

Geospatial Information Systems in Disaster Risk Reduction for Vocational Education: A Post-Sendai Bibliometric and Systematic Literature Review

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ABSTRACT

Despite increasing attention to Disaster Risk Reduction (DRR), research remains fragmented across infrastructure, spatial governance, and geospatial systems. This study examines DRR in vocational education during the post-Sendai Framework period (2015–2025) using bibliometric analysis and a PRISMA-based Systematic Literature Review. Scopus data produced two datasets: 98 publications for bibliometric mapping and 12 studies for thematic synthesis. Results show an annual publication growth of 18%, with Asia-Pacific countries contributing 62% of the output. Three research clusters emerged: disaster mitigation policy and planning, business continuity management, and earthquake-resistant construction. Guided by the Sendai Framework's Priority 3 and Transformative Learning Theory, the study highlights the importance of integrating disaster-resistant construction standards, GIS-based school risk zoning, and real-time geospatial monitoring into vocational education. This integrated framework strengthens institutional resilience and equips students with practical spatial risk literacy for sustainable disaster preparedness.

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Introduction

The Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2015) identifies vocational and technical education as an underutilized lever for building disaster-resilient societies, yet the mechanisms through which vocational institutions can translate this mandate into

institutional practice remain structurally underdeveloped. Vocational schools face a compound vulnerability: they depend on non-transferable physical infrastructure for laboratory and workshop-based learning; they serve communities in geographically exposed locations; and their graduates are expected to enter labor markets where disaster risk competencies are increasingly mandatory (Poza-Vilches et al., 2025; Righi et al., 2021). Despite this positioning, DRR research has systematically underrepresented the vocational context, concentrating instead on general schools, urban infrastructure, and sector-specific engineering without integrating the pedagogical and institutional dimensions specific to vocational education (Lassa et al., 2025; Opabola et al., 2023; Segarra-Alméstica et al., 2022).

Three interrelated structural failures characterize the current state of DRR in vocational education. First, most vocational schools in Indonesia and comparable developing-country contexts were sited without systematic spatial risk assessment: National Agency for Disaster Management (BNPB) data indicate approximately 3,000 disaster events annually over the past five years, and UNESCO estimates that over 75% of schools in disaster-prone zones experience at least one month of instructional disruption per year, with vocational schools disproportionately affected due to their dependence on physical resources that cannot be substituted by remote modalities Takinana and Baars (2023). Second, school infrastructure continues to be built to generic standards that do not incorporate disaster resilience criteria specific to the vocational function: workshops, laboratories, and practice halls present distinct structural and evacuation challenges absent from general school building standards (Nakum et al., 2022; Paci-Green et al., 2020). Third, geospatial risk assessment technologies that are standard instruments in the construction and urban planning sectors remain almost entirely absent from vocational educational settings, even in programs that train future construction professionals (Kholoshyn et al., 2021; Zhu et al., 2018).

Earlier research has made partial advances. Socialization-based mitigation programs have produced measurable knowledge gains (Hamid et al., 2021; Ramadhan et al., 2019), and technology-supported learning environments have improved disaster comprehension Rusilowati et al (2021). Audio-visual media have demonstrated effectiveness in improving risk awareness among students in disaster-prone regions Amri et al (2021). However, these contributions are concentrated in primary and secondary general education and address individual components in isolation, rather than the integrated system that vocational education requires. Spatial planning studies have focused on urban and rural regional scales, not on school-site decision-making. Construction engineering research has advanced fragility modeling and GIS-based vulnerability assessment but has not

applied these to vocational institutional contexts (Alam and Haque, 2020; Zain et al., 2024). The specific combination of infrastructure resilience, spatial governance, and GIS-based technology within vocational education has not been examined as an integrated system. The Sendai Framework's Priority 3 (investing in DRR for resilience) provides both the temporal anchor and the policy rationale for this review. Its emphasis on risk-based infrastructure investment, spatial risk governance, and the use of science and technology for risk assessment directly maps onto the three cluster dimensions identified in this study. By situating this review within the post-Sendai period (2015-2025), this study examines how global DRR policy commitments have translated, or failed to translate, into research on vocational education. Two theoretical lenses complement the Sendai Framework as analytical tools. Transformative Learning Theory (Kitagawa, 2021; Mezirow, 1991) grounds the pedagogical argument that DRR competence in vocational education cannot be achieved through compliance-based training alone: it requires the construction of spatial risk literacy as a professional identity component, particularly among students in construction programs; Building Design and Modeling (DPIB) and Construction and Housing Engineering (TKP). The Disaster-Safe Education Unit (SPAB) framework provides the Indonesian institutional context, demonstrating that school safety depends on the simultaneous integration of structural hardening, spatial risk governance, and community preparedness capacity within a unified policy architecture.

A systematic bibliometric and literature mapping is required to determine where the post-Sendai research record stands on these three dimensions and to identify the integrative gaps that constrain evidence-based DRR practice in vocational education. This study addresses that need through the following research questions:

RQ1: How has the volume and geographic distribution of publications on disaster mitigation in vocational education evolved within the 2015-2025 post-Sendai period, and what are the dominant journal sources?

RQ2: What dominant thematic clusters and knowledge gaps emerge from keyword co-occurrence analysis of the 2015-2025 corpus?

