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Towards a risk governance framework for reducing the seismic vulnerability of existing buildings: a comparative analysis of national strategies with implications for Algeria

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Abstract

Every major earthquake is a reminder that buildings do not collapse because of geology alone: they collapse because the societies in which they stand have not invested in making them safer. This study examines national governance frameworks for reducing the seismic vulnerability of existing buildings through a comparative analysis of six high-seismicity countries (Japan, New Zealand, California in the United States, Turkey, Italy, and Greece). Using a five-pillar analytical framework spanning regulatory, technical, financial, institutional, and cultural dimensions, we identify the mechanisms that distinguish effective governance from ineffective intent. Our central finding is that successful seismic risk reduction is never the product of a single policy instrument but emerges from the coherent alignment of five interdependent conditions: enforceable legislation specifically targeting the existing building stock, performance-based financial incentives capable of mobilising private capital, comprehensive national building-risk inventories, coordinated multi-level governance, and a deeply embedded societal risk culture. These findings are translated into a phased and operationally specific governance framework for Algeria, a country whose location on one of the Mediterranean basin's most active seismic belts, combined with a critically vulnerable pre-code building stock and a currently reactive policy architecture, makes the transition to proactive seismic risk governance both urgent and achievable.

Keywords. seismic vulnerability; risk governance; existing buildings; retrofitting policy; Algeria; comparative analysis; disaster risk reduction

Short summary

Earthquakes kill people mainly because buildings are not strong enough to survive the shaking. In countries like Algeria, most buildings were constructed before any rules about earthquake safety existed, and there is currently no national programme to make them safer. This study compares what six other earthquake-prone countries have done to identify what actually works and why. The key lesson is that five things must work together: clear laws for existing buildings, financial help for owners who strengthen their homes, accurate knowledge of which buildings are

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most at risk, good coordination between government agencies, and a society that genuinely understands earthquake risk. The study then spells out what Algeria specifically needs to do, in practical steps, to move from reacting to disasters toward systematically preventing them.

1 Introduction

On the morning of 21 May 2003, an earthquake of magnitude 6.8 struck the Boumerdes region, 50 km east of Algiers. Within seconds, thousands of buildings collapsed, killing 2278 people and leaving 150 000 homeless. What made this outcome particularly painful was its preventability. Many of the buildings that collapsed had been designed without any provision for seismic forces, predating the first Algerian Seismic Code (Reglement Parasismique Algerien, hereafter RPA) by a decade or more. The code existed; the buildings predated it; and there was no programme to address them.

Twenty years later, the structural conditions for a similar or worse disaster remain largely unchanged. The Algerian building stock is dominated by unreinforced masonry heritage structures, poorly detailed reinforced concrete frames from the rapid construction era of the 1960s to 1980s, and a sprawling informal sector that has never been subject to technical oversight of any kind. The regulatory framework, embodied in successive revisions of the RPA, is a code for new construction. For the millions of buildings already standing, there is no mandatory assessment methodology, no national vulnerability inventory, no performance classification system, and no financial incentive to retrofit.

This is not an unusual situation. Almost every country with a high seismic risk has faced some version of this challenge, and the international record shows that it is possible to address it effectively. Japan rebuilt its governance architecture after the 1995 Kobe earthquake to achieve one of the highest rates of seismic retrofitting of critical infrastructure in the world. Italy designed a tax incentive mechanism so well-calibrated to building-owner decision-making that it stimulated tens of billions of euros in private retrofit investment within six years. New Zealand enacted legislation that gives building owners clear deadlines and makes non-compliance legally and commercially untenable. These are not merely interesting case studies but evidence-based models whose governing logic can be extracted, understood, and adapted.

This article makes three contributions. First, it proposes an integrated five-pillar risk governance framework for seismic vulnerability reduction, grounded in the theoretical literature on disaster risk governance (Olson, 2005; Kurdi, 2021; Castano-Rosa et al., 2022). Second, it provides a comparative analysis of strategies in six reference countries across all five pillars, generating a synthesised evidence base spanning regulatory, technical, financial, institutional, and cultural dimensions. Third, it translates that evidence base into a phased, operationally specific

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governance framework for Algeria, calibrated to its institutional realities, building-stock characteristics, and resource constraints. The result is not a catalogue of foreign practices but an argument about why certain governance architectures work and what Algeria would need to do to build one.

2 Seismic context and building stock vulnerability in Algeria

2.1 Tectonic exposure and urban concentration

Algeria occupies one of the Mediterranean basin's most seismically active zones, positioned along the convergence boundary between the African and Eurasian tectonic plates (Benfarhat et al., 2020). The resulting seismicity is concentrated in the northern Tell Atlas belt, which runs along the coastline through Algiers, Oran, Constantine, and Annaba: the country's most densely populated and economically productive corridor. The 1980 Chlef earthquake (moment magnitude 7.1, 2633 fatalities) and the 2003 Boumerdes earthquake (moment magnitude 6.8, 2278 fatalities) are the most destructive recent events, but the geological record shows a pattern of large-magnitude earthquakes at intervals of 20 to 50 years throughout the historical period (Lanseur et al., 2021). The question is therefore not whether a major earthquake will strike northern Algeria again, but whether the built environment will be measurably safer when it does.

Rapid urbanisation driven by demographic pressure and rural-to-urban migration has intensified the exposure problem. Metropolitan areas in the northern corridor have grown faster than the regulatory, planning, and technical capacity of the institutions responsible for managing them (Mahrad et al., 2020). The result is a peri-urban landscape of high-density informal construction that sits outside any regulatory framework, adjacent to ageing formal stock that has never been assessed for seismic performance.

