunce et al. (2015), highlights the capacity of institutions to anticipate, absorb, and adapt to disaster-related pressures through governance structures and information systems (RQ5). These three frameworks form an analytical hierarchy: technical resilience as the physical foundation; spatial resilience as the determinant of risk zoning; and institutional resilience as the integrative layer enabling response and recovery capacity. The lack of integration among these three layers in the vocational education literature constitutes the critical gap this study seeks to address.

## Research Design

The study employs a combination of two methods. Bibliometric analysis is a quantitative, data-driven approach that maps the intellectual structure of a research field by analyzing publication metadata, including author networks, citation patterns, keyword co-occurrence, and source distributions. It reveals *who* is producing knowledge, *where* it appears, and *how* concepts cluster, but does not interpret the substantive content of individual studies. Systematic Literature Review (SLR), by contrast, is a structured, protocol-governed synthesis method that identifies, screens, and critically appraises primary studies based on explicit inclusion/exclusion criteria. Where bibliometric analysis provides macro-level structural mapping, SLR provides micro-level conceptual interpretation. In this study, bibliometric analysis was employed to address RQ1-RQ3 through quantitative mapping of trends, keyword networks, and co-citation patterns, while the SLR based on the PRISMA 2020 framework (Haddaway et al., 2022; Moher et al., 2009) was employed to address RQ4-RQ5 through in-depth qualitative thematic synthesis. This combined approach enables complementary structural (bibliometric) and substantive (SLR) analyses.

## Data Collection

A literature search was performed utilizing the Scopus database (2004–2024) with the search string: ("vocational education" OR "technical education" OR "SMK") AND ("disaster" OR "hazard" OR "risk") AND ("building" OR "infrastructure" OR "spatial"). Scopus was chosen for its extensive coverage of over 25,000 peer-reviewed articles and its robust reliability for bibliometric analysis. The preliminary search produced 162 documents, as seen in Figure 1.



**Figure 1.** The Literature Selection Process Based on the PRISMA method

The selection procedure occurred in phases: from the 162 initial documents, 82 were eliminated for not being primary publications (e.g., non-peer-reviewed conference proceedings and technical reports), 14 for not being in English, and 50 for lacking open access. This yielded a final sample of 16 articles, corresponding to an inclusion rate of 9.8%. The low inclusion rate reflects the limited number of studies that combine the three areas and supports the stated research gap.

A sensitivity analysis was performed to mitigate potential publication bias associated with the open-access criterion by loosening this filter. This resulted in 23 supplementary articles, of which only 4 presented theme information not previously addressed by the primary 16 articles. The results validate the consistency of the identified topic clusters and the strength of the recognized research gap. The open-access criteria were maintained to ensure reproducibility. Researchers with institutional access to databases such as Web of Science and ERIC are urged to replicate and expand upon this analysis.

### Instrument

To systematically identify and evaluate relevant studies, this research applies predefined inclusion and exclusion criteria, followed by a structured quality assessment, as summarized in Tables 1 and 2.

**Table 1.** Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Peer-reviewed journal articles; published in English; full open access; addressing disaster mitigation within the context of vocational education; and containing empirical data or clearly defined methodologies.	Conference proceedings, book chapters, and review articles; non-English publications; non-peer-reviewed works; limited-access publications; off-topic; and purely descriptive narratives lacking empirical data.

Table 1 operationalizes the boundaries of the literature corpus. The inclusion criteria prioritize methodological rigor and contextual relevance: studies must present empirical data or explicitly defined procedures, be published in peer-reviewed English-language journals with full open access, and address disaster mitigation within vocational education settings. The exclusion criteria remove sources that, despite topical proximity, lack the evidentiary basis required for systematic synthesis including conference proceedings, book chapters, non-peer-reviewed works, and purely descriptive narratives. The open access requirement, while introducing a potential publication bias, was retained to ensure full reproducibility of the search and screening process (Page et al., 2021). A sensitivity analysis relaxing this criterion, reported in the Data Collection section, confirmed that the identified thematic clusters remain stable across the expanded corpus. To further ensure that included studies meet a minimum standard of analytical quality beyond mere

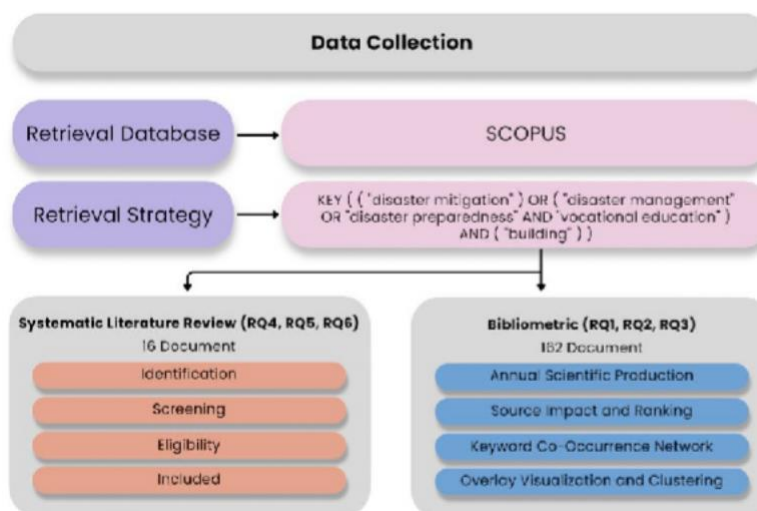
topical fit a structured quality assessment was applied to each candidate article (Olsson et al., 2022). The six criteria constituting this assessment are presented in Table 2.