RQ3: Which documents within the 2015-2025 corpus exercise the greatest intellectual influence through co-citation, and what gaps do they collectively reveal?

RQ4: How can disaster-resilient infrastructure design and management strategies be implemented in vocational learning environments, and what role does Virtual Reality play as a pedagogical instrument?

RQ5: How can spatial planning policies and the SPAB framework support disaster risk reduction

in disaster-prone vocational schools in Indonesia?

RQ6: How can geospatial information systems and participatory technology deepen disaster mitigation evaluation and spatial risk literacy in vocational education?

Theoretical Framework

Three conceptual frameworks, each operating at a distinct analytical level, underpin this study's interpretive architecture (Table 1). At the macro-policy level, the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2015) supplies both the temporal boundary and the normative logic of this review: its Priority 3 commitment to investing in DRR for resilience through structural, spatial, and institutional mechanisms maps precisely onto the three bibliometric clusters identified in the corpus. Aligning this review with the post-Sendai decade (2015-2025) is therefore not a technical choice but a substantive one, enabling assessment of how global policy commitments have translated into research output on vocational education. Table 1 maps each framework to its core proposition, analytical role, and linked research question.

Table 1. Theoretical Framework Matrix: Conceptual Anchors, Core Propositions, and Research Question Linkages

Framework	Core Proposition	Application in This Study
Sendai Framework for DRR 2015-2030 (UNDRR, 2015)	Priority 3: Investing in DRR for resilience through structural, spatial, and institutional mechanisms	Grounds the 2015-2025 temporal scope; anchors all three cluster dimensions (infrastructure, spatial policy, GIS) within a global policy mandate
Transformative Learning Theory (Mezirow, 1991; Kitagawa, 2021)	Learning transforms perspective through critical reflection on disorienting dilemmas, producing autonomous, risk-aware agents	Grounds the pedagogical argument that DRR in vocational education must produce spatial literacy and risk agency, not only technical compliance
SPAB Policy Framework - Satuan Pendidikan Aman Bencana (SPAB) (Amri et al., 2022; Nakum et al., 2022)	School safety depends on the integration of structural hardening, spatial risk governance, and school community preparedness capacity	Provides the Indonesian institutional context linking all three clusters; validates the transdisciplinary framework within the national vocational policy landscape

At the pedagogical level, Transformative Learning Theory (Kitagawa, 2021; Mezirow, 1991) argues that substantive DRR competence requires perspective transformation through engagement with authentic, disorienting risk scenarios, producing learners who construct spatial risk literacy as a professional identity rather than acquiring it as procedural compliance. Applied to vocational construction programs, this theory mandates active engagement with GIS tools, fragility data, and participatory mapping rather than passive safety instruction. At the institutional level, the SPAB framework operationalizes school safety in Indonesia through three simultaneous pillars: structural facility safety, school disaster management, and DRR education and resilience culture. These three frameworks are hierarchically nested: SPAB defines what institutional DRR requires; Transformative Learning Theory specifies how vocational pedagogy must deliver it; and the Sendai Framework establishes the global standard against which both are evaluated.

Method

The method section structure should: describe the materials used in the study, explain how the materials were prepared for the study, describe the research protocol, explain how measurements were made and what calculations were performed, and state which statistical tests were done to analyze the data.

This study employs a systematic literature review (SLR) with integrated bibliometric analysis. The article search and selection process adhered to the PRISMA guidelines (Haddaway et al., 2022; Moher et al., 2009). PRISMA was selected for its capacity to support transparent, structured organization of search, screening, and synthesis while minimizing selection and reporting bias (Booth et al., 2021; Snyder, 2019). The literature search was conducted using the Scopus database, restricted to 2015-2025 to align with the post-Sendai Framework implementation period. This boundary is not merely technical: it ensures that reviewed studies reflect the policy context in which risk-based infrastructure investment, spatial governance reform, and GIS deployment in education became internationally mandated priorities. The initial query yielded 98 documents. At the identification stage, 2 duplicate records were removed before screening, leaving 98 unique records for title and abstract review. During the screening phase, 86 records were excluded on three grounds: 30 for being non-journal document types, 20 for non-English language, and 36 for not being open-access publications. The remaining 12 articles advanced to full-text eligibility assessment. Table 2 presents the inclusion and exclusion criteria.

Table 2. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Peer-reviewed scientific journal articles • Written in English • Published between 2015-2025 (post-Sendai Framework) • Full text available (Open Access) • Explicitly addresses DRR in vocational or educational settings • Contains empirical data or validated methodology	• Conference papers, book chapters, review articles, short surveys • Non-English language articles • Articles published before 2015 or after 2025 • Non-peer-reviewed sources • Articles with restricted access (non-OA) • Descriptive narrative without empirical data or validated framework

Each article was assessed against eight quality criteria (Table 3): clarity of research objectives, methodological rigor and justification, explicit definition of the vocational education context, discussion of pedagogical or implementation challenges, grounding in empirical data or validated frameworks, articulation of policy or practice implications, integration of spatial or technological evidence, and transparency sufficient for methodological replication. Of the 16 articles assessed, every one met a minimum of seven out of eight criteria; no article was retained on fewer than seven. Inter-rater reliability was assured through independent double-coding with discrepancies resolved by consensus. Quantitative mapping employed VOSviewer v1.6.20 and bibliometrix v5.0 in R. Co-occurrence network analysis addressed RQ1-RQ2; co-citation network analysis addressed RQ3; Bradford's Law and M-index calculations characterized source influence patterns. For RQ4-RQ6, a layered thematic synthesis matrix was constructed, cross-referencing each article's findings against the three theoretical frameworks (Sendai, Transformative Learning, SPAB) to identify convergences, gaps, and integration opportunities. Quality Assessment Criteria explain in Table 3.