2.2 Building stock stratification and vulnerability typology

The vulnerability of Algeria's existing building stock is not uniform but stratified across three distinct historical strata, each with its own technical profile, institutional status, and governance implications (Fig. 1).

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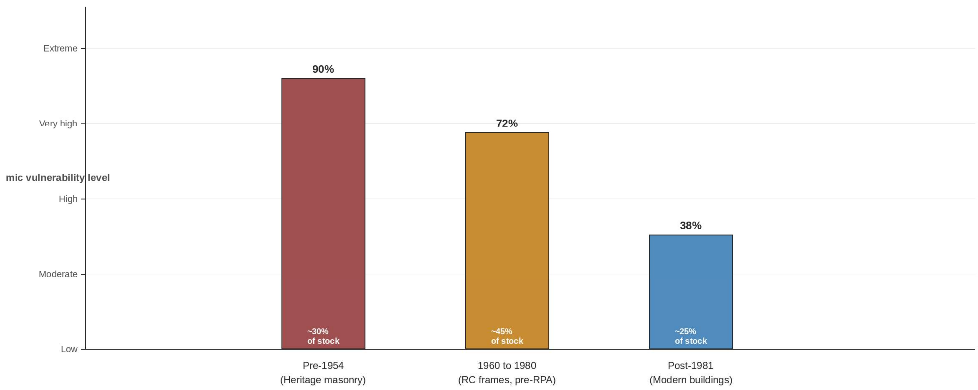

Figure 1. *Typology and seismic vulnerability of Algeria's existing building stock. Bar height represents relative vulnerability level; stock proportions are illustrative estimates based on available literature (Benfarhat et al., 2020; Lanseur et al., 2021; Henni-Chebra et al., 2024). Figure created by the authors.*

The pre-1954 stratum comprises predominantly stone or brick masonry structures, including the rich architectural heritage of northern Algerian casbahs and colonial-era city centres. These buildings are characterised by thick but poorly bonded walls, the complete absence of reinforced concrete elements, and centuries of deferred maintenance. Henni-Chebra et al. (2024), in a detailed assessment of the El Feth High School in Blida (a 19th-century masonry structure typical of this stratum), found systematic non-compliance with every modern seismic design principle, combined with irreplaceable cultural heritage value that complicates demolition-based solutions. The 1960 to 1980 stratum, constructed during Algeria's post-independence mass housing era, consists largely of reinforced concrete frame structures designed exclusively for gravity loads with no provision for lateral seismic forces. These buildings predate the RPA 1981 by a decade or more, and their structural deficiencies are compounded by the poor concrete quality and inadequate reinforcing practice characteristic of rapid construction under limited technical supervision (Hansu and Oguz, 2025). The post-RPA stratum, though nominally subject to seismic design requirements, carries substantial residual risk attributable to persistent enforcement deficits, non-compliant construction practice, and the widespread phenomenon of informal self-construction that characterises peri-urban growth (Benfarhat et al., 2020; Lanseur et al., 2021).

2.3 Policy context: what exists and what is missing

Algeria's current seismic policy framework consists, in its essentials, of the RPA: a code for new construction. The RPA has been revised in 1981, 1999, and 2003, with each revision incorporating lessons from the most recent destructive earthquake, and a further revision (RPA 2024) is now in development. The Technical Construction Control agency (CTC) exercises oversight of

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construction quality for new buildings and conducts post-earthquake damage assessments, but without a national mandate, methodology, or resource allocation for systematic proactive assessment of existing buildings. No national seismic risk classification system exists. No financial incentive for voluntary or mandatory retrofitting exists. And no binding timeline for assessment or intervention has been established for any building category (Souidi et al., 2025).

This policy gap is not simply a technical omission but a structural feature of a governance architecture designed around crisis response rather than risk reduction. The political economy of prevention is difficult everywhere: a retrofitted building that survives an earthquake is invisible in the news cycle, while a collapsed building generates immediate political pressure. Breaking this pattern requires purpose-built institutional mechanisms that sustain long-term investment across electoral cycles and make the cost of inaction as visible as the cost of action.

3 Analytical framework and methodology

3.1 The five-pillar governance framework

The governance framework proposed in this article rests on five interdependent pillars, illustrated in Fig. 2. The interdependence is the core theoretical claim: a country can have the best retrofitting code in the world and see it fail for want of certified contractors; the most generous tax incentive and find no uptake because building owners do not believe the risk is real; the most advanced technical methodology and no institutional capacity to deploy it. The five pillars are therefore not parallel tracks but a system, and the international evidence shows that their alignment is what distinguishes countries that have achieved measurable risk reduction from those that have not.

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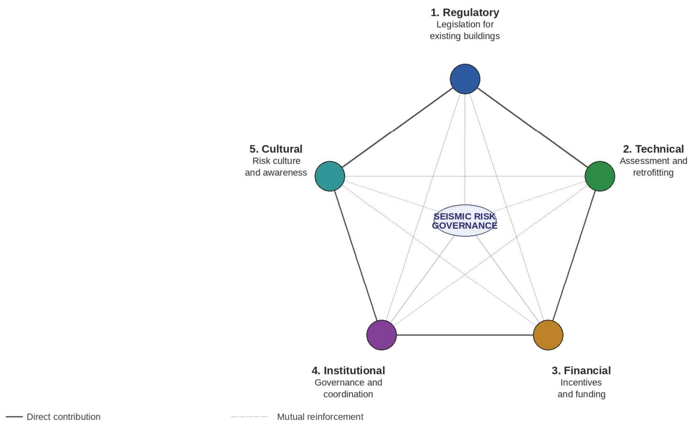

Figure 2. *The integrated five-pillar seismic risk governance framework. Solid arrows show direct contribution of each pillar to overall resilience; dashed arrows indicate mutual reinforcement between pillars. The five-pillar structure is adapted from the disaster risk governance literature (Olson, 2005; Passoni et al., 2022). Figure created by the authors.*