**Table 2.** Quality Assessment Criteria (QA)

No	Quality Criteria	Justification
1	The research objectives are clearly stated.	Ensuring alignment with the research questions (RQs).
2	The research methods are described and justifies.	Enabling the evaluation of methodological rigor
3	The vocational education context/domain is explicitly defined.	Ensuring contextual specificity.
4	Implementation or pedagogical challenges are addressed.	Indicating practical relevance.
5	The study is based on empirical data, case studies, or validated frameworks.	Ensuring a strong evidence base.
6	Implications for practice or policy are discussed.	Reflecting the study's policy contribution.

Table 2 establishes quality thresholds that distinguish analytically substantive studies from those that merely touch on the topic. Criteria 1 and 2 target internal validity: a study without clearly stated objectives or described methods cannot be systematically compared with other studies in a synthesis matrix. Criterion 3 ensures contextual specificity; studies that address educational institutions in general, without defining the vocational context, cannot yield actionable implications for vocational school settings. Criteria 4 and 5 address practical and empirical grounding, filtering out purely theoretical or normative pieces that lack an evidence base. Criterion 6 requires that studies translate findings into policy or practice implications, consistent with the applied orientation of this research. The application of explicit quality criteria is recommended to improve methodological transparency and ensure that evidence synthesis is based on studies with sufficient analytical rigor and contextual relevance (Munn et al., 2018; Sargent et al., 2021). Articles satisfying at least five of the six criteria were included in the final analysis, yielding a corpus of 16 articles from the initial 162 documents retrieved.

## Data Analysis



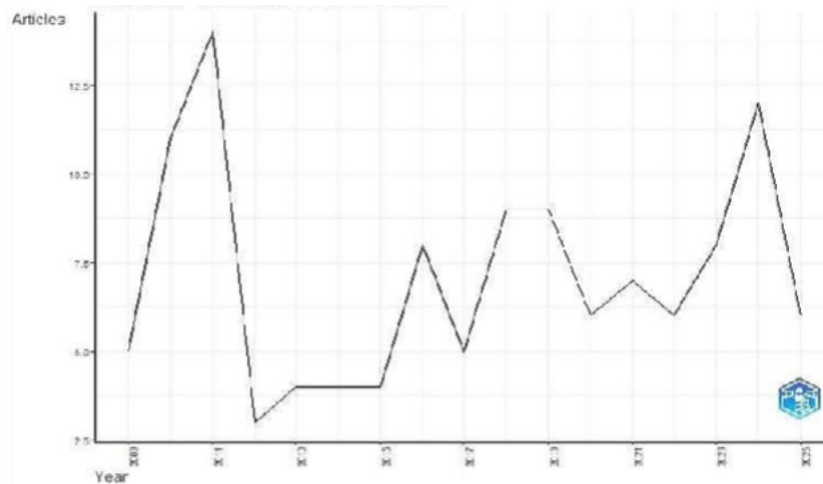
**Figure 2.** Research Procedure

Each article was independently assessed by two researchers (double coding) using the six-quality assessment (QA) criteria. Discrepancies were resolved through consensus discussion. Inter-rater reliability was measured using Cohen's Kappa ( $\kappa = 0.84$ ; target  $\kappa \geq 0.80$ , indicating “almost perfect” agreement). Articles meeting at least five of the six criteria were included in the analysis. Bibliometric analysis was conducted using Bibliometrix v5.0 and VOSviewer v1.6.20. Thematic synthesis for RQ4–RQ5 was performed using a framework analysis approach with a layered thematic matrix. A schematic representation of the research workflow is presented in Figure 2, highlighting the data retrieval process, screening stages, and subsequent analytical approaches applied in this study.

## FINDINGS

### RQ1: Publication Trends, Journals, and Countries

Over the past two decades, Disaster Risk Reduction (DRR) publications in the context of vocational education have gone through three distinct phases of development. The incubation phase (1978–2004) is characterized by highly sporadic publication rates (<2 per year), reflecting disciplinary separation among engineering, education, and disaster studies. The transition phase (2005–2015) shows a significant increase, with a peak of 13 publications in 2011, coinciding with the impact of the 2011 Tōhoku earthquake and tsunami, which heightened global attention to the resilience of educational infrastructure. The consolidation phase (2016–2024) demonstrates a stable trend of 5–11 articles per year, accompanied by improved methodological quality, marked by the emergence of multi-hazard studies and systematic policy analyses. An average annual growth rate of 18% over the past decade indicates that this field is transitioning from the periphery toward the mainstream of DRR research, as illustrated in Figure 3.



**Figure 3.** Annual Scientific Production of Disaster Risk

Figure 3 showed the temporal publication pattern also highlights a persistent interdisciplinary gap. Despite the increasing volume of publications, the dominant sources continue to originate primarily from the engineering community rather than the vocational education field. This finding indicates that discussions surrounding DRR in vocational education remain largely fragmented and technically oriented, with limited integration into educational and pedagogical discourse. To further examine the disciplinary orientation of the literature, Bradford’s Law was applied to identify the core journals contributing to Disaster Risk Reduction (DRR) research within vocational education. This analysis helps reveal the dominant publication sources, their thematic domains, and the extent to which the existing literature emphasizes technical, spatial, or educational perspectives. The results of the core source analysis are presented in Table 3.