Table 3. Quality Assessment Criteria

Quality Assessment Criteria (8 Items)
1. Is the purpose of the study clearly stated and aligned with DRR in vocational education?
8. Is the study methodology replicable and sufficiently transparent?

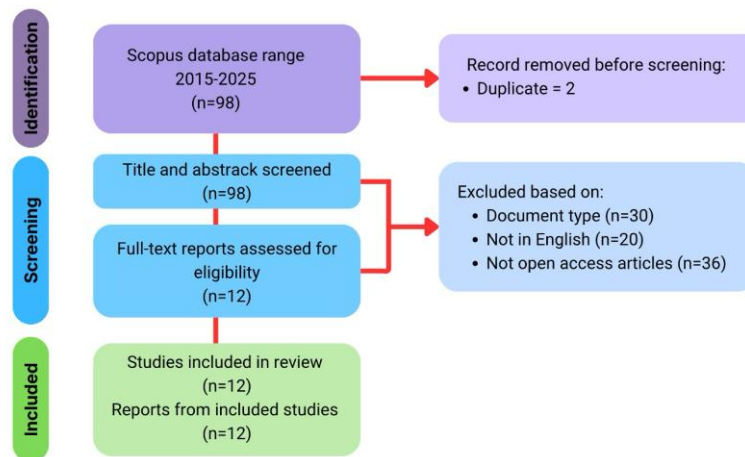


Fig 1: Literature selection process using the PRISMA method

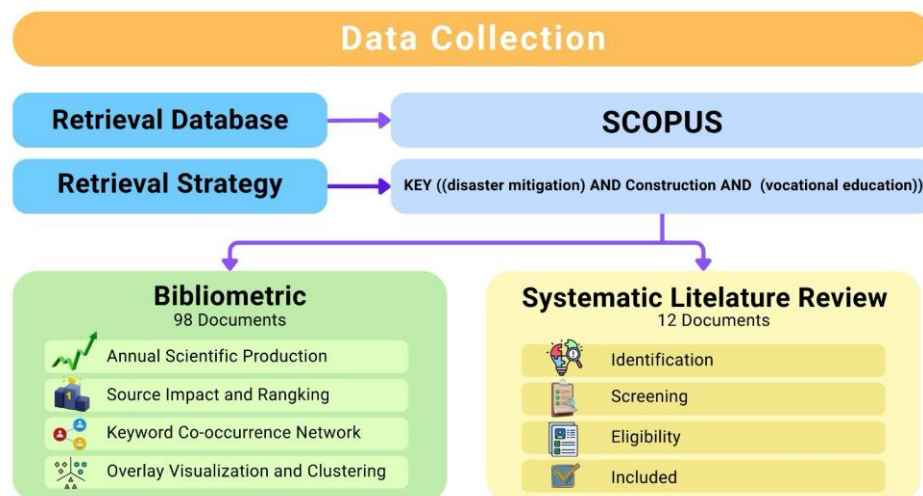


Fig 2: Integrated research workflow

Result and Discussion

RQ1: Publication Trends, Core Journals, and Contributing Countries (2015-2025)

Within the post-Sendai period (2015-2025), the bibliometric corpus of 98 documents retrieved from Scopus using KEY ((disaster mitigation) AND (construction) AND (vocational education)) reveals consistent growth in scholarly output at an estimated 18% average annual increase. Annual output ranged from five to eleven articles between 2015 and 2024, with 2025 already recording six publications at the time of data collection. This trajectory reflects the increasing recognition, catalyzed by the Sendai Framework, of educational institutions as critical nodes in national disaster risk reduction systems (Riyadh et al., 2024; Trupp et al., 2025). Despite this growth, temporal

analysis reveals that publications remain primarily reactive, driven by post-disaster events: the 2016 peak corresponds to responses to the 2015 Nepal earthquake, while subsequent surges in 2019-2020 correlate with heightened regional flood disasters across Southeast Asia.