The regulatory pillar concerns the legal architecture for existing buildings: what is mandatory, what is incentivised, for whom, and by when (Olson, 2005). The technical pillar addresses vulnerability assessment methodologies, retrofitting technologies including base isolation, fibre-reinforced polymer (FRP) systems, fabric-reinforced cementitious matrix (FRCM) composites, and exoskeleton systems, as well as the standardisation of professional practice (Ademovic et al., 2022; Karaki and Hawileh, 2025). The financial pillar encompasses subsidies, performance-based tax incentives, guarantee funds, insurance linkages, and integrated seismic-energy renovation packages (Almeida et al., 2024; Musolino et al., 2025). The institutional pillar focuses on coordination between government levels, technical agencies, and the private sector, including life-cycle thinking in public expenditure decisions (Passoni et al., 2022; Caruso et al., 2021). The cultural pillar addresses risk communication, community preparedness, professional education, and the social demand for safety that drives voluntary action beyond what the law requires (Castano-Rosa et al., 2022).

3.2 Country selection and comparative methodology

The six reference countries were selected to cover two complementary perspectives. Japan, New Zealand, and California (USA) represent internationally recognised leaders in seismic risk management, each embodying a distinct governance model: Japan for its risk-culture approach and decentralised incentive architecture (Palm, 2019); New Zealand for its coercive mandatory framework with legally binding timelines (Hoang, 2022); and California for its innovative public-private financial mechanisms and risk quantification infrastructure (Sattar, 2021; Zhang et al.,

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2022). Turkey, Italy, and Greece were selected for their Mediterranean geodynamic context, which closely mirrors Algeria's seismic environment, and for the particular relevance of their post-disaster regulatory evolution and heritage conservation challenges (Hansu and Oguz, 2025; Karaki and Hawileh, 2025).

The comparative methodology combines a systematic review of peer-reviewed literature and policy documents with qualitative assessment of each country's performance across the five pillars. For each country, evidence is structured according to the five criteria, followed by a cross-sectional synthesis identifying convergences, divergences, and transferable governance logic. The aim is not to rank countries but to extract the mechanisms that make certain policy architectures more effective than others, and to assess their adaptability to the Algerian context. A multi-criteria prioritisation framework informed by Mesta et al. (2023) and Caruso et al. (2021) underpins the intervention sequencing recommendations in Sect. 5.

4 Comparative analysis of national vulnerability reduction strategies

The comparative evidence across six countries reveals a consistent pattern: seismic vulnerability reduction succeeds when it is governed, not merely regulated. The distinction matters, because regulation sets standards while governance delivers outcomes. The following subsections trace this distinction across four thematic areas, with the regulatory timeline for all six countries summarised in Fig. 5 and the cross-country performance assessment visualised in Fig. 6.

4.1 Regulatory frameworks: from prescriptive minimums to performance mandates

The international trajectory of seismic regulation has shifted from prescriptive life-safety minimums towards performance-based standards that define multiple objectives for multiple hazard levels and make compliance enforceable through institutional mechanisms rather than professional goodwill (Sattar, 2021; Zhang et al., 2022). This shift is clearest in New Zealand, where the Building (Earthquake-prone Buildings) Amendment Act 2016 names a specific performance threshold (67% of the New Building Standard), assigns it to building categories, and gives owners legal deadlines to meet it, backed by a publicly accessible register that makes non-compliance commercially and socially costly (Hoang, 2022). Japan's approach is more graduated but equally systematic: the Act on Promotion of Seismic Retrofitting of Buildings mandates assessment for all critical public infrastructure and uses a sophisticated subsidy and tax-incentive architecture to motivate private compliance, adapted after the 2011 earthquake to give regional governments greater flexibility (Palm, 2019).

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Turkey's trajectory carries the most important cautionary lesson for Algeria. After 1999, Turkey revised its code to among the most technically sophisticated in the world, culminating in the 2018 TBDY revision. Yet the 2023 Kahramanmaras earthquake killed over 50 000 people. The code failed not because it was technically deficient but because the enforcement capacity required to make it real on construction sites was inadequate (Hansu and Oguz, 2025). Regulatory sophistication without enforcement infrastructure is theatre. For Algeria, this means that the priority is not drafting a perfect standard but building the institutional capacity to implement whatever standard exists. A comparative overview of regulatory frameworks and their assessed effectiveness is provided in Table 1.

Table 1. Comparative regulatory frameworks for seismic vulnerability reduction of existing buildings.

Country	Key legislation	Scope	Approach	Main features	Strength
Japan	Act on Promotion of Seismic Retrofitting (1995, amended 2013, 2020)	Public and private; pre-1981 priority	Coercive plus incentive	Mandatory assessment for critical buildings; subsidies; decentralised implementation	5/5
New Zealand	Building (Earthquake-prone Buildings) Amendment Act 2016	All buildings; URM; 3 seismic zones	Mandatory	Legal obligation to reinforce or demolish; public register; 7.5 to 25-year deadlines	5/5
California	Field Act (1933); Soft-Story Ordinances (2015)	Public schools, URM, soft-story	Mandates plus incentives	CEA-funded EBB grants; local ordinances; risk-based prioritisation	4/5
Turkey	DBYYHY-2007; TBDY-2018; Urban Transformation Law 2012	All existing buildings; dense urban areas	Reactive, evolving to proactive	Post-earthquake code revisions; Urban Renewal; AFAD coordination	3/5
Italy	NTC-2008 and NTC-2018; Seismic Risk Classification (2017)	All buildings; heritage; strategic	Incentive-based	Risk classification A to G; Sismabonus 50 to 85%; combined seismic and energy retrofitting	4/5
Greece	EAK 2000; KAN.EPE 2012	All buildings; RC and masonry	Standards plus preparedness	KAN.EPE protocols; FRP retrofitting; civil protection exercises	3/5
Algeria	RPA 1981; RPA 99/v2003 (new construction only)	New buildings only; limited existing stock provisions	Reactive; post-disaster	No mandatory framework for existing buildings; CTC case-by-case assessments	2/5

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Strength ratings are on a 5-point scale (1/5 = nascent, 5/5 = excellent) based on the authors' assessment of regulatory scope, enforceability, and demonstrated outcomes. URM: unreinforced masonry; NBS: New Building Standard; RPA: Algerian Seismic Code; CTC: Technical Construction Control agency.