**Table 3.** Core Sources by Bradford’s Law (Zone 1)

Rank	Source Journal	Freq	cumFreq	Domain	Relevance to DRR-Vocational
1	Building Research and Information	7	7	Construction	High – infrastructure-focused
2	Int. J. Disaster Resilience Built Environ.	6	13	Disaster-Construction	High – building resilience
3	8th US Conf. Earthquake Engineering 2006	5	18	Civil Engineering	Moderate – technical proceedings
4	Int. J. Environmental Research Public Health	5	23	Environmental Health	Moderate – community aspects
5	AIJ Journal of Technology and Design	4	31	Architecture (Japan)	High – building design
6	IOP Conf. Series: Earth & Environmental Sci.	4	35	Multidisciplinary	Moderate

7	Journal of Disaster Research	4	39	Disaster Studies	High – disaster management
8	Lecture Notes in Civil Engineering	4	43	Civil Engineering	Moderate
9	Earthquake Spectra	3	46	Seismic Engineering	High – earthquake risk
10	Proceedings of SPIE	3	49	Optics-Technology	Low – sensor technology

Based on Table 3, all ten core journals originate from the domains of civil engineering, construction, and disaster studies, with no vocational education–specific journals represented in Zone 1. This bibliometric evidence confirms that DRR research in the vocational context has been predominantly driven by the engineering community rather than by the vocational education community. The implication is that the resulting technical findings have not been adequately contextualized within the pedagogical realities of vocational schools (Cabello et al., 2021; Chmutina & von Meding, 2022). Journals in vocational education, such as *Journal of Vocational Education & Training* and TVET-oriented outlets, are absent from the core zone, further confirming the interdisciplinary gap that constitutes the central focus of this study.

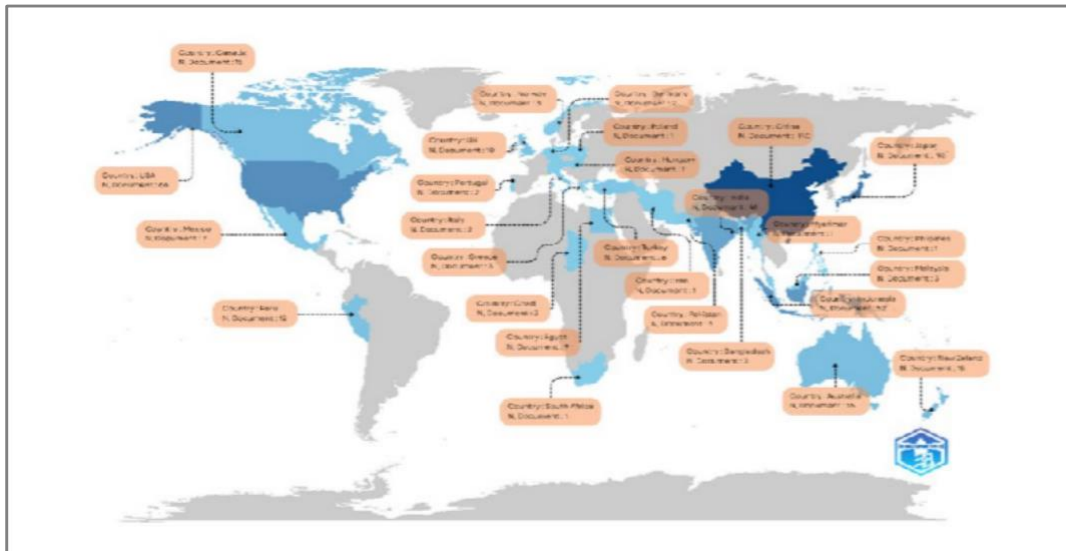
Three structural consequences follow from this publication pattern. First, the concepts and standards developed in engineering-dominated journals on structural fragility, probabilistic hazard modeling, and spatial risk mapping reach the DRR field without being translated into vocational pedagogy or curriculum. Second, the reverse is equally true: vocational education research rarely enters the engineering DRR discourse, producing parallel literatures that do not cite each other. Third, this separation creates a policy vacuum: national standards for school buildings and institutional DRR guidelines are developed without input from vocational education researchers who understand the operational realities of workshops, laboratories, and practice-based instruction. These three consequences collectively justify the transdisciplinary framework proposed in this study, which deliberately bridges the engineering and vocational education domains (Ishiwatari et al., 2024; Righi et al., 2021).

To examine the influence of individual journals within the identified core zone, Table 4 presents local impact indicators—H-index, G-index, and M-index—for selected high-impact sources, enabling a comparative assessment of citation density and publication momentum across the field.

**Table 4.** Sources' Local Impact (Selected High-Impact Journals)

Source	H-index	G-index	M-index	Total Citations	NP	First Year	Interpretations
Building Research & Information	7	7	0.318	333	7	2004	The most influential journal, with an average of 47.6 citations per article.
Int. J. Disaster Resilience Built Environ.	5	6	0.454	129	6	2015	Rapid growth, with a high M-index indicating strong research momentum.
Int. J. Environmental Research Public Health	4	5	0.800	78	5	2021	The highest M-index, suggesting a relatively new journal with substantial impact.
Coastal Engineering Journal	2	2	0.200	75	2	2016	High impact per article, averaging 37.5 citations per publication.
Engineering Structures	2	2	0.133	97	2	2011	High total citations (TC), indicating the dominance of structural construction research.
Earthquake Spectra	2	3	0.050	45	3	1986	The oldest journal, serving as the historical foundation for seismic studies.

As shown in Table 4, the International Journal of Environmental Research and Public Health exhibit the highest M-index (0.800), despite only emerging in the dataset since 2021, indicating an accelerated scholarly focus on community health aspects within DRR. This trend aligns with the post-COVID-19 paradigm shift, which positions the resilience of educational institutions as a public health concern. This shift is directly relevant to vocational education, as the vulnerability of vocational schools is not solely a matter of physical infrastructure, but also of the health and well-being of the learning community, thereby requiring cross-sectoral institutional responses.