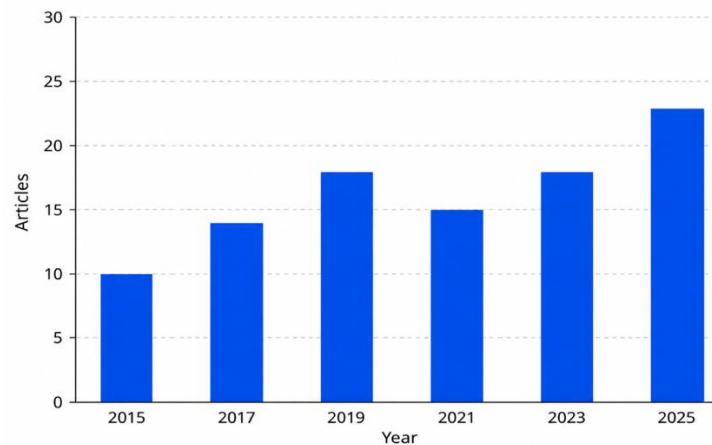


Fig 3: Trajectory of scholarly output on DRR in vocational education by publication year

Bradford's Law applied to the 98 document bibliometric corpus identifies ten Zone 1 core journals (Table 4). Building Research and Information and the International Journal of Disaster Resilience in the Built Environment lead the field, confirming that the literature remains strongly anchored in construction and infrastructure domains. The presence of Sustainability and the International Journal of Disaster Risk Reduction in the core set reflects the widening scope toward socio-institutional and policy dimensions during this period, consistent with Righi et al (2021)'s argument for multidisciplinary DRR education frameworks. Notably, no specialist vocational education journal appears in Zone 1, confirming that the vocational education research community has not yet entered this discourse as a primary producer. Core Sources by Bradford's Law explain in Table 4.

Table 4. Core Sources by Bradford's Law

Source	Rank	Freq	Cum. Freq	Zone
Building Research and Information	1	7	7	Zone 1
International Journal of Disaster Resilience in the Built Environment	2	6	13	Zone 1
Earthquake Spectra	8	3	37	Zone 1
International Journal of Disaster Risk Reduction	9	3	40	Zone 1
Sustainability	10	3	43	Zone 1

Table 5 evaluates journal influence through H-index, G-index, and M-index metrics. Building Research and Information leads with H-index and G-index of 7, accumulating 333 citations. The International Journal of Disaster Resilience in the Built Environment shows an M-index of 0.454 since its 2015 baseline. High M-index values for newer journals (International Journal of Environmental Research and Public Health, Progress in Disaster Science, Disasters) indicate rapid recent growth in impact, reflecting the field's expansion into public health and policy dimensions since 2020. Sources' Local Impact explain in Table 5.

Table 5. Sources' Local Impact

Source	H-index	G-index	M-index	TC	NP	PY Start
Building Research and Information	7	7	0.318	333	7	2015
Int. J. Disaster Resilience in the Built Environment	5	6	0.454	129	6	2015
Int. J. Environmental Research and Public Health	4	5	0.800	78	5	2021
Coastal Engineering Journal	2	2	0.200	75	2	2016
International Journal of Disaster Risk Reduction	3	4	0.600	98	4	2015
Journal of Disaster Research Sustainability	3	4	0.375	45	4	2015
Natural Hazards	2	3	0.400	22	3	2021
Progress in Disaster Science	2	2	0.250	18	2	2015
Disasters	2	2	0.500	15	2	2021
	2	2	0.333	12	2	2023

Geographically, China leads publication contributions within the 98-document bibliometric corpus, followed by Japan, the United States, and Indonesia. Indonesia's position among the top four reflects both the country's high disaster exposure and its sustained commitment to DRR research under the SPAB framework Amri et al (2022). Sahil and Sood (2021) attribute China and Japan's dominance to governmental policy support for hazard research following high-profile seismic events. Importantly, the dominance of Asia-Pacific contributions (62%) confirms that the empirical evidence base for this study's recommendations is substantially drawn from geopolitical and infrastructural contexts directly comparable to Indonesia.

**Fig 4:** Geographic distribution of contributing countries by publication volume

RQ2: Thematic Clusters and Knowledge Gaps - Keyword Co-occurrence Analysis

Keyword co-occurrence analysis of the 98-document bibliometric corpus confirms that disaster mitigation research is globally anchored in civil engineering, risk management, and public policy, with limited integration into educational and pedagogical discourse Zhao (2024). This finding is methodologically significant: it demonstrates that the knowledge infrastructure of DRR research has been constructed largely without the participation of vocational education researchers, producing a domain characterized by technical depth and pedagogical shallowness. Figure 5 presents the keyword co-occurrence network generated in VOSviewer, in which node size reflects keyword frequency and node color denotes cluster membership; the connecting lines indicate conceptual associations between co-occurring terms (Cen, 2025; Guo et al., 2024). Keyword co-occurrence network (VOSviewer) explain in Figure 5.

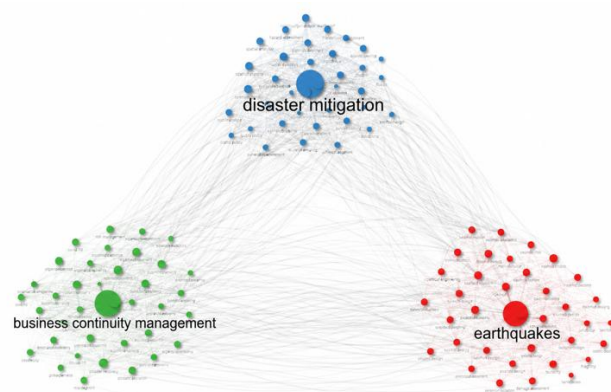


Fig 5: Keyword co-occurrence network (VOSviewer)