4.2 Technical approaches: the era of integrated retrofit

The technical landscape for seismic retrofitting has been transformed over the past two decades. The conventional toolkit of reinforced concrete jacketing and shear wall addition, though effective, is intrusive, costly, and typically requires building evacuation during works. The current frontier is defined by minimally invasive systems that can be applied externally without displacing occupants: FRP composites, FRCM systems, steel exoskeletons, and base isolation platforms (Ademovic et al., 2022; Formisano and Longobardi, 2025; Karaki and Hawileh, 2025). Italy's experience with FRCM for historic masonry is of particular relevance to Algeria's heritage building stock, combining structural reinforcement with low visual intrusiveness and reversibility that satisfies heritage conservation requirements (Caprino et al., 2021; Coscia and Senatore, 2017).

A development of strategic importance for the political economy of retrofitting is the growing evidence for combined seismic-energy retrofit: integrated interventions that simultaneously improve structural safety and thermal energy performance, substantially improving cost-benefit ratios and creating a multi-objective value proposition that reaches building owners, energy policy actors, and financial institutions simultaneously (Almeida et al., 2024; Formisano and Longobardi, 2025). Italy's integration of the Sismabonus (seismic incentive) and Ecobonus (energy efficiency incentive) under the Superbonus 110% programme demonstrated that this convergence can produce unprecedented private investment mobilisation in a short time frame (Musolino et al., 2025). The adaptive reuse frameworks developed by Zhang et al. (2025) and Wang and Zakaria (2025) for heritage buildings offer methodological resources for integrating seismic safety and conservation objectives in Algerian historic urban fabric.

4.3 Financial mechanisms: making retrofitting economically rational

The financing challenge is where most vulnerability reduction programmes fail. Public budgets are finite, electoral cycles are short, and private building owners (particularly low- and middle-income households) lack both the capital and the informational basis to make voluntary retrofitting decisions rationally (Almeida et al., 2024; Musolino et al., 2025). The international evidence points clearly to one model that has overcome these barriers more successfully than any other: the performance-based tax incentive linked to a certified, independent assessment of risk class improvement. Italy's Sismabonus is the paradigm case. By linking the size of the tax deduction (50 to 85%) directly to the demonstrable improvement in the building's certified risk

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classification on the NTC scale from A to G, the mechanism creates a financial reward commensurate with actual risk reduction, transparent to building owners, and verifiable by the state. Between 2017 and 2023, the programme stimulated tens of billions of euros in private retrofit investment and created a new professional ecosystem of certified assessors and contractors (Musolino et al., 2025). A comparative overview of financial mechanisms is provided in Table 2.

Table 2. Comparative financial mechanisms for seismic retrofitting.

Country	Direct subsidies	Tax incentives	Preferential loans	Insurance link	Dedicated fund	Rating
Japan	Up to 50% of retrofit cost	Tax deductions for owners	Low-interest municipal loans	Partial; CAT bonds	National and municipal funds	5/5
New Zealand	Limited central funding	Variable at local level	Market rate only	EQC partial coverage	EQC natural hazards fund	3/5
California	EBB grants (max USD 3000)	State and federal tax credits	PACE financing	CEA insurance linked to EBB	CEA dedicated fund	4/5
Turkey	Urban transformation grants	Limited schemes	State banks (Halkbank)	Partial TCIP/DASK	AFAD disaster fund	3/5
Italy	Direct aid for low income	Sismabonus 50 to 85%	Green bonds; CDP loans	Limited; not mandatory	FPCAS national plan	5/5
Greece	Post-disaster reconstruction	Limited schemes	Partial EU-backed	Limited; not mandatory	Partial EU structural funds	3/5
Algeria	None systematic	No specific tax scheme	No dedicated product	No seismic insurance	No dedicated fund	1/5

EQC: Earthquake Commission (New Zealand); CEA: California Earthquake Authority; PACE: Property Assessed Clean Energy; AFAD: Turkish Disaster Management Authority; CDP: Cassa Depositi e Prestiti (Italy); EBB: Earthquake Brace and Bolt programme; USD: US dollar.

California's Earthquake Brace and Bolt (EBB) programme demonstrates what well-targeted, low-cost incentives can achieve. By focusing on a single, highly cost-effective intervention (cripple wall bracing for wood-frame houses) and subsidising it with grants of up to USD 3000 funded by the California Earthquake Authority (CEA), the programme achieved substantial uptake among risk-averse private owners who would not have acted voluntarily (Zhang et al., 2022). The combination of a clearly defined risk target, a well-designed financial instrument, and an insurance architecture that prices seismic risk and links premium reduction to retrofit completion is, in California's case, the key to making the financial system work for risk reduction rather than against it (Caruso et al., 2021).