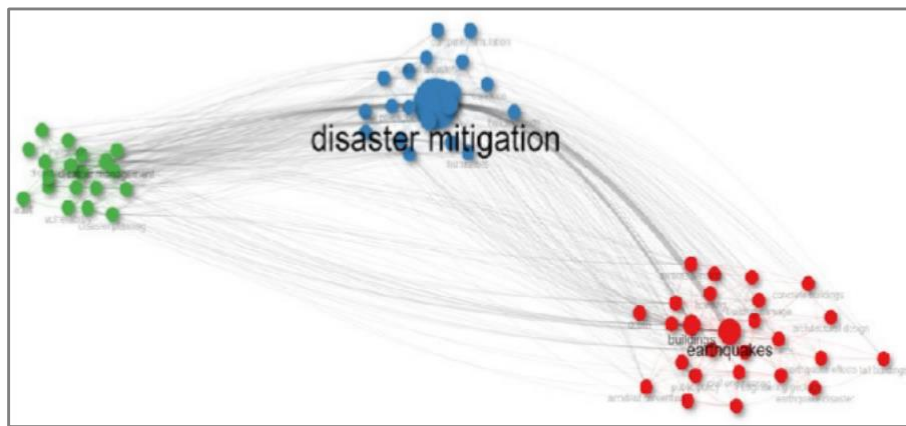
**Figure 4.** Global Distribution of Scientific Production on DRR in Vocational Education

Based on Figure 4, China (140 documents), Japan (95), the United States (66), and Indonesia (52) dominate research production. Three critical interpretations can be drawn. First, the dominance of the Asia-Pacific region (62% of total output) is consistent with the high frequency of disasters along the Pacific Ring of Fire, indicating that research is driven more by contextual urgency than solely by academic capacity (Sahil & Sood, 2021). Second, Indonesia’s position as the fourth globally, surpassing developed countries such as the United Kingdom and Australia, reflects heightened institutional awareness following major disasters, including the 2004 Indian Ocean tsunami, 2006 Yogyakarta earthquake, and 2018 Sulawesi earthquake and tsunami.

Third, however, Indonesia’s publication volume is not yet matched by methodological depth. A significant proportion of studies remain descriptive, with limited integration of quantitative risk analysis into institutional policy frameworks (Amri et al., 2022). Quantitatively, among the 52 Indonesian publications, only 6 (11.5%) employ risk-based quantitative approaches, while the remaining 88.5% are descriptive or qualitative. This gap between volume and analytical depth represents a strategic opportunity for advancing vocational education–based research in Indonesia.

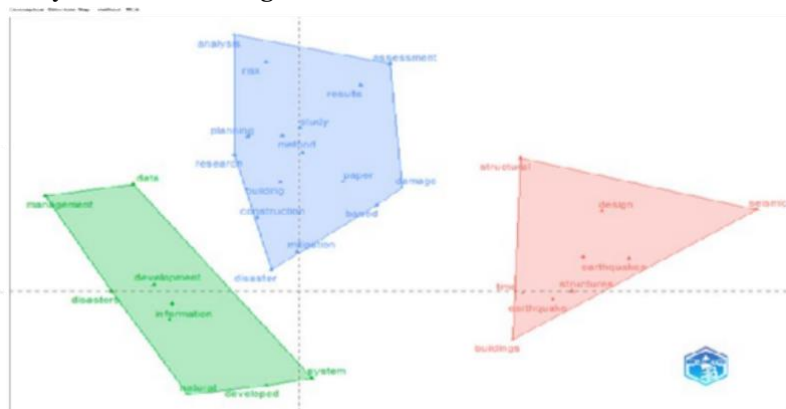
**RQ2: Key Trends and Thematic Clusters based on Keyword Co-occurrence Analysis**

Keyword co-occurrence analysis identifies “disaster mitigation” as the central node with the highest degree in the network, connected to 47 unique terms. Three dominant clusters form the intellectual structure of this field, as illustrated in Figure 5.



**Figure 5.** Keyword Co-occurrence Clustering in DRR-Vocational Education Research

The Red Cluster (seismic–infrastructure) is characterized by dominant nodes such as earthquake, building, seismic, structural design, and damage, indicating that over the past two decades, the DRR paradigm in construction has been dominated by a deterministic, strength-based structural approach. The Blue Cluster (policy–risk), with dominant nodes including risk, assessment, planning, policy, and mitigation, reflects a shift toward a probabilistic, risk-based approach involving regulatory instruments. The Green Cluster (technology–information), represented by nodes such as management, data, GIS, information system, and monitoring, marks the emergence of a third generation of DRR grounded in data and digital technologies. A critical implication is that these three clusters operate in separate bibliometric silos, with no strong bridging nodes linking “seismic” (Red Cluster) to “policy” (Blue Cluster) or “GIS” (Green Cluster). The absence of such bridge nodes quantitatively confirms the fragmentation identified in the narrative review.



**Figure 6.** Thematic Factorial Analysis of DRR Research in Vocational Education

The thematic mapping (Figure 6) classifies the Red Cluster as a niche theme, indicating high relevance but not yet positioned as a motor theme (i.e., high relevance and high centrality). This suggests that seismic infrastructure represents a highly specialized area of research, yet its integration into vocational education discourse remains limited. The Green Cluster (spatial planning and risk policy) is positioned within the basic themes quadrant, characterized by high centrality but moderate thematic development, reflecting its role as a foundational component of DRR that has not been specifically tailored to the vocational context. The Blue Cluster (information systems and technology) is identified as an emerging theme, with low centrality but increasing relevance, indicating untapped potential for further development within the vocational domain. Motor themes that should integrate these three clusters have not yet emerged, reinforcing the need for the transdisciplinary framework proposed in this study. Following the thematic factorial analysis, a structured synthesis matrix is constructed to integrate the identified clusters with their respective contributions to the three resilience-oriented theoretical frameworks, as shown in Table 5.