Three distinct clusters emerge from the network. The Blue Cluster, anchored by the high-frequency node "disaster mitigation," encompasses hazard assessment, spatial analysis, multi-hazard analysis, public policy, and vulnerability assessment, representing the policy-and-planning dimension of the field. The Green Cluster, centered on "business continuity management," groups risk management, organizational resilience, disaster recovery, preparedness, and COVID-19-related terms, reflecting the institutional and organizational-continuity dimension. The Red Cluster, dominated by the "earthquakes" node, brings together seismic design, structural design, geotechnical engineering, fragility, and landslides, representing the technical-structural engineering paradigm that has driven DRR construction research over the past decade. The prominence of the Red Cluster positions construction and civil engineering programs in vocational institutions as the most proximate entry points for DRR curriculum integration. A critical bibliometric finding is that, although all three clusters are densely interconnected internally, the bridging links between them

are comparatively sparse, indicating that the technical-structural, policy-planning, and organizational-continuity approaches have largely developed as parallel research streams rather than as integrated components of a unified vocational DRR framework.

The thematic map (Figure 6), generated through factorial analysis on the centrality-density plane, repositions these themes according to their structural role in the field. The Red Cluster (seismic, structure, structures, region, simulation, earthquake, buildings) occupies the high-centrality zone, with "seismic" pushing furthest to the right, identifying it as a motor theme: highly central to the field and relatively well developed, yet still concentrated in technical engineering rather than vocational education discourse. The Blue Cluster (analysis, risk, results, study, method, research, construction, mitigation, cluster, paper, image) sits in the high-density, moderate-centrality quadrant, functioning as the methodological backbone of the literature but remaining only partially connected to vocational applications. The Green Cluster (management, data, disaster, development, information, system, social development) lies in the low-centrality, low-to-moderate-density quadrant, marking it as an emerging and underdeveloped theme with substantial untapped potential for vocational education and data-driven decision support. The structural separation of these three clusters across distinct quadrants, with no theme bridging the technical (Red), methodological (Blue), and organizational-developmental (Green) domains, constitutes the central bibliometric finding of this study: a structurally confirmed integration gap rather than a merely rhetorical claim.

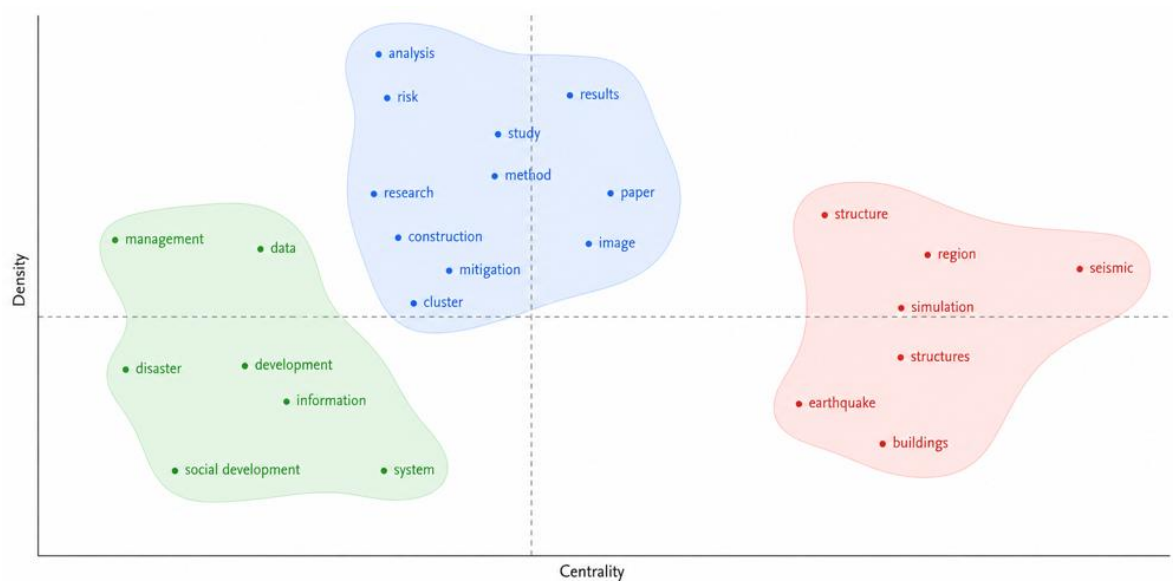


Fig 6: Thematic mapping through factorial analysis

RQ3: Most Influential Documents - Co-citation Analysis

Works that recur together in reference lists reveal the conceptual architecture of a research field. When two publications are repeatedly cited by the same third works, their joint appearance signals intellectual proximity: shared theoretical commitments, methodological overlap, or convergent empirical findings Kleminski et al (2022). Mapping these citation linkages within the post-Sendai corpus therefore illuminates not only what the field has built upon, but what questions it has persistently left unanswered, particularly those concerning vocational education. Table 6 presents the 11 most co-cited documents with their domain and contribution to the research gap.