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4.4 Institutional governance and risk culture: the foundations that determine everything else

Technical excellence and well-designed financial instruments cannot succeed without the institutional architecture to deliver them. Effective seismic risk governance requires coordinated engagement across at least four institutional domains: standard-setting (engineers, code writers), financing (finance ministry, development banks, insurance sector), enforcement (building inspectors, professional certification bodies), and communication (civil protection, education sector) (Passoni et al., 2022). In Japan, this coordination is achieved through a decentralised architecture where national frameworks set standards and incentive parameters while regional and municipal authorities implement them with context-specific flexibility (Palm, 2019). Turkey's AFAD provides centralised coordination that proved essential in managing the 2023 earthquake response, but the absence of equally strong decentralised enforcement capacity at the municipal level contributed to the enforcement gap that allowed non-compliant construction to proliferate (Hansu and Oguz, 2025).

Risk culture, the final pillar, is perhaps the hardest to build and the easiest to neglect. Japan's deep integration of seismic risk into school curricula, professional training, media coverage, and community preparedness exercises took a generation to construct and reflects a consistent, multi-decade institutional investment (Palm, 2019). California's ShakeOut programme, mobilising tens of millions of annual participants through a standardised, media-supported preparedness drill, demonstrates that risk culture can be built more rapidly when institutional design is creative and well-resourced. Greece's integration of civil protection exercises into municipal governance cycles normalises earthquake preparedness as a civic responsibility rather than a personal anxiety (Castano-Rosa et al., 2022; Mahrad et al., 2020).

5 A risk governance framework for Algeria

The comparative evidence points towards a governance architecture for Algeria built around three operational priorities: building the knowledge base, designing the financial architecture, and constructing the institutional framework to deliver both. These priorities must be pursued in parallel because each depends on the others.

5.1 Building the knowledge base: national inventory and risk prioritisation

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Algeria cannot prioritise interventions it cannot see, and it currently lacks the national building inventory that would enable evidence-based prioritisation. The first operational step is therefore a technical one: a georeferenced digital inventory of the existing building stock, classified by age, structural type, construction material, occupancy, and location, building on methodological frameworks adapted to the Algerian context by Lanseur et al. (2021) and heritage assessment approaches developed by Henni-Chebra et al. (2024). Administrative data sources and social media analytics can accelerate and dynamically update such inventories at scale (Zadeh, 2022).

With inventory in place, a four-criterion prioritisation matrix allocates public attention where it generates the highest risk reduction per unit of expenditure: life safety risk (collapse probability multiplied by occupancy density); functional criticality (hospitals, schools, emergency command centres); economic and heritage value (Coscia and Senatore, 2017; Zhang et al., 2025); and implementation feasibility (contractor capacity, intervention cost, owner cooperation). This approach mirrors California's Rapid Obsolescence Rating system and Italy's CARTIS methodology, producing a ranked national agenda for intervention that is transparent, auditable, and defensible (Mesta et al., 2023).

5.2 Designing the financial architecture: the Algerian Sismabonus

The central financial recommendation is the design and introduction of an Algerian Sismabonus: a graduated tax deduction of 50 to 85% on the cost of certified seismic retrofitting, linked directly to the certified improvement of the building's classification on a national seismic risk scale analogous to Italy's A-to-G system (Musolino et al., 2025; Almeida et al., 2024). The performance-based linkage between incentive size and measurable risk reduction is the key innovation. It makes the financial reward commensurate with actual outcomes, creates a market for certified assessment and retrofit, and generates a stream of performance data that enables transparent public reporting on national risk reduction progress. The self-reinforcing logic of this mechanism is illustrated in Fig. 3.

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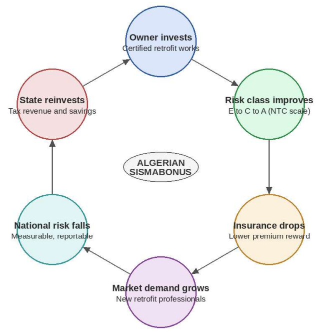

Figure 3. *The Algerian Sismabonus virtuous cycle, showing how individual investment generates national risk reduction and market development through a self-reinforcing mechanism. The Italian Sismabonus (Musolino et al., 2025) provides the international evidence base for this design. Figure created by the authors.*

The cost-benefit case for this investment is unambiguous. Figure 4 illustrates the illustrative return on investment ratios for each of Algeria's three major building typologies, showing that every unit invested in certified retrofitting avoids two to four units in future losses. This is consistent with rigorous cost-benefit analyses for comparable building stocks in Lisbon (Marques et al., 2018), Nepal (Mesta et al., 2023), and Italy (Dolce et al., 2021; Caruso et al., 2021). A national guarantee fund to de-risk bank lending for retrofit projects, and a mandatory seismic risk component in home insurance premiums in high-risk northern zones, would complete the financial architecture.

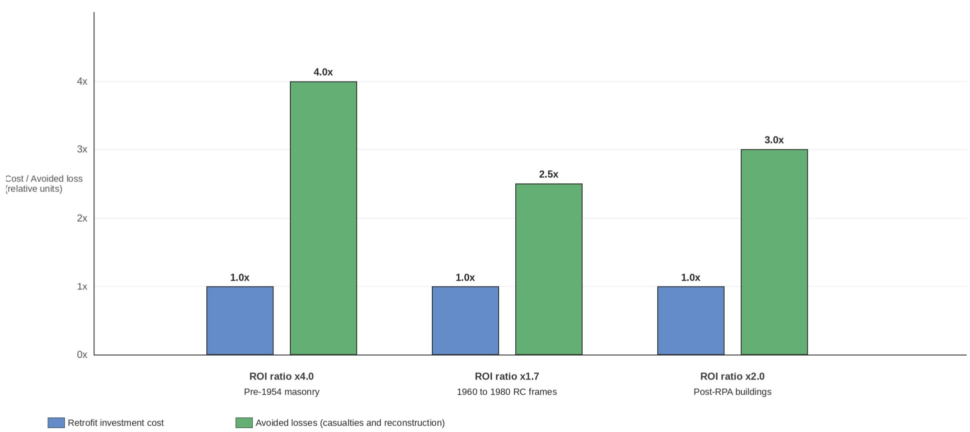

Figure 4. *Illustrative cost-benefit comparison of seismic retrofitting versus inaction by building typology in Algeria. The return on investment (ROI) ratio represents the ratio of avoided future losses to retrofit*

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investment cost. Based on international literature (Mesta et al., 2023; Caruso et al., 2021; Dolce et al., 2021). Figure created by the authors.