**Table 5.** Synthesis Matrix: Articles per Cluster and Contributions to Three Theoretical Frameworks

No	Author (Year)	Main Topic	Cluster	Technical Resilience	Spatial Resilience	Institutional Resilience	Gap
1	Alam &	Seismic	Red	✓	—	—	No specific

No	Author (Year)	Main Topic	Cluster	Technical Resilience	Spatial Resilience	Institutional Resilience	Gap
	Haque (2020)	vulnerability of educational buildings					vocational context
2	Amini et al. (2024)	Multi-hazard spatial model (earthquake + tsunami)	Red	✓	✓	—	Does not address educational infrastructure
3	Fukuwa et al. (2009)	PSHA, ground motion prediction	Red	✓	✓	—	No pedagogical component
4	Gadagamma et al. (2018)	Fragility functions of concrete buildings	Red	✓	—	—	No vocational school context
5	Miyaji et al. (2020)	Inclusive evacuation design, cyclone shelters	Red	✓	—	✓	Social inclusivity; not vocational-specific
6	Tabucanon et al. (2021)	Flood damage, adaptive drainage	Red	✓	✓	—	Does not address educational facilities
7	Zain et al. (2024)	Machine learning for seismic vulnerability of school buildings	Red	✓	—	—	General schools; not vocational-specific
8	Bosher (2014)	Socio-technical resilience, integrated DRR	Green	✓	✓	✓	Most comprehensive; not vocational-specific
9	Egbelakin et al. (2025)	Risk-based spatial planning regulation reform (earthquake)	Green	—	✓	✓	General policy; does not address education
10	Hanna et al. (2025)	Flood policy, land use planning	Green	—	✓	✓	No educational infrastructure dimension
11	Opabola & Galasso (2024)	DRR based on recovery analysis, educational infrastructure	Green	✓	—	✓	Most relevant to vocational context; still general
12	Opabola et al. (2023)	Investment in school physical preparedness	Green	✓	—	✓	General schools; spatial aspect not examined
13	Ishiwatari et al. (2024)	Disaster resilience PPP, local wisdom	Blue	✓	✓	✓	Most integrative; Japan context
14	Lyu et al. (2023)	Economic flood losses (input-output)	Blue	—	✓	✓	Regional economy; not education-specific
15	Que et al. (2022)	Participatory community risk mapping	Blue	—	✓	✓	Community-focused; no infrastructure dimension
16	Titko et al.	Community	Blue	—	—	✓	Risk literacy; no

No	Author (Year)	Main Topic	Cluster	Technical Resilience	Spatial Resilience	Institutional Resilience	Gap
	(2021)	preparedness survey, risk literacy					technical dimension

Table 5 presents the synthesis matrix, categorizing the 16 selected articles by thematic cluster and mapping each article's contribution to the three theoretical resilience frameworks. Several patterns warrant specific attention before the aggregate distribution is examined. Within the Red Cluster, all seven studies address technical resilience, but only three engage spatial resilience, and one engages institutional resilience. This confirms that infrastructure engineering studies in this corpus treat physical structure as a closed system, one that can be strengthened independently of site location policies or governance capacity. This tendency is evident in studies that develop technically rigorous fragility models for school buildings while providing limited discussion of regulatory implementation or site-selection criteria (Gadagamma et al., 2018; Zain et al., 2024).

Within the Green Cluster, the pattern is reversed. Studies in this cluster address spatial and institutional dimensions while largely omitting analysis of technical infrastructure, leading to policy recommendations that apply to general public facilities without specifying the structural characteristics of vocational school buildings (Egbelakin et al., 2025; Hanna et al., 2025). The closest approximation to an integrated approach combines recovery analysis with policy implications; however, its scope remains focused on educational facilities in general rather than vocational education specifically (Opabola & Galasso, 2024). The Blue Cluster contains the study with the highest level of integration, addressing technical, spatial, and institutional resilience simultaneously through a public-private partnership model implemented in Japan (Ishiwatari et al., 2024). This article is the only fully integrative study identified within the corpus, a finding quantified across the overall distribution in Table 6.

Table 6 summarizes the cluster-level distribution of articles and the proportional coverage of each theoretical framework, providing a quantified view of the fragmentation pattern identified qualitatively in Table 5.

**Table 6.** Recapitulation of Cluster Distribution and Coverage of Theoretical Framework

Cluster	Theme	N Article	%	R Technical	R Spatial	R Institutional	Integrative Article
Red	Adaptive Infrastructure Design	7	43,75%	7/7 (100%)	3/7 (43%)	1/7 (14%)	0 (0%)
Blue	Information Systems and Technology	4	25%	1/4 (25%)	3/4 (75%)	4/4 (100%)	1/4 (25)
Green	Spatial Planning Policy	5	31,25%	2/5 (40%)	4/5 (80%)	4/5 (80%)	0 (0%)
Total	—	16	100%	10/16 (62,5%)	10/16 (62,5%)	9/16 (56,25%)	1/16 (6,25%)

Table 6 reveals a critical finding: only 1 out of 16 articles (6.25%) simultaneously addresses all three dimensions of resilience. The Blue Cluster produces one integrative article (1/4 = 25%), namely Ishiwatari et al. (2024), which integrates physical resilience, spatial zoning, and institutional capacity within a public-private partnership (PPP) model in Japan. The Red Cluster (infrastructure) demonstrates strong performance in the technical dimension (100%) but shows minimal engagement with the institutional dimension (14%) and limited spatial integration (43%). This indicates that most DRR infrastructure studies generate technically robust solutions that are not embedded within institutional governance systems, thereby limiting their systemic implementation.