Table 6. Most Globally Cited Documents (2015-2025) and Contribution to Research Gap

Paper Title	Author and Year	Citations	Contribution to Gap
Supporting post-disaster social recovery to build back better	Mannakkara and Wilkinson (2015)	46	Post-disaster resilience policy framework
Investing in disaster preparedness of school infrastructure	Opabola et al (2023)	38	School-level recovery investment analysis
Informing DRR policies for education infrastructure	Opabola and Galasso (2024)	34	Scenario-based policy decision tool
Pathways to DRR education integration: SPAB Indonesia	Amri et al (2022)	29	National SPAB implementation evidence
School resilience framework for risk-informed decision-making	Nakum et al (2022)	24	Institutional resilience decision model
Disaster risk reduction activities as learning	Kitagawa (2021)	21	Transformative learning in DRR context
Vulnerability of school education to climate hazards	Pal et al (2023)	18	Multi-hazard school vulnerability review
Spatial analysis of disaster resilience: bibliometric study	Riyadh et al (2024)	15	Bibliometric methodology for resilience
Machine Learning algorithms for seismic vulnerability of school buildings	Zain et al (2024)	12	Data-driven infrastructure assessment
Disaster resilience PPP for sustainable urban development	Ishiwatari et al (2024)	11	Integrative PPP model; Japan context

Four citation-network patterns carry direct implications for the vocational education DRR agenda. First, the Opabola and Galasso paired publications (2023; 2024) have achieved the fastest citation growth among recent entries, confirming that the research community has recognized school infrastructure recovery and DRR policy design as urgent priority domains, even though their analyses address general school systems rather than vocational ones. Second, Amri et al. (2022) SPAB evaluation study stands as the most cited Indonesia-specific empirical contribution,

establishing that when spatial risk data is embedded within school accreditation standards, measurable preparedness gains follow across all three SPAB pillars. Third, Kitagawa (2021) occupies a distinct position as the only entry that explicitly theorizes DRR activities as learning processes: this framing is the conceptual bridge connecting the Sendai Framework's knowledge-sharing mandate to Mezirow (1991) account of transformative professional identity formation through active engagement with risk contexts. Fourth, the combined citation trajectory of Zain et al (2024) and Riyadh et al (2024) signals a methodological turn toward data-driven, spatially explicit vulnerability assessment, consistent with the increasing analytical emphasis observed across the post-Sendai period.

The co-citation map simultaneously reveals a structural vacancy that defines the field's primary limitation. Scanning all 11 high influence documents, none situates the integration of infrastructure vulnerability modeling, GIS-based spatial governance, and institutional preparedness within the pedagogical and operational context of vocational education. Among the 11, Ishiwatari et al. (2024) achieve the broadest disciplinary reach through a public-private partnership model that connects physical resilience, spatial zoning, and governance capacity within a Japanese urban development setting, yet the study does not engage with practice based learning environments or vocational curriculum design. This vacancy is a structural property of the citation network itself, not an oversight by individual researchers: engineering journals and vocational education journals occupy distinct scholarly communities with minimal bibliographic overlap, and the post-Sendai decade has produced no bridging publication capable of spanning the red, blue, and green clusters within a vocational frame. Resolving this vacancy through a transdisciplinary framework is the primary contribution of this study.

RQ4: Disaster-Resilient Infrastructure Design in Vocational Learning Environments

Implementing disaster-resilient infrastructure in vocational schools requires simultaneous engagement with technical, social, and institutional dimensions. Within the post Sendai 2015-2025 literature, four design principles emerge with consistent empirical support. First, quantitative vulnerability assessment using fragility functions calibrated for reinforced concrete buildings Gadagamma et al (2018) enables probabilistic earthquake damage estimation applicable to vocational school workshops and laboratories in high-seismic zones including Sumatra, Sulawesi, and West Nusa Tenggara. Second, adaptive multi-hazard design (Amini et al., 2024; Tabucanon et al., 2021) integrates earthquake and tsunami risks within unified spatial models, requiring minimum floor elevation, adaptive drainage, and coastal buffer standards for vocational schools in

areas like Palu, Lombok, and Nias. Third, inclusive evacuation design Miyaji et al (2020) must account for gender, disability, and local cultural values within vocational settings, which involve diverse learner populations and non-standard spatial configurations distinct from general school layouts.

Opabola et al (2023) provide direct evidence from Indonesian schools that proactive structural investment yields measurable recovery performance advantages over post-disaster repair, with cost-effectiveness ratios that justify pre-event infrastructure upgrades. Their follow-on policy study Opabola and Galasso (2024) translates structural vulnerability data into scenario-based recovery analyses directly applicable to vocational school infrastructure planning. Yokouchi (2015) demonstrates that community participatory design is not optional in culturally embedded building zones: it is a determinant of mitigation effectiveness, a principle applicable to vocational schools embedded in communities with distinct cultural spatial practices and land-use governance systems.

Crucially, adaptive infrastructure need not require large budgets, an essential point given the severe fiscal constraints of most Indonesian Vocational School. The literature supports a tiered, cost-sequenced pathway. At the lowest tier, non-structural mitigation, anchoring shelving, machinery, and gas cylinders, securing equipment, relocating hazardous materials, and signposting exit routes, can be done almost without budget, ideally by students and teachers as applied DPIB and TKP learning. At the intermediate tier, low-cost retrofitting (steel or bamboo-composite bracing, ferrocement jacketing, strengthening masonry wall-to-roof connections) can target the highest-risk buildings first via rapid visual screening, it can draw on school workshops and student labor. For flood-prone schools, raising equipment and sockets, permeable drainage, and removable barriers offer high protection at minimal cost Tabucanon et al (2021). Full seismic reconstruction is reserved for critically vulnerable buildings through phased budgeting or public-private partnerships Ishiwatari et al (2024). This model lets even budget-constrained schools begin immediately and scale up as funding allows.