5.3 Building the institutional framework: legislation, coordination, and accountability

The legislative foundation is a dedicated chapter within the RPA for existing buildings, or preferably a standalone National Seismic Safety Act for Existing Buildings, establishing mandatory assessment methodologies, a national risk classification system, binding compliance timelines for strategic building categories, and a certification framework for assessment professionals and retrofit contractors. This act must be developed by an interministerial committee spanning Housing, Finance, Interior, and Education ministries, coordinated by a CTC with an explicitly strengthened mandate covering enforcement, certification, and annual public progress reporting. The full set of pillar-by-pillar recommendations, with their international evidence base, is summarised in Table 3 and visualised in Fig. 7.

Table 3. Strategic recommendations for Algeria's national seismic vulnerability reduction policy, organised by governance pillar.

Strategic pillar	International model	Recommended action for Algeria
Regulatory framework	Japan: coercive (public) and incentive (private) New Zealand: mandatory timelines and registry Italy: risk classification A to G (NTC-2018)	Dedicated 'existing buildings' chapter in the RPA or standalone regulation Mandatory assessment for hospitals, schools, and critical infrastructure within 5 years Gradual mandatory framework for private owners in high-risk zones
Technical approaches	California: HAZUS national risk mapping Italy: CARTIS inventory and fragility curves Greece: KAN.EPE protocols	National digital building inventory (type, age, condition, vulnerability) Local vulnerability indices for Algerian typologies Cost-effective FRP and reinforced concrete jacketing solutions adapted to local skills
Financial mechanisms	Italy: Sismabonus (50 to 85% linked to risk class) California: EBB grants and PACE and CEA fund Japan: municipal subsidies and low-interest loans	Algerian Sismabonus: performance tax credits for measurable risk class improvement National seismic retrofitting guarantee fund Mandatory seismic insurance component for high-risk zones
Institutional governance	Japan: decentralised multi-agency and regional Turkey: AFAD centralised coordination New Zealand: local authority and national oversight	Interministerial coordination committee (Housing, Finance, Interior, Education) Strengthen CTC mandate, technical capacity, and enforcement role Annual national seismic risk progress reports for public accountability
Risk culture and awareness	Japan: school programmes, drills, preparedness deeply embedded	Integrate seismic risk education into primary and secondary school curricula

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	Greece: resilience exercises and civil protection education	Launch national 'Culture of Resilience' public awareness campaign
	California: ShakeOut campaign (millions of participants annually)	Train engineers, architects, and craftsmen through continuing professional development

CPD: continuing professional development; LCSE: life cycle structural engineering; CTC: Technical Construction Control agency; RPA: Algerian Seismic Code; FRP: fibre-reinforced polymer; RC: reinforced concrete.

The regulatory evolution evidence base is presented in Fig. 5, the comparative performance assessment across all five pillars in Fig. 6, and the integrated strategic framework in Fig. 7.

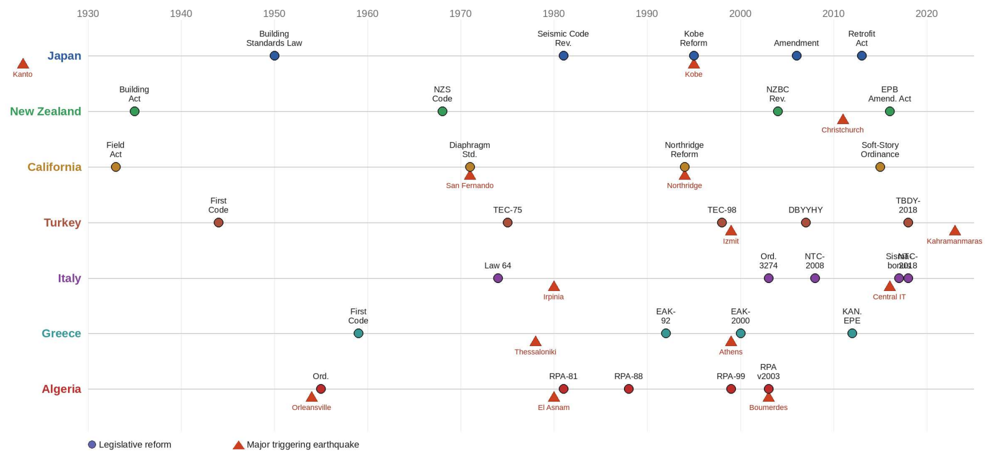

Figure 5. *Timeline of seismic regulatory evolution by country (1933 to 2023). Circle size indicates the relative significance of each legislative milestone. Key events driving regulatory change are marked. Algeria's regulatory trajectory shows a persistent gap in provisions for existing buildings. Figure created by the authors.*