In contrast, the Blue Cluster (technology) is dominant in institutional resilience (100%) and relatively strong in spatial aspects (75%), but remains weak in the technical dimension (25%). This suggests that information systems are often developed without sufficient grounding in structural vulnerability analysis. Meanwhile, the Green Cluster (spatial planning policy) exhibits moderate to strong coverage in spatial (80%) and institutional (80%) dimensions, but remains limited in technical integration (40%), indicating a

disconnect from the physical realities of infrastructure systems. This lack of integration is not a methodological artifact, but rather a structural reflection of the separation between engineering and vocational education research communities, consistently confirmed across all research questions. It should therefore be understood not as a failure of individual researchers, but as a limitation of the research incentive system, which has not effectively encouraged transdisciplinary collaboration.

### RQ3: Most Influential Documents based on Co-citation Analysis

Co-citation analysis identifies the documents that form the intellectual foundation of this field. High co-citation indicates that two documents are frequently cited together by a third article, reflecting similarity in their conceptual or methodological positioning (Kleminski et al., 2022). To further examine the intellectual structure of the field, the most globally cited and co-cited documents are synthesized, highlighting their contribution to the development of the research domain, as presented in Table 7.

Three critical convergence patterns emerge from this co-citation analysis. First, there is a clear dominance of the policy–economic perspective. Kunreuther (2006), with 184 citations, significantly surpasses the next most cited technical study (Spence, 2004, with 92 citations). This gap of more than 100 citations is not incidental; rather, it indicates that the DRR research community collectively acknowledges that the effectiveness of mitigation is shaped more by policy frameworks and economic incentives than by structural strength alone. The implication for vocational education is that technical standards for school buildings, such as SNI, are insufficient without complementary institutional incentive structures and risk-based location policies. Second, a clear methodological evolution is observed, transitioning from descriptive to probabilistic and ultimately to data-driven approaches. Early studies from 1999 to 2006 (Pomonis, Spence, Schilderman) primarily relied on descriptive and qualitative methods. This was followed by the period from 2009 to 2016 (Fukuwa, Suppasri, Wilkinson), which introduced probabilistic modeling approaches. More recent studies from 2020 to 2025 (Zain et al., Amini et al.) incorporate machine learning and multi-hazard spatial analysis. Given that vocational education is only beginning to engage with this discourse, it is essential to directly adopt these third-generation approaches rather than revisiting earlier descriptive stages that have already been surpassed.

**Table 7.** Most Globally Cited Documents in the Corpus (n = 162)

Paper	Author	Year	Total Citations	Primary Domain	Relevance to Research Gap
Ann Am Acad Polit Soc Sci	Kunreuther H	2006	184	Policy–Economics	Emphasizes the policy dimension as a key determinant of effective DRR
Build Res Inf	Spence R	2004	92	Construction	Provides a foundational framework for building vulnerability assessment
J Volcanol Geotherm Res	Pomonis A	1999	85	Volcanology–Geology	Establishes methodological foundations for fragility assessment
Build Res Inf	Schilderman T	2004	82	Community Construction	Introduces participatory approaches in reconstruction
Build Res Inf	Bosher L	2014	80	Socio-technical	Most integrative resilience framework, cited across clusters
J Hydrol	Cheng JD	2005	76	Hydrology	Basis for watershed-based flood risk analysis
Coast Eng J	Suppasri A	2016	63	Coastal Engineering	Tsunami damage modeling, relevant for coastal vocational schools
J Wind Eng Ind Aerodyn Eng Struct	Kopp GA	2012	57	Wind Engineering	Building resilience against extreme wind hazards
	Morrison MJ	2011	57	Structural Engineering	Structural performance of lightweight buildings
Int J Disaster	Wilkinson S	2016	46	Resilience	Framework for evaluating

Resilience Built Environ MTS/IEEE OCEANS	Kaneda Y	2010	43	Seismic Monitoring	built environment resilience Real-time sensor systems for earthquake detection
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A third pattern reveals a bibliometrically confirmed integrative gap. None of the 11 influential documents explicitly integrate the technical, spatial, and institutional dimensions within the context of vocational education. (Bosher, 2014) comes closest by linking technical and institutional aspects, yet it does not address the vocational context. This gap is not incidental; rather, it reflects the absence of the vocational education research community within infrastructure-based DRR discourse, and vice versa. The transdisciplinary framework proposed in this study directly addresses this gap. To strengthen the novelty claim beyond the scope of Scopus, additional searches were conducted in Google Scholar and ERIC using the keywords “disaster risk reduction” AND “vocational education” AND “infrastructure.” No studies were identified that simultaneously integrate the technical, spatial, and institutional components within the vocational context across these databases. This gap is therefore not an artifact of database limitation, but rather reflects the empirical absence of such research globally.

#### RQ4: Disaster Resilient Infrastructure Design Strategy in Vocational Education

The synthesis of 12 relevant articles (from the red and green clusters) identifies four strategic design dimensions that must be integrated simultaneously, rather than partially, in order to achieve truly resilient vocational education infrastructure.