Virtual Reality (VR) represents the most pedagogically significant technology for embedding disaster-resilient design competencies within vocational learning. In research by Kuncoro et al (2023) demonstrate that VR-based instruction on earthquake-resistant construction significantly improves civil engineering students' technical understanding and design skills. Meta-analysis confirms that VR applications in construction safety training statistically outperform conventional approaches in both behavioral and skills-based outcome measures. Next, the research by Adami et al (2021) further establish that VR-based training for complex technical operations enhances

operational competence and safety behavior. These findings collectively position VR not merely as an educational tool but as a mechanism for the transformative learning that Mezirow (1991) framework identifies as essential: VR creates the disorienting, immersive dilemma conditions through which students construct new risk-aware professional identities as construction practitioners.

RQ5: Spatial Planning Policies and the SPAB Framework in Indonesian Vocational Schools

Spatial planning policy is a structural determinant of vocational school safety that operates upstream of any infrastructure investment decision. Site-selection errors, once institutionalized through construction, generate multi-generational vulnerability that no structural hardening can fully remediate. Evidence from New Zealand demonstrates that schools built in flood-prone areas due to misaligned planning regulations have required costly relocation and reconstruction, highlighting the long-term consequences of inadequate spatial planning Hanna et al (2025). The development of risk-based seismic location standards for public buildings has likewise been linked to adaptive spatial regulatory reform coordinated across sectors and supported by local government authority Egbelakin et al (2025). In Indonesia, where many vocational schools are situated on mountain slopes, riverbanks, or coastal lowlands, effective spatial risk governance is particularly important.

The SPAB framework provides the Indonesian institutional architecture for spatial risk integration into school planning. SPAB's three pillars, safe school facility, school disaster management, and risk reduction and resilience education, map directly onto this study's three cluster dimensions: structural resilience (Red Cluster), spatial governance (Blue Cluster), and GIS-based technology (Green Cluster). When spatial risk data is systematically incorporated into SPAB accreditation and school planning standards, institutional preparedness improves measurably across all three dimensions.

Evidence from Kenya's integrated development planning framework indicates that local adaptive capacity is strengthened when spatial-physical, institutional, and educational planning dimensions are evaluated collectively rather than in isolation Kowalczyk and Dorevitch (2024). This finding is directly transferable to the Indonesian vocational context, where GIS-based spatial vulnerability mapping and risk zoning should be incorporated as regulatory criteria for both the siting of new vocational schools and the periodic accreditation of existing facilities. Critically, spatial governance literacy can be embedded within vocational construction and civil engineering programs, enabling students to interpret, evaluate, and apply geographic risk data in infrastructure

planning. Such integration simultaneously enhances technical competence and strengthens students' risk agency as future construction professionals, thereby supporting the objectives of transformative learning.

RQ6: Geospatial Information Systems and Spatial Risk Literacy in Vocational Education

The geospatial information systems dimension contributes substantially to the 98-document bibliometric corpus, and its practical significance for vocational education exceeds its bibliometric share. GIS and related geospatial technologies appear as the most consistently applied decision-support instruments across all three cluster dimensions: supporting structural vulnerability mapping within the technical-structural (Red) cluster, spatial risk zoning and hazard siting within the policy-and-planning (Blue) cluster, and real-time institutional monitoring and continuity planning within the organizational (Green) cluster. Table 7 synthesizes the five core GIS application modalities identified in the 2015-2025 literature, with specific implications for vocational education in Indonesia.

Table 7. GIS Application Modalities in DRR: Evidence Base and Implications for Indonesian Vocational Schools

GIS Application	Description	Evidence Base	Practical Implication for Vocational School
Spatial risk zoning	GIS-based identification of fault lines, flood plains, and liquefaction zones for school siting decisions	(Egbelakin et al., 2013; Hanna et al., 2025)	Vocational schools in DPIB/TKP programs can map local hazard zones as project-based learning tasks
Participatory risk mapping	Community-based GIS processes that integrate local spatial knowledge with official hazard data	(Ishiwatari et al., 2024; Que et al., 2022)	The construction programs in vocational school can collaborate with local government in participatory mapping projects for disaster preparedness plans

An economic rationale for GIS-based disaster risk reduction investments is provided through input-output analysis showing that indirect flood-disaster costs can be quantified and incorporated into cost-benefit assessments of infrastructure interventions Lyu et al (2023). This evidence is particularly relevant for vocational school administrators seeking to justify investments in IoT-based monitoring systems or participatory mapping programs within institutional budgeting processes. Furthermore, machine learning algorithms applied to GIS-derived building datasets have been shown to outperform conventional inspection-based approaches in seismic vulnerability classification, offering a scalable and cost-effective tool for national school safety initiatives.