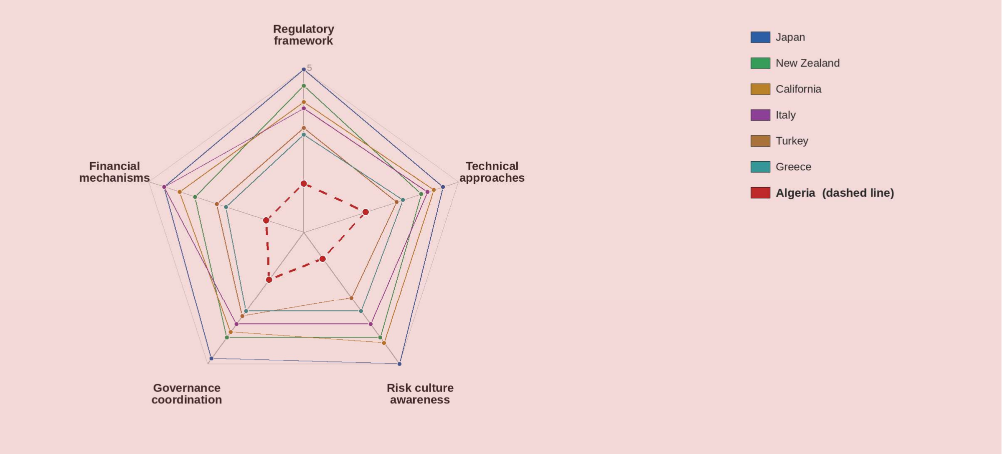

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Figure 6. *Comparative performance of national seismic vulnerability reduction strategies across five analytical dimensions (1 = nascent, 5 = excellent). Algeria's current performance is shown by the dashed line. The chart illustrates both the extent of the gap and the specific pillars where international models offer the most relevant lessons. Figure created by the authors.*

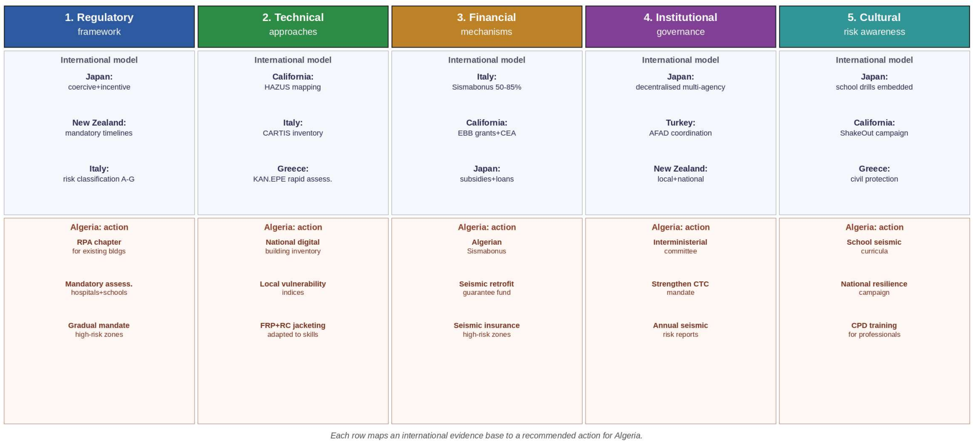

Figure 7. *Integrated strategic framework for Algeria's national seismic resilience policy. Each row maps an international evidence base to a specific recommended action for Algeria across five governance pillars. Figure created by the authors.*

6 Discussion

6.1 The hardest transition: from reactive to proactive governance

Figure 8 illustrates the contrast between Algeria's current governance logic (organised around responding to earthquakes after they occur) and the proactive governance logic that the international evidence supports. The contrast is not merely technical but cognitive and political. A reactive system produces outcomes that are visible and photogenic: reconstruction, new buildings, ribbon-cutting. A proactive system produces outcomes that are invisible: a building that survives, a family that does not lose its home. This visibility asymmetry creates a structural political disincentive for prevention that explains why retrofitting programmes struggle to gain traction without purpose-built institutional mechanisms that sustain them across electoral cycles.

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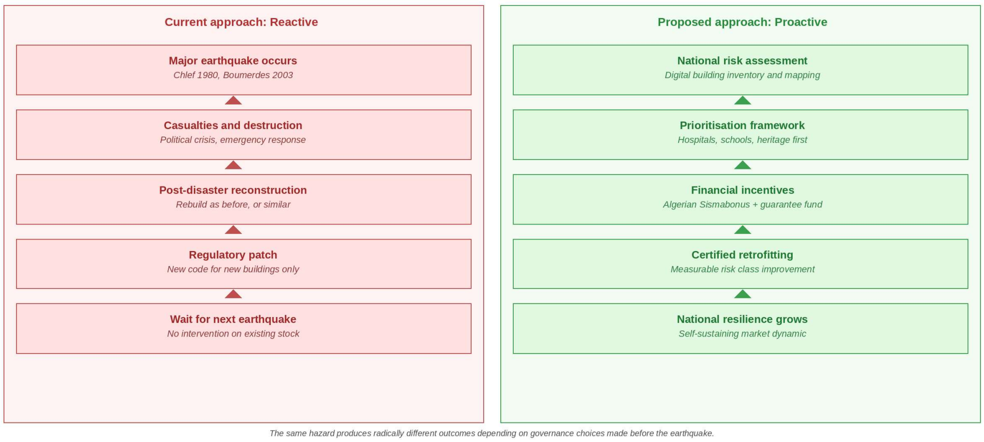

Figure 8. *Reactive versus proactive seismic governance: two contrasting policy logics for the same hazard. The reactive cycle is self-reinforcing in the absence of deliberate institutional intervention. The proactive cycle requires institutional investment to initiate but generates its own reinforcing dynamics once established. Figure created by the authors.*

The quantitative case for the transition is not subtle. Meta-analyses of seismic risk mitigation cost-benefit studies consistently find benefit-to-cost ratios of 2.5 to 6, meaning that every unit of prevention investment avoids two and a half to six units of future losses through reduced casualties, lower reconstruction expenditure, and preserved economic continuity (Mesta et al., 2023; Caruso et al., 2021). For Algeria, where reconstruction costs after Boumerdes (2003) exceeded USD 5 billion and the social costs of displacement persisted for years, the investment case for prevention is overwhelming. The challenge is not analytical but political: constructing the institutional architecture that makes long-term prevention investment sustainable.