**Table 8.** Synthesis of Disaster Resilient Infrastructure Design Strategies for Vocational Education

Strategic Dimension	Description and Specific Evidence	Supporting Articles	Number	Applicability to Indonesian Vocational Schools
Quantitative Vulnerability Assessment	Application of fragility functions for reinforced concrete (RC) buildings and probabilistic assessment of earthquake-induced damage. The pushover analysis approach generates vulnerability curves that can be calibrated for specific vocational school building types (laboratories, workshops, practice halls).	(Alam & Haque, 2020; Gadagamma et al., 2018; Zain et al., 2024)	3	High – vocational schools in Sumatra, Sulawesi, and West Nusa Tenggara require prioritized seismic vulnerability assessments
Adaptive Multi-Hazard Design	Integration of earthquake and tsunami risks within a unified spatial model (multi-hazard framework). For coastal vocational schools, minimum floor elevation, adaptive drainage systems, and coastal buffer zones should be mandatory design requirements.	(M. Amini et al., 2024; Fukuwa et al., 2009; Tabucanon et al., 2021)	3	Very High – vocational schools in Aceh, Palu, Lombok, and Nias are located in high multi-hazard zones
Inclusive Evacuation Design	Integration of evacuation routes into architectural design, considering user diversity (gender, disability, age) and local cultural values. Shelters are designed to function dually as daily practice spaces.	(Bosher, 2014; Ishiwatari et al., 2024; Miyaji et al., 2020)	3	High – vocational school students are diverse, and practice spaces often lack standardized evacuation routes
Integrated Socio-Technical Resilience	Physical infrastructure must be complemented by emergency management systems, evacuation SOPs, regular training for teachers and students, and community partnerships. Top-down approaches (technical standards)	(Bosher, 2014; Opabola et al., 2023; Opabola & Galasso, 2024; Yokouchi, 2015)	4	High – most vocational schools lack disaster SOPs integrated with building design

and bottom-up approaches (school community participation) must operate simultaneously.

As shown in Table 8, none of the studies in the corpus integrates all four identified dimensions simultaneously within the context of vocational education. (Opabola & Galasso, 2024) come closest by combining vulnerability assessment and policy analysis, yet without incorporating multi-hazard considerations and inclusive evacuation design. (Bosher, 2014) addresses socio-technical and multi-hazard aspects, but does not specifically focus on vocational education. This gap confirms that vocational school infrastructure is currently designed in a partial manner, neglecting the interdependence among these dimensions. Empirical evidence from Indonesia illustrates the consequences of this gap. Vocational schools in Lombok, following the 2018 earthquake, experienced severe damage to practice laboratories, requiring more than eight months for recovery. This was largely due to the absence of fragility-based design and the lack of evacuation procedures for practice equipment integrated into the physical building design (Amri et al., 2022). Similarly, vocational schools in Palu after the 2018 tsunami demonstrate that site vulnerability (spatial dimension) had not been systematically linked to infrastructure design and institutional capacity in an integrated manner.

### RQ5: Utilization of Technology and Data for Disaster Mitigation Evaluation in Vocational Education

The synthesis of four articles from the green cluster and three supporting studies identifies three generations of technology relevant to Disaster Risk Reduction in vocational education as shown in Table 9.

**Table 9.** Synthesis of Technology and Data Approaches for DRR Evaluation in Vocational Education

Technology Generation	Specific Technologies/Methods	Function in DRR–Vocational Context	Supporting Articles	Limitations
Generation 1: Deterministic Quantitative Analysis	Probabilistic Seismic Hazard Analysis (PSHA); input–output analysis of flood economic losses; building fragility functions	Provides a quantitative basis for national building standards (SNI); supports infrastructure investment decision-making for vocational schools; serves as foundational material in building engineering education	(Fukuwa et al., 2009; Gadagamma et al., 2018; Lyu et al., 2023)	Requires detailed local data; not real-time
Generation 2: Spatial Analysis and Multi-Hazard Modeling	GIS-based multi-hazard modeling; spatial risk mapping; community-based participatory mapping	Supports risk zoning for vocational school locations; identifies priority areas for relocation or reinforcement; integrates into DPIB/TKP curriculum as localized case studies	(M. Amini et al., 2024; Kholoshyn et al., 2021; Que et al., 2022)	Requires GIS human resource capacity, which is not evenly distributed across vocational schools
Generation 3: Artificial Intelligence and Participatory Technologies	Machine learning for seismic vulnerability prediction; hybrid approaches (science, local knowledge, and digital systems); community-based digital preparedness surveys	Enables large-scale and efficient vulnerability assessment of vocational school buildings; supports vocational training models integrating real disaster data; enhances risk literacy among students and teachers	(Ishiwatari et al., 2024; Titko et al., 2021; Zain et al., 2024)	Requires data infrastructure and digital competencies that are not yet evenly developed

Based on Table 9, there is a significant gap in technology generation adoption between developed countries such as Japan and the United States, which have reached Generation 3, and Indonesia, where adoption remains largely at Generations 1 and 2. More importantly, no single study integrates all three generations within a unified evaluation system for vocational education institutions. (Ishiwatari et al., 2024) comes closest through a public-private partnership model in Japan that combines digital technology with local wisdom. However, Japan's policy context and institutional capacity differ fundamentally from those of Indonesia. The implication is that Indonesia requires a hybrid approach that combines Generation 2 technologies, such as Geographic Information Systems, with participatory local knowledge associated with Generation 3 before fully adopting machine learning. This is primarily due to constraints in data availability and human resource capacity, which remain the main bottlenecks. The feasibility of this hybrid approach is supported by precedents from developing Asia Pacific contexts. (Que et al., 2022) successfully implemented participatory GIS-based risk mapping in urban communities in China under similar data limitations. Likewise, Paci-Green et al. (2020) demonstrated the effectiveness of community-based school construction in developing countries without advanced data infrastructure. These studies confirm that a hybrid Generation 2 and 3 approaches can be effectively implemented in Indonesia with appropriate contextual adaptation.