Participatory GIS represents the most important convergence point between the technical and transformative learning dimensions of this study. Evidence indicates that community-based risk mapping can reveal spatial and cultural risk factors often overlooked by purely technical models, including informal land-use practices, concentrations of social vulnerability, and locally embedded early-warning knowledge systems Que et al (2022). Participatory preparedness surveys further contribute to the development of risk literacy among student participants while generating valuable contextual information for institutional planning Titko et al (2021). In addition, vocational education models have demonstrated the feasibility of integrating GIS-based disaster data collection and school-community participatory mapping as core components of technical training programs. Embedding participatory GIS within the vocational curriculum as a discipline-specific competency, rather than as an extracurricular addition, therefore represents a promising approach for building and construction vocational education programs in Indonesia.

The integration of GIS literacy into vocational construction programs (DPIB and TKP) is not simply a pedagogical enhancement: it constitutes the operationalization of the Sendai Framework's knowledge-sharing mandate and the SPAB framework's risk reduction education pillar within the vocational sector. Students who graduate with competencies in spatial vulnerability assessment, multi-hazard mapping, and participatory risk documentation become the technical workforce capable of implementing evidence-based DRR at the community and institutional level, thereby fulfilling vocational education's structural role as a driver of resilient community development.

Conclusion

Grounded in the post-Sendai 2015-2025 period, this review shows that DRR research in vocational education has grown at 18% annually, dominated by Asia-Pacific output (62%). Using two Scopus corpora, 98 documents for bibliometric mapping and 12 PRISMA-screened articles for

SLR synthesis, three thematic clusters were identified: a disaster-mitigation policy-and-planning cluster (Blue), a business-continuity-management organizational cluster (Green), and an earthquake-seismic technical-structural cluster (Red). The most influential works centered on school infrastructure recovery, national DRR education evaluation, and disaster learning theory, marking a clear shift toward integrated school resilience frameworks and data-driven vulnerability tools.

The central finding is a structurally confirmed integration gap: no document in the corpus combines technical resilience, spatial governance, and GIS-based decision-support within a vocational. This reflects the persistent separation between engineering and vocational education research communities. Integrating these three dimensions into one transdisciplinary framework offers far greater DRR effectiveness than the fragmented single-dimension approaches that currently prevail.

The proposed framework rests on three pillars: the Sendai Framework (policy mandate), Transformative Learning Theory (pedagogical mechanism), and SPAB (Indonesian institutional architecture). It treats the three dimensions as an interdependent system: spatial governance directs where to invest in structural resilience, GIS-based monitoring evaluates that investment, and transformative vocational education produces the workforce to operate it.

Five practical recommendations follow: (1) embed disaster-resistant construction standards and multi-hazard GIS mapping into DPIB and TKP programs as core competencies; (2) make GIS-based risk zoning a mandatory criterion for school siting and SPAB accreditation; (3) deploy IoT-based structural monitoring in high-risk school facilities; (4) build school-community participatory GIS platforms with BNPB and local agencies; and (5) develop and validate a vocational-specific multi-hazard resilience index. Future research should test these across multiple school sites and disaster types in Indonesia.

For local policymakers, Education Department, Regional Disaster Management Agency, and vocational school supervisory bodies, six concrete steps follow, sequenced from zero-cost to capital-intensive. First, conduct a rapid visual screening audit of all vocational school within twelve months using free BNPB hazard maps, classifying each into green, yellow, or red risk tiers. Second, ring-fence a minimum share of existing maintenance funds for non-structural mitigation so low-cost, high-impact measures are funded immediately. Third, issue a binding local regulation requiring GIS hazard-zone clearance before any new vocational school building permit. Fourth, formalize tripartite partnerships between Education Department D, Regional Disaster Management Agency,

and construction industry associations, turning red-tier retrofitting into a supervised student practicum with donated materials and mentorship. Fifth, embed disaster-mitigation competency into the vocational school curriculum charter and teacher development budget. Sixth, maintain a shared digital risk register with the BPBD recording each school's risk tier, completed actions, and outstanding needs as a basis for transparent multi-year budgeting. This sequence lets local governments show immediate progress while building the case for larger phased investment.

To strengthen WBL programme quality in the automotive service production unit, schools should take the following concrete steps. First, instructors supervising WBL must possess current industry experience and should receive periodic refresher training to ensure that their feedback to students reflects actual industry standards. Second, workshop equipment must be maintained and updated to match the technology currently used in the automotive service industry; outdated tools limit the authenticity of the learning environment and reduce the relevance of students' practical experience. Third, schools should set a structured minimum WBL duration and evaluate whether extended participation beyond six months produces measurably stronger readiness outcomes. Fourth, periodic competency assessments during WBL should be implemented to identify and address skill gaps before graduation. Fifth, structured reflection sessions aligned with Kolb's reflective observation stage should be integrated into WBL activities to help students process and internalise their learning more deeply.

The remaining 39.7% of unexplained variance indicates that work readiness is shaped by multiple interacting factors beyond WBL participation alone. Future research should investigate the roles of instructor supervision quality, workshop facility conditions, student learning styles, motivation, and socioeconomic background through multi-variable designs. A longitudinal study tracking graduates' actual job placement rates and early career trajectories would provide stronger evidence of the long-term workforce impact of production unit-based WBL. A multi-school comparative design would also allow researchers to examine how variation in production unit quality and institutional resources moderates the WBL-work readiness relationship across different SMK contexts in Indonesia.

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