6.2 Implementation barriers and how to address them

Three structural barriers stand between Algeria's current position and the governance framework proposed here. The first is the absence of a professional ecosystem capable of delivering retrofitting at scale: there are insufficient certified structural assessors, insufficient contractors trained in FRP and FRCM application, and insufficient continuing education infrastructure to replenish this capacity over time (Lanseur et al., 2021). Developing this ecosystem is a parallel requirement, not a precondition: programmes can be launched while professional certification systems are built, but the scaling rate will be constrained by capacity until the ecosystem catches up. The second barrier is the informal construction sector, which represents a substantial fraction of peri-urban housing stock and is legally and technically complex to address through standard retrofitting frameworks (Benfarhat et al., 2020). A governance framework for informal stock requires a different set of instruments, including community-based assessment, negotiated compliance pathways, and insurance products specifically designed for buildings without formal ownership documentation. The third barrier is risk culture: without a population that perceives seismic risk as real and manageable, financial incentives will generate low uptake regardless of their design quality.

6.3 The synergy principle and why all five pillars must move together

Italy's Sismabonus experience between 2017 and 2023 is the clearest empirical demonstration of what governance synergy produces: a well-designed performance-based incentive mechanism, embedded in an existing technical classification system, promoted through a communications architecture that made the A-to-G risk label meaningful to ordinary building owners, and supported by a certified assessor network created specifically to serve the new demand. The outcome was a self-reinforcing market dynamic that the state could not have produced by direct investment alone (Musolino et al., 2025). The subsequent integration of seismic and energy efficiency incentives under the Superbonus 110% framework widened the political coalition supporting the programme and substantially improved its cost-effectiveness (Karaki and Hawileh, 2025; Almeida et al., 2024; Caprino et al., 2021). For Algeria, the lesson is that the five pillars of the governance framework are not options to be selected from a menu but a system that generates outcomes only when its components are aligned. A national risk inventory without a financial mechanism to act on it is an expensive dataset. A financial mechanism without a certified assessor network is a programme that cannot be accessed. A certified assessor network without a regulatory mandate is a professional community with no clients.

7 Conclusions

Algeria will face another major earthquake. This is not a probabilistic statement requiring qualification but a geological certainty. The question is whether the society that confronts that earthquake will have used the time available to make its buildings measurably safer. The answer, at present, is that it has not: not for want of technical knowledge or international precedent, but for want of the governance architecture to translate both into sustained, systematic action.

This article has argued that effective seismic risk governance is not a single policy instrument but a system of five interdependent pillars: enforceable regulation for existing buildings, performance-based financial incentives that mobilise private capital, a comprehensive national risk inventory, coordinated multi-level institutional governance, and a risk culture embedded across all societal levels. The comparative evidence from Japan, New Zealand, California, Turkey, Italy, and Greece, synthesised across all five dimensions and visualised in Fig. 6, shows

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that the alignment of these pillars (not the sophistication of any individual instrument) is what distinguishes countries that achieve measurable risk reduction from those that do not.

For Algeria, the framework proposed here implies three immediate priorities. First, a national building inventory and risk prioritisation system, without which the problem remains invisible and unaddressed. Second, a performance-based financial incentive mechanism analogous to Italy's Sismabonus, without which the cost of retrofitting will remain prohibitive for private building owners who represent the vast majority of the vulnerable stock. Third, a dedicated regulatory instrument for existing buildings, establishing mandatory assessment methodologies, risk classification criteria, and compliance timelines for strategic building categories. These three priorities are the preconditions for all subsequent action; everything else (institutional coordination, professional certification, cultural investment) follows from them.

The implementation roadmap for these priorities is illustrated in Fig. 9. Short-term actions (0 to 3 years) focus on legal and institutional foundations. Medium-term actions (3 to 10 years) begin delivering measurable risk reduction through mandatory assessment and scaled incentive programmes. Long-term actions (beyond 10 years) embed the framework into a self-sustaining national risk reduction system.

Figure 9. *Implementation roadmap for Algeria's national seismic resilience policy (2025 to 2035 and beyond). Reg.: Regulatory; Tech.: Technical; Fin.: Financial; Gov.: Governance; LCSE: Life Cycle Structural Engineering. Figure created by the authors.*

The measure of this framework's success will not be the quality of its design but whether, when the next major earthquake strikes Algeria's northern corridor, fewer buildings collapse and fewer families lose everything. That outcome is achievable, given the resources and institutional capacity Algeria possesses. Whether it is achieved is a question of political will and governance choice, not technical possibility.

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Code and data availability

No new primary datasets were generated or analysed in the course of this research article. All data underlying the cost-benefit estimates in Fig. 4 are derived from published literature cited in the reference list and are fully reproducible from those sources. The building stock proportion estimates in Fig. 1 are illustrative and based on the qualitative synthesis of available literature; they are not derived from a primary dataset and should not be treated as measured values. No computer code was developed or used in this study. All figures were produced by the authors and are original works. Quantitative scores used in Tables 1 and 2 and Fig. 6 are based on the authors' qualitative assessment of documented policy performance across the five analytical dimensions, as described in Sect. 3.2; they are not derived from a dataset or model and are intended as comparative analytical tools rather than measured indicators.

Author contributions

B. Benfarhat: conceptualisation, methodology, investigation, formal analysis, writing (original draft), writing (review and editing). D. Benouar: supervision, project administration, writing (review and editing), scientific guidance and domain expertise.

Competing interests

The contact author has declared that neither of the authors has any competing interests.

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