## DISCUSSION

This analysis provides bibliometric corroboration of the fragmentation phenomenon, which has previously been discussed only narratively in the Disaster Risk Reduction (DRR) and vocational education literature. The findings reveal that only 6.25% of the reviewed studies, or 1 out of 16 articles, simultaneously address the three dimensions of technical, spatial, and institutional resilience within the vocational education context (Masocha et al., 2025). Most studies remain focused on isolated dimensions, particularly infrastructure vulnerability, policy analysis, or technological assessment, without integrating these dimensions into a unified resilience framework. This finding indicates that DRR research in vocational education remains structurally fragmented despite the increasing complexity of disaster risks affecting educational infrastructure and institutional preparedness.

Cross-analysis of the research questions further confirms this fragmentation pattern. RQ1 identifies the absence of vocational education journals within Bradford's core publication zone, while RQ2 demonstrates the lack of bridge nodes connecting technical and pedagogical clusters. Similarly, RQ3 confirms that no influential co-cited documents integrate all three resilience dimensions simultaneously. In addition, RQ4 and RQ5 reveal that existing mitigation strategies and evaluative technologies remain partial and insufficiently contextualized for vocational education settings. The convergence of all research questions toward the same conclusion strengthens the external validity of the proposed transdisciplinary framework. Therefore, the novelty of this study lies not only in identifying disciplinary fragmentation but also in proposing an integrated resilience perspective that connects infrastructure design, spatial governance, and evaluative technologies within vocational education DRR research.

From the perspective of spatial resilience, as stressed in the Sendai Framework for Disaster Risk Reduction 2015–2030, risk-based zoning analysis has progressed greatly. However, its implementation in choices regarding the location of vocational schools remains limited in Indonesia. This shows that the framework has not yet been transformed into operational policy within the vocational education sector. From the perspective of institutional resilience proposed by Aldunce et al. (2015), the capacity of vocational education institutions to integrate disaster preparedness into curricula and operational procedures is rarely explored empirically. This highlights the most urgent gap that should be addressed in future studies. In the global context, findings from Indonesia indicate that most studies remain monodisciplinary, with no formal mechanisms that encourage integration among the Ministry of Education, Culture, Research, and Technology, the Ministry of Public Works and Housing, and the National Disaster Management Authority (NDMA) within vocational education. This circumstance should not be understood as a failure of researchers, but rather as a constraint of the research incentive system, which has not yet established cross-ministry financing schemes to enable integrated research in this subject (Bednar & Welch, 2020; Cabello et al., 2021; Schröder, 2019).

The limitations of this study should be acknowledged explicitly. The inclusion rate of 9.8% and a corpus of 16 articles provide a strong directional insight but remain limited in representativeness. The open-access criterion excludes potentially high-quality studies that are not freely available; this bias should be addressed in future research by providing institutional access to databases such as Web of Science and ERIC. In addition, the bibliometric analysis in this study is synchronic, meaning it does not capture temporal dynamics, particularly the evolution and interactions of clusters over time. Longitudinal approaches, such as historiographic analysis or diachronic co-citation analysis, are therefore necessary to map trajectories of

interdisciplinary integration. The policy implications of these findings must be operational rather than generic. First, national standards for school buildings, such as SNI 03-1726-2019, need to be revised to include specific requirements for vocational school laboratories and workshops located in high-risk zones, based on fragility functions calibrated to the dominant construction types in Indonesia. Second, curriculum frameworks, particularly in building-related programs such as Building Information and Modeling Design (DPIB) and Construction and Housing Engineering (TKP), should integrate spatial risk assessment competencies and the use of Geographic Information Systems as part of graduate competency standards at Level 3 of the Indonesian National Qualifications Framework, referring to Permendikbudristek No. 165/M/2021. Third, site verification mechanisms for new vocational schools should require them to obtain multi-hazard maps from NDMA as a prerequisite for operational permits, rather than relying solely on technical construction requirements.

## CONCLUSION

This bibliometric and Systematic Literature Review (SLR) study provides three systematically validated contributions to Disaster Risk Reduction (DRR) research within vocational education. First, it empirically confirms the field's persistent fragmentation, showing that only 6.25% of the reviewed studies integrate technical, spatial, and institutional resilience simultaneously, with no bibliometric bridge nodes connecting the engineering and pedagogical domains. Second, the study identifies a differentiated gap structure across thematic clusters: the Red Cluster emphasizes infrastructure resilience but lacks institutional integration; the Green Cluster advances spatial policy perspectives yet remains disconnected from building-level realities; and the Blue Cluster strengthens institutional and technological approaches while providing limited technical integration. Third, this study conceptualizes a transdisciplinary resilience framework that integrates infrastructure design, spatial governance, and evaluative technologies into a unified vocational education DRR system. This contribution is particularly important because vocational education possesses unique characteristics compared to general education, including its dependence on practice-based learning, specialized workshops and laboratories, and high exposure to infrastructure-related hazards that require contextualized mitigation strategies. Future research should focus on empirical validation of the proposed framework through multi-site studies, the development of integrated vulnerability assessment instruments, the expansion of bibliographic databases beyond Scopus, and the implementation of GIS- and IoT-based risk governance systems within vocational education environments. Ultimately, strengthening disaster resilience in vocational education should not be viewed merely as infrastructure protection, but as a long-term transformation toward adaptive, technology-integrated, and risk-informed educational ecosystems capable of sustaining learning continuity in an era of increasing global uncertainty.